The Impact of Bilingualism on Conflict Control

Célia Guido Mendes

A thesis submitted for the degree of

Doctor of Philosophy

at the University of Otago, Dunedin,

New Zealand.

26th June 2015

Abstract

In recent years, a substantial amount of research has been published on the *bilingual advantage hypothesis* in executive functions, according to which the continuous and consistent experience of managing two languages leads to cognitive gains, particularly in cognitive control functions related to conflict monitoring and resolution. Researchers have presented evidence that bilinguals exhibit significantly smaller conflict effects than monolinguals, as well as overall faster reaction times in both congruent and incongruent trials. The former are interpreted as evidence of the benefits of bilingualism to inhibitory control, while the latter are seen as evidence of bilinguals' advantage in conflict monitoring processes. Nevertheless, there have also been an extensive number of studies reporting no bilingual advantage in conflict monitoring and/or resolution, which have thrown doubts on the existence of a bilingual advantage. It has been proposed that the elusiveness of the bilingual advantage may be due to: features of the bilingual experience —such as proficiency in the second language or frequency of use of both languages— which may restrict or boost bilinguals' performance in conflict control tasks; poor control of confounding variables, such as socio-economic status, which have considerable impacts on the development of executive functions; or insufficient statistical power of some of the studies, since most studies showing a bilingual advantage were performed with smaller numbers of participants per group, while studies with large *n*'s tend to show null results. It has therefore been proposed that the bilingual advantage hypothesis may be unsustainable.

We set out to contribute to this area of research, by comparing the performance of a group of bilingual participants with a control group of

monolinguals in two tasks measuring different mechanisms of conflict monitoring and resolution —the Simon task and the Attention Network Test. Our main goals were to investigate: (a) whether a bilingual advantage was to be found in conflict control tasks requiring both interference control and suppression of a prepotent response; (b) whether this bilingual advantage, if present, stemmed from an improved inhibition control mechanism or from a more efficient monitoring function; (c) whether general individual-difference variables and/or bilingualism-specific variables could be responsible for boosting or restricting the bilingual advantage. Participants completed two executive control tasks —a Simon task and an Attention Network Test—, as well as an English proficiency test, a fluid intelligence task, a Language History Questionnaire, a Socio-Economic Status Questionnaire, and a Questionnaire on Activities with an Impact on Executive Functions.

Our results in both the Attention Network Test and the Simon task, in reaction times as well as in accuracy rates, showed no differences between monolinguals and bilinguals in any of the measures analysed: overall reaction times, overall accuracy rates, conflict effects, alerting effect, orienting effect, sequential congruency effects, and working memory costs. Moreover, our analyses have identified age, fluid intelligence and gender as variables that have a significant effect in the performance of both groups of participants in these tasks. Additionally, none of the variables specific to bilingualism showed a statistically significant effect on any of the measures analysed, when controlling for age, fluid intelligence, and gender.

We interpret our results as evidence against a bilingual advantage in conflict monitoring and resolution. The results obtained in our study are discussed in relation to the broader literature on bilingualism and cognition and current theories of conflict monitoring and control.

We finish by presenting a hypothesis according to which intense and rich language processing experience may be a better predictor of cognitive control than bilingualism, and that it may, in fact, act as a mediator in the relationship between bilingualism and cognitive control. We draw on research showing a consistent link between cognitive control and language processing, by an activation of the same neural area —the left inferior frontal gyrus. We also address the question of how this hypothesis could be tested.

Acknowledgements

Mine has been an amazing PhD experience and I have a lot to be thankful for. I have no doubts that the successful completion of this journey was only made possible thanks to the support and supervision I have received from Prof. Jeff Miller, Dr. Tamar Murachver, and Dr. Mele Taumoepeau. I know exactly how lucky I was to have had these three great academics and people by my side throughout the last three years. I am truly grateful for their feedback and their encouragement, for making me push my limits and learn new invaluable skills, for giving me direction when I needed it but also allowing me to roam free and take charge of my project. I particularly want to thank Tamar for her sincere enthusiasm for my research, Mele for always checking up on me and never failing to encourage me, Jeff for pushing me and raising the bar. You all have made me a better researcher, much more prepared for the challenges of academia and research. I am equally thankful to the Department of Psychology for providing an ideal working environment and invaluable support, and to the University of Otago, for the funding without which I would never have been able to complete this PhD. I must also thank all the participants who enthusiastically gave their time to allow me to collect the data I needed for my study. A huge "thank you" to all my good friends and office mates, who put up with all my PhD-related moods and who were always there to encourage and support me. Finally, a huge chunk of my gratitude goes to my parents, for their love and support, and for teaching me to always do better today than yesterday. For their sacrifice I will always be grateful.

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1 Introduction

In the last ten to fifteen years, we have witnessed a research boom in the area of bilingualism and cognition, which started mainly with a focus on cognitive development and has lately turned more towards cognitive aging. The areas of cognition studied are plentiful and the variety of approaches ample. With the present thesis, it is our aim to critically analyse the research that has been published on the impact of bilingualism, specifically on conflict control, report on the results obtained in our own study, and discuss the implications our findings may have to the field, as well as the new challenges faced in this research area.

In this chapter, we present and discuss the history and state-of-the-art of research on bilingualism and conflict control, as well as the issues that might have important implications for both the design of studies and the interpretation of results in the area. We start by going through the research that gave birth to the area of bilingualism and cognition, and then focusing our attention on the bilingual advantage hypothesis, in section *1.2 The Bilingual Advantage Hypothesis*. We then explore in some detail the theoretical bases of this hypothesis, looking initially at the possibility of a bilingual advantage in inhibitory control, and then at the possibility of a bilingual advantage in conflict monitoring. We address the literature in the area critically, looking both at studies that have reported a bilingual advantage in conflict control and studies that have not found such a bilingual advantage. In section *1.3 Measuring Bilingualism and Conflict Control*, we consider issues associated with defining bilingualism, as well as methodological issues related to confounding variables and task design, which might be key to understand the inconsistencies in results found in studies of the bilingual advantage hypothesis. We then describe the goals of the present thesis, formulated as a series of questions, in section *1.4 Our Study*.

1.1 The Impact of Bilingualism on Cognitive Abilities

Bilingualism is usually associated with access to richer life experiences, both culturally and socially, as well as with a broader view of the world, made possible by the fact that speaking a different language allows for a slightly different way of interpreting —or verbalising— the external world (Boroditsky, 2011; Boroditsky, Fuhrman, & McCormick, 2011). However, for a long time, bilingualism was actually not encouraged by educational specialists, fearing that having to deal with two linguistic codes would hamper children's ability to learn. The claim that bilingual children experienced academic and intellectual insufficiencies when compared to their monolingual peers pervaded most of the 20th century (for reviews, see Bhatia & Ritchie, 2006; Oller & Eilers, 2002).

In a paper that revolutionised the field of bilingualism, Peal and Lambert (1962) noted that previous studies comparing the performance of bilinguals and monolinguals in verbal and non-verbal intelligence tasks had not adequately controlled for variables that could have a significant impact on the participants' outcomes. In their own study, and controlling for factors such as socio-economic status (SES), gender, age, second language proficiency, language of testing, attitudes towards language communities, balancedness of bilingualism, and length of bilingualism, among many others, Peal and Lambert (1962) found a significant bilingual advantage in measures of verbal and non-verbal intelligence.

Since Peal and Lambert's (1962) original studies, a body of evidence has accumulated suggesting that being proficient in more than one language leads to the improvement of verbal abilities, such as metalinguistic awareness (Barac & Bialystok, 2012; Bialystok & Barac, 2012), theory of mind and false-belief understanding (Berguno & Bowler, 2004; Goetz, 2003; Kovács, 2009; Rubio-Fernández & Glucksberg, 2012; Yow & Markman, 2015), perspective taking (S. P. Fan, Liberman, Keysar, & Kinzler, 2015), divergent thinking (Kharkhurin, 2008, 2009, 2010), convergent thinking (Hommel, Colzato, Fischer, & Christoffels, 2011), verbal and non-verbal intelligence (Barik & Swain, 1976; Hakuta, 1987; Hakuta & Diaz, 1985), abstract or symbolic reasoning, and problem solving.

There have also been various studies on the impact of bilingualism on executive functions. *Executive functioning* comprises the management of high-level general-purpose cognitive processes, such as working memory, task switching, problem solving, sustained attention, as well as planning and execution (see Jurado & Rosselli, 2007, for a review of the different proposals for the possible components of executive functions). A bilingual advantage has been found in such executive functions, including: task switching (Barac & Bialystok, 2012; Garbin et al., 2010; Prior & MacWhinney, 2010), working memory (Bialystok, Craik, Klein, & Viswanathan, 2004; Bogulski, Rakoczy, Goodman, & Bialystok, 2015; Feng, Bialystok, & Diamond, 2009; Linck, Hoshino, & Kroll, 2008), and inhibition or conflict control (Barac & Bialystok, 2012; Bialystok, 2006; Bialystok et al., 2004; Bialystok & DePape, 2009; Bialystok & Majumder, 1998; Bialystok & Senman, 2004; Carlson & Meltzoff, 2008; Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009; Costa, Hernández, & Sebastián-Gallés, 2008; Engel de Abreu, Cruz-Santos, Tourinho, Martin, & Bialystok, 2012; Feng et al., 2009; Fernandez, Tartar, Padron, & Acosta, 2013; Linck et al., 2008; Luk, De Sa,

& Bialystok, 2011; Poarch & van Hell, 2012) (see Adesope, Lavin, Thompson, & Ungerleider, 2010; Hilchey & Klein, 2011; Paap, Johnson, & Sawi, 2014, 2015; and Ricciardelli, 1992, for extensive reviews and meta-analyses of many of these studies).

More recently, a growing number of studies have showed evidence that bilingualism might act as a *cognitive reserve* (Stern, 2002; Stern, Alexander, Prohovnik, & Mayeux, 1992) that protects against age-related cognitive decline (Abutalebi, Canini, Della Rosa, Green, & Weekes, 2015; Bak, Nissan, Mllerhand, & Deary, 2014; Bialystok & Craik, 2010; Bialystok et al., 2004). Bilingualism is suggested as one of many lifetime factors such as education, socio-economic status, occupation, or physical exercise that have been found to enhance premorbid cognitive ability, with bilinguals experiencing a delay in the onset of symptoms of dementia of approximately four to five years (Alladi et al., 2013; Bialystok, Craik, Binns, Ossher, & Freedman, 2014; Bialystok, Craik, & Freedman, 2007; Bialystok, Craik, & Luk, 2012; Craik, Bialystok, & Freedman, 2010; Woumans et al., 2014).

However, the literature shows contradictory results, as many studies fail to find a bilingual advantage in tasks measuring cognitive abilities or present inconsistent results, with one measure showing a bilingual advantage and other measures not supporting that advantage. Bilinguals have been consistently outperformed by monolinguals in verbal fluency and word retrieval tasks, a result that is usually explained by the interference of the non-target language (Bialystok & Feng, 2009; Engel de Abreu, 2011; Fernandes, Craik, Bialystok, & Kreuger, 2007; Gollan, Fennema-Notestine, Montoya, & Jernigan, 2007; Gollan, Montoya, Fennema-Notestine, & Morris, 2005; Kaushanskaya & Marian, 2007; Roberts, Garcia, Desrochers, & Hernandez, 2002). Moreover, several studies comparing monolinguals and bilinguals on non-verbal cognitive abilities have also failed to find evidence supporting a bilingual effect (Abutalebi et al., 2012; Antón et al., 2014; Bajo, Padilla, & Padilla, 2000; Clare et al., 2014; Colzato et al., 2008; Costa et al., 2009; Duñabeitia et al., 2014; Engel de Abreu, 2011; Gathercole et al., 2014; Goldman, Negen, & Sarnecka, 2014; Gutiérrez-Clellen, Calderón, & Weismer, 2004; Hilchey & Klein, 2011; Kirk, Scott-Brown, & Kempe, 2013; Kousaie & Phillips, 2012a, 2012b; Morton & Harper, 2007; Paap, 2014; Paap & Greenberg, 2013; Paap et al., 2014; Paap & Liu, 2014; Paap & Sawi, 2014; Paap, Sawi, Dalibar, Darrow, & Johnson, 2015) and longitudinal or prospective studies on the relationship between bilingualism and cognitive decline (with one exception, Wilson, Boyle, Yang, James, & Bennett, 2015) consistently show no differences between bilinguals and monolinguals and usually trend toward a monolingual advantage (Crane et al., 2009; Lawton, Gasquoine, & Weimer, 2015; Sanders, Hall, Katz, & Lipton, 2012; Yeung, St. John, Menec, & Tyas, 2014; Zahodne, Schofield, Farrell, Stern, & Manly, 2014). It is also worth mentioning that negative or null results often go unreported (Adesope et al., 2010; de Bruin, Treccani, & Della Sala, 2015; R. M. Klein, 2015; Paap & Liu, 2014).

1.2 The Bilingual Advantage Hypothesis

One explanation for the existence of a bilingual advantage in cognitive ability tasks is that the experience of acquiring two (or more) languages and simultaneously managing those languages —inhibiting non-target linguistic information so that one language can be accessed and used without interference from the other language(s)—allows bilinguals to develop skills that extend into other tasks and domains (Abutalebi & Green, 2007; Bialystok, 2001, 2007; Bialystok, Craik, Green, & Gollan, 2009; D. W. Green, 1998). Support for this view comes from research on parallel activation of languages in the bilingual brain, showing that while one language is being used, non-target language(s) can simultaneously become activated (Christoffels, Firk, & Schiller, 2007; Costa, La Heij, & Navarrete, 2006; De Groot, Delmaar, & Lupker, 2000; Dijkstra, Van Jaarsveld, & Brinke, 1998; Guo & Peng, 2006; Jared & Kroll, 2001; Kaushanskaya & Marian, 2007; Marian & Spivey, 2003; Weber & Cutler, 2004). If both languages are simultaneously activated even though only one of them is being used, then it should follow that some sort of control mechanism must be called into action, to ensure that the competition and conflict generated by the parallel activations of two linguistic systems are resolved. Sustained experience in using such a control mechanism would then translate into benefits for other tasks needing the same control mechanism.

The possibility that having added experience in one cognitive ability could have repercussions into other cognitive areas was for a long time considered to be impossible by functional localizationist models. For these models, the generalizability of learning was restricted, with specific skills being confined to localized regions in the brain (see Poggio & Bizzi, 2004, for a review). Research has, indeed, shown evidence for task-specific learning (Ball et al., 2002; Saffell & Matthews, 2003). There are, however, a mounting number of studies demonstrating a connection between extensive engagement in certain activities and significant impacts in general cognitive functioning (Reuter-Lorenz, 2002). Examples of such potentially cognition-altering factors are: an active and socially integrated lifestyle (Fratiglioni, Paillard-Borg, & Winblad, 2004), fitness and physical activity (Chang, Labban, Gapin, & Etnier, 2012; Colcombe & Kramer, 2003; Lucas et al., 2012; Yaffe, Barnes, Nevitt, Lui, & Covinsky, 2001), music training (Bialystok & DePape, 2009; Forgeard, Winner, Norton, & Schlaug, 2008; Ho, Cheung, & Chan, 2003; Schellenberg, 2004), migration and multicultural experience (Hill, Angel, & Balistreri, 2012; Kharkhurin, 2008; Lee, Therriault, & Linderholm, 2012), meditation (MacLean et al., 2010; Tang et al., 2007; Zeidan, Johnson, Diamond, David, & Goolkasian, 2010), and video-game playing (Gong et al., 2015; C. S. Green & Bavelier, 2003; Kühn, Gleich, Lorenz, Lindenberger, & Gallinat, 2014).

These results are in line with the *cognitive enrichment hypothesis* (Hebb, 1947, 1949), according to which various prolonged lifestyle experiences have extensive beneficial effects on cognitive functioning well into old age. These results are also in line with the more recent concept of *cognitive reserve* (Stern, 2002; Stern et al., 1992), which we have introduced earlier, and which posits that certain lifestyle factors have a protective effect on cognitive abilities, thus delaying the onset of cognitive decline or degeneration.

As the findings of the studies previously mentioned indicate, lifelong plasticity in the organization of cortical functions is supported by very robust evidence, showing that cognitive processes can be modified by experience. Moreover, studies have shown that repeated experience in one task produces an improvement in the functioning of an executive process for tasks different than the one performed during the experience. If this is the case, then we can apply the same rationale for bilingualism and expect that the practice obtained in using executive processes to control attention to two competing language systems might boost the ability to perform certain non-verbal tasks that demand executive control.

Some authors argue that the language-control mechanism used by bilinguals is language-specific (Costa, Miozzo, & Caramazza, 1999; Costa, Santesteban, & Ivanova, 2006; La Heij, 2005). According to language-specific selection models, both languages would be active but speakers would develop an ability to selectively focus on lexical items from the language at use. In this case, the selection mechanism would operate before any type of conflict could arise, thus bypassing the need to call into action a conflict-resolving mechanism. Alternatively, other authors believe that language control is attained through a control mechanism like inhibition, which might be a domain-general control mechanism. These latter models suggest that activation of competitor items in the non-target language would require inhibitory processes to take action, in order for speakers to produce words in the relevant language (Abutalebi & Green, 2007; Bialystok, 2001; D. W. Green, 1998; Kroll, Bobb, Misra, & Guo, 2008). It is, however, still unclear whether the bilingual language-control system is completely subsidiary to the domain-general executive control system or whether it also involves language-specific control mechanisms.

Whether inhibition is the specific attention-control process to be involved in bilingual language control might still be up for discussion, but researchers do not seem to harbour many (if any) doubts that executive control processes are indeed involved in language control. An increasing body of neuroimaging data has shown that the control mechanism used in language control involves to some extent domain-general executive control mechanisms (Branzi, Della Rosa, Canini, Costa, & Abutalebi, 2015), and similar brain activation has been found for language control and for non-verbal executive control (Abutalebi et al., 2012). More specifically, the dorsal anterior cingulate cortex (ACC), a brain structure tightly bound to domain-general executive control functions, has been found to play an important role not only in non-linguistic conflict resolution, but also in bilingual language control (Abutalebi et al., 2012).

If domain-general control mechanisms are at play, as research indeed seems to show they are, then experience with bilingual language control could be expected to transfer into other domain areas requiring the intervention of the same type of executive control, such as conflict control. In the present study, we are particularly interested in investigating the possibility of a bilingual advantage in conflict control. Therefore, in the following sections we will emphasize research focused on the impact of bilingualism on the mechanisms of conflict monitoring and resolution.

1.2.1 An Advantage in Inhibitory Control

Most of the research conducted on bilingual advantages in executive control has developed following D. W. Green's *inhibitory control theory* (1998), which builds on the supervisory attentional system model of Norman and Shallice (1980). According to this theory, an inhibitory control mechanism mediates the suppression of task-irrelevant language in bilinguals. The model hypothesizes that bilinguals' parallel language activation causes competition to arise between linguistic units, and that this conflict is then resolved by a supervisory attentional system via inhibition.

Inhibitory control

Inhibitory control is thought to be a controlled process (as opposed to an automatic process), which filters out an irrelevant stimulus or activity. However, the construct of *inhibition* in cognitive control is not usually seen as a single unitary process (Nigg, 2000), but rather it is thought to comprise several different *inhibition-related functions* (Friedman & Miyake, 2004). Nigg (2000), for instance, classified effortful inhibitory processes into four types: (a) *interference control*, which prevents interference due to resource or stimulus competition, (b) *cognitive inhibition*, which is the suppression of non-pertinent information to protect working memory/attention, (c) *behavioural inhibition*, which translates as suppression of a prepotent response, and (d) *oculomotor inhibition*, which is the suppression of reflexive saccades.

The inhibition processes or functions that seem to be of most interest when looking at the possibility of a bilingual advantage in inhibitory control are *interference control* and *suppression of a prepotent response*. With respect to bilingual language control, and assuming an inhibition mechanism at work, speakers would need to make use of a mechanism of suppression of a prepotent language when speaking in a less-dominant language. The native language (L1) would in most cases be considered the most dominant language and, therefore, the one that would be more strongly activated. This would trigger an inhibitory mechanism of suppression of that language, in order for the bilingual speaker to be able to speak in a second or less-dominant language (L2) without interference from the L1. In the reverse situation, when bilinguals are using their L1, they would need to make use of the inhibitory mechanism of interference control, to suppress any potential interference from their less-dominant L2, even though this inhibition would not be nearly as strong since L2 is not as active while speaking L1, as compared with the reverse (Blumenfeld & Marian, 2007; Weber & Cutler, 2004).

The inhibitory control theory

Green's (1998) assumption that the simultaneous activation of two languages in the brain leads to frequent cross-language competition between two semantic representations, which in turn creates a conflict that needs to be resolved before a lexical candidate is produced, has been somewhat validated by empirical data. As mentioned earlier, studies have shown that bilinguals perform worse than monolinguals on verbal fluency and lexical-access tasks (Gollan et al., 2007; Gollan et al., 2005; Gollan, Montoya, & Werner, 2002; Roberts et al., 2002), which has been interpreted by some authors as a direct result of the interference of the non-target language on task-relevant language production. This occurrence of conflict, produced by the parallel activation of lexical units in two languages, would be the reason behind bilinguals' slower reaction times (RTs) in word-retrieval tasks, as bilinguals would have to resolve this conflict by suppressing any non-target linguistic competitors (Dijkstra et al., 1998; D. W. Green, 1998).

However, this bilingual disadvantage can be interpreted differently, as the consequence of lower frequencies of use of lexical items, given the much larger number of different linguistic items bilinguals have at their disposal across their two or more languages. This hypothesis has been referred to as the *weaker links (or frequency-lag) hypothesis* (Gollan et al., 2002; Gollan & Silverberg, 2001). According to this hypothesis, older bilinguals would exhibit less of a disadvantage in naming tasks than younger bilinguals, given that they would have had more time to use all the words in their languages (Gollan, Montoya, Cera, & Sandoval, 2008). That was exactly what Gollan and colleagues (2008) found when testing younger and older bilinguals and monolinguals on a naming task: when using their non-dominant language, increased age of bilinguals attenuated word-frequency effects. These results seem to contradict the hypothesis offered by the inhibitory control model of bilingual language control, according to which the bilingual disadvantage in word-retrieval tasks is due to cross-language competition for production: if that were the case, then the disadvantage should increase with age (Hasher & Zacks, 1988). There is, in fact, evidence showing significant reductions in inhibition control in older populations (Darowski, Helder, Zacks, Hasher, & Hambrick, 2008; Hasher, Lustig, & Zacks, 2007; Hedden & Gabrieli, 2004), but available evidence on language comprehension and production seems to show a remarkable age constancy in many aspects of language production (Burke, 1997). Results are, thus, contradictory in this respect, which weakens the suggestion that the interference experienced by bilinguals in naming tasks can be seen as evidence that bilingual language control makes use of general inhibition control mechanisms.

Another type of evidence usually given in support of the inhibitory control hypothesis for bilingual language control is the existence of asymmetrical switching costs between a dominant and a non-dominant language. When tested in language-switching tasks, bilingual speakers tend to exhibit larger switching costs when switching into the easier or more dominant language (Costa & Santesteban, 2004; Meuter & Allport, 1999). This asymmetry in the language-switching costs is usually explained in the same manner as domain-general asymmetrical switching costs, which are widely known in the literature: it is argued that the magnitude of the inhibition exerted is dependent on the relative dominance or strength of the two tasks/languages (Allport, Styles, & Hsieh, 1994). Therefore, whenever a speaker switches into a more dominant language, the switching cost would be higher:

> Because overcoming prior inhibition will be a function of the prior amount of suppression, it can be predicted that the cost of switching will be asymmetric. It will take longer to switch into a language which was more suppressed —for unbalanced bilinguals this will be L1, their dominant language. (D. W. Green, 1998, p. 74)

This explanation of the observed asymmetrical switching costs between languages is therefore consistent with Green's (1998) reactive inhibition assumption, which, following Allport and colleagues (1994), posits that the level of inhibition exerted is stronger or weaker, depending on the level of activation of the non-target language: the stronger the activation of a language, the stronger the inhibition. Additionally, Jackson, Swainson, Cunnington, and Jackson (2001), using event-related potential (ERP) techniques, also showed an asymmetry in language-switching costs in bilinguals. More importantly, they also found a correspondence in results with a non-linguistic go/no-go reaction-time task, which may imply that similar inhibitory mechanisms are involved in both response suppression and language switching.

However, several studies conducted with highly proficient bilinguals —also called *balanced* bilinguals, as opposed to bilinguals for whom one of the languages is more dominant than the other— have shown no asymmetrical switching costs when the bilingual speakers were asked to switch between their equally proficient languages (Costa & Santesteban, 2004; Costa, Santesteban, et al., 2006; Ibáñez, Macizo, & Bajo, 2010). This would be expected, as the two languages of a balanced bilingual should present a very similar level of difficulty. However, this lack of asymmetry in switching costs between languages is still present when the same bilinguals are asked to switch between languages of different proficiency levels. More interestingly, this switching-cost symmetry in language-switching tasks does not seem to transfer into non-linguistic switching tasks, regardless of the level of difficulty introduced by each language (M. Calabria, Hernández, Branzi, & Costa, 2012): participants still exhibited asymmetrical switching costs between easier and harder non-linguistic tasks. This suggests that the bilingual language-control mechanism is (at least) not completely ancillary to the domain-general executive control system. If bilingual language-control were completely dependent on a domain-general control system, then we would expect to see the same pattern of switching costs on both linguistic and non-linguistic tasks. The fact that some participants exhibit symmetrical switching costs in linguistic tasks but asymmetrical switching costs in non-linguistic tasks, when both sets of tasks were designed to trigger asymmetrical switching costs, tells us that different control mechanisms might intervene in each task. Therefore, this conclusion does not support the hypothesis advanced by some authors that the bilingual language-control mechanism is subordinate to a domain-general control mechanism.

In order to explain why the bilinguals in their study showed symmetrical costs between languages of similar difficulty, but also between languages of different difficulty, Costa and Santesteban (2004) suggested that, at a higher level of bilingual proficiency, bilinguals develop a language-specific selection mechanism, which is applied to any language learned, independently of proficiency level. However, Costa, La Heij, and Navarrete (2006), using the same paradigm, found symmetrical switching costs between L2 and L3 in proficient bilinguals, but asymmetrical switching costs for the same bilinguals between L3 and L4, as well as between L1 and a recently acquired language. These results clearly cast doubt on Costa and Santesteban's (2004) hypothesis of a selection mechanism specific to linguistic tasks.

In summary, even though the evidence on asymmetric language-switching costs is compelling and consistent with an inhibition-control model of bilingual language control, an explanation would need to be found within this model for the symmetric language-switching costs exhibited by the same participants (Costa, 2005), which are inconsistent with Green's (1998) reactive inhibition assumption.

A second assumption of Green's inhibitory control model is that the conflict between competing linguistic representations is resolved by a control mechanism not necessarily language-specific. Theoretically, it does not seem problematic to conceive of a language-specific mechanism that would inhibit one of the languages when using the other, instead of a general control mechanism (Hilchey & Klein, 2011). However, testing this assumption demands methodological caution from the researcher, as it is imperative to use tasks that are non-linguistic to ascertain if a general-purpose mechanism is used instead of a language-specific one.

The inhibitory control theory of bilingual language control (D. W. Green, 1998) entails a *bilingual inhibitory control advantage (BICA)* (Hilchey & Klein, 2011):

> Frequent use of the inhibitory processes involved in language selection in bilinguals will result in more efficient inhibitory processes, which will confer general advantages on nonlinguistic interference tasks —that is, those requiring conflict resolution. These advantages will be reflected in reduced interference effects in bilinguals as compared to monolinguals. In other words, bilinguals should show an advantage over monolinguals on trials with response conflict. (Hilchey & Klein, 2011, p. 628)

When and if observed, the bilingual advantage should translate as better or faster performance in the presence of conflict. Some of the most ubiquitous paradigms used by researchers working on inhibition and conflict resolution are the colour-word Stroop task (Stroop, 1935), the Simon task (Simon, 1990), and the flanker task (Eriksen & Eriksen, 1974). These are tasks where there is a substantial amount of task-irrelevant input to be ignored (Stroop task and flanker task) and/or a prepotent response needs to be suppressed (Stroop and Simon tasks). In all these tasks, participants respond to trials where no conflict is introduced (congruent trials), and these trials are interspersed with other trials that trigger competition between two different inputs, two different input qualities, and/or two different responses (incongruent trials). The BICA hypothesis predicts that bilinguals should outperform monolinguals in these tasks, specifically in incongruent trials: their extensive experience in inhibition functions and in resolving conflict should give bilinguals an advantage when presented with incongruent trials, precisely because these require conflict resolution and inhibition processes.

These tasks measure the participants' susceptibility to interference, which is usually computed as the difference in reaction times and in error rates between responses to congruent trials and responses to incongruent trials. These differences are called effects: the Stroop Effect, the Simon Effect, and the Conflict Effect (they are all conflict —or congruence— effects, but the first two carry the name of the task in which they are measured). Since bilinguals are predicted to perform better and faster in incongruent trials, it is also expected for them to display smaller conflict effects. A smaller Stroop/Simon/Conflict Effect would be interpreted as a reduced susceptibility to interference and better inhibition abilities.

However, tasks involving linguistic input, like the Stroop task, are not the most appropriate when searching for a transfer in experience from a language inhibitory control mechanism to a general inhibitory control mechanism, as any difference in results between monolinguals and bilinguals might be due to differences in language-control mechanisms between participants. In order to gather evidence of transfer between language control and general, non-linguistic inhibition control mechanisms, it is necessary to use non-language-based inhibition control tasks, such as the Simon or the flanker tasks.

Costa and colleagues (2009) reviewed the results of 37 tasks requiring some sort of attentional control, which were included in 11 different studies/articles comparing monolinguals with bilinguals in interference control, published between 2004 and 2008. Of the 37 tasks, only 21.6% (8 of the 37 tasks, in 3 out of the 11 studies) showed results indicating a bilingual advantage for the Conflict Effect.

In their review of 31 studies on the bilingual advantage in executive control published between 2004 and 2010, Hilchey and Klein (2011) also found no solid evidence of a bilingual advantage in conflict effects:

> The magnitudes of the interference effects between monolinguals and bilinguals are very similar for young adults and children. The absence of a bilingual

> advantage in these age groups is simply inconsistent with the proposal that bilingualism has a general positive effect on inhibitory control processes (i.e., BICA). (Hilchey & Klein, 2011, p. 629)

Importantly, the authors noted that the magnitude of the conflict effects seems to become markedly more pronounced in the middle-aged and old-aged participants, for whom the bilingual advantage appears to be robust. However, Hilchey and Klein (2011) suggested methodological issues in the measurement of the reaction times might explain these results. Specifically, the authors questioned Simon Effects reported in the literature of sometimes 750 to 1,800 ms in range (Bialystok et al., 2004; Bialystok, Martin, & Viswanathan, 2005), when usually the Simon Effect in older participants seems to stay in a much lower range of 30 to 50 ms (Kubo-Kawai & Kawai, 2010; Van der Lubbe & Verleger, 2002).

More recently, Paap, Johnson, and Sawi (2014) compiled and analysed all studies published after Hilchey and Klein's (2011) review, comparing monolinguals and bilinguals in executive control. These included 56 non-verbal interference tasks, of which only 12 (21.4%) obtained results supporting a bilingual advantage in inhibition control. Paap (2014) and Paap, Johnson, and Sawi (2014) argued that most of the inconsistency in results obtained by studies on the bilingual advantage derives from low experimental power, due to the use of small sample sizes. The authors presented two histograms based on the information from the studies included in their review, and argued that the frequency of significant and non-significant bilingual advantages in both conflict effects and conflict monitoring measures is a function of the mean number of participants per language group: "bilingual advantages cluster at the low *n* end and are overwhelmed by those not showing bilingual advantages" (Paap et al., 2014, p. 632).

These results seem to indicate that evidence of a bilingual advantage in inhibitory control is very inconsistent and, therefore, questionable. Of course, a careful analysis of all the studies that so far have investigated the possibility of a bilingual advantage in inhibitory control also show inconsistencies and sometimes seemingly insurmountable methodological differences between studies, which makes it so much harder to compare results. Additionally, the elusiveness of evidence in favour of the BICA hypothesis might be due to the fact that such a bilingual advantage might be restricted to a specific type of task or task design, or to a specific type of bilingual experience (Hilchey & Klein, 2011; Paap et al., 2014; Valian, 2015). We will further explore these possibilities in section *1.3 Measuring Bilingualism and Conflict Control*.

1.2.2 An Advantage in Conflict Monitoring

If the hypothesis of a bilingual advantage in inhibition control seems to be only sporadically supported by the evidence reviewed, there is an area in which Hilchey and Klein (2011) found a robust advantage for bilinguals: overall reaction times. In their review of the literature, Hilchey and Klein (2011) refer to the unexpected finding that bilinguals typically outperform monolinguals on both congruent and incongruent trials (Bialystok, 2006; Bialystok, Craik, et al., 2005; Bialystok et al., 2004; Bialystok, Craik, & Ryan, 2006; Bialystok & DePape, 2009; Bialystok, Martin, et al., 2005; Costa et al., 2009; Costa et al., 2008; Martin-Rhee & Bialystok, 2008; Morton & Harper, 2007). As Hilchey and Klein (2011) pointed out, a bilingual advantage in overall RTs cannot be explained by Green's (1998) inhibitory control theory, which predicts an advantage in incongruent trials only. In an attempt to explain this advantage, Hilchey and Klein (2011) present the *bilingual executive processing advantage (BEPA) hypothesis*, according to which “bilinguals enjoy domain-general executive functioning advantages, as indexed by largely equivalent performance benefits on all conditions in nonlinguistic interference tasks” (p. 629).

Based on the idea that a higher frequency of inter-trial switches might be the reason behind the bilingual advantage in overall RTs (Costa et al., 2009), Hilchey and Klein (2011) introduced the *conflict-monitoring hypothesis* (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Botvinick, Cohen, & Carter, 2004; Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999; Carter, Botvinick, & Cohen, 1999; Carter et al., 1998) as a possible theoretical framework that might shed some light on the overall RT advantage. This theory postulates the existence of a complex neural network that monitors and detects conflict, causing trial-by-trial modulations of cognitive control when facing the need to suppress task-irrelevant information.

The conflict-monitoring hypothesis

Between 1998 and 2001, a group of authors proposed the existence of a conflict-monitoring function, the purpose of which was to signal the occurrence of conflicts in information processing, thus triggering compensatory adjustments in cognitive control (Botvinick et al., 2001; Botvinick et al., 1999; Carter et al., 1999; Carter et al., 1998). According to this hypothesis, specific brain structures, and in particular the ACC —where the conflict-monitoring function is supposedly located— would detect conflict when, for instance, task-relevant and task-irrelevant input trigger competing responses. In such circumstances, the conflict-monitoring system would raise the level of cognitive control, in order to reduce the effect of the task-irrelevant input and response selection.

One prediction of the conflict-monitoring hypothesis is that variations in the frequency of trial types (congruent or incongruent) in a task should affect the level of activation of the ACC: conflict effects should increase as incongruent trials become overall less frequent (Botvinick et al., 2001; Gratton, Coles, & Donchin, 1992). These effects have been reported in a number of experiments. Botvinick and colleagues (2001), for instance, designed a Stroop task with three conditions —one with 75% of the trials being incongruent, another with 50% of trials incongruent, and a last one with 25% of trials being incongruent— and reported a decrease in RTs for incongruent trials and an increase in RTs for congruent and neutral trials as the proportion of incongruent trials increased, which resulted in the largest conflict effects being found in the condition with only 25% of incongruent trials. Consistent with this prediction and results, ACC activation has been found to be greater when incongruent trials are less frequent (Carter et al., 2000). Data from studies on bilingualism considering the effect of trial-type frequency are very rare: as far as we know, only Costa and colleagues (2009) investigated this issue. The authors used four different conditions in two studies: (1) 8% of trials congruent, 92% incongruent; (2) 92% of trials congruent, 8% incongruent; (3) 75% of trials congruent, 25% incongruent; and (4) 50% of trials congruent, 50% incongruent. Costa et al. (2009) did not find a bilingual advantage in the conflict effect, but they observed a bilingual advantage in overall RTs in condition (4) only, which suggests that bilinguals could have an advantage in high conflict-monitoring conditions, allowing them a faster performance in both congruent and incongruent trials. Similarly, other studies have suggested that a bilingual advantage in executive control tasks might be restricted to (or might be more robust in) task conditions in which the demands for conflict control or for other executive-control processes are high (Bialystok, 2006; Bialystok et al., 2004; Ryan, Bialystok, Craik, & Logan, 2004, as cited in Bialystok, Craik, & Ruocco, 2006; Bialystok, Craik, & Ryan, 2006; Feng et al., 2009; Martin-Rhee & Bialystok, 2008). However, other authors found no evidence of a bilingual advantage in highly demanding task conditions (Bialystok & Martin, 2004; Duñabeitia et al., 2014; Paap & Greenberg, 2013).

A second prediction of the conflict-monitoring theory is that the level of cognitive control activated in each individual trial should vary depending on the level of ACC activation during the preceding trial. According to this theory, an incongruent trial triggers higher ACC activation than a congruent trial, which should translate into a higher level of focus on conflict, leading to less conflict interference in the subsequent trial. The level of conflict interference in the following trial reduces because of the increased focus caused by the previous trial. Consequently, the theory predicts that ACC activation on incongruent trials should be greater following congruent trials than following incongruent trials. This prediction has been confirmed by neuroimaging studies (Botvinick et al., 1999; Durston et al., 2003).

This idea of trial-by-trial modulation of cognitive control follows previous robust findings on *first-order sequencing effects* (also called the *Gratton effect*) in interference tasks: reaction times to congruent and incongruent trials are affected by whether they are preceded by congruent or incongruent trials (Chen, Li, He, & Chen, 2009; Gratton et al., 1992; Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002). However, the novelty introduced by the conflict-monitoring model is in the explanation given to these first-order sequencing effects (and described in more detail in the previous paragraph), which the proponents of the model describe as being a result of the adaptation to conflict by the ACC, with the resulting modulations in cognitive control. This response of the conflict-monitoring system is also known as the *conflict adaptation effect* (Botvinick et al., 2001; Botvinick et al., 1999; Egner & Hirsch, 2005; Kerns et al., 2004).

First-order sequencing effects lead to *sequential congruency effects*: the conflict effect is smaller following an incongruent trial than following a congruent one (Egner, 2007). For those of us investigating a potential bilingual advantage in conflict control, this seems like a good place to look for it. If there is a bilingualism-related benefit to conflict monitoring, a prediction could follow that bilinguals would present reduced first-order sequencing effects, as a more efficient conflict-monitoring system should produce an advantage in conflict adaptation (Hilchey & Klein, 2011). Even though we do not see reduced first-order sequencing effects as necessarily advantageous on their own, it would nevertheless be of the utmost interest to see if bilinguals and monolinguals present different patterns of behaviour in conflict control tasks depending on previous trial type. However, to our knowledge, this has not been investigated in studies on bilingualism, except for Costa et al.'s (2008) study. The authors, comparing monolinguals' and bilinguals' performance on the Attention Network Test (ANT), started out with the conflict-monitoring hypothesis as a theoretical framework. They then went on to analyse trial-sequence effects, but applying a task-switching framework, instead of a conflict-adaptation one. Following Allport and colleagues' (1994) rationale for asymmetrical switching costs between languages, Costa et al. (2008) predicted that switching from an incongruent trial to a congruent trial (IC trials) would incur more costs than switching from a congruent trial to an incongruent one (CI trials). However, as we have seen, the conflict-monitoring model predicts the opposite (and evidence has been shown to support this prediction): RTs to CI trials are consistently slower than RTs to IC trials. Following a conflict-monitoring approach, the relevant comparison should thus be between trials preceded by congruent versus trials preceded by incongruent trials. Despite the different viewpoint in their trial-sequence analyses, Costa et al. (2008) have, nevertheless, opened the door for a different avenue of investigation of the possible existence of a link between bilingualism and conflict adaptation: if we are to assume that bilinguals enjoy an advantage in conflict monitoring, then it should follow that: (a) bilinguals should outperform monolinguals in tasks involving high levels of cognitive control, and (b) this better performance should translate as overall faster RTs, (c) as well as reduced first-order sequencing effects (Hilchey & Klein, 2011).

Despite the interesting and promising avenues of research the conflict-monitoring hypothesis brings to the field of bilingualism, this model is not without criticism. The conflict-adaptation effect, which is presented as empirical support for the conflict-monitoring model, is explained by other authors by means of a memory-based priming account or a *feature-integration account* (Hommel, Proctor, & Vu, 2004; Lamers & Roelofs, 2011; Lanting, 2013; Mayr, Awh, & Laurey, 2003; Nieuwenhuis et al., 2006). According to this account, first-order sequencing effects are a result of repetitions and alternations of stimuli and/or responses, with stimulus repetitions resulting in faster RTs —the *repetition priming effect*.

It is worth noting, though, that the conflict-monitoring and feature-integration models do not postulate the existence of mutually exclusive mechanisms, which allows for the possibility that both might be at work simultaneously, affecting performance on the same events (Egner, 2007). As a matter of fact, the existing empirical evidence cannot rule out either of these models as operating elements in sequential congruency effects (Burle, Allain, Vidal, & Hasbroucq, 2005; Egner, 2007; Hommel et al., 2004; Mayr et al., 2003), with some authors suggesting that these effects entail both conflict-adaptation and feature-integration mechanisms (Davelaar & Stevens, 2009; Stürmer et al., 2002).

Nevertheless, as pointed out by Egner (2007), data from neurophysiological studies of the Stroop and Simon tasks have, by and large, confirmed the predictions derived from the conflict-adaptation model, according to which incongruent trials following other incongruent trials (II trials) incur low conflict interference due to a high level of cognitive control, whereas incongruent trials following congruent ones (CI trials) incur high conflict interference due to a low level of cognitive control. These data showed, as predicted by the model, increased neural activity during II trials in brain regions associated with cognitive control, as compared with CI trials (see Egner, 2007 for a review; Egner, Etkin, Gale, & Hirsch, 2008; Egner & Hirsch, 2005; Kerns, 2006; Kerns et al., 2004).

In the previous section, we concluded that if there is a bilingual advantage in inhibitory control, this advantage should manifest as faster RTs in incongruent trials, and therefore smaller conflict effects for bilinguals in cognitive control tasks. In this section, we discussed the possibility of a bilingual advantage in conflict monitoring, which entails different predictions, namely that: (a) bilinguals would outperform monolinguals in executive control task conditions with higher conflict-monitoring demands, by means of faster overall RTs, (b) they would also present reduced first-order sequencing effects, which would be interpreted as enhanced conflict adaptation. In order to gather evidence in favour of a bilingual advantage in conflict monitoring, it would thus be necessary to use cognitive control tasks with a high frequency of switching between congruent and incongruent trials, in order to increase conflict-monitoring demands.

1.2.3 An Overall Executive Functioning Advantage

In recent years, there has been a shift from viewing inhibition as the single hypothesized attentional control mechanism in bilingual language control to a more global executive functioning idea (Bialystok, 2007, 2010, 2011; Costa et al., 2009; Hilchey & Klein, 2011). The executive control system includes a set of mechanisms, such as inhibitory control, monitoring, shifting, attention, and working memory (Miyake et al., 2000). Of these, it is thought that executive functioning components related to attention, inhibition, monitoring and switching are recruited for language control. This view is supported by neuroimaging studies of bilinguals, showing recruitment of the general executive control system for language switching, with the same neural regions (the dorsolateral prefrontal cortex, the ACC and the caudate nucleus) being engaged during language-control tasks (Abutalebi et al., 2013; Abutalebi et al., 2012; Garbin et al., 2011; Hernandez, Dapretto, Mazziotta, & Bookheimer, 2001; Hernandez, Martinez, & Kohnert, 2000; Luk, Green, Abutalebi, & Grady, 2011; Price, Green, & von Studnitz, 1999) and non-linguistic switching tasks (Botvinick et al., 2001; Botvinick et al., 2004; Botvinick et al., 1999; Crone, Wendelken, Donohue, & Bunge, 2006). This evidence supports the hypothesis that the mechanisms for bilingual language control are subordinate to those of the domain-general executive control.

However, Abutalebi and colleagues (2008) have also found that the neural networks activated during bilingual language control might fall outside the general executive control system, which suggests that some of the mechanisms involved in bilingual language control may be specific to language and not involved in non-verbal switching tasks. Likewise, Calabria, Branzi, Marne, Hernández, and Costa (2013), investigating age-related changes to bilingual language control mechanisms and the relation between bilingual language control and domain-general executive control, found age-related changes in non-linguistic switching costs but not in language switching costs. These results suggest that the bilingual language control system is not affected by age in the same way the executive control system is, which implies that the bilingual language control system is not fully dependent on the executive control system.

There is also interesting evidence of a difference in neural substrates of cognitive control between bilinguals and monolinguals. Garbin and colleagues (2010), for instance, found that, on a non-verbal switching task, monolinguals and bilinguals activated different neural networks: the activation pattern in monolinguals was congruent with non-verbal task switching, while the activation pattern in bilinguals matched networks known to support language control. Similarly, Luk, Anderson, Craik, Grady, and Bialystok (2010) found distinct activation patterns in monolinguals and bilinguals in a flanker task, particularly in trials requiring interference suppression. Rodríguez-Pujadas et al. (2013) also compared early bilinguals and monolinguals on a switching task and found that the bilingual participants used language-control areas — such as the left caudate, and left inferior and middle frontal gyri— more than monolinguals. Finally, Ansaldo, Ghazi-Saidi, and Adrover-Roig (2015) also found evidence of differential neural activation for monolinguals and bilinguals in interference trials.

Anatomical brain changes resulting from bilingualism have also been described in several studies. Luk, Bialystok, Craik, and Grady (2011) found higher white matter integrity in the corpus callosum in elderly lifelong bilinguals than in elderly monolinguals, which was associated with a stronger anterior to posterior functional connectivity in bilinguals when compared to monolinguals. Mårtensson et al. (2012)

reported increases in hippocampus volume and in cortical thickness of the left middle frontal gyrus, inferior frontal gyrus (IFG), and superior temporal gyrus for interpreters relative to monolingual controls. Additionally, the right hippocampus and the left superior temporal gyrus seemed structurally more malleable in highly proficient interpreters, while low-proficiency interpreters displayed larger grey matter increases in the middle frontal gyrus. Klein, Mok, Chen, and Watkins (2014) found that later age of onset of L2 acquisition was associated with significantly thicker cortex in the left IFG and thinner cortex in the right IFG, whereas early-onset bilinguals presented no differences in cortex thickness when compared with monolinguals. Finally, Abutalebi, Canini, et al. (2015) also reported plastic changes induced by bilingualism: older bilinguals presented higher grey matter volumes in the inferior parietal lobules than their monolingual counterparts.

The evidence presented above, showing that bilingualism is associated with changes both at the behavioural and neural levels, implies that the bilingual advantage, if one exists, might be at a more complex level than the ones analysed so far. Differences and/or gains in working memory, attention control, inhibition, monitoring and switching —which on their own may not lead to significant advantages in particular executive control tasks— may come together in specific tasks and/or task conditions, resulting in more efficient performance for bilinguals. On the other hand, if true, the possibility that monolinguals and bilinguals make use of different neural networks would make us reconsider most of the research conducted in the area so far, which is based on the assumption that both groups use the same modules.

We do not intend to minimise the possibility of several parallel advantages for bilingualism in working memory, task switching, attentional control, and/or other executive control processes. However, for the purposes of this study, our main focus of interest shall remain on the impact of the bilingual experience specifically on conflict control mechanisms, and on the potential differences between monolinguals and bilinguals in activating and using these mechanisms.

Before we describe our study and discuss the results obtained, we will dedicate the next few sections to reviewing factors that might have major implications for both the design of studies and the analysis of results in this field of research. Three main groups of factors will be presented and discussed: bilingualism-specific factors, individual-difference confounding variables, and choice and design of tasks. Specific aspects of these three factors may differentially influence the mechanisms of conflict control and/or the interpretation of its measuring instruments, hence the relevance of considering them at this stage.

1.3 Measuring Bilingualism and Conflict Control

1.3.1 Diversity of the Bilingual Experience

Defining Bilingualism

When conducting research comparing monolinguals and bilinguals, researchers have to consider the question "Who is bilingual?" Reducing the spectrum of bilingual knowledge and experience into a two-level categorical variable (monolingual, bilingual) may be necessary for research purposes, but it obscures factors that might be of extreme importance for any analysis of bilingualism.

Before we consider some of these bilingualism-specific factors that sculpt the bilingual experience, our initial question still needs to be answered: who is bilingual? Here too opinions vary. Some authors value (near-)equal fluency in both languages as the defining characteristic of bilingualism (Bloomfield, 1933; Thiery, 1978), but this position has been criticised by authors such as Grosjean (1989, 2010), for confining the definition to an ideal of bilingual, instead of the reality of bilingualism. For this author, bilinguals are instead "those people who use two or more languages in their everyday lives" (1989, p. 4), even though they may not be equally or completely fluent in the two languages —fluency develops as given needs arise. This perspective views bilingualism more as a communicative competence than a linguistic one, as it emphasises the ability to use a language over the knowledge of that language.

These and other points of view have permeated the definitions of bilingualism used in the literature. As García-Vásquez, Vázquez, López, and Ward (1997) pointed out, early research used a social definition of bilingualism, more focused on oral language competence and socio-cultural experience, whereas more recent research has turned to a cognitive definition of bilingualism, emphasising language proficiency over language use. Bilingualism is obviously composed of many aspects: it is a cognitive ability that characterises individuals who possess and use two or more linguistic systems; it is a social psychological concept, through which individuals construct their personal identity and establish ways in which to relate to the world; and it is also a societal construct, in the sense that it modulates not only the relationships between individuals, and between individuals and groups, but also between social groups and institutions (Hakuta, Ferdman, & Diaz, 1987).

More recently, particularly in the area of research on bilingualism and cognition, bilingualism has more often been defined according to levels of proficiency, sometimes with an added emphasis on language functional use. For Bialystok (2001), for instance, "bilinguals must use their two languages in the same types of contexts", and they should be functionally fluent or proficient in both languages (p. 19).

Bialystok's position tries to bring together previous definitions of bilingualism, by attempting to reconcile knowledge of the languages with the ability to correctly use those languages in similar circumstances. Unfortunately, this is very rarely the case. If bilinguals can —and very commonly do— attain comparable levels of fluency and proficiency in both or all their languages, it is rarely the case that their languages will be used in the same contexts (Milroy & Muysken, 1995). Very frequently, one language (usually the dominant language in the country or region) will be used mainly in professional and formal settings, while the other language might be restricted to socializing and interacting within the family setting.

Generally speaking, I would agree with Grosjean's (2010) definition of bilingualism: bilinguals are individuals who know and use two or more languages in their everyday lives. However, for the purposes of research, sometimes definitions must be more restrictive. In our case, there is a key assumption that should constrain our definition of bilingual —the assumption that extensive, frequent, and proficient bilingual experience may have an impact on cognition. Based on this assumption, and for the purposes of this study, we will define bilinguals as individuals who use and have used two languages actively for a significant amount of time, and who are highly proficient in both of their languages.

Age of acquisition of L2 / Age of arrival

Age of acquisition of L2 —or *age of arrival*, when referring to immigration-led bilingualism— is one of the most used, if not the most used, variable in the literature on bilingualism and cognition. The *critical period hypothesis*, which postulates a developmental threshold for language acquisition (DeKeyser, 2000; Johnson & Newport, 1989; Lenneberg, 1967; Pinker, 1994), together with the *fundamental difference hypothesis* (Bley-Vroman, 1990), articulated as the existence of a significant difference between second language acquisition in young versus old age, were strong footings for the idea that true bilingualism is only attainable when both languages are acquired at a young age. For this reason, age of acquisition has been considered a critical variable in the literature, mainly to distinguish between early-onset bilinguals and late-onset bilinguals.

It is widely accepted that there is an incremental decline in language-learning abilities with age (Birdsong & Molis, 2001; Hakuta, Bialystok, & Wiley, 2003; Johnson & Newport, 1989; Stevens, 1999), but there is no agreement in the literature on the actual end of the critical or sensitive period: proposals range from age 5 to age 15 (Johnson & Newport, 1989; Krashen, 1973; Lenneberg, 1967; Pinker, 1994; Stevens, 1999). Some authors in the area of bilingualism seem to believe that bilingual speakers who have not acquired their second language early in life tend to show lower levels of proficiency in that language (Bialystok, 2001). However, proficiency in the L2 is usually determined less by age of acquisition than by level of education, socio-economic status, language of education, opportunities to practice the L2, learning context (classroom or immersion), motivation, and family background, among other variables (Bialystok, 2001; Flege, Yeni-Komshian, & Liu, 1999; Grosjean, 1989, 2010; Kaushanskaya & Prior, 2015; Luk, 2015; Stevens, 1999). Moreover, there is an abundance of late-onset bilinguals who attain native-like proficiency levels, which has been viewed as evidence against the critical period hypothesis in second language acquisition (Birdsong, 2003; Bongaerts, 1999; Ioup, Boustagui, El Tigi, & Moselle, 1994).

Despite all of these considerations, *age of L2 acquisition* has been presented in the literature as one of the most defining factors in bilingualism and its impact on cognitive abilities, with research usually reporting that early bilinguals outperform late bilinguals in executive control tasks (Bialystok & Craik, 2010; Bialystok, Craik, et al., 2005; Bialystok, Craik, & Luk, 2008; Bialystok, Craik, & Ruocco, 2006; Bialystok, Craik, & Ryan, 2006; Bialystok, Martin, et al., 2005; Colzato et al., 2008; Costa et al., 2008; Hernández, Costa, Fuentes, Vivas, & Sebastián-Gallés, 2010). Fewer studies have looked for enhanced cognitive abilities in late bilinguals, but some have found them (Bialystok, Craik, & Ryan, 2006; Linck et al., 2008; Pelham & Abrams, 2014; Tao, Marzecová, Taft, Asanowicz, & Wodniecka, 2011). In these studies, it is L2 proficiency level, and not age of acquisition, that usually emerges as the strongest predictor of performance in executive control tasks.

It is important to make a distinction here between late bilinguals and second-language learners, a category that sometimes appears in the literature, in comparisons with monolinguals and early bilinguals (Poarch & van Hell, 2012). In contrast with late bilinguals, who have acquired their L2 later in life, second-language learners are still in the process of learning their L2, and very commonly in the very early stages of it, and therefore have lower proficiency levels in the L2. This is a very valid and interesting comparison (Sullivan, Janus, Moreno, Astheimer, & Bialystok, 2014), but not one that should be interpreted as an age effect on the benefits of bilingualism for cognition.

Age of onset of active bilingualism

Age of acquisition of L2 might tell us something about age effects in second language acquisition, but it does not tell us much about the bilingual experience of the speaker. Since acquiring a second language is a long on-going process, and one that will vary from speaker to speaker, some researchers give more importance to the time from which speakers can be considered active and proficient bilinguals. Thus, this variable —*age of onset of active bilingualism*— seems to be a much more informative variable, as it is not limited by the age at which language acquisition began, referring instead to the age at which bilinguals began actively using both languages on a daily basis —that is, the age at which they began being *active bilinguals* (Luk, De Sa, et al., 2011).

This notion of age of onset of (active, proficient) bilingualism is quite useful for researchers working on bilingualism-led impacts on cognition. If we base our research on the assumption that it is abundant and extended bilingual experience that makes an impact on cognitive abilities, then the variable *age of onset of active bilingualism* should allow us to establish the time from which bilingualism should begin to make a significant impact on cognition —the approximate time from which onwards the use of both languages is active (i.e., daily) and proficient. By contrast, age of onset of L2 acquisition is not very informative here, as onset of acquisition refers to onset of exposure (the age at which the speaker becomes exposed to the second language), and does not equal proficiency or usage —a speaker can be exposed to a L2 for years and yet never become bilingual, because he understands two languages but is only able to use one of them, because he knows two languages but only has very limited opportunities to use one of them, or because of one of dozens of possibilities and contexts that would restrict his bilingualism and refrain him from becoming an active bilingual.

However, studies on bilingualism using this variable *age of onset of active bilingualism* do not all share the same definition of "onset of bilingualism". On the one hand, authors such as Tse and Altarriba (2012), for instance, defined "onset age of active bilingualism" as "the age at which [participants] considered that they had actively begun using their L2" (p. 668), and Luk, De Sa, and Bialystok (2011) defined "onset age of bilingualism" as "the age at which the bilinguals began using both languages on a daily basis" (p. 589). The latter authors also used two separate variables to account for onset of acquisition, on the one hand, and for onset of active bilingualism, on the other. Similarly, Pelham and Abrams (2014) used two separate variables in their study —age of L2 acquisition and age of fluency in L2— and classified their participants as early or late bilinguals "based on the age at which they became fluent in their L2" (p. 317). However, most studies use *age of onset of bilingualism* interchangeably with *age of onset of L2 acquisition* (Ben-Zeev, 1977; Hull & Vaid, 2007; Montrul, 2002; Tao et al., 2011; Vaid & Lambert, 1979), which allows for an important degree of confusion in the interpretation and comparison of results.

Some of the authors who did report on *age of onset of active bilingualism* observed lower conflict resolution abilities in late-onset bilinguals on a flanker task (Luk, De Sa, et al., 2011), as well as a relation between later onset of active bilingualism and poorer performance in a Stroop task (Tse & Altarriba, 2012). In contrast, Pelham and Abrams (2014) found equivalent beneficial cognitive effects for early and late bilinguals on an Attention Network Test. Here too, proficiency level and habitual use of the L2 may have an important impact on results.

Early and late bilinguals and the cut-off point

Whether dealing with *age of acquisition of L2* or *age of onset of active bilingualism*, one issue that permeates the literature is the distinction between *early bilingual* and *late bilingual*. The cut-off age chosen to separate early-onset from late-onset L2 acquisition ranges from 6 years of age (Ansaldo et al., 2015; A. Calabria et al., 2013; Cattaneo et al., 2015; Hull & Vaid, 2007; Morales, Gómez-Ariza, & Bajo, 2013; Prior & MacWhinney, 2010; Tao et al., 2011; Verreyt, Woumans, Vandelanotte, Szmalec, & Duyck, 2015), to 8 years (D. Klein et al., 2014; Kousaie & Phillips, 2012a; Montrul, 2002), 9 years (Rubio-Fernández & Glucksberg, 2012), 10 years (De Carli et al., 2014; Fiszer, 2008), or even 12 years of age (Tao et al., 2011). Some authors are even less specific at differentiating early and late bilinguals, simply identifying them as bilinguals who acquired their L2 before or after adolescence (Buchweitz & Prat, 2013). And the same happens for *age of onset of active bilingualism*, set at 10 years of age by Luk, De Sa, and Bialystok (2011), and at age 13 by Pelham and Abrams (2014).

Other authors (wisely) avoid setting a cut-off age in the differentiation between early and late bilinguals by using *age of L2 acquisition* and/or *age of onset of active bilingualism* as a continuous variable, which makes more sense from a statistical analysis point of view, as an artificial cut-off point is not forced on the data, and there is no loss of information, allowing the numbers to speak for themselves, without imposing pre-conceived notions on the data related to the classification of early and late bilingualism.

Monolinguals

Another issue that sometimes seems to be ignored, or maybe not given the attention it deserves, is the definition of *monolingual*. Even though this is not an aspect of the bilingual experience, we think it is important to address it in this section, as it should come hand-in-hand with the definition of *bilingual*.

In a globalised world, where most societies are multilingual and where exposure to foreign languages is almost unavoidable, finding true monolinguals can turn out to be a daunting —if not impossible—task. It is, thus, extremely important to ensure that monolinguals are, at least, as monolingual as they can be. Most monolinguals will have some knowledge of another language or languages, which is why many authors will base their classification of participants as monolingual depending on self-rating scores on a scale indicating level of proficiency in a L2 (Pelham & Abrams, 2014). However, very commonly, no information is given in published research about what measures were taken in order to avoid issues of wrongful classification of participants as monolinguals.

Length of bilingualism

Another dimension of the bilingual experience that should be taken into account is the *length of bilingualism*. As Luk (2015) points out, if we assume that the intensity and duration of the bilingual experience is relevant to executive control performance, then we need to ask: "how much bilingual experience is enough?" Despite the importance of the age at which bilingualism begins, continual bilingual practice might be more critical for attaining a high degree of proficient bilingualism, as well as play an important role in cognitive change (Abutalebi, Canini, et al., 2015; De Carli et al., 2014). If experience is the trigger for change in the brain, then it should follow that continuous and lengthy experience should result in greater changes than short-lived and inconsistent experience. Furthermore, previous research has indicated that more experience in being bilingual confers more advantages in cognitive control, namely less interference on a flanker task (Bialystok & Barac, 2012; Luk, De Sa, et al., 2011), and more accuracy on a recent-probe working memory task (Bogulski et al., 2015).

The problem with the variable *length of bilingualism* is that, if length of experience using two languages is critical for cognitive benefits to emerge, then early bilinguals should naturally enjoy greater cognitive advantages than late bilinguals, at least if compared at the same age. As Luk, De Sa, and Bialystok (2011) point out, "it is inevitable that the early bilinguals also became proficient in their L2 at an earlier age than the late bilinguals, confounding length of time being bilingual and age of acquisition of a second language" (p. 593). Of course, the way to get around this confounding effect is to collect data from bilinguals of different ages, different ages of onset of active bilingualism, and different lengths of bilingual experience, and include all these variables as predictors in a multiple regression analysis model. However, sometimes there is no simple way of disentangling these factors, as they are so closely connected to each other.

Proficiency in L2

Also very tightly connected with length of active bilingual experience is *proficiency in L2*. High levels of proficiency in L2 are justifiably expected to correlate significantly with both age of onset and length of active bilingualism.

Several studies point to the fact that the cognitive benefits of bilingualism might only be attainable beyond a certain threshold of proficiency (Cummins, 1976). It seems that the degree of structural grey matter reorganisation that occurs in bilingual brains is modulated by level of proficiency (Abutalebi, Canini, et al., 2015; Luk, Bialystok, et al., 2011; Mechelli et al., 2004). Additionally, parallel dual-language activation only seems to occur with high levels of proficiency (Blumenfeld & Marian, 2007; Guo & Peng, 2006; Jared & Kroll, 2001; Perani et al., 1998). There is also evidence from picture-naming and task-switching tasks showing that proficiency could modulate the engagement of executive control areas in bilinguals (Abutalebi et al., 2013; Singh & Mishra, 2013). It also seems to be the case that bilinguals with lower levels of proficiency face increased cognitive demands in language control tasks, when compared with highly proficient bilinguals, who have had the time, exposure and practice necessary to develop a more efficient and automatic processing of conflict (Abutalebi & Green, 2007; Ghazi Saidi et al., 2013). If that is the case, and following the bilingual advantage in inhibitory control hypothesis, their more efficient conflict-processing mechanisms would allow highly proficient bilinguals to outperform both low-proficiency bilinguals and monolinguals in conflict control tasks. This possibility alone makes it vital to carefully measure and control for this variable in studies on bilingualism and cognition. In addition, there seem to be plenty of other reasons to consider *proficiency in L2*, as high levels of second-language proficiency have also been linked in the literature to a myriad of other cognitive abilities and better performance on different executive control tasks, including: better short-term memory and working memory (Biedron & Szczepaniak, 2012; Linck, Osthus, Koeth, & Bunting, 2014; Rosselli, Ardila, Lalwani, & Vélez-Uribe, 2015), higher IQ scores (Barik & Swain, 1976), better convergent thinking (Hommel et al., 2011), faster RTs on a Stroop task (Tse & Altarriba, 2012), and better performance on a Simon task (Rosselli et al., 2015).

Once again, though, we need to pause and consider for a moment the definition of *proficiency*. What researchers consider to be the correct definition of proficiency will of course determine the instrument they choose to measure it, and will ultimately also influence the interpretation of the results they obtain. For this reason, it would be desirable to ensure the use of a common understanding of what constitutes proficiency, so as to guarantee the comparability of studies and corresponding results. Language proficiency can be defined as "the ability to function in a situation that is defined by specific cognitive and linguistic demands, to a level of performance indicated by either objective criteria or normative standards" (Bialystok, 2001, p. 18). Naturally, the cognitive and linguistic demands of each situation may vary immensely, depending on the age of the speaker and the context of the situation. Considering Grosjean's (2010) definition of bilingualism, which is much more oriented towards a pragmatic use of language, we may consider functional proficiency to be of more importance than formal proficiency: the bilingual speaker may have conversational skills and carry out similar activities in each of his languages, even though he may not exhibit native-like fluency in either of his languages (Grosjean, 1985, 1989, 2010). We agree with

Bialystok (2001) that, "ultimately, language proficiency must include both formal structure and communicative application" (p. 14). However, in order to measure second-language proficiency in a way that proves suitable for isolating individual differences that might have an impact on the participants' performance on cognitive control tasks, it may be useful to follow Hulstijn's (2011) distinction between basic and higher language cognition, where *basic language cognition* is restricted to the processing of oral language, containing high-frequency linguistic items, whereas *higher language cognition* also includes the processing of written language and the use of low-frequency linguistic items. Basically, the definition of language proficiency we should be using, particularly when working with adult speakers, should be one that is equally applicable to L1, and the assessment of which makes it possible to distinguish between a speaker who has a basic although solid knowledge and ability to use a language in everyday common contexts, and a speaker who is able to use her (second) language in more than a restricted set of situations, at a superior level of linguistic complexity.

So far, however, there is no universally accepted standard scale of proficiency. Therefore, proficiency has been measured by researchers using translation tests (Abutalebi et al., 2008; Abutalebi et al., 2012), self-, teacher- or parent-reported ratings (Bialystok et al., 2008; Bialystok, Craik, & Ruocco, 2006; Blumenfeld & Marian, 2014; Bogulski et al., 2015; A. Calabria et al., 2013; Cattaneo et al., 2015; Clare et al., 2014; Coderre, Van Heuven, & Conklin, 2013; Duñabeitia et al., 2014; Emmorey, Luk, Pyers, & Bialystok, 2008; Foy & Mann, 2014; Goral, Campanelli, & Spiro, 2015; Gutiérrez-Clellen et al., 2004; D. Klein et al., 2014; Luk et al., 2010; Paap & Liu, 2014; Sabourin & Vinerte, 2015; Tao et al., 2011; Tse & Altarriba, 2012; Verreyt et al., 2015; Woumans et al., 2014), and/or vocabulary tests, such as picture-naming tasks, and animacy-judgement tasks (Abutalebi, Guidi, et al., 2015; Bialystok & Barac, 2012;

Bialystok & Martin, 2004; Bialystok, Peets, & Moreno, 2014; Carlson & Meltzoff, 2008; Hommel et al., 2011; Kousaie & Phillips, 2012a; Luk et al., 2010; Prior & MacWhinney, 2010; Qu, Low, Zhang, Li, & Zelazo, 2015; Vega-Mendoza, West, Sorace, & Bak, 2015). More worryingly, in an analysis of 140 articles comparing groups of language speakers, Hulstijn (2012) found that only 45% of the studies reported the use of an objective language proficiency measure, while 29% of the studies did not include any measure of language proficiency. Additionally, in his analysis of the construct of proficiency used in studies on bilingualism and cognition, Hulstijn (2012) carefully described the drawbacks of using self-assessment as a measure of language proficiency, as well as certain problematic issues related to some of the other assessment types. Hulstijn's (2012) proposal to overcome most of the concerns related to language proficiency assessment within bilinguals and between languages was "to administer tests designed to tap roughly the same LP [language proficiency] component in each language and compare bilinguals' performance to the performance of native-speaker (NS) reference groups in each language" (p. 428). Of course, as the author himself noted, this proposal will be limited by each study's design and specificities. However, an awareness of the potential problems involved in each type of assessment and a thorough description and justification of the instrument(s) used would, no doubt, help establish a much better comparability between studies and results.

Balancedness of proficiency in L1 and L2

An additional issue in the assessment of second language proficiency is the necessary assessment of L1 proficiency, which, as Hulstijn (2012) recommends, should make use of the same measuring instrument used for L2, in order to ensure a desirable level of comparability between assessments of proficiency in both languages, with the ultimate goal of obtaining a measure of the relative proficiency in both languages.

However, this is not always feasible, as some studies include bilingual speakers with varied native languages, which makes it very hard to control for comparability of assessment in L1 and L2.

Some research seems to show that the cognitive benefits of bilingualism are more salient for those bilinguals who are more balanced in their proficiency in both languages. A higher degree of balance between languages has been related to better performance in metalinguistic tasks requiring high levels of analysis (Bialystok, 1988), in problem-solving tasks (Secada, 1991), in go-no/go tasks (Kushalnagar, Hannay, & Hernandez, 2010), in the flanker task (Bialystok & Barac, 2012), and in other tasks involving high levels of control of attention (Bialystok & Majumder, 1998). However, Goral et al. (2015), in a study comparing dominant bilinguals (i.e., less balanced, for whom one of the languages is more dominant) with balanced bilinguals in three different executive control tasks, found that only balanced bilinguals showed age-related inhibition decline (a greater Simon Effect with increasing age). Similarly, Paap, Johnson, and Sawi (2014) found that a higher degree of balancedness was associated with an increase in the Simon Effect (i.e., greater levels of conflict interference).

It may also be the case that different aspects of the bilingual experience may impact the mechanisms of cognitive control in different ways: being a more balanced bilingual might be associated with using different cognitive-control mechanisms than being a more dominant bilingual (Paap et al., 2014). In fact, Tao and colleagues (2011) tested bilinguals with different levels of balancedness using the Attention Network Test, and reported that less balanced bilinguals showed greater advantages in monitoring, whereas more balanced bilinguals showed greater advantages in conflict resolution.

Balancedness of bilingual language use

Another feature of bilingualism that might have a significant impact on cognitive abilities is *balancedness of bilingual language use*, or the degree to which both languages are being used. Some authors also refer to this variable as *frequency of language use* (Heidlmayr et al., 2014). Bilingualism is a very diverse experience marked by individual and contextual factors such as diglossia (when the members of a community speak two languages, with common switching between them), restriction of language use to specific contexts (e.g., L2 at work and native language at home), social prestige associated with each language, and social ties with the linguistic communities of interest. Factors such as these will shape the bilingual experience, in most cases leading to a greater use of one language in comparison to the other.

If an advantage in cognitive abilities is partly due to the experience in switching between two languages, then it should follow that the more balanced the use of the two languages, the more language control experience the speakers will obtain, and thus more chances of gaining cognitive benefits. A bilingual speaker who only uses one of his languages 20% of the time should, therefore, show lesser cognitive advantages than a bilingual speaker who uses each of her languages 50% of the time, since the latter has had much more experience at managing two linguistic systems than the former. Unfortunately, little is known about the role of balancedness of bilingual language use in cognitive control task performance, as this factor has not systematically been taken into account. Heidlmayr et al.'s (2014) study is a rare exception: the authors investigated the role of the frequency of daily use of L2 and L3 on conflict resolution, measured by means of a colour-word Stroop task, and found that the more the bilinguals used an additional third language, the smaller their Stroop effect was.

Heidlmayr et al. (2014) interpreted these results as suggesting that experience in controlling a L3 confers better conflict-resolution abilities in the Stroop task.

However, Von Bastian, Souza, and Gade (2015, as cited in Paap, Johnson, et al., 2015) conducted a study using age of acquisition, usage, and proficiency as continuous predictors of executive function, and found no connection between any of these three aspects of bilingualism and any of the cognitive control measures, which included inhibitory control, monitoring, and switching.

As with most of the features of bilingual experience, it is quite problematic to measure the *balancedness of bilingual language use*. On the one hand, the researcher is limited to a self-reported assessment, as there is no other way to ascertain language use. On the other hand, there are many different language-use configurations to a reported 50%–50% balancedness level: a bilingual speaker who spends the first part of his day using his L1 and the second part of the day using his L2 and a bilingual speaker who has to keep switching between languages throughout the day both will report a 50%–50% balancedness level of bilingual language use. These limitations must be acknowledged when interpreting any results obtained using this variable.

Language-switching frequency

One way of overcoming the limitations of a variable such as *balancedness of bilingual language use* is by collecting additional data on daily frequency of switching between languages. Some authors will use the term *language-switching frequency* to refer to frequency of language use, though, which can lead to confusion. *Frequency of language use* refers to daily percentage use of each language; *frequency of language switching*, on the other hand, refers to how often in a day speakers switch from one language to the other.

Language switching has been of interest in the bilingual advantage literature in studies that investigated the relationship between language control and inhibitory control, where participants usually performed language-switching tasks and non-linguistic task-switching tasks in order to compare these two different cognitive control mechanisms (Abutalebi et al., 2008; Abutalebi et al., 2013; Abutalebi et al., 2012; Garbin et al., 2011; Linck, Schwieter, & Sunderman, 2012; Luk, Green, et al., 2011). However, it is not common to see it used as an individual-difference variable, even though some authors have noted the need to take a closer look at this factor (Fiszer, 2008; Kaushanskaya & Prior, 2015). If dual-language control delivers cognitive control benefits, it should follow that bilinguals who switch between languages more frequently would have a more extensive (and intensive) experience of parallel language activation. This experience would presumably translate into more efficient executive control. For this reason, *language-switching frequency* appears to be an important variable to take into consideration.

Language switching, or *code switching*, is a phenomenon that has captured linguists' attention for a long time (Sankoff & Poplack, 1981). It is usually defined as "the ability on the part of bilinguals to alternate between their linguistic codes in the same conversational event" (Toribio, 2001, p. 204), but includes different bilingual behaviours: sometimes the switching occurs between the turns of different speakers, sometimes between utterances within a single speaker's turn, and sometimes even within a single utterance. It seems useful to clarify that code switching does not refer to a compensatory process, by which speakers make up for a lack of vocabulary or linguistic knowledge in one language by resorting to the other language. It is, on the contrary, a linguistic phenomenon consciously performed mainly by and among highly proficient bilinguals (Toribio, 2001), which has meaning in and of itself. Bilingual speakers may switch between languages, for instance, as a way of signalling to their interlocutors how they wish their utterances to be interpreted (Wei, 2013), or as a structuring device to emphasise a point, or to clarify or focus issues under discussion (Moyo, 1996). Language switching does not occur randomly either, as the switching from one language to the other obeys coherence principles and linguistic structure demands. Moreover, the code-switching speaker needs to monitor the conversational context for cues that may help indicate whether switching would be appropriate or not, having thus to deal with increased attentional control demands.

There are a very small number of studies that investigated the impact of language-switching frequency on cognitive control performance, using either a numerical or ordinal coding of the variable. Prior and Gollan (2011) compared habitual language-switching bilinguals, low-frequency language-switching bilinguals, and a monolingual control group on task-switching and language-switching tasks performance. The authors found that habitual language switching is associated with performance advantages in both non-linguistic and linguistic switching tasks. Similarly, Yim and Bialystok (2012) found that participants who engaged in more frequent code switching showed smaller costs in a verbal switching task but not on a non-linguistic switching task. Finally, Verreyt and colleagues (2015) compared the performance of unbalanced bilinguals, balanced non-switching bilinguals, and balanced switching bilinguals on a Simon task and on a flanker task. The authors found that frequent language-switching bilinguals outperformed the other two groups in task performance.

As the bilingualism trait probably more at the centre of research on bilingualism and executive functioning, it seems counterintuitive that *language-switching frequency* has been so overlooked as a confounding variable and is not included in more studies.

If language-switching experience is conducive to changes in executive control, mixing high-switching and non-switching bilinguals in the same sample without controlling for this variable might lead to compromised results.

Summary

Many more facets of the bilingual experience, which may have an important effect on executive control abilities, could be presented here. The diversity of the bilingual experience is vast and the individual differences multiply, according to the contexts of language use, language of instruction, mode of language learning (instructional or conversational), political, social and cultural hierarchical differences between languages, number of languages known and actively used by the speakers, language family and language group the L1 and L2 belong to, or linguistic typological proximity between L1 and L2.

Many of the existing studies on bilingualism and cognition have revealed a tendency to include, in the same bilingual sample, individuals whose bilingual experience characteristics and histories differ significantly, without attempting to investigate the importance of such variables, focusing instead on group-level comparisons (Baum & Titone, 2014). However, these different dimensions of the bilingual experience, in isolation or in combination, may exert distinct effects upon different aspects of executive control. We thus second Kaushanskaya and Prior's (2015) proposal to change directions:

> We urge researchers to move away from attempting to equate experimental groups on extraneous variables in order to pinpoint the effects of bilingualism on EF [executive functioning], and to move toward distilling bilingualism to a few key continuous variables, linking these variables to EF using individual-variability approaches. … Once group-based constraints are lifted, the multi-

dimensional effects of bilingualism on EF can be considered within the broader milieu of human experience. (Kaushanskaya & Prior, 2015, pp. 1-2)

1.3.2 Individual-Difference Variables

Despite Peal and Lambert's (1962) criticism of previous research for not controlling significant factors that had been proven to impact executive functions, some studies still show methodological weaknesses in this respect. More recently, other authors have reiterated this caution (Bialystok, 2001; Hilchey & Klein, 2011), but inconsistencies and insufficiencies persist in this literature. There are several individual-difference variables non-specific to bilingualism that are known to impact individuals' cognitive development and abilities that must be controlled for as well as possible, in order to avoid confounding effects. In the next sections we will describe and discuss some of these variables, as well as the methodological weaknesses showed by some studies that failed to fully control for them.

Age

Age is no doubt one of them, as it is common knowledge that there are strong age effects on the development and decline of cognitive abilities (Craik & Bialystok, 2006; Daniels, Toth, & Jacoby, 2006; Mezzacappa, 2004) and that older age correlates significantly with cognitive decline in specific cognitive abilities (Hasher et al., 2007; Hasher & Zacks, 1988).

In studies on bilingualism, it is common to see groups of participants matched for age, placing together in the same group participants with ages between, for instance, 19 and 32 years old (Costa et al., 2008), or 18 and 35 years old (Kousaie & Phillips, 2012a, 2012b). Even though we appreciate that this matching of groups for age is an attempt to control for this powerful variable, it would be much more informative in our opinion to include *age* as a continuous variable. Grouping participants around a mean and fitting them all into one or two age groups leads to the loss of the variance accounted for by the individual ages of each participant, and the statistical analysis thus loses considerable statistical power. Of course, in order to include *age* as a continuous variable, robust sample sizes would be needed, and that is not always possible in research. However, matching groups for age without adding *age* to the analyses, as a continuous variable, or restricting samples in age can only give us incomplete snapshots of the relationship between bilingualism and cognition, as we are only accessing a very narrow moment in the development of cognitive abilities. We know that cognitive control peaks in the late teens and early twenties and declines with aging (Craik & Bialystok, 2006), which makes it challenging to compare results of studies performed on children with studies performed on young adults. One of the consequences of this methodological choice is the fact that, initially in this field, a substantial amount of research only examined bilingualism in children (Bialystok & Majumder, 1998; Bialystok & Martin, 2004; Hakuta, 1987; Hakuta & Diaz, 1985; Kovács, 2009). Then, some studies started to be conducted on bilingualism in young adults (Bialystok & DePape, 2009; Blumenfeld & Marian, 2014; Costa et al., 2008; Luk et al., 2010; Tao et al., 2011). And lately there have been a growing number of studies on bilingualism in older age (Abutalebi, Canini, et al., 2015; Ansaldo et al., 2015; A. Calabria et al., 2013; Goral et al., 2015; Kousaie & Phillips, 2012a). However, not many studies have been performed on bilingualism in adolescence or adulthood.

Fluid intelligence

Intelligence is similarly known to modulate cognitive control (Gray, Chabris, & Braver, 2003). Additionally, it is connected with *age* as well, with intellectual abilities related to fluid intelligence declining from young to older adulthood, while crystalized intelligence seems to rise until the age of 70 (Horn & Cattell, 1967; Jones & Conrad, 1933). *Crystallized intelligence* is shaped by learning and culture, and it reflects experience and knowledge, whereas *fluid intelligence* refers to the ability to identify complex relations and to draw inferences on the basis of that comprehension (Cattell, 1987). This differentiation between these two types of intelligence is of special relevance in the field of bilingualism and cognition: *crystallized intelligence* is highly dependent on education level, cultural background and socio-economic status, but most importantly, it is measured using language. These factors make it impossible to measure bilinguals and monolinguals using the same scale, particularly when so many of the bilingual samples are migrant and come from very different cultural backgrounds. Therefore, the more appropriate variable to measure and include in the studies on bilingualism should be instead *fluid intelligence*, as it is less restricted by other extraneous variables, it is not verbal in nature, and it is not measured through the use of language.

Some studies have found a relationship between bilingualism and intelligence. Particularly since Peal and Lambert's (1962) study, other authors found that bilinguals exhibited higher scores on IQ tests than their monolingual peers (Barik & Swain, 1976), and that more proficient bilinguals, with lengthier bilingual experience, also outperformed less proficient bilinguals (Barik & Swain, 1976; Hakuta, 1987; Hakuta & Diaz, 1985). More recently, criticism regarding methodological issues with measuring intelligence, controlling for confounding variables, and ensuring comparability between groups has distanced the field of bilingualism from the notion that bilingualism may impact intelligence (Edwards, 2006). There is, however, overall agreement that higher intelligence is related to greater success in second language acquisition (Teepen, 2005), but no causation can be established, of course.

A connection between non-verbal intelligence and executive functions has also been reported. Rosselli and colleagues (2015) compared the performance of balanced and unbalanced bilinguals and monolinguals of different levels of proficiency on non-verbal working memory, updating, shifting, and inhibition tasks. The authors reported that non-verbal intelligence significantly predicted performance on verbal working memory and verbal and non-verbal inhibition tasks, and concluded that non-verbal intelligence was a better predictor of executive function performance than bilingualism or language proficiency.

Socio-economic status

Socio-economic status too has been associated with differences in performance in a number of attention control tasks (Farah & Noble, 2005; Mezzacappa, 2004; Morton & Harper, 2007; Noble, Norman, & Farah, 2005). However, as Hilchey and Klein (2011) point out, *SES* is rarely controlled for in the literature on bilingualism and cognitive control. In fact, Morton and Harper (2007, 2009) replicated previous studies that had reported a bilingual advantage on the Simon task, but introduced a direct control for *SES*, and found a monolingual advantage on the Simon effect, instead of a bilingual advantage. Significantly, Morton and Harper's (2007) results highlight the importance of directly controlling for *SES* in studies on bilingualism —using, whenever possible, a composite measure of education level, income level, and occupation—, instead of relying on indirect evidence, such as education level alone or area of residence, as representative of *SES* homogeneity (Bialystok, 2011; Bialystok, Peets, et al., 2014; Emmorey et al., 2008; Feng et al., 2009).

Education level

Education has been shown to be the main life course factor strongly associated with global cognition, episodic memory, semantic memory, and visuospatial ability, particularly in older age (Jefferson et al., 2011). It has also been suggested that education might protect against cognitive decline, delaying the onset of Alzheimer's disease (Bennett et al., 2003; Stern et al., 1992). For this reason, *education level* needs to be controlled for in studies on bilingualism and cognition, as differences in education may explain and clarify some of the results obtained in executive control tasks. Gollan, Salmon, Montoya, and Galasko (2011), for instance, found that degree of bilingualism was related to later onset age of dementia only for bilinguals with lower education, while there was no such association for bilinguals who had a high-school level of education or higher. Prior and Gollan (2011) also found an impact of education level on their results, with switching costs exhibited by a sample of bilinguals being negatively correlated with education levels, and with a bilingual advantage in switching costs only visible after controlling for education.

Immigration status

There has been substantial discussion over the impact of *immigration status* on bilingualism, especially since some bilingual samples are from countries or regions where native bilingualism is a social and cultural reality (e.g., French-English bilinguals in Canada or Catalan-Spanish bilinguals in Spain), whereas most bilingual samples are part of immigrant communities. These different bilingual realities entail very dissimilar bilingual experiences: while in the first case, bilinguals are born and raised in a bilingual environment, and that life experience does not distinguish them from the other members of the same community, immigrant bilinguals' experience contrasts strikingly with the life experience of non-immigrant non-bilingual members of their community. Non-immigrant bilinguals are often immersed in both of their languages, which usually have similar official status, whereas immigrant bilinguals will usually be immersed in their L2, and use their L1 mainly to communicate with family and friends. Non-immigrant bilinguals tend to learn both their languages from an early age, while immigrant bilinguals will either learn the L2 at a later age through instruction or through interaction with people. Additionally, different immigrant communities will have different socio-economic profiles, which translate as sometimes strikingly different SES and education levels: some immigrant communities will have higher education levels than the native population but lower SES, while other immigrants' education level and SES will be lower than that of the native population. Therefore, all these differences between immigrant and non-immigrant bilingual populations make it necessary to take *immigration status* into account when investigating the relationship between bilingualism and cognitive control.

Engel de Abreu and colleagues (2012), for instance, compared Portuguese immigrant bilingual children living in Luxembourg with Portuguese monolingual children living in Portugal on different cognitive control measures, and found a bilingual advantage in the performance on the cognitive control tasks. The authors claim that their results show that economic and cultural differences can be ruled out as a competitive explanation for the advantage found. However, the two groups did not differ only on whether or not they were bilingual; one of the groups had migrated to another country and lived as immigrants in a foreign country, which might act as a confounding factor. There is some evidence indicating that exposure to a multilingual environment alone might be enough for advantageous cognitive changes to occur (S. P. Fan et al., 2015). Some other authors have chosen to control for *immigration status* by using non-immigrant groups of bilinguals and monolinguals (Kousaie & Phillips, 2012a). Alternatively, Bialystok and Viswanathan (2009) compared non-immigrant monolinguals, non-immigrant bilinguals, and immigrant bilinguals on a behavioural version of an anti-saccade task, and found that both bilingual groups were equally faster than the monolingual group in conditions based on inhibitory control and cognitive flexibility but there was no significant difference between groups in response suppression. The authors interpreted the results as ruling out the role of immigration experience in the participants' performance. However, it would have been useful to have a group of immigrant monolinguals to compare with the remaining groups. These studies are, unfortunately, alone in investigating the role of this variable in bilingualism and cognitive control; more studies should control for *immigration status*.

Activities known to impact executive control abilities

As we have mentioned earlier (see section *1.2 The Bilingual Advantage Hypothesis*), a large number of studies show that intensive and long-lasting engagement in certain activities appear to have significant impacts in general cognitive functioning (Reuter-Lorenz, 2002). Some of these lifestyle experiences include: social engagement, an active routine, fitness and physical activity, music training, exposure to other cultures, meditation, and video game playing. Valian (2015) argues that the lack of study of these and other cognitively enriching experiences may account for the inconsistency of results investigating a potential cognitive advantage due to bilingualism. We agree with Valian (2015), as the skills necessary to complete successfully some of the widely used cognitive control tasks may be obtained or exercised through other activities that are not bilingualism. This issue leads to the question: what are we measuring when we measure cognitive control?

1.3.3 Measuring Conflict Control

As Valian (2015) points out, "tasks measuring executive function measure multiple processes simultaneously, including processes that are not part of executive function, like response readiness" (p. 4). Even if we were able to control for all individual-difference and bilingualism-specific variables, we would still be left with the fact that the task we have chosen to measure conflict monitoring or inhibition control will also introduce further variables that might influence results.

The use of different tasks that are meant to measure executive functions introduces a comparability problem. Since all tasks measure slightly different abilities or conglomerates of different abilities, comparing results obtained by using different tasks becomes problematic (Valian, 2015). Take two tasks that seem as similar as the Simon task and the Attention Network Test, which are supposed to measure the same construct —the ability to select the appropriate response and simultaneously ignore irrelevant information. There is indeed evidence to suggest that similar brain regions, most notably the anterior cingulate cortex, support performance in both tasks (Botvinick et al., 1999; Peterson et al., 2002). However, some authors suggest that, even though there is common activation of the same brain regions across both tasks, there may exist different networks to solve these two types of conflict tasks, since there are significant differences between the way in which these brain areas are activated during each task (J. Fan, Flombaum, McCandliss, Thomas, & Posner, 2003). Moreover, reaction times have been found to be slower and conflict effects to be more accentuated in the ANT than in the Simon task (Stins, Polderman, Boomsma, & de Geus, 2005). These differences in timing, together with a possible dissociation in brain-area activation, seem to suggest that conflict affects at least somewhat different cognitive-control processes in each task (Mansfield, van der Molen, Falkenstein, & van Boxtel, 2013). These differences between tasks also seem to be reinforced by very weak or non-existent correlations between conflict effects in the two tasks, despite usually strong correlations in overall reaction times (Stins et al., 2005).

Additionally, task design introduces yet another source of variability. Comparing just a few of the studies that used the Simon task to compare the performance of bilinguals and monolinguals, we see that there are differences in the procedures. In the Simon task, a trial is usually comprised of a fixation point, followed by a blank interval, followed by the stimulus, followed by a second blank interval. However, the variation we see between studies in the duration (or even inclusion) of each step is remarkable: the fixation cross at the beginning of each trial is sometimes presented on the screen during 150 ms (Bialystok, Craik, et al., 2005), other times during 300 ms (Bialystok et al., 2004, studies 2 and 3), 500 ms (Blumenfeld & Marian, 2014; Paap & Greenberg, 2013), or 800 ms (Bialystok, 2006; Bialystok et al., 2004, study 1; Morton & Harper, 2007; Poarch & van Hell, 2012). This fixation point will sometimes be followed by a blank interval lasting 250 ms (Bialystok, 2006; Bialystok et al., 2004, study 1; Morton & Harper, 2007; Poarch & van Hell, 2012) or 350 ms (Bialystok, Craik, et al., 2005), and sometimes there will be no blank interval at all (Bialystok et al., 2004, studies 2 and 3; Blumenfeld & Marian, 2014; Paap & Greenberg, 2013). The stimulus will then be presented during 400 ms (Bialystok, Craik, et al., 2005), 700 ms (Blumenfeld & Marian, 2014), or 1000 ms (Bialystok, 2006; Bialystok et al., 2004, study 1; Morton & Harper, 2007; Poarch & van Hell, 2012). Discrepancies are also found on the blank interval at the end of each trial. These sorts of procedural differences lead to potential interference of other factors such as *temporal preparation* effects. It is known that manipulation of the foreperiod (the neutral warning signal that precedes the target stimulus by a specific amount of time) leads to optimal performance for relatively short foreperiods at around 400 ms and to a performance decrement with longer foreperiods (Seibold & Rolke, 2014).

1.4 Our Study

The main objective of this study was the investigation of the potential impact of bilingualism on conflict control. Taking into consideration all the theoretical and methodological issues discussed so far, we set out to find answers to a number of questions:

Is there a difference in performance in conflict control tasks between monolinguals and bilinguals?

In order to answer this question, we compared the performance of a group of monolingual speakers and a group of bilingual speakers on two conflict control tasks, namely the Simon task and the Attention Network Test. We used these tasks in order to replicate and extend the studies led by Bialystok and colleagues (2004), which used an altered version of the Simon task (study 2), and by Costa and colleagues (2009), who opted for an adapted version of the ANT (experiment 2, version 1). Both adapted versions of these tasks were originally altered in order to increase conflict control demands, as well as working memory demands (in the case of the Simon task used by Bialystok et al., 2004).

Importantly, the two studies on which the current procedures were based reported bilingual advantages in conflict monitoring and/or resolution. Bialystok et al. (2004) found an association between bilingualism and smaller Simon Effects, as well as a bilingual advantage in overall RTs in conditions that included greater working-memory demands. A more robust bilingual advantage was additionally found for older adults when compared with younger bilinguals. In their experiments, Costa et al. (2009) used different task versions, with different proportions of congruent and incongruent trials in order to investigate whether the bilingual advantage typically found in overall RTs was due to an advantage in monitoring. They found the effect of bilingualism on overall RTs to be restricted to a high-monitoring condition using 50% of congruent trials and 50% of incongruent trials.

In case a difference is found between groups, is it related to monitoring mechanisms or to inhibition control?

Participants' performance was compared and analysed on reaction times, accuracy rates (ARs), conflict effects, and sequential congruency effects. A significant difference between groups in conflict effects would support the existence of a difference between monolinguals and bilinguals on inhibitory control mechanisms, while a significant difference in overall reaction times would indicate a difference in conflict monitoring abilities.

We would like to highlight the fact that we analysed the performance of bilinguals and monolinguals in sequential congruency effects, which is, as far as we know, the first time such an analysis was carried out in the field of bilingualism and cognition. This analysis aimed at investigating whether bilinguals exhibited reduced sequencing effects, as would be expected if there is a bilingual advantage in conflict adaptation (Hilchey & Klein, 2011).

Do the results obtained in these tasks reveal any other differences in cognitive abilities between groups?

We took the opportunity of using these particular tasks to look at the participants' performance in other measured abilities that may contribute to the results on conflict control. The additional components we analysed were: the alerting effect, the orienting effect, and working memory costs.

Which individual-difference variables have a significant effect on performance in conflict control tasks?

In order to address this question, we collected and analysed data on a variety of individual-difference variables, which we considered might have a relevant impact on the bilingual experience and/or on executive functions. These included: age, gender, fluid intelligence, education level, socio-economic status, immigration status, length of immigration experience, and frequency of music playing, video-game playing, exercise, and meditation.

Which features of the bilingual experience have a significant effect on performance in conflict control tasks?

So as to address this question, we collected data on a variety of bilingualism-specific variables, which we believe may have a relevant impact on the bilingual experience. These included: proficiency in English, age of onset of active bilingualism, length of active bilingualism, balancedness of bilingual language use, and language-switching frequency.

In the following chapter, we describe every step of our methodological approach to these research questions.

2 Methodology

2.1 Participants

All participants went through a pre-screening procedure, in which they answered a short questionnaire (see Appendix A) about their age, country of origin, languages spoken, language proficiency, language use (including length of active bilingualism and balancedness of bilingual language use), and length of immigration experience. All recruited participants had to meet certain criteria in order to be accepted in the study, namely: having been a migrant in an English-speaking country for the 5 years prior to the study, being 18 years of age or older, and having a high level of proficiency in English. Bilingual participants also had to qualify as active bilinguals (i.e., speaking at least two languages every day or almost every day) for at least the 5 years prior to the present study.

Of the 137 participants who met the pre-screening criteria, 17 were excluded from the study for not obtaining an English proficiency score that would categorize them as highly proficient in English and thus match their pre-screening self-rated scores. Additionally, 5 participants had to be excluded from the study for not having provided sufficient data when answering the background measures questionnaires.

The final sample comprised 115 adults, of whom 38 were English monolinguals and 77 were bilinguals. The bilingual participants all had English as a second language, and had many different first languages: Arabic (2), Chinese (14), Filipino (1), Finish (1), French (4), German (12), Hindi (6), Hungarian (4), Italian (3), Korean (7), Marathi (1), Persian (1), Polish (1), Portuguese (4), Russian (1), Serbian (1), Sinhala

(2), Slovak (1), Spanish (4), Swedish (1), Tamil (1), Thai (1), Turkish (2), Ukrainian (1), and Urdu (1).

The ages of participants ranged between 18 and 57 years old for monolinguals (*M* = 31.1, *SD* = 12), and 19 and 55 years old for bilinguals (*M* = 31.6, *SD* = 10). The monolingual group included 26 females and 12 males (68% and 32%, respectively), while the bilingual group had 58 females and 19 males (75% and 25%, respectively). The participants did not differ significantly by *Gender*, $\chi^2(1, N = 115) = .62, p = .43$. Of the monolinguals, 32 self-identified as being right-handed, 5 left-handed, and 1 ambidextrous (84%, 13% and 3% of the monolingual sample, respectively). In the bilingual group, 65 participants identified themselves as right-handed, 9 as left-handed, and 3 as ambidextrous (84%, 12% and 4%, respectively). The participants also did not differ significantly by handedness, $\chi^2(2, N = 115) = .16, p = .92$.

Groups

Participants were classified as monolinguals if they had little or no knowledge of another language. When asked about whether they knew or had ever learned a second language, participants who replied affirmatively were then requested to rate their own proficiency in such language(s) on a Likert scale of 1 to 7, where 1 corresponded to “very poor” and 7 to “native-like” (see Appendix B). Participants who self-rated as having a degree of proficiency in a language other than their native language of 3.5 points or higher were not considered monolingual for the purposes of this study and were therefore excluded from the sample. The 27 monolingual participants who reported having some knowledge of a second language, at a very poor to low level of proficiency, also indicated not ever having been able to communicate in another language apart from their native tongue (English), which eliminates the possibility of these participants ever having had enough knowledge of a second language to be classified as bilinguals.

The participants included in the study as bilinguals also needed to meet some eligibility criteria. English was the assessed language, with proficiency in it being compared among all participants, so, in order to be considered bilingual and be eligible to participate in this study, bilingual participants had to have English as a second language and to be highly proficient in this language (they needed to score 48 points or higher on a 60-point test. For more information on this English proficiency test, please see section *2.4 Measures*). Participants also had to be highly proficient in their native language. Since our bilingual group had so many different L1s, adequate testing of L1 proficiency was not feasible, so we had to rely on self-assessment scores on reading, writing, speaking and oral comprehension, obtained on Likert scales of 1 to 7, where 1 corresponded to "very poor" and 7 to "native-like" (see Appendix B). The 4 scores were then averaged. All bilingual participants had a total L1 proficiency score of 5.5 or higher. Bilinguals also had to have used both English and their native language on a very regular basis (daily or almost daily) for at least the 5 years prior to the data collection, which should have been spent in an English-speaking country. In other words, at the time of the experimental session, bilinguals had to have been active and highly proficient L2-immersed bilinguals, for at least the previous 5 years. No restrictions were made on the number of languages or the specific languages the participants mastered.

Education level

Information regarding participants' education level was collected as part of the Socio-Economic Status Questionnaire (see Appendix C). Participants selected their education level from a list comprising eight levels: (1) Less than High School, (2) High

School, (3) Certificate, (4) Diploma, (5) Bachelor's degree, Graduate Diploma or Graduate Certificate, (6) Postgraduate Diploma, Postgraduate Certificate or Bachelor's degree with Honours, (7) Masters, and (8) Doctorate. This list is an adapted version of the New Zealand Qualifications Framework (NZQF) (New Zealand Qualifications Authority, 2011).

After the data were collected, the list was recoded: level 1 (Less than High School) was eliminated, as no participants placed themselves in this category; and levels 2 (High School), 3 (Certificate), and 4 (Diploma) were collapsed into one, given to low numbers in each group. The final list of education levels used in this study was: (1) High School, Certificate or Diploma, (2) Bachelor's degree, Graduate Diploma or Graduate Certificate, (3) Postgraduate Diploma, Postgraduate Certificate or Bachelor's degree with Honours, (4) Masters, and (5) Doctorate.

Socio-economic status

Given that the sample also included full-time students ($N = 61$), we calculated socio-economic status according to the New Zealand Socio-Economic Index 2006 (NZSEI-06) (Milne, Byun, & Lee, 2013), whose authors suggest that, for full- or part-time workers, SES level should be determined from their occupation, while for full-time students the average of both parents' occupations should be used instead to calculate the participants' SES (Milne et al., 2013, p. 118).

The NZSEI-06 recommends 6 SES levels, 1 being the highest and 6 the lowest (Milne et al., 2013, p. 48). When parents' occupations were used, the final score was the average of both parents' scores, rounded up (e.g., participants whose parents' occupational levels averaged 2.5 were given an SES score of 2). For ease of analysis, one participant with a score of 6 was added to the group of participants who scored 5, which means that, for the purposes of this study, only 5 levels of SES were used (the 5 highest levels of the NZSEI-06).

Proficiency in English

Even though the participants had been asked, during the pre-screening process, to self-rate their proficiency in English, using a Likert scale of 1 ("very poor") to 7 ("native-like") (see Appendix A), the English proficiency scores obtained this way were only used as an initial and temporary assessment of whether the participants met the criterion of being highly proficient in English. This assessment was later corrected, by means of an English proficiency test. For reasons already explored earlier in this thesis (see section *1.3.1 Diversity of the Bilingual Experience – Proficiency in L2*), we believe that objective testing scores tend to be more reliable than self-assessment ones, which is the reason why the actual English proficiency scores used in this study were the ones obtained by participants in the English proficiency test, which was taken as part of the data collection session. Both monolingual and bilingual participants completed the English proficiency test, since English was the language all participants had in common in this study, and also to ensure that all participants went through the same experimental procedure. We assessed English proficiency by means of the Oxford Quick Placement Test (OQPT) (Oxford University Press & University of Cambridge Local Examinations Syndicate, 2001). Participants with a score level of *Advanced* or *Very Advanced* were deemed highly proficient in English and included in the study.

Analysis of background measures

The mean scores for the main background measures —namely, *Age*, *Education Level*, *Socio-Economic Status*, *Fluid Intelligence* and *English Proficiency*— can be observed in Table 1. More information about the instruments used to measure these variables will be provided in section *2.4 Measures*.

Table 1

Means (M) and Standard Deviations (SD) for Background Measures

		Age	*Education Level*	*SES*	*Fluid Intelligence*	*Proficiency in English*
Group	*N*	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
Monolingual	38	31.1 (12)	2.2 (1.3)	2.6 (1.2)	113.1 (15)	58 (2)
Bilingual	77	31.6 (10)	3.0 (1.4)	2.3 (1.4)	112.7 (14)	55 (3)

Notes: *N* = number of participants. Education level [1 = lowest to 5 = highest], socio-economic status (SES) [1 = highest to 5 = lowest]. Proficiency in English [60 = highest possible score].

One-way ANOVAs were performed to ascertain if the two groups of participants differed significantly in the main background measures. Monolinguals and bilinguals did not show statistically significant differences in *Age*, $F(1, 113) = .063$, $p = .80$, 95% CI [-4.6, 3.6], *SES*, $F(1, 113) = 1.05$, $p = .31$, 95% CI [-.26, .82], or *Fluid Intelligence*, $F(1, 113) = .022$, $p = .88$, 95% CI [-5.4, 6.2]. However, they did differ in *Education Level*, with the bilingual participants presenting a slightly higher education level than the monolinguals, $F(1, 113) = 8.25$, $p = .005$, 95% CI [-1.3, -.24]. Participants also differed significantly in the *English Proficiency* results, with the monolinguals showing a higher proficiency in the language than the bilinguals, $F(1, 113) = 23$, $p < .001$, 95% CI [1.6, 3.9].

Immigration status and length of immigration

The two groups of participants were matched for *Immigration Status*, which was one of the criteria to participate in the study. All participants, monolinguals included, were immigrants in New Zealand at the time of the data collection. Monolinguals had an average of 10.8 years and bilinguals an average of 11.9 years of immigration experience in English-language countries. A one-way ANOVA showed no significant difference between the two groups on *Length of Immigration*, $F(1, 113) = .60$, $p = .44$, 95% CI [-4.09, 1.80].

Activities with an impact on executive functions

The participants were also asked to fill out a questionnaire where they indicated if and how frequently (on a scale of "0 = Never" to "5 = Very Frequently") they played a musical instrument, played video games, exercised, or meditated (see Appendix D). The mean scores for these variables can be observed in Table 2.

Table 2

Means (M) and Standard Deviations (SD) for Activities with an Impact on Executive Functions

		Music Playing	*Video-Game Playing*	*Physical Exercise*	*Meditation*
Group	*N*	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
Monolingual	38	2.05 (1.5)	1.76 (1.3)	2.95 (1.4)	.63 (1.0)
Bilingual	77	2.40 (1.6)	1.49 (1.6)	2.61 (1.4)	.73 (1.1)

Notes: *N* = number of participants. All variables measured on a Likert scale of "0 = Never" to "5 = Very Frequently".

One-way ANOVAs revealed that monolinguals and bilinguals did not show statistically significant differences in how frequently they performed any of these activities: *Music Playing*, $F(1, 113) = 1.25$, $p = .27$, 95% CI [-.97, .27], *Video-Game Playing*, $F(1, 113) = .80$, $p = .37$, 95% CI [-.33, .87], *Physical Exercise*, $F(1, 113) = 1.43$, $p = .23$, 95% CI [-.22, .90], and *Meditation*, $F(1, 113) = .20$, $p = .66$, 95% CI [-.52, .33].

Bilinguals

Bilinguals of all *Ages of Onset of Active Bilingualism* were included in the study, with the final sample containing 38 bilinguals (49.4%) who became active bilinguals, with English as a second language, before and including 13 years of age (M = 6.5), and 39 participants (50.6%) who became active bilinguals, with English as a second language, between the ages of 15 and 49 years old (M = 23.3).

Length of Active Bilingualism was measured as the number of years during which the participants were exposed to both English and their native language, using both languages very frequently (every day or almost every day). The participants reported between 5 years and 41 years of active bilingual experience (M = 15.7).

In order to measure the *Balancedness of Bilingual Language Use*, bilingual participants were asked to give two types of information at different points: initially, as part of a pre-screening process, participants were asked what percentage of their daily language usage corresponded to the use of English and what percentage corresponded to the use of their native language (see Appendix A); later, during the data-collection session, they also gave more detailed information about how many hours per week they spent, on average, in different linguistic activities (talking, writing, watching TV, browsing the internet, etc.) for each of their languages (see Appendix B). The total of hours spent using each language were converted into percentage scores, with 100% representing the total of both languages' use in all activities. These scores were then averaged with the first percentages provided by the participants in the pre-screening questionnaire. The final scores for *Balancedness of Bilingual Language Use* correspond to the proportion of time participants reported using English. Bilingual participants reported using English daily on average 71% of their time, in comparison with 29% reported daily use frequency for their native language.

Participants also provided information about *Language-Switching Frequency*, by indicating how frequently they found themselves in situations in which language switching occurred, using a six-point Likert scale ranging from "never" (0) to "very frequently" (5) (see Appendix B). Participants reported a language-switching frequency average of 3.1.

2.2 Research Design

The research undertaken follows an experimental design in line with the previous studies found in the literature on bilingualism and cognition. In order to investigate our questions related to a possible bilingual advantage in non-verbal conflict control, we designed an experiment in which we compared monolinguals and bilinguals in tasks measuring conflict monitoring and resolution.

The dependent variables were reaction times and accuracy rates. The main independent variable of interest was *Group* (monolinguals, bilinguals). However, we were also interested in other variables that could be important predictors of participant performance in the attention control tasks, such as: *Age*, *Gender*, *Fluid Intelligence*, *Socio-Economic Status*, and *Education Level*. Additionally, and in order to address our question related to what bilingualism-specific factors might contribute to a bilingual advantage in conflict control, we measured and controlled for the variables *Age of Onset of Active Bilingualism*, *Length of Active Bilingualism*, *Balancedness of Bilingual Language Use*, and *Language-Switching Frequency*.

Procedural variables were also used for counterbalancing purposes, which will be described in section *2.4 Measures*. A description of the measurement instruments used will also be given further ahead in this chapter, in section *2.4 Measures*.

2.3 Setting and Apparatus

The data collection sessions took place in the Thought and Language Lab, at the University of Otago, in Dunedin, New Zealand. Participants completed all the tasks sitting at a desk, either by using a computer or responding on paper. A room divider surrounded the desk, to decrease the possibility of visual distraction. For the attention tasks, the window blinds were drawn and the room lights turned off. To decrease eyestrain, the computer screen brightness was set at the lowest level possible. The experimental sessions were individual, with one participant being assessed at a time. The same experimenter conducted all sessions.

All tasks and tests except for the Cattell – Culture Fair Intelligence Test (CFIT), which is a pen-and-paper test, were performed on a desktop computer (Intel® Core™ 2 Duo Processor E8500, 3.16 GHz, 3.49GB RAM, with a ViewSonic G90f 17” CRT Monitor, 1280x1024 pixels resolution, 85Hertz screen refresh rate). The Oxford Quick Placement Test and the Background Measures Questionnaires were run in MediaLab™ (Version 2006.2, Empirisoft), with participants using a regular keyboard and mouse to respond. The Attention Network Test and the Simon task were run in E-Prime® (Version 2.0 Standard, 2002, Psychology Software Tools), and participants responded using a Serial Response Box™ (Model 200, Psychology Software Tools). The response box has five buttons, but participants were instructed to ignore the three middle ones and respond by pressing the farther left or right buttons using their left and right hands, correspondingly. Participants were advised to sit comfortably, at an approximate distance from the screen of 65 cm, providing such distance would not cause any discomfort or physical strain.

2.4 Measures

2.4.1 Background Measures

2.4.1.1 Oxford Quick Placement Test

The level of proficiency in English was measured by the Oxford Quick Placement Test (Oxford University Press & University of Cambridge Local Examinations Syndicate, 2001). This test was chosen for being a quick, easy-to-administer test that can be used for placement purposes with participants of any degree of proficiency. The OQPT has gone through Cambridge ESOL quality procedures and more than 6,000 students in 20 countries have been tested to validate it. As for its reliability, the Standard Error of Measurement of the test is around 4 and the reliability reported is close to 0.90 (Geranpayeh, 2003).

The OQPT comprises 60 multiple-choice format questions, each worth 1 point. For the present study and to ensure a faster completion time, this pen-and-paper test was prepared in MediaLab, so that participants could take it on a computer. There was no time limit established to complete this test, but participants took on average between 15 and 20 minutes to finish it. The OQPT comprises two parts: all candidates take Part 1; Part 2 is intended for high ability candidates only. All participants in our study completed both Parts 1 and 2 of the test. Scores for the OQPT are linked to the ALTE – Association of Language Testers in Europe and Council of Europe levels (Council of Europe, 2001), which are divided into six levels: A1 and A2 (basic user), B1 and B2 (independent user), and C1 and C2 (proficient user). As a criterion to be included as a participant in the present study, participants had to reach an ALTE score level of C1 –

Advanced (48 to 54 points) or C2 – *Very Advanced* (55 to 60 points). Seventeen bilingual participants who had passed the pre-screening phase were excluded from the study for not reaching a C1 English proficiency score.

2.4.1.2 Cattell – Culture Fair Intelligence Test

Participants' non-verbal intelligence was measured by means of the Cattell – Culture Fair Intelligence Test: Scale 3, Form A (Cattell & Cattell, 1963). This instrument was chosen because it was quick, requires low knowledge dependence and has a high correlation with Spearman's *g* (Carroll, 1993; Duncan, Burgess, & Emslie, 1995). The Cattell – CFIT also reduces dependency on verbal fluency to complete the test, since all instructions are given before the test to the participant's satisfaction, and no verbal instructions or cues are to be found in the items. The test is designed to reduce the influence of culture and educational level, by means of novel problem-solving items. This test of *g* is reported to have a reliability of 0.69 to 0.74 and a validity of 0.85 (correlation with *g*) (Cattell & Cattell, 1973, pp. 10-11).

The Cattell – CFIT included a total of 50 items, divided between 4 separate sub-tests, each of which focuses on different perceptual tasks: Series (13 items), Classifications (14 items), Matrices (13 items), and Conditions (or Topology) (10 items). The times allotted to each sub-test were 3, 4, 3 and 2.5 minutes, respectively. Before the test, participants were given extensive instructions on the format of the test and on how to correctly respond to the items. The participants were allowed to ask questions during this instruction phase, and the subtests were not initiated until the participants had no doubts about how they were expected to proceed. Specific instructions, with 2 to 3 practice items, were given before each sub-test. The participants' raw scores in the test were converted to interpretable normalised standard score IQs, following the authors' instructions (Cattell & Cattell, 1973).

2.4.1.3 Background Measures Questionnaires

At the end of the session, all participants completed a series of background measures questionnaires, consisting of: a Language History Questionnaire (see Appendix B), a Socio-Economic Status Questionnaire (see Appendix C) and an additional Questionnaire on Activities with an Impact on Executive Functions (see Appendix D). The Language History Questionnaire collected information on the participants' use and knowledge of their language(s), as well as on the language(s) learning mode, frequency and context of use, and self-assessed proficiency levels. The Socio-Economic Status Questionnaire comprised questions about the participants' and their parents' income, occupation, living conditions and educational level. Finally, the Questionnaire on Activities with an Impact on Executive Functions gathered information on the participants' frequency and level of involvement with activities which previous research has found to have a potential impact on executive functions, such as physical exercise, music, meditation and video-game playing. For ease of completion, the questionnaires were computer-based (prepared in MediaLab), with as many questions as possible presented in a multiple-choice format.

2.4.2 Conflict Control Tasks

In order to test the hypothesis that bilinguals have gained an enhanced non-language-specific conflict monitoring and resolution ability, researchers have used various non-linguistic content-free paradigms. These are tasks in which some sort of irrelevant information is presented to the participants that they will have to ignore so as to complete the task successfully. Two of the most used tasks in the literature are the Attention Network Test (J. Fan, McCandliss, Sommer, Raz, & Posner, 2002) and the Simon task (Simon, 1990).

Despite the fact that the two tasks are measures of interference control, they in fact differ in the task characteristics used to generate the conflict. In the Simon task, participants are asked to press a left or right button depending on the colour of a square that is shown in the left or right side of a computer screen. In this task, there are two stimulus dimensions —colour (relevant dimension) and location (irrelevant dimension)— and one response dimension (location), with a stimulus-response overlap of the irrelevant stimulus dimension and the response dimension. The participant, therefore, will have to ignore the irrelevant location of the stimulus when responding. In the ANT, participants are asked to press a left or right button depending on whether the relevant stimulus (an arrow) points towards the left or the right. The central arrow is, however, accompanied by two identical flanker arrows on each side (irrelevant stimulus), which can be pointing in the same direction (congruent) or in the opposite direction (incongruent). In this task both relevant and irrelevant stimuli share the same dimension (direction), with this dimension overlapping with the response dimension. In this case, the participant must ignore the direction indicated by the irrelevant stimulus, and focus attention on the relevant central arrow.

There are other ways in which the ANT and the Simon task differ from each other, namely in what they measure additionally to conflict effects, as will be described in more detail below in connection with each task. The ANT is designed to look into three hypothesised networks of attention (alerting, orienting and executive control).

The functioning of the executive control network is measured through the use of congruent and incongruent stimuli and calculating the conflict effect. The functioning of the alerting and orienting networks is tapped into by using cues, which precede the stimulus in each trial. Thus, using the ANT would give us the possibility of looking into differences between groups in the three networks of attention. On the other hand, the version of the Simon task we used (Bialystok et al., 2004) also permits a comparison between conditions with different working memory loads, which allows us to measure working memory costs. Thus, using a modified Simon task would also allow us to measure differences between groups in working memory costs.

2.4.2.1 Attention Network Test

The ANT was originally designed to examine three hypothesised attentional networks, namely: alerting, orienting and executive attention (Posner & Petersen, 1990): "Alerting is defined as achieving and maintaining an alert state; orienting is the selection of information from sensory input; and executive control is defined as resolving conflict among responses" (J. Fan et al., 2002, p. 1). The task was conceived as a combination of a cued reaction time task (Posner, 1980) and a flanker paradigm (Eriksen & Eriksen, 1974), which evaluates conflict resolution abilities.

There are four cue conditions, which are used to tap into the alerting and orienting networks of attention. The cue conditions are: *a)* no cue, *b)* double cue, which consists of two asterisks that appear simultaneously above and below the fixation point, *c)* centre cue, which consists of an asterisk that appears at the exact location of the fixation point, replacing it, and *d)* spatial cue, which consists of an asterisk that appears either above or below the fixation point. One of these conditions applies in each trial, with a cue preceding the target stimulus (or no cue, in the case of the no-cue condition). Comparisons among these cuing conditions allow the assessment of two of the three hypothesised networks of attention: the alerting and orienting networks.

First, the contrast between the double-cue condition and the no-cue condition allows researchers to measure the functioning of the alerting network: the double cue would trigger the initiation and maintenance of an alerting state; in contrast, by not showing any cue before the stimulus (no-cue condition), the alerting network would not be triggered. The contrasting effect of these two cue conditions (triggering vs. non-triggering of an alerting state) permits the measurement of the functioning of the alerting network, by calculating the difference in reaction times obtained in the two conditions. Data consistently show that participants tend to respond faster in double-cue trials than in no-cue trials.

Second, the functioning of the orienting network of attention is measured in the ANT by contrasting the spatial-cue condition, which directs the participant's attention to the location where the stimulus will appear on the screen, with the centre-cue condition, which gives no clue where the stimulus will be shown. In both cases, the alerting state should be triggered by cue onset; the important difference between the two cues is that one directs attention, by focusing it on one specific location (spatial cue), while the other merely triggers an alerting state (centre cue). The reaction time advantage for the spatial cue condition over the centre cue condition is a measure of the functioning of the orienting network.

Third, the executive control network is called into action when there is a need for the resolution of conflict among responses. In order to measure the performance of this third network, the main stimulus, in the shape of a horizontal arrow, is presented along with two flanker arrows on each side, which can be either pointing in the same direction as the central arrow (congruent trials) or in the opposite direction (incongruent trials). Participants are typically faster and more accurate when responding to congruent trials, since incongruent trials demand the processing and resolution of conflicting directional information. The functioning of the executive control network is measured by contrasting the reaction times obtained in congruent and incongruent trials, the difference between the two being the Conflict Effect.

The original Attention Network Test designed by Fan and colleagues (2002) also included a neutral condition, in which the flanker arrows were replaced by straight horizontal lines, with no arrowheads, additionally to the congruent and incongruent conditions, with a third of the total number of trials representing each condition (33.3% neutral, 33.3% congruent, 33.3% incongruent). However, the version of the ANT used in this study (we used version 1 of the ANT used in Costa et al., 2009, experiment 2) was slightly different from the original version of the task. Following the rationale that the bilingual advantage is somehow related to the functioning of the conflict-monitoring system and that such an advantage would derive from a more efficient way of monitoring and resolving conflicting information, it would be expected that the higher the conflict-monitoring demands, the greater the bilingual advantage (Bialystok, 2006; Bialystok et al., 2004; Costa et al., 2009; Feng et al., 2009). For this reason, we decided to use the already mentioned Costa et al.'s (2009) version of the ANT, which aimed at manipulating the involvement of the conflict-monitoring system, by eliminating the neutral flanker condition and including an equal number of congruent and incongruent trials. By increasing the proportions of congruent and incongruent trials (50% each), we intended to increase the conflict-monitoring and resolution demands, in hopes that such conditions would make the bilingual advantage (if there is one) more visible.

This modified version of the ANT thus included two within-subjects factors: *Congruency* (congruent, incongruent) and *Cue* (no cue, double cue, centre cue, spatial cue). All eight possible combinations of these two factors were included in the experimental design, each with an equal number of trials per condition. Other features of the experiment also warranted counterbalancing, namely: *Target Direction* (left, right) and *Target Position* (above fixation point, below fixation point). The trials were counterbalanced, so that there were equal numbers of trials with the target stimulus pointing to the right and to the left, and located above or below the fixation point.

The task was set out following Fan and colleagues' (2002) procedure (see Figure 1). Each trial started with a variable fixation period (between 400 and 1,600 ms), during which a fixation point (a black plus sign) was shown at the centre of the screen, against a light grey background. The fixation point remained at the centre of the screen for the entire duration of the task. A cue would then appear for 100 ms (except in no-cue trials, where there was a 100 ms fixation with no cue). The cue was followed by another fixation period of 400 ms, after which the target stimulus was presented for 1,700 ms or until the participant responded. After participants responded, the target and flankers disappeared and were followed by a post-target fixation period of a variable duration, calculated as 3,500 ms minus the duration of the pre-cue fixation, minus the participant's reaction time. After this interval, a new trial began.

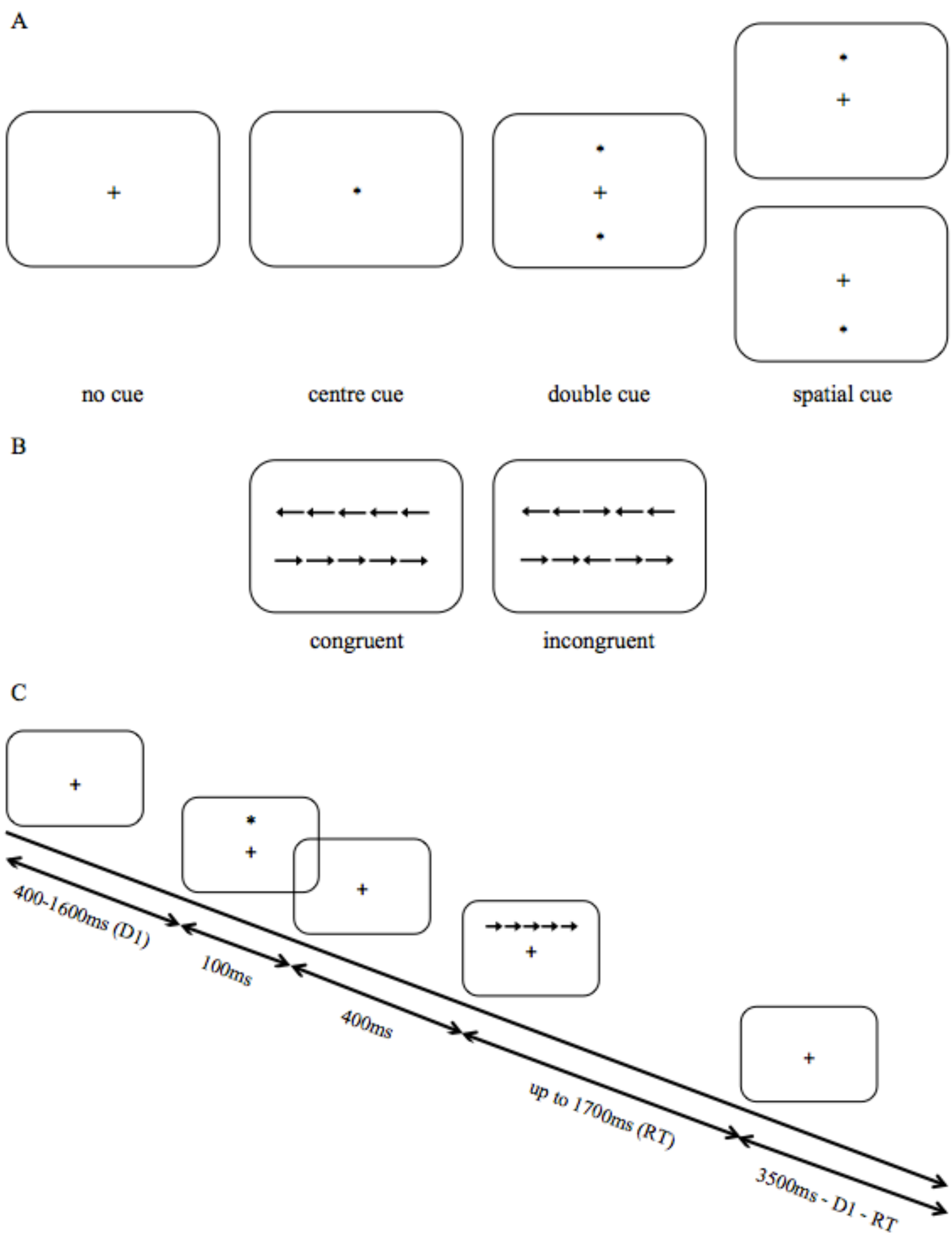

Figure 1. Attention Network Test experimental procedure (adapted from Fan et al., 2002): A – Cue conditions; B – Congruency conditions; C – An example of the procedure sequence for a congruent trial preceded by a spatial cue.

The target stimulus consisted of a horizontal arrow, accompanied by two flanker arrows on each side. Each arrow subtended 0.55º of visual angle (approximately 6 mm in width) and the contours of the adjacent arrows were separated by 0.06º of visual angle, the full set of central arrow and four flankers consisting of 3.08º of visual angle (or approximately 3.5 cm in length). The target stimulus was randomly presented 1.06º

(11 mm) above or below the fixation point, which meant that the target location was always uncertain, except when preceded by a spatial cue. All visual angle calculations were performed for a distance to the screen of 65 cm.

Before the experiment, a training phase of 32 trials was administered with the same proportion of congruency as the upcoming experimental version. The task consisted of two experimental blocks of 96 trials each (4 cue conditions x 2 congruency conditions x 2 target locations x 2 target directions x 3 repetitions), with an overall total of 6 trials per combination of all four factors. The order of the presentation of the trials was random for each participant. No more than two trials corresponding to the same combination of factors were presented in a row.

The participants' task was to identify the direction of the centrally presented arrow by pressing a left-positioned button when the target stimulus pointed towards the left and a right-positioned button when the target stimulus pointed towards the right. Participants were instructed to focus their gaze on the centrally located fixation point throughout the task, and to respond as quickly and accurately as possible.

The total duration of the ANT was of approximately 15 minutes.

2.4.2.2 Simon task

In the standard Simon task (Craft & Simon, 1970), participants are required to discriminate a stimulus based on a non-spatial dimension (colour or shape), which appears irrelevantly on the left or right side of a screen, by means of a manual response, where each hand is usually aligned with the location where the stimuli appear on screen. Even though stimulus location is irrelevant, responses are usually faster when there is a spatial congruency between the location of the target stimulus and the location of the response. When the two are not congruent, the participant is forced to disregard the irrelevant conflicting information concerning the location of the stimulus. This phenomenon is usually referred to as the Simon Effect and is measured as the difference, mostly in reaction times but also in accuracy rates, between congruent and incongruent stimulus-response trials.

In this study, we decided to use a modified version of the Simon task (Bialystok et al., 2004, study 2), which attempts to isolate the contributions of interference and working memory load to task performance. This version of the Simon task integrates and combines several experimental conditions: a control condition, in which reaction times are measured independently of the conflict effect, by placing the stimulus in the centre of the screen (Centre-2 condition); the traditional Simon task condition, with a stimulus in one of two colours, appearing on either side of the screen (Side-2 condition); and two other conditions similar to the two previous ones, differing only in the fact that there are 4 colour-response associations to be memorised instead of only 2 (Centre-4 and Side-4 conditions). The introduction of a control condition (Centre-2) allowed us to measure speed of responding independently of the conflict interference, and the addition of different working memory allowed for the isolation of the contribution of working memory and conflict resolution to task performance.

To control for possible effects of experimental condition sequence, we counterbalanced four different sequences across participants: *a)* Centre-2 → Side-2 → Centre-4 → Side-4; *b)* Centre-4 → Side-4 → Centre-2 → Side-2; *c)* Centre-2 → Centre-4 → Side-2 → Side-4; and *d)* Centre-4 → Centre-2 → Side-4 → Side-2. Participants completed four sets of trials, one per experimental condition, in one of the given sequences. These sets of conditions were then repeated by the participants, in a second block of trials, in the reversed order. In between blocks 1 and 2, the participants completed the Cattell – CFIT.

We followed Bialystok and colleagues' procedure (2004, study 2), the only difference between our version of the task and theirs being our omission of the sound (a computer "bing") accompanying the fixation point, which we eliminated after participants in the pilot study complained that the sound was distracting and slightly irritating. As in the Attention Network Test, each trial began with a fixation point (a black plus sign, measuring 9x9 mm) at the centre of the screen, which remained visible for 300 ms (see Figure 2). This fixation period was followed by the target stimulus (a coloured square, measuring 35x35 mm), which appeared at the centre of the screen (centre squares), $x = 0.28°$, $y = 0.38°$ (left side squares), or $x = 0.72°$, $y = 0.38°$ (right side squares), and remained visible until a response was given (Note: these are not visual angle measurements, but coordinates for the screen. $x = 0°$, $y = 0°$ was the lower-left corner of the screen. Since the screen used was a flat screen, only x went all the way to 1°). The squares were either blue or brown in the 2-colour conditions, and pink, yellow, red or green in the 4-colour conditions. The fixation point reappeared 500 ms after the response was given, signalling the beginning of the following trial.

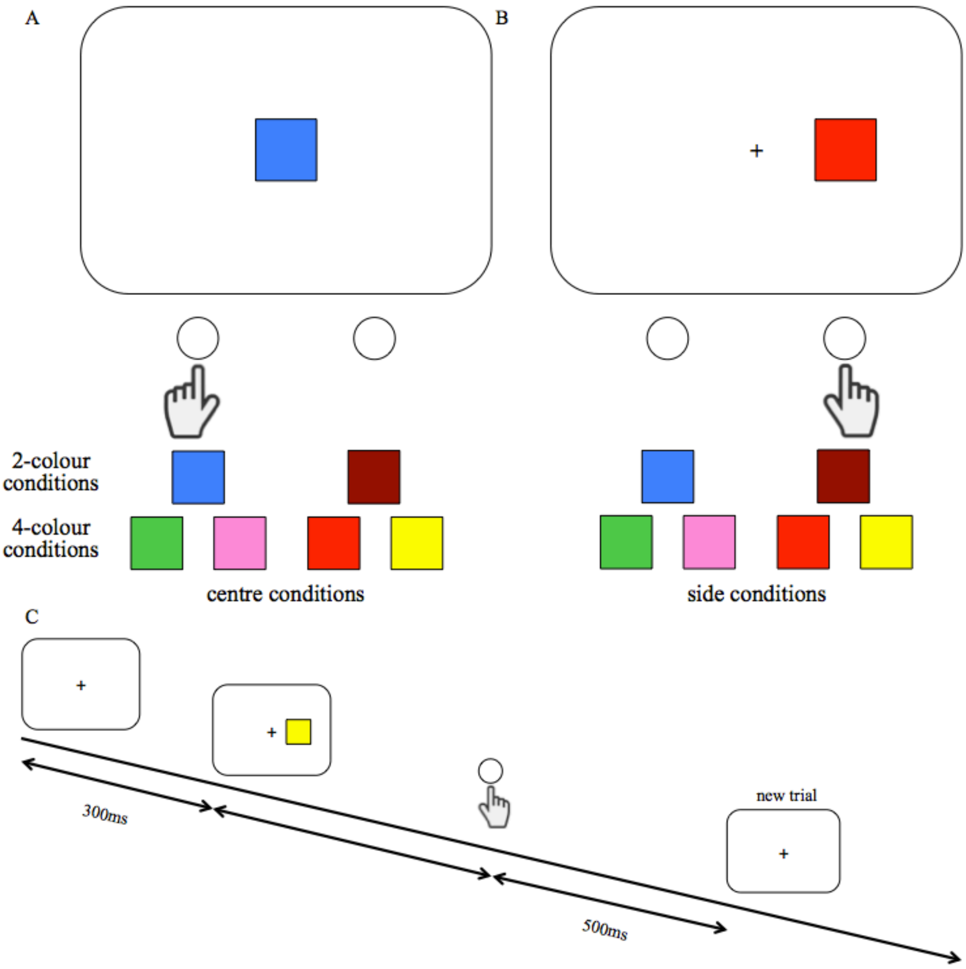

Figure 2. Simon task experimental procedure: A – Centre conditions; B – Side conditions; C – An example of the procedure sequence for a side-4 congruent trial.

A set of practice trials preceded each condition: the 2-colour conditions were preceded by 4-trial practice sets and the 4-colour conditions were preceded by 8-trial practice sets. The parameters of the practice trials were identical to the parameters of the experimental trials. Participants had to complete all practice trials correctly before they could proceed to the experimental trials. If a mistake occurred, the computer program automatically recycled until all practice trials were completed without error. The task consisted of two experimental blocks of 96 trials each (24 trials per condition: Centre-2, Side-2, Centre-4, and Side-4). The order of trials was randomized and divided equally between congruent and incongruent items, in the side conditions.

Participants were instructed to press the left button when they saw a blue (2-colour conditions) / green or pink (4-colour conditions) square and the right button when they saw a brown (2-colour conditions) / red or yellow (4-colour conditions) square, independently of the location of the square on the screen. The instructions were presented as four individual rules (i.e., "press the left button for green"; "press the left button for pink") and not as two paired rules (i.e., "press the left button for green or pink"). Participants were asked to respond both as quickly and accurately as possible.

2.5 Procedure

Recruitment advertisement was disseminated via email, social networks, and posters, aiming mainly at but not restricted to the University of Otago population. Potential participants were invited to get in touch with the experimenter, who would respond with an email enclosing the initial pre-screening questionnaire (see Appendix A). All participants who considered themselves to meet the necessary criteria were then invited to participate in the study and were sent an information sheet (see Appendix E) describing in more detail the objectives of the study, the procedure of data collection and, once again, the criteria for participants to be included in the study. If participants agreed to participate in the study, an experimental session was then scheduled.

At the beginning of the experimental session, participants were asked to fill out an information sheet (see Appendix F), with some basic personal information (e.g., name, gender, date of birth, contact details, etc.), to be kept separate from the data to be collected, in order to preserve the anonymity of the data during the analysis stage. Participants were also asked to read and sign a consent form (see Appendix G). The experimental session started with the instructions for the overall session, whereby participants were informed about the structure of the session and the nature of the tasks. Participants were invited to take short breaks between tasks.

All tasks and tests were completed in one single experimental session lasting approximately 90 minutes. To counteract any potential impact of task order in the participants' performance, we used two different sequences of tasks, which were counterbalanced: *a)* the first task sequence started with the ANT, followed by the English proficiency test, the Simon task (block 1), the Cattell – CFIT, the Simon task (block 2), and the background measures questionnaires; *b)* the second task sequence started with the Simon task (block 1), followed by the Cattell – CFIT, the Simon task (block 2), the English proficiency test, the ANT, and the background measures questionnaires. Of the 115 participants, 57 (19 monolinguals, 38 bilinguals) undertook the tasks following sequence 1 and 58 (19 monolinguals, 39 bilinguals) followed sequence 2.

2.6 Data Processing and Analysis

For each participant, mean response latencies and mean percentages of correct responses were calculated, using MATLAB® (Version R2013b, MathWorks®). The individual-trial RT data from each task were plotted in histograms (see Figures 3 and 4) in order to better identify and eliminate outliers, as these could bias the means, inflate standard deviations and lead to inflated error rates, as well as to substantial distortions of parameter and statistical estimates. After visual inspection of the distributions of individual data points, it was decided to exclude as outliers trials with RTs shorter than 200 ms or longer than 1,200 ms, as these were located outside the bell curves' tails.

The upper threshold of 1,200 ms was above the 3-standard-deviations rule sometimes applied in the literature (which would have been 902 ms for the ANT and 1,081 ms for the Simon task). The outliers were eliminated from both the RTs and the ARs analyses. The excluded trials represented 0.21% of the original number of trials in the ANT and 1.20% of the original number of trials in the Simon task. Incorrect trials were also excluded from the RT analyses.

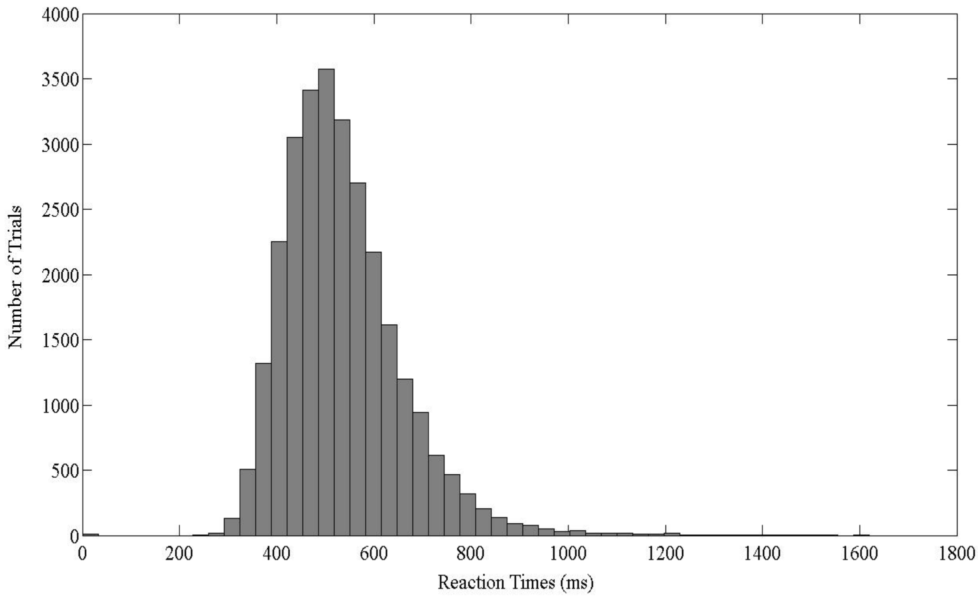

Figure 3. Distribution of individual trials' reaction time values in the Attention Network Test, before elimination of outliers.

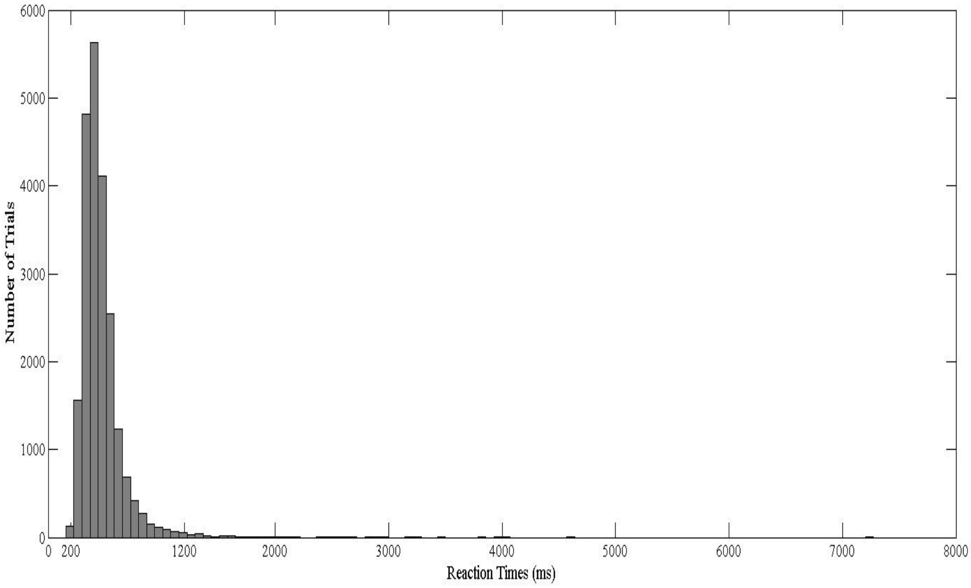

Figure 4. Distribution of individual trials' reaction time values in the Simon task, before elimination of outliers.

All statistical analyses were performed using SPSS® Statistics software (version 21, IBM®). An alpha level of .05 was used for all statistical tests.

Preliminary tests revealed that all AR results, in both tasks, presented ceiling effects. In order to bring this data closer to normal distribution, arcsine transformations were implemented, using the equation $Y = 2 \arcsin \sqrt{X}$ (Sheskin, 2003), where Y is the transformed AR score and X is the original AR score. All AR analyses were thus performed with transformed means and all AR means reported here correspond to back-transformations (i.e., estimates of means in the original scale, based on reverse-transforming the means of the transformed values).

All scale variables included in the analyses as covariates were centred around the mean, by subtracting the mean of all scores in each variable from each individual score. The variables that were centred were: *Age*, *Fluid Intelligence*, *Age of Onset of Active Bilingualism*, *Length of Active Bilingualism* and *Balancedness of Bilingual Language Use*. These variables were centred in order to allow for a more meaningful interpretation of any interaction terms that include any of these predictor variables. The variables *Group*, *Gender*, *SES*, and *Language-Switching Frequency* were not centred, given that they are not scalar, *Group*, *Gender*, and *L1 Family* being categorical variables and *SES* and *Language-Switching Frequency* being ordinal variables.

2.7 Ethical Considerations

This study was approved by the Department of Psychology and the University of Otago Human Ethics Committee.

Participants were thoroughly informed of the nature of the study and the type of data to be collected, as well as the manner in which that data would be gathered and processed. Any questions or doubts presented by the participants were comprehensively answered and clarified by the experimenter.

Participants were asked to sign a consent form (see Appendix G), expressing knowledge that their participation in the study was entirely voluntary, that they were free to withdraw from the project at any time without any disadvantage, and that results would be published and made available in the University of Otago Library.

Participants' anonymity was and will continue to be preserved and no personal identifying information has been made available to anyone outside the study, nor will it be made available at any time. All personal identifying information will be destroyed at the end of the project.

Participants were compensated for their time and travel expenses by means of a NZD $20.00 groceries or petrol voucher.

2.8 Summary

The present study aimed to investigate the existence of a bilingual advantage in conflict monitoring and resolution. In order to do so, we collected data from 77 bilinguals and 38 monolinguals on several performance measures related to executive control, as well as background measures on English language proficiency, fluid intelligence, language history and bilingual experience, socio-economic background, and other activities that could have an impact on executive control. To collect these data, we used modified versions of the Attention Network Test and the Simon task, the Oxford Quick Placement Test, the Cattell – Culture Fair Intelligence Test, as well as three background measures questionnaires.

In order to prepare the data for statistical analysis, the dependent variables were cleaned of outliers and arcsine-transformed where pertinent, and the independent variables were measured, coded and in some cases centred around the mean.

In the following chapter, we will describe the analyses performed on the data collected from the Attention Network Test and the Simon task, guided by our endeavour to test for the existence of a bilingual advantage in conflict monitoring and resolution.

3 Results

This chapter describes the results obtained in both tasks —Attention Network Test and Simon task. For each task, results will be described in the following order: descriptions of data preparation and preliminary analyses first, followed by general analyses for the overall results in reaction times and accuracy rates, after which specific results for each component of interest will be presented. More specifically, the analyses performed for the ANT will include: Conflict Effect, Alerting Effect, Orienting Effect and Sequential Congruency Effects. The analyses of the Simon task data will focus on: Simon Effect, Working Memory Costs and Sequential Congruency Effects.

Also, in order to answer our main questions, separate analyses will be performed: *a)* comparing monolinguals with bilinguals, so as to ascertain whether there is a bilingual advantage in RTs and/or ARs, and *b)* comparing bilinguals with each other, assessing individual-difference variables specific to bilingualism as possible predictors of performance among bilinguals.

3.1 Attention Network Test

3.1.1 Preliminary Analyses – Counterbalancing

The ANT was designed to look into the three hypothesised attentional networks, namely: alerting, orienting and executive attention (J. Fan et al., 2002). For this reason, the task includes two experimental variables: *Congruency* (congruent, incongruent) and *Cue* (no cue, double cue, centre cue, spatial cue). All possible combinations of these two variables were counterbalanced in the experimental design, to ensure an equal number of trials per condition.

Target Direction and Target Position

However, other features of the experiment also warranted counterbalancing, namely: *Target Direction* and *Target Position*. The procedure variable *Target Direction* is introduced by the variable *Congruency*: in order to have congruent and incongruent trials, the target stimulus —an arrow— can be pointing towards the right or the left side of the screen. The trials were thus counterbalanced so that 50% of trials' target stimuli were pointing to the right and 50% were pointing to the left. The variable *Target Position* is due to one of the cues related to the orienting network —spatial cue— which can appear above or below the fixation cross at the centre of the screen, orienting the participants towards the position where the target stimulus will appear. For this reason, all trials in the ANT presented the target stimulus in the same two possible positions, either above or below the fixation point. These two possibilities were also counterbalanced, with 50% of the trials' target stimuli being shown above the fixation cross and 50% below it.

Task Order

In order to determine if the participants' reaction times were influenced by whether they took the tasks in one sequence or the other, an additional counterbalancing variable was used —*Task Order*— which is related to the two possible orders in which participants undertook the tasks:

- <u>Sequence 1</u>: ANT → English proficiency test → Simon task block 1 → Cattell → Simon task block 2 → background measures questionnaires

- Sequence 2: Simon task block 1 → Cattell → Simon task block 2 → English proficiency test → ANT → background measures questionnaires

3.1.1.1 Effect of procedural variables in groups' reaction times

In order to determine if the procedural variables had any significant impact on the results obtained by monolinguals and bilinguals, a 2x2x2x2 factorial ANOVA was performed with RTs as the dependent variable (DV), *Target Direction* (left, right) and *Target Position* (above, below) as within-subjects factors, and *Task Order* (ANT first, Simon task first) and *Group* (monolinguals, bilinguals) as between-subjects factors.

Main effects of the procedural variables

The analysis showed a significant main effect of *Target Direction* on reaction times, $F(1, 111) = 9.94$, $p = .002$, $\eta_p^2 = .082$, with faster responses to trials in which the stimulus was pointing towards the right ($M = 528$, $SD = 64$) than to trials in which the stimulus pointed towards the left ($M = 537$, $SD = 65$).

There was also a significant main effect of *Target Position* on the RTs, $F(1, 111) = 80$, $p < .001$, $\eta_p^2 = .42$. RTs to trials where the stimulus was located above the fixation cross were on average faster ($M = 523$, $SD = 63$) than RTs to trials where the target stimulus was situated below the fixation point ($M = 541$, $SD = 65$).

Finally, there was a non-significant main effect of *Task Order* on the RTs, $F(1, 111) = .037$, $p = .85$, $\eta_p^2 < .001$, revealing that the order in which the tasks were taken by the participants had no bearing on their reaction times.

Interaction between Target Direction and Target Position

The interaction between *Target Direction* and *Target Position* was significant, $F(1, 111) = 7.39$, $p = .008$, $\eta_p^2 = .062$. Post-hoc comparisons using Fisher's LSD test revealed that the difference between RTs to trials with left-facing stimuli and right-facing stimuli was only significant for trials where the stimulus was presented above the fixation cross ($p < .001$), but was not significant in trials where the stimulus was presented below the fixation point ($p = .099$).

Interaction between Target Direction and Task Order

There was also a significant interaction effect between *Target Direction* and *Task Order*, $F(1, 111) = 4.56$, $p = .035$, $\eta_p^2 = .039$. Post-hoc comparisons using Fisher's LSD test revealed that the difference between RTs to trials with left-facing stimuli and right-facing stimuli was only significant when the task was taken at the beginning of the experimental session ($p < .001$), but was not significant when the ANT was taken after the Simon task, in the middle of the experimental session ($p = .47$).

Main effect of Group

The main effect of *Group* on the RTs was not statistically significant, $F(1, 111) = 2.05$, $p = .16$, $\eta_p^2 = .018$. More importantly, none of the interactions of *Group* with the procedural variables *Target Direction*, *Target Position* or *Task Order* were statistically significant (all Fs$(1, 111) \leq .94$, ps $\geq .33$, η_p^2s $\leq .008$).

No other main effects or interactions were statistically significant (all Fs$(1, 111) \leq .75$, ps $\geq .39$, η_p^2s $\leq .007$).

In short, *Target Direction* and *Target Position* both had a significant impact on reaction times, and *Task Order* did not. However, the trials were counterbalanced to safeguard against contamination by these effects. The crucial result of this analysis is the absence of any significant interaction effects between the procedural variables and *Group*, which shows that the procedural variables played no significant role in the potential differentiation between monolinguals and bilinguals.

3.1.1.2 Effect of procedural variables in groups' accuracy rates

Next, a similar 2x2x2x2 factorial ANOVA was performed, using this time the arcsine-transformed ARs as the DV, *Target Direction* (left, right) and *Target Position* (above, below) as within-subjects factors, and *Task Order* (ANT first, Simon task first) and *Group* (monolinguals, bilinguals) as between-subjects factors.

Main effects of the procedural variables

The analysis showed no significant main effect of *Target Direction* on accuracy, $F(1, 111) = 2.36$, $p = .13$, $\eta_p^2 = .021$.

The test yielded a significant main effect of *Target Position* on accuracy, $F(1, 111) = 35$, $p < .001$, $\eta_p^2 = .24$, with responses to trials in which the stimulus was located above the fixation cross being on average more correct ($M = .989$, $SD = .015$) than responses to trials where the target stimulus was situated below the fixation point ($M = .980$, $SD = .020$).

The analysis showed also a non-significant main effect of *Task Order* on accuracy, $F(1, 111) = .10$, $p = .75$, $\eta_p^2 = .001$.

Main effect of Group

There was a non-significant main effect of *Group* on accuracy, $F(1, 111) = .41$, $p = .53$, $\eta_p^2 = .004$.

Interaction between Group and Task Order

However, the interaction between *Task Order* and *Group* turned out to be significant, $F(1, 111) = 6.32$, $p = .013$, $\eta_p^2 = .054$. Post-hoc comparisons using Fisher's LSD method revealed a significant difference between the ARs of monolinguals and bilinguals when the ANT was taken at the beginning of the session ($p = .028$), with bilinguals being on average more accurate than monolinguals, but no significant difference between the groups when the Simon task was taken at the beginning of the experimental session ($p = .19$).

I believe the statistical significance of this interaction to be a Type I error, since there seems to be no reason why *Task Order* would impact differently the two groups of participants. However, given this significant interaction, the procedural variable *Task Order* will be included as an independent variable in any further analyses on ARs in the ANT.

No other main effects or interactions were statistically significant.

3.1.2 General Analyses – Reaction Times

3.1.2.1 Monolinguals versus bilinguals

Table 3 shows the mean reaction times obtained by monolinguals and bilinguals, in each block separately, as well as in the overall results of the ANT.

Table 3

Means (M) and Standard Deviations (SD) of Reaction Times in the Attention Network Test

		Block 1		Block 2		Total	
Group	*N*	*M*	(*SD*)	*M*	(*SD*)	*M*	(*SD*)
Monolinguals	38	523	(53)	518	(55)	520	(53)
Bilinguals	77	541	(68)	536	(68)	538	(67)
Total	115	535	(64)	530	(65)	532	(63)

Note: *N* = number of participants.

The first step in our analysis was to establish if there were any differences in reaction times between monolinguals and bilinguals, as well as between blocks 1 and 2. We were also interested in knowing if any of the individual-difference variables (*Age*, *Gender*, *SES* and *Fluid Intelligence*) could be good predictors of RTs in the ANT, in order to control for those in between-group comparisons. With these goals in view, a 2x2x2 factorial ANCOVA was performed, with *Block* (block 1, block 2) as a within-subjects factor, and *Group* (monolinguals, bilinguals) and *Gender* (male, female) as between-subjects factors. *Age*, *SES* and *Fluid Intelligence* were also added to the model, as covariates. The variables *Age of Onset of Active Bilingualism*, *Length of Active Bilingualism*, *Balancedness of Bilingual Language Use* and *Language-Switching Frequency* were not added to this analysis since they are specific to bilinguals and thus would not inform our comparison between monolinguals and bilinguals. These will be included in a separate analysis looking at bilinguals' results alone, in the upcoming section *3.1.2.2 Bilinguals' within-group analyses*.

Main effect of Group

There was a non-significant main effect of *Group* on reaction times, $F(1, 108) = .32$, $p = .57$, $\eta_p^2 = .003$, indicating no significant differences in RTs between monolinguals and bilinguals.

Main effect of Block

There was a non-significant main effect of *Block* on reaction times, $F(1, 108) = .13$, $p = .72$, $\eta_p^2 = .001$, denoting no significant differences in RTs between blocks 1 and 2. In other words, a practice effect in RTs was not observed in the ANT.

Main effects of the individual-difference variables

The analysis showed a significant main effect of *Age* on reaction times, $F(1, 108) = 26.9$, $p < .001$, $\eta_p^2 = .20$, with younger age being associated with faster RTs. The main effect of *Gender* was also significant, $F(1, 108) = 4.28$, $p = .041$, $\eta_p^2 = .038$, with males presenting faster RTs than females. There was as well a significant main effect of *Fluid Intelligence* on RTs, $F(1, 108) = 10$, $p = .002$, $\eta_p^2 = .085$, with higher *Fluid Intelligence* scores being associated with faster RTs. Together, these three variables explain 32.3% of the variation in RTs. The main effect of *SES* on RTs was not significant, $F(1, 108) = .13$, $p = .72$, $\eta_p^2 = .001$, and thus this covariate was dropped from any further analyses on reaction times in the ANT.

No interactions reached statistical significance (all Fs$(1, 108) \leq 2.22$, ps $\geq .14$, η_p^2s $\leq .020$).

3.1.2.2 Bilinguals' within-group analyses

In order to test whether individual-difference variables specific to bilingualism had an impact on bilinguals' RTs in the ANT, multiple linear regressions were performed for all possible combinations of the independent variables (IVs): *Age*, *Gender* (male, female), *Fluid Intelligence*, *Age of Onset of Active Bilingualism*, *Length of Active Bilingualism*, *Balancedness of Bilingual Language Use*, and *Language-Switching Frequency*. (For a description of each variable, please refer to section *2.1 Participants*.) The overall mean correct RTs for all trials in the ANT were used as the DV.

Since *Age of Onset of Active Bilingualism* and *Length of Active Bilingualism* are proxies of *Age*, and were thus strongly correlated with *Age* (*Age of Onset of Active Bilingualism* and *Age*: $r(113) = .62$, $p < .001$; *Length of Active Bilingualism* and *Age*: : $r(113) = .32$, $p = .005$), we wanted to ascertain whether those variables would provide significant additional information to our analysis on the RTs of bilinguals, after controlling for *Age*. In order to do so, we compared three models, all of which including *Age*, *Gender*, *Fluid Intelligence*, *Balancedness of Bilingual Language Use* and *Language-Switching Frequency*. We then added *Age of Onset of Active Bilingualism* to form the second model and *Length of Active Bilingualism* to form the third model. Extra sum of squares comparisons revealed that neither the second nor the third models were significantly better than the first (both F_{extra}s ≤ 2.78, *p*s > .050), and so *Age of Onset of Active Bilingualism* and *Length of Active Bilingualism* were dropped from this and any further analyses on the same DV.

Table 4 shows the summary of the multiple linear regression analysis of the smaller model, which included *Age*, *Gender*, *Fluid Intelligence*, *Balancedness of*

Bilingual Language Use and *Language-Switching Frequency* as IVs and the RTs as the DV.

Table 4

Summary of Multiple Regression Analysis for Variables Predicting Reaction Times for the Bilingual Group in the Attention Network Test

Variable	*B*	*SE B*	β
Age	2.43	.67	.35**
Gender	17.25	7.69	.22*
Fluid Intelligence	-1.32	.45	-.28**
Balancedness of Bil. Lang. Use	.12	.49	.03
Language-Switching Frequency	6.29	5.85	.13

Notes: $R^2 = .38$. $^*p < .05$, $^{**}p < .01$. Gender [M = -1, F = 1]. Bil. Lang. Use = Bilingual Language Use.

The forced-entry model selected three significant predictors of reaction times for bilinguals: *Age*, $B = 2.43$, $t(71) = 3.65$, $p = .001$, with younger age being associated with faster RTs; *Gender*, $B = 17.3$, $t(71) = 2.24$, $p = .028$, with male gender being associated with faster RTs; and *Fluid Intelligence*, $B = -1.32$, $t(71) = -2.92$, $p = .005$, with higher *Fluid Intelligence* scores being associated with faster RTs. Approximately 37.8% of the variance in reaction times in bilinguals could be accounted for by this model, $R^2 = .38$, $F(5, 71) = 8.65$, $p < .001$.

In short, this analysis revealed that none of the individual-difference variables specific to bilingualism added any statistically significant information to the models, when these included *Age*, *Gender* and *Fluid Intelligence*, which were the same variables that were previously selected as significant predictors of RTs for all the participants. For this reason, no further within-bilinguals analyses were performed on

RTs in the ANT, as they would have been redundant with the analyses including all the participants.

3.1.3 General Analyses – Accuracy Rates

3.1.3.1 Monolinguals versus bilinguals

Table 5 shows the mean accuracy rates for the Attention Network Test, obtained by both groups of participants, in each block and overall in the task.

Table 5

Means (M) and Standard Deviations (SD) of Accuracy Rates in the Attention Network Test

		Block 1		Block 2		Total	
Group	*N*	*M*	(*SD*)	*M*	(*SD*)	*M*	(*SD*)
Monolinguals	38	.983	(.02)	.984	(.01)	.984	(.01)
Bilinguals	77	.984	(.02)	.985	(.02)	.985	(.02)
Total	115	.984	(.02)	.985	(.01)	.984	(.01)

Note: *N* = number of participants.

A 2x2x2x2 factorial ANCOVA was performed, with the arcsine-transformed accuracy rates as the DV, *Block* (block 1, block 2) as a within-subjects factor, *Group* (monolinguals, bilinguals), *Gender* (male, female) and *Task Order* (ANT first, Simon first) as between-subjects factors, and *Age*, *SES* and *Fluid Intelligence* as covariates. As with the analysis done for RTs, we were interested in determining if accuracy changed between groups and/or between blocks. We were also interested in establishing if any of the individual-difference variables were good predictors of accuracy in the ANT.

Main effect of Group

The main effect of *Group* on accuracy rates was not statistically significant, $F(1, 104) = .35$, $p = .56$, $\eta_p^2 = .003$, indicating that monolinguals and bilinguals did not differ in accuracy rates.

Main effect of Block

There was also a non-significant main effect of *Block* on accuracy rates, $F(1, 104) = .002$, $p = .97$, $\eta_p^2 < .001$, denoting no significant practice effect in ARs in the ANT.

Main effects of the individual-difference variables

None of the individual-difference variables reached statistical significance (all Fs$(1, 104) \leq 2.23$, ps $\geq .14$, η_p^2s $\leq .021$). Since there were no statistically significant main effects of any of the covariates on accuracy, no individual-difference variables were included in any later analyses on overall accuracy rates.

Interaction between Group and Task Order

There was a significant interaction effect between *Group* and *Task Order*, $F(1, 104) = 4.82$, $p = .030$, $\eta_p^2 = .044$. Pairwise comparisons performed using Fisher's LSD test showed, as before, no significant difference between the ARs obtained in both task orders, for monolinguals ($p = .30$). However, for bilinguals, there was a significant difference between the ARs obtained in the two task orders ($p = .024$): bilinguals were more accurate when the ANT was the first task in the sequence ($M = .989$, $SD = .01$) than when the Simon task was the first task in the sequence ($M = .981$, $SD = .02$). However, the pairwise comparisons showed no significant differences between groups in either of the task orders, even though there was a near significant difference in ARs between groups when the ANT was the first task in the experimental session (p = .066).

Since this interaction was statistically significant, we decided to include *Task Order* in all further analyses of accuracy rates in the ANT.

There were no other significant interaction effects in this model (all Fs(1, 104) ≤ 2.72, ps $\geq .10$, η_p^2s $\leq .025$).

3.1.3.2 Reaction times and accuracy rates in the ANT

The overall reaction times and accuracy rates observed in the ANT were moderately correlated, $r(113) = .35$, $p < .001$, indicating a significant association between high accuracy and slow reaction time (see Figure 5).

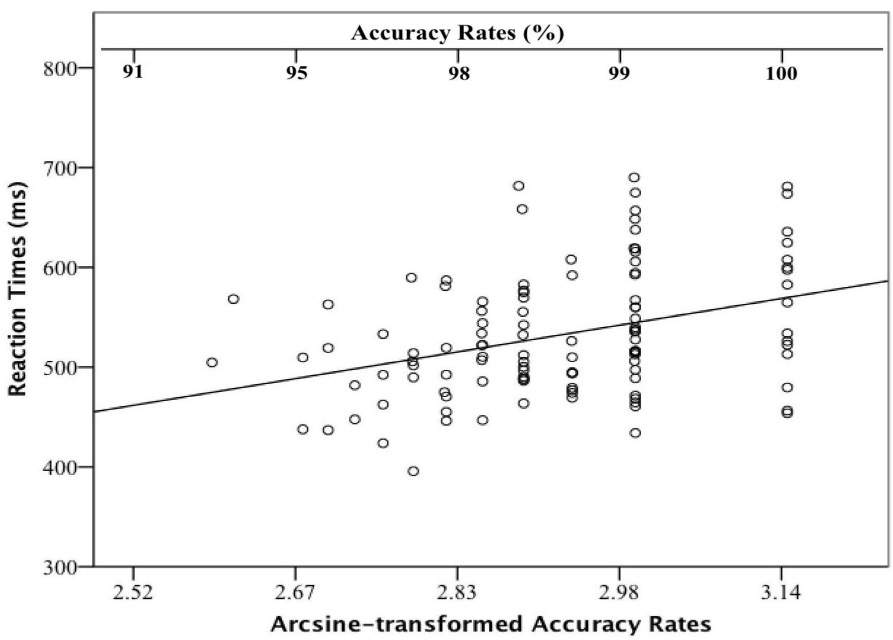

Figure 5. Mean reaction times (in milliseconds) by mean accuracy rates in the Attention Network Test. This graph depicts a correlation performed on the RTs and the arcsine-transformed ARs, and thus both an arcsine-transformation scale and a regular percentage scale are provided for the AR scores.

3.1.3.3 Bilinguals' within-group analyses

In order to test whether individual-difference variables specific to bilingualism had an impact on the performance of bilinguals in terms of ARs in the ANT, multiple linear regressions were performed, with the arcsine-transformed ARs as the DV and *Age*, *Gender* (male, female), *Task Order* (ANT first, Simon task first), *Fluid Intelligence*, *Age of Onset of Active Bilingualism*, *Length of Active Bilingualism*, *Balancedness of Bilingual Language Use*, and *Language-Switching Frequency* as IVs.

As before with the RT results, and because *Age of Onset of Active Bilingualism* and *Length of Active Bilingualism* are proxies of *Age*, extra sum of squares comparisons were performed between a model containing only *Age*, *Gender*, *Fluid Intelligence*, *Task Order*, *Balancedness of Bilingual Language Use* and *Language-Switching Frequency* and two other models, one of which also contained *Age of Onset of Active Bilingualism* and the other *Length of Active Bilingualism*. The extra sum of squares comparisons revealed that neither the second nor the third models were significantly better than the first (both F_{extra}s $\leq .11$, ps $> .050$), and so *Age of Onset of Active Bilingualism* and *Length of Active Bilingualism* were dropped from this and any further analyses on ARs.

Table 6 shows the summary of the multiple linear regression analysis of the smaller model, which included *Age*, *Gender*, *Task Order*, *Fluid Intelligence*, *Balancedness of Bilingual Language Use* and *Language-Switching Frequency* as IVs and the arcsine-transformed ARs as the DV.

Table 6

Summary of Multiple Regression Analysis for Variables Predicting Accuracy Rates for the Bilingual Group in the Attention Network Test

Variable	*B*	*SE B*	β
Age	.0003	.002	-.022
Gender	-.006	.019	-.038
Task Order	-.039	.016	-.287*
Fluid Intelligence	.0004	.001	.043
Balancedness of Bil. Lang. Use	.001	.001	.059
Language-Switching Frequency	.026	.014	.261

Notes: R^2 = .12. *p < .05, **p < .01. Gender [M = -1, F = 1], Task Order [ANT first = -1, Simon task first = 1]. Bil. Lang. Use = Bilingual Language Use.

The forced-entry model selected one significant predictor of accuracy rates for bilinguals: *Task Order*, *B* = -.039, $t(70) = -2.46$, $p = .016$, with bilinguals who started the experimental session with the ANT (instead of the Simon task) being more accurate than the bilinguals who took the Simon task first. Approximately 12.3% of the variance in accuracy rates in bilinguals could be accounted for by this model, $R^2 = .12$, $F(6, 70) = 1.63$, $p = .15$.

In sum, this analysis revealed that none of the bilingualism-specific individual-difference variables were selected as good predictors of ARs and, therefore, no further within-bilinguals analyses were performed on ARs in the ANT, as they would have been redundant with the analyses including all the participants.

3.1.4 Conflict, Alerting and Orienting Effects

The following sections will present the results relating to the Conflict, Alerting, and Orienting Effects, in that order. There will be a certain degree of redundancy between these different analyses, since they involve overlapping cue conditions and the same experimental factors, as well as the same covariates. However, as outlined before, these attention networks are believed to index different processes and, therefore, should be analysed separately, in order to try to understand them individually.

Results from reaction times and accuracy rates will be presented separately. For each effect, a statistical test including all variables pertinent to each analysis will be performed, followed by the description of significant and/or pertinent main effects and interactions. Where relevant, interactions between congruency and cue conditions will be explored.

Following the description of the results obtained per effect analysed, a summary of the findings in the Attention Network Test will be provided at the end of the chapter.

3.1.5 Conflict Effect in Reaction Times

Table 7 shows the mean reaction times in the ANT, by group and by congruency condition, as well as the Conflict Effect, calculated by subtracting the RTs obtained in congruent trials from the RTs observed in incongruent trials.

Table 7

Means (M) and Standard Deviations (SD) of Reaction Times, and Mean Conflict Effect scores in the Attention Network Test

		Congruency					
		Congruent		Incongruent		**Conflict Effect**	
	N	*M*	(*SD*)	*M*	(*SD*)	***M***	**(*SD*)**
Monolinguals	38	471	(49)	571	(60)	**99**	**(25)**
Bilinguals	77	492	(61)	586	(76)	**94**	**(30)**
Total	115	485	(58)	581	(71)	**96**	**(27)**

Note: *N* = number of participants.

3.1.5.1 Conflict Effect in reaction times – Main analysis

A 2x2x2x2 factorial ANCOVA was performed, to determine the occurrence of the Conflict Effect in the ANT, as well as to see if there were any differences in congruency between monolinguals and bilinguals and between blocks. The analysis included the RTs as the DV, *Block* (block 1, block 2) and *Congruency* (congruent, incongruent) as within-subjects factors, *Group* (monolinguals, bilinguals) and *Gender* (male, female) as between-subjects factors, and *Age* and *Fluid Intelligence* as covariates.

To avoid repeating information that was already provided in the section *3.1.2 General Analyses – Reaction Times*, the description of the main effects of *Group*, *Block*, *Age*, *Gender* and *Fluid Intelligence* will not be described again in this section, which will focus instead only on the main effect of *Congruency* and on any significant interactions that include this factor.

Main effect of Congruency (Conflict Effect)

The test revealed a significant main effect of *Congruency* on RTs, $F(1, 109) = 1105$, $p < .001$, $\eta_p^2 = .91$, showing the expected Conflict Effect, with RTs to congruent trials being significantly faster than RTs to incongruent trials (see Table 7).

Interaction between Congruency and Age

The interaction effect between *Congruency* and *Age* was also statistically significant, $F(1, 109) = 11.4$, $p = .001$, $\eta_p^2 = .095$. Comparisons between unstandardized beta weights from the parameter estimates obtained as part of the ANCOVA revealed that the association of older age with slower RTs was significantly more accentuated for incongruent trials ($B = 2.97$) than for congruent trials ($B = 2.16$).

Interaction between Congruency and Fluid Intelligence

The interaction effect between *Congruency* and *Fluid Intelligence* also resulted significant, $F(1, 109) = 8.89$, $p = .004$, $\eta_p^2 = .075$. Comparisons between unstandardized beta weights from the parameter estimates showed that the relation between higher *Fluid Intelligence* and faster RTs was also more accentuated for incongruent trials ($B = -1.35$) than for congruent ones ($B = -.84$).

In other words, both *Age* and *Fluid Intelligence* significantly determined individual susceptibility to the Conflict Effect in RTs: the association of older age and slower RTs being more accentuated in incongruent trials translates into a significant association between older age and greater susceptibility to the Conflict Effect; on the other hand, the relation between high *Fluid Intelligence* scores and faster RTs being more accentuated in incongruent trials has a very different effect, causing an association between higher *Fluid Intelligence* and smaller Conflict Effects.

No other interactions reached statistical significance (all *F*s(1, 109) ≤ 2.52, *p*s ≥ .12, η_p^2s ≤ .023).

3.1.5.2 Conflict Effect in reaction times – Analysis by cue condition

Since the ANT task taps into three different attention networks, and there were different conditions in the task to allow for that, my next objective was to determine if there were differences in Conflict Effect, depending on the experimental condition. Table 8 presents the RTs in the Attention Network Test, by experimental conditions *Congruency* and *Cue*.

Table 8

Means (M) and Standard Deviations (SD) of Reaction Times in the Attention Network Test, by Congruency and Cue Conditions, with Mean Scores for the Conflict Effect

	Congruency								
	Congruent			Incongruent			**Conflict Effect**		
	Mon.	Bil.	**Total**	Mon.	Bil.	**Total**	Mon.	Bil.	**Total**
Cue	*M* (*SD*)	*M* (*SD*)	***M* (*SD*)**	*M* (*SD*)	*M* (*SD*)	***M* (*SD*)**	*M*	*M*	***M***
None	508 (47)	530 (63)	**523 (59)**	600 (60)	611 (76)	**607 (71)**	91	81	**84**
Double	469 (52)	490 (63)	**483 (60)**	575 (64)	594 (78)	**588 (74)**	105	105	**105**
Centre	471 (53)	489 (63)	**483 (60)**	583 (64)	601 (82)	**595 (77)**	112	112	**112**
Spatial	437 (52)	458 (63)	**451 (60)**	526 (63)	539 (78)	**535 (73)**	89	81	**84**

Notes: Mon. = monolinguals, Bil. = bilinguals.

In order to establish if the Conflict Effect varied significantly depending on the experimental condition, a 2x2x4x2x2 factorial ANCOVA was performed, with the RTs as the DV, *Block* (block 1, block 2), *Congruency* (congruent, incongruent) and *Cue* (no cue, double cue, centre cue, spatial cue) as within-subjects factors, *Group* (monolinguals, bilinguals) and *Gender* (male, female) as between-subjects factors, and *Age* and *Fluid Intelligence* as covariates.

The main effects of *Group*, *Block*, *Congruency*, *Age*, *Gender* and *Fluid Intelligence*, and the interactions between *Congruency* and *Age* and between *Congruency* and *Fluid Intelligence*, which were already explored in the previous ANCOVAs, obtained similar levels of statistical significance in this analysis, as expected, and therefore will not be described here in detail, so as to avoid redundant information.

Main effect of Cue

Mauchly's test indicated that the assumption of sphericity had been violated ($\chi^2(5) = 39.3$, $p < .001$) for the main effect of *Cue*, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .82$). The test revealed a significant main effect of *Cue*, $F(2.45, 267) = 246$, $p < .001$, $\eta_p^2 = .69$, with significant differences in RTs between all cue conditions (all *p*s ≤ .011, according to post-hoc comparisons using Fisher's LSD test). Participants were faster in spatial-cue trials, followed by double-cue trials, centre-cue trials, and finally no-cue trials, which was the slowest of all cue conditions (see Table 8 and Figure 6).

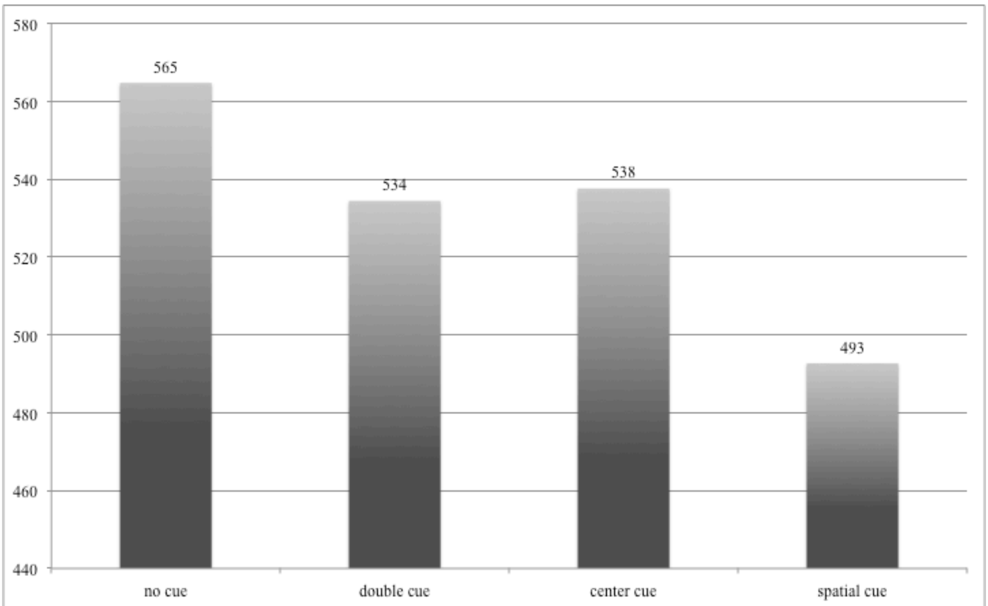

Figure 6. Mean reaction times in the Attention Network Test, by cue condition.

The level of preparedness induced in the participants by the cues might explain these differences. In the absence of a cue, for instance, and given that the post target fixation period had a variable duration, participants had no way of guessing when or where the target stimulus would appear on the screen, which would explain the slower RTs. The double and centre cues both had an alerting effect, since they both preceded the target stimulus by the same amount of time (400 ms), eliminating some uncertainty and allowing the participants to be faster. Finally, the spatial cue was the one that not only alerted the participants of the imminent target stimulus appearance, also preceding it by 400 ms, but it also oriented the participants' gaze, as it informed them of the location on the screen where the stimulus would appear. Hence, spatial-cue trials would be expected to obtain the fastest RTs.

Interaction between Congruency and Cue

The main effect of *Congruency* was significant, as in the previous analysis, but, more importantly, there was a statistically significant interaction between *Congruency* and *Cue*, $F(3, 327) = 25.3$, $p < .001$, $\eta_p^2 = .19$. Using Fisher's LSD test, post-hoc comparisons were performed between cue conditions, which showed statistically significant Conflict Effects in all cue conditions (all *p*s < .001). On the other hand, the pairwise comparisons between cue conditions revealed that there was no significant difference between the RTs obtained in the double- and centre-cue conditions in congruent trials ($p = .31$). However, all other differences between cue conditions, in both congruent and incongruent trials, were statistically significant (all *p*s < .007). Figure 7 shows the values for the Conflict Effects in each cue condition. These values indicate smaller Conflict Effects in the spatial-cue ($M = 83.5$, $SD = 30.6$) and no-cue ($M = 84.3$, $SD = 37.6$) conditions, and larger Conflict Effects in the double-cue ($M = 105$, $SD = 33.7$) and centre-cue ($M = 112$, $SD = 37.8$) conditions. These results point towards an interesting conclusion: that certain cue conditions —namely, the no-cue and spatial-cue conditions— seem to be associated with smaller Conflict Effect in RTs, while other cue conditions —double- and centre-cue conditions— are associated with larger ones.

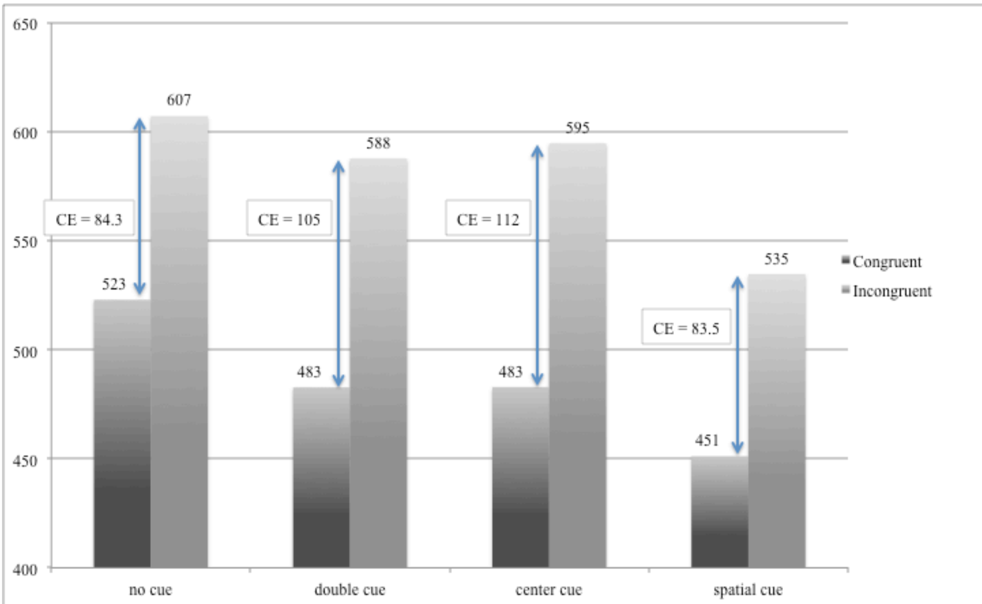

Figure 7. Mean reaction times in the Attention Network Test, by congruency and cue conditions, with Conflict Effect (CE) scores.

Additionally, these results show that the alerting network had an inhibitory effect on the executive network of attention (with a larger Conflict Effect in double-cue trials than in no-cue trials), and that the orienting network, on the other hand, had a positive effect on the executive network of attention (with a smaller Conflict Effect in spatial-cue trials than in centre-cue trials), in line with what other authors have found (Callejas, Lupiánez, & Tudela, 2004; Funes & Lupiáñez, 2003; Posner, 1994).

Interaction between Congruency, Cue and Age

There was a near significant interaction between *Congruency*, *Cue* and *Age*, $F(3, 327) = 2.38$, $p = .070$, $\eta_p^2 = .021$. Comparisons between unstandardized beta weights from the parameter estimates obtained as part of the ANCOVA showed that, even though the association between older age and slower RTs is more accentuated in incongruent trials ($B = 2.96$) than in congruent ones ($B = 2.16$), this relationship is even stronger in no-cue trials (incongruent: $B = 2.94$; congruent: $B = 1.69$) than in any other cue condition (double cue: incongruent: $B = 2.68$, congruent: $B = 2.21$; centre cue: incongruent: $B = 3.18$, congruent: $B = 2.38$; spatial cue: incongruent: $B = 3.05$, congruent: $B = 2.35$). In fact, the no-cue condition was the least impacted by *Age* in the congruent trials, followed by the double-cue condition, but it lost that position in the incongruent trials, where these two cue conditions exchanged places.

In sum, incongruency is associated with a greater impact of *Age* on RTs. Moreover, the difference in *Age* impact on RTs between congruent and incongruent trials is more accentuated in no-cue trials, revealing that the association between older age and a greater susceptibility to Conflict Effects is greater in no-cue trials.

Interaction between Block and Cue

There was a significant interaction effect between *Block* and *Cue*, $F(3, 327) = 10.1$, $p < .001$, $\eta_p^2 = .084$. Pairwise comparisons performed using Fisher's LSD test indicated that there was no significant practice effect in the double-cue condition ($p = .13$). However, there were significant practice effects in all other cue conditions (all *p*s $< .035$) (see Figure 8). It is interesting to note that, even though in most conditions participants responded faster in block 2 than in block 1, the opposite is true for the no-cue condition, where faster responses were obtained in block 1.

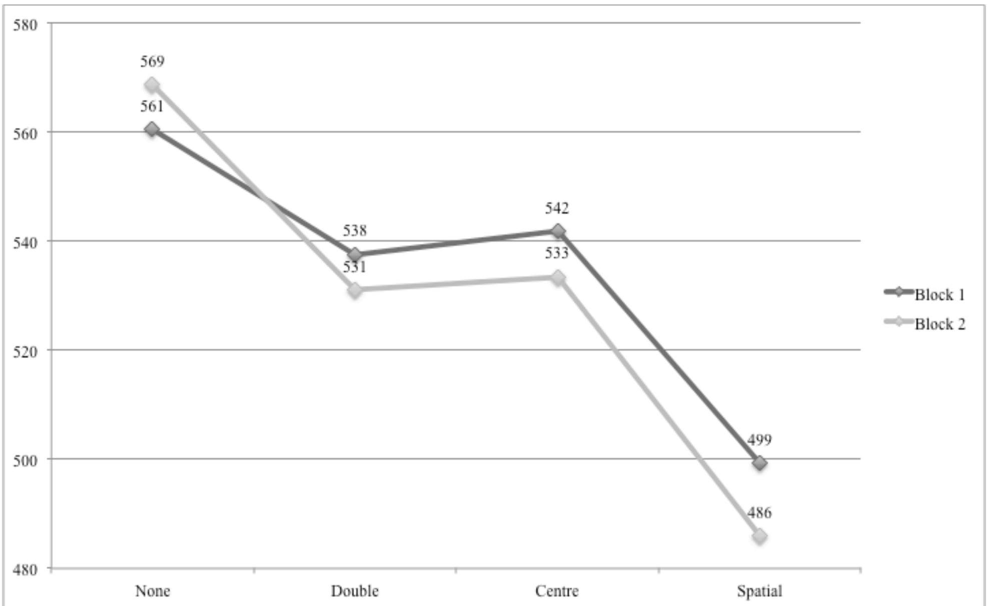

Figure 8. Mean reaction times in the Attention Network Test, by cue condition and by block.

Interaction between Block, Cue and Age

The three-way interaction between *Block*, *Cue* and *Age* also turned out to be statistically significant, $F(3, 327) = 3.27$, $p = .021$, $\eta_p^2 = .029$. Comparisons between unstandardized beta weights from the parameter estimates obtained as part of the ANCOVA showed that, while for double- and spatial-cue conditions, there was a stronger association of younger age and faster RTs in block 1 (double cue: $B = 2.53$; spatial cue: $B = 2.84$) than in block 2 (double cue: $B = 2.36$; spatial cue: $B = 2.56$), for the centre- and no-cue conditions, the opposite was true, with younger age being more strongly associated with faster RTs in block 2 (no cue: B = 2.61; centre cue: B = 2.79) than in block 1 (no cue: B = 2.03; centre cue: B = 2.77). In other words, even though younger participants had significantly faster reaction times in all cue conditions and in both blocks (all ps < .001), it seems that *Age*'s impact on RTs tends to diminish with time and practice in double- and spatial conditions. Conversely, in the no- and centre-cue conditions, practice is associated with an increase in *Age*'s impact on RTs. This is a rather strange pattern, which I have never seen replicated in the literature, so I will err in the side of caution and consider it a Type I error.

All remaining interactions were statistically non-significant (all $F \leq 2.68$, $p \geq .10$, $\eta_p^2 \leq .024$).

3.1.6 Conflict Effect in Accuracy Rates

Table 9 shows the mean accuracy rates obtained in the ANT, by group and by congruency condition. The Conflict Effect was calculated by subtracting the ARs observed in congruent trials from the ARs of incongruent trials.

Table 9

Means (M) and Standard Deviations (SD) of Accuracy Rates, and Mean Conflict Effect Scores in the Attention Network Test

		Congruency					
		Congruent		Incongruent		**Conflict Effect**	
	N	*M*	(*SD*)	*M*	(*SD*)	***M***	**(*SD*)**
Monolinguals	38	.996	(.01)	.971	(.02)	**-.026**	**(.02)**
Bilinguals	77	.997	(.01)	.973	(.03)	**-.024**	**(.03)**
Total	115	.997	(.01)	.972	(.03)	**-.024**	**(.03)**

Note: *N* = number of participants.

3.1.6.1 Conflict Effect in accuracy rates – Main analysis

A 2x2x2x2 factorial ANOVA was performed, with the overall arcsine-transformed ARs as the DV, *Block* (block 1, block 2) and *Congruency* (congruent, incongruent) as within-subjects factors, and *Group* (monolinguals, bilinguals) and *Task Order* (ANT first, Simon task first) as between-subjects factors.

To avoid repeating information that was already provided in section *3.1.3 General Analyses – Accuracy Rates*, the description of the main effects of *Group* and *Block*, as well as the interaction between *Group* and *Task Order*, will not be described again in this section, which will focus instead only on the main effect of *Congruency* and on any significant interactions that include this factor.

Main effect of Congruency (Conflict Effect)

The main effect of *Congruency* was statistically significant, $F(1, 111) = 129$, $p < .001$, $\eta_p^2 = .54$, revealing a significant Conflict Effect in accuracy.

Interaction between Block, Congruency and Task Order

There was a significant interaction between *Block*, *Congruency* and *Task Order*, $F(1, 111) = 6.60$, $p = .012$, $\eta_p^2 = .056$. Pairwise comparisons using Fisher's LSD test revealed higher accuracy rates in incongruent trials in both blocks when the ANT was taken first, and therefore smaller Conflict Effects (see Figure 9).

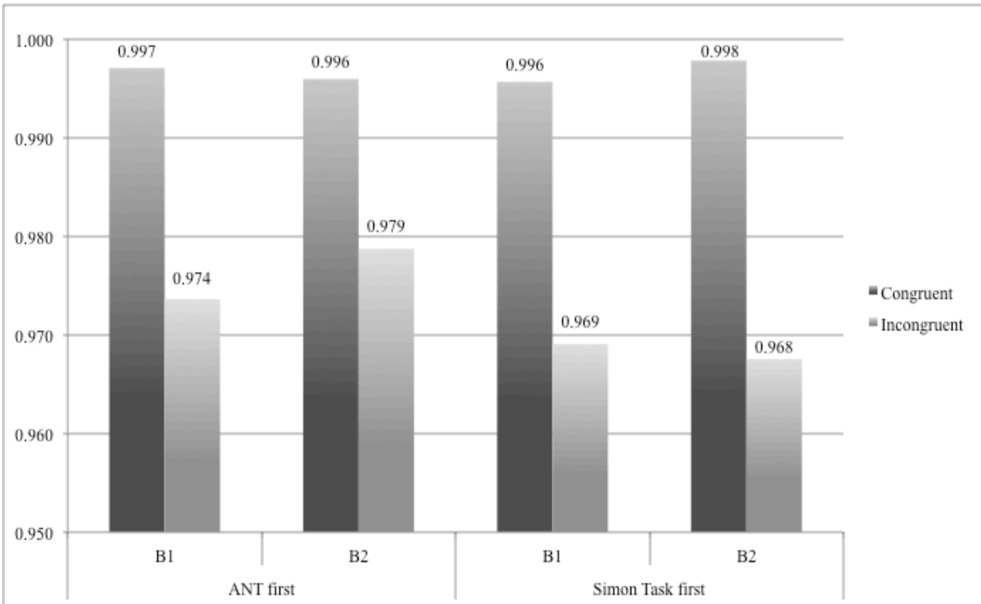

Figure 9. Mean accuracy rates in the Attention Network Test, by task order, block and congruency.

There were non-significant practice effects in all of the *Task Order* by *Congruency* combinations (all ps $\geq .11$), as well as significant Conflict Effects in all *Block* by *Task Order* combinations (all ps $< .001$). The comparison between task orders also showed no significant differences in any of the *Block* by *Congruency* combinations (all ps $\geq .058$).

A possible explanation for this interaction between *Block*, *Congruency* and *Task Order* relates to the level of fatigue the participants might have felt during the experimental session. Participants who took the ANT task first would have been able to focus more easily during that task because it was the very first task of the session, while participants who took the ANT in the middle of the experimental session had already gone through the Simon task and the English proficiency test before they took the ANT. However, it is still interesting to note that this did not affect the participants' reaction times, but only their accuracy rates.

Interaction between Block, Congruency, Task Order and Group

Also statistically significant was the interaction between *Block*, *Congruency*, *Task Order* and *Group*, $F(1, 111) = 4.52$, $p = .036$, $\eta_p^2 = .039$. Post-hoc comparisons using Fisher's LSD test revealed a near significant difference in ARs between task orders in monolinguals' block 1 incongruent trials ($p = .070$) and significant differences in ARs between task orders in monolinguals' block 2 congruent trials ($p = .048$), bilinguals' block 1 incongruent trials ($p = .033$), and bilinguals' block 2 incongruent trials ($p = .030$). These differences translate into a different Conflict Effect pattern for both task orders, as can be seen in Figure 10: bilinguals who took the ANT first exhibited smaller Conflict Effects than bilinguals who took the Simon task first; monolinguals who took the ANT first, on the other hand, showed larger Conflict Effects in block 1 than in block 2, while monolinguals who took the Simon task first showed the opposite pattern, with larger Conflict Effects in block 2 than in block 1.

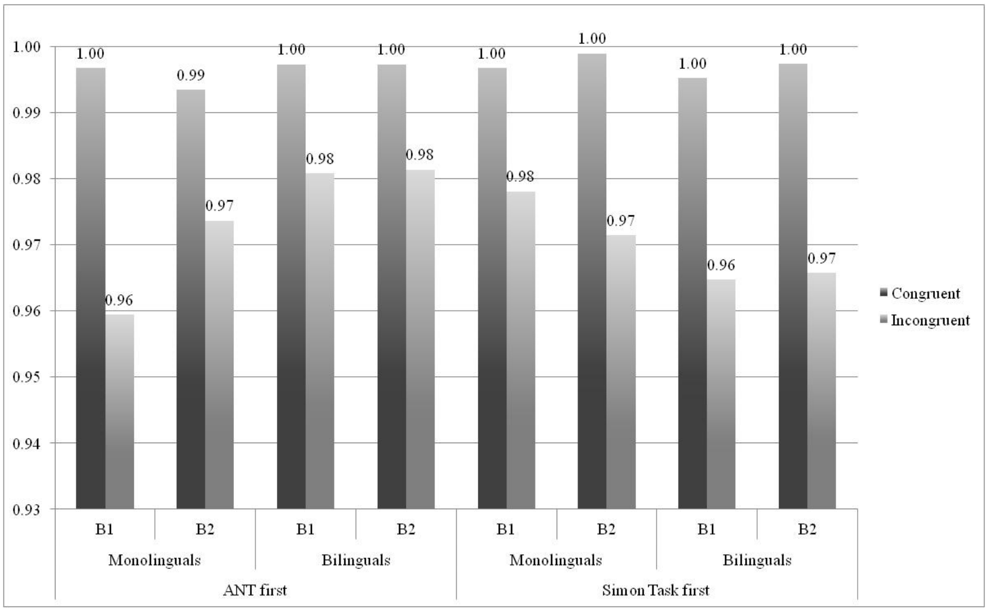

Figure 10. Mean accuracy rates in the Attention Network Test, by task order, block, congruency and group.

There were significant Conflict Effects in all combinations of *Block*, *Task Order* and *Group* (all ps ≤ .005), non-significant practice effects in all combinations of *Congruency*, *Task Order* and *Group* (all ps ≥ .051), as well as non-significant differences between monolinguals and bilinguals in all combinations of *Block*, *Congruency* and *Task Order* (all ps ≥ .23).

No other main effects or interactions were statistically significant (all Fs(1, 111) ≤ 2.65, ps ≥ .11, η_p^2s ≤ .023).

3.1.6.2 Conflict Effect in accuracy rates – Analysis by cue condition

Since there were significant differences between RTs depending on the cues presented to the participants before the target stimuli, there was likewise an interest in determining if the Conflict Effect in accuracy was also influenced by cue condition.

Table 10 presents the ARs in the Attention Network Test, by congruency and cue conditions.

Table 10

Means (M) and Standard Deviations (SD) of Accuracy Rates in the Attention Network Test, by Congruency and Cue Conditions, with Mean Scores for the Conflict Effect

	Congruency								
	Congruent			Incongruent			**Conflict Effect**		
	Mon.	Bil.	**Total**	Mon.	Bil.	**Total**	Mon.	Bil.	**Total**
Cue	*M* (*SD*)	*M* (*SD*)	***M* (*SD*)**	*M* (*SD*)	*M* (*SD*)	***M* (*SD*)**	*M*	*M*	***M***
None	.992 (.02)	.993 (.02)	**.993 (.02)**	.977 (.03)	.978 (.04)	**.977 (.04)**	-.015	-.015	**-.015**
Double	.998 (.01)	.997 (.01)	**.997 (.01)**	.963 (.04)	.971 (.04)	**.968 (.04)**	-.035	-.026	**-.029**
Centre	.997 (.01)	1.000 (.01)	**.999 (.01)**	.954 (.05)	.960 (.06)	**.958 (.05)**	-.043	-.039	**-.040**
Spatial	.999 (.01)	.998 (.01)	**.998 (.01)**	.989 (.02)	.983 (.03)	**.985 (.03)**	-.010	-.015	**-.013**

Notes: Mon. = monolinguals, Bil. = bilinguals.

A 2x2x4x2x2 factorial ANOVA was performed, with the arcsine-transformed ARs as the DV, *Block* (block 1, block 2), *Congruency* (congruent, incongruent) and *Cue* (no cue, double cue, centre cue, spatial cue) as within-subjects factors, and *Group* (monolinguals, bilinguals) and *Task Order* (ANT first, Simon task first) as between-subjects factors.

Since this analysis replicates almost completely the previous one (conducted in section *3.1.6.1 Conflict Effect in accuracy rates – Main analysis*), the only difference between the two being the added within-subjects factor *Cue*, we will restrict our description of the analysis to the results related to this new variable, as all other results will have already been described in the mentioned section.

Main effect of Cue

Mauchly's test indicated that the assumption of sphericity had been violated ($\chi^2(5) = 20.1$, $p = .001$) for the main effect of *Cue*, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .91$). The test revealed a significant main effect of *Cue*, $F(2.72, 302) = 10.8$, $p < .001$, $\eta_p^2 = .088$. ARs differed significantly between almost all cue conditions (all ps $\leq .021$), except for the differences between the no- and double-cue conditions ($p = .44$) and between the double- and centre-cue conditions ($p = .18$). Participants were more accurate in spatial-cue trials, followed by no-cue trials, double-cue trials and, finally, centre-cue trials (see Table 10 and Figure 11).

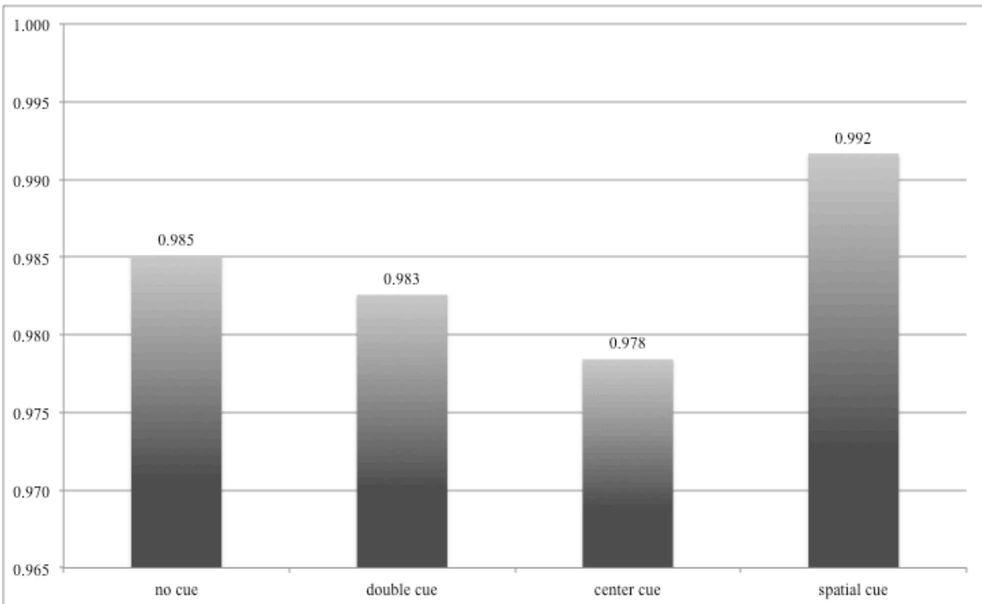

Figure 11. Mean accuracy rates in the Attention Network Test, by cue conditions.

It seems that participants performed at near-maximum accuracy in all cue conditions, when the trials were congruent. It is only in incongruent trials that the differences in ARs between cue conditions are visible. Again, the alerting and orienting properties of the spatial cue might explain the higher rates of accuracy obtained in the spatial-cue condition. However, the properties of the remaining cues do not seem to explain as easily the accuracy results for the corresponding cue conditions. It would be expected, for instance, that the no-cue condition would yield the lowest accuracy rates; however, that was not the case.

Interaction between Congruency and Cue

There was a statistically significant interaction between *Congruency* and *Cue*, $F(3, 333) = 11.7$, $p < .001$, $\eta_p^2 = .095$. Using Fisher's LSD test, post-hoc comparisons showed significant Conflict Effects in all cue conditions (all *p*s < .001). It is only when we compare cue conditions separately for congruent and incongruent trials that the interaction becomes more evident (see Figure 12). In congruent trials, only the no-cue condition displays ARs significantly different from the ARs observed in all other cue conditions (all *p*s ≤ .048). The double-, centre- and spatial-cue conditions do not differ significantly from each other (all *p*s ≥ .47). On the other hand, in incongruent trials, the difference in ARs between the double- and centre-cue conditions is non-significant ($p = .11$), the difference between the no- and double-cue conditions is near significant ($p = .056$), but all remaining differences between cue conditions are significant (all *p*s ≤ .019).

Figure 12 also shows the values of the Conflict Effects in each cue condition. Reflecting the ARs observed for each congruency and cue condition, larger Conflict Effects can be observed in the double-cue and centre-cue conditions, while the no-cue and spatial-cue conditions display smaller Conflict Effects. These results reinforce the results obtained with the RTs, revealing that the no-cue and spatial-cue conditions are associated with smaller conflict effects, while the double- and centre-cue conditions are associated with larger ones.

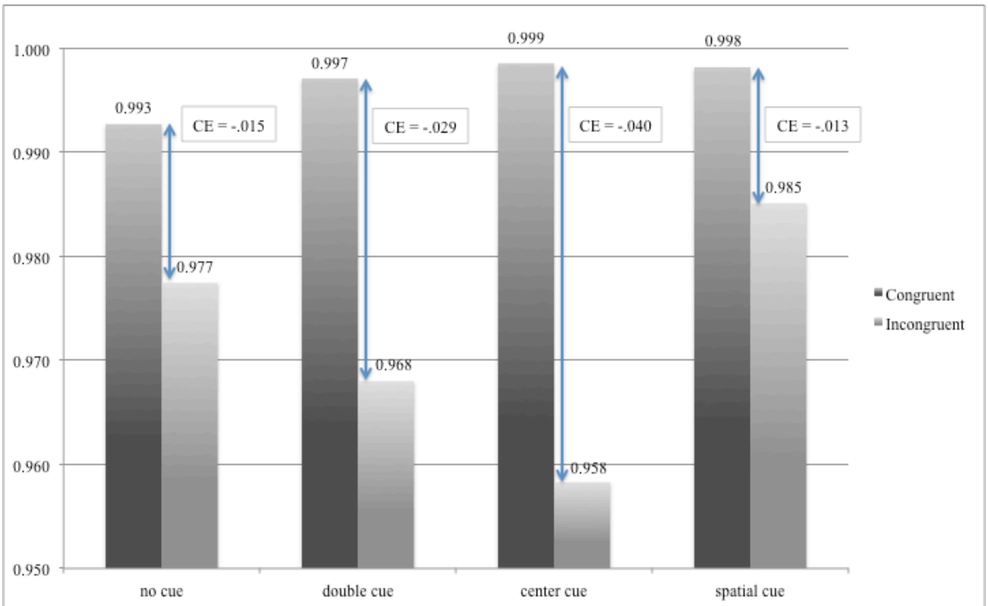

Figure 12. Mean accuracy rates in the Attention network Test, by cue and congruency conditions, with Conflict Effect (CE) scores.

As in the RT results, the alerting network had an inhibitory effect on the executive network of attention (with a larger Conflict Effect in double-cue trials than in no-cue trials), and the orienting network had a positive effect on the executive network of attention (with a smaller Conflict Effect in spatial-cue trials than in centre-cue trials), in line with previous findings (Callejas et al., 2004; Funes & Lupiáñez, 2003; Posner, 1994).

The interaction between *Block*, *Cue* and *Task Order* was also statistically significant, $F(3, 333) = 3.07$, $p = .028$, $\eta_p^2 = .027$, but we will leave the analysis of this interaction to the sections on the Alerting and Orienting Effects, where this interaction seems to be more informative.

No other interactions that included the variable *Cue* were statistically significant (all Fs ≤ 1.80, ps $\geq .15$, η_p^2s $\leq .016$).

3.1.7 Alerting Effect in Reaction Times

Table 11 shows the mean reaction times in the ANT, by cue condition, as well as the Alerting Effect scores, calculated by subtracting the RTs in double-cue trials from the RTs observed in no-cue trials.

Table 11

Means (M) and Standard Deviations (SD) of Reaction Times in the No-Cue and Double-Cue Conditions of the Attention Network Test, and Mean Scores for the Alerting Effect

	Block 1			Block 2			Total		
	No Cue	Double C.	**Alert. Ef.**	No Cue	Double C.	**Alert. Ef.**	No Cue	Double C.	**Alert. Ef.**
	M (*SD*)	*M* (*SD*)	***M***	*M* (*SD*)	*M* (*SD*)	***M***	*M* (*SD*)	*M* (*SD*)	***M***
Monolinguals	550 (50)	523 (58)	**26.8**	557 (58)	518 (57)	**38.8**	553 (52)	521 (56)	**32.7**
Bilinguals	566 (68)	545 (71)	**21.0**	574 (70)	537 (70)	**37.2**	570 (67)	541 (69)	**29.1**
Total	561 (63)	538 (68)	**22.9**	569 (66)	531 (66)	**37.7**	565 (62)	534 (65)	**30.3**

Notes: C. = cue, Alert. Ef. = Alerting Effect.

3.1.7.1 Alerting Effect in reaction times – Main analysis

A 2x2x2x2 factorial ANCOVA was conducted to determine whether there was a significant Alerting Effect in RTs. The analysis included the RTs in no-cue and double-cue trials as the DV, *Block* (block 1, block 2) and *Cue* (no cue, double cue) as within-subjects factors, *Group* (monolinguals, bilinguals) and *Gender* (male, female) as between-subjects factors, and *Age* and *Fluid Intelligence* as covariates.

Main effect of Cue (Alerting Effect)

The main effect of *Cue* was significant, $F(1, 109) = 160$, $p < .001$, $\eta_p^2 = .59$, denoting a significant Alerting Effect in RTs, in the ANT, with participants being on average faster responding to double-cue trials ($M = 534$, $SD = 65.3$) than to no-cue trials ($M = 565$, $SD = 62.4$).

Main effect of Group

The main effect of *Group* in reaction times was non-significant, $F(1, 109) = .59$, $p = .45$, $\eta_p^2 = .005$, showing a non-significant difference between monolinguals and bilinguals. Moreover, the interaction between *Group* and *Cue* was also non-significant, $F(1, 109) = .73$, $p = .40$, $\eta_p^2 = .007$, indicating no differences in Alerting Effect in RTs between groups.

Main effect of Block

There was a non-significant main effect of *Block* on RTs, $F(1, 109) = .17$, $p = .68$, $\eta_p^2 = .002$, revealing no significant practice effect.

Interaction between Block and Cue

The interaction between *Block* and *Cue* was significant, $F(1, 109) = 10.3$, $p = .002$, $\eta_p^2 = .087$. Post-hoc comparisons using Fisher's LSD test revealed that there was a significant practice effect in no-cue trials ($p = .039$), but a non-significant one in double-cue trials ($p = .15$). However, as we have seen before, the practice effect found in no-cue trials is an inverse practice effect, in that the RTs become slower in block 2, instead of faster.

Interaction between Block, Cue and Age

There was also a significant interaction between *Block*, *Cue* and *Age*, $F(1, 109) = 5.58$, $p = .020$, $\eta_p^2 = .049$. Comparisons between unstandardized beta weights from the parameter estimates obtained as part of the ANCOVA revealed that the relation between older age and slower RTs was stronger in the double-cue trials ($B = 2.54$) in block 1 than in the no-cue trials ($B = 2.03$). However, in block 2, the opposite was true, with *Age* having a stronger effect on RTs in the no-cue trials ($B = 2.63$) than in the double-cue trials ($B = 2.38$).

In short, while at first older *Age* is associated with smaller Alerting Effects, with time and practice, the relationship changes and older *Age* becomes associated with larger Alerting Effects.

Main effects of the individual-difference variables

The main effects of the individual-difference variables on RTs were all significant: *Age*, $F(1, 109) = 25.5$, $p < .001$, $\eta_p^2 = .19$; *Gender*, $F(1, 109) = 5.19$, $p = .025$, $\eta_p^2 = .045$; *Fluid Intelligence*, $F(1, 109) = 9.43$, $p = .003$, $\eta_p^2 = .080$. The same interpretation given for the results on the whole data are also true for this data subset: younger age, higher *Fluid Intelligence* and male gender were significantly associated with faster RTs.

Interaction between Cue and Fluid Intelligence

There was a significant interaction between *Cue* and *Fluid Intelligence*, $F(1, 109) = 4.64$, $p = .033$, $\eta_p^2 = .041$. Comparisons between unstandardized beta weights from the parameter estimates obtained as part of the ANCOVA showed that the association between higher *Fluid Intelligence* and faster RTs is more accentuated in double-cue trials ($B = -1.21$) than in no-cue ones ($B = -.89$).

In other words, participants with higher *Fluid Intelligence* scores benefitted more from the alerting cue. However, by having a greater effect in double-cue trials, higher *Fluid Intelligence* was associated with larger Alerting Effects.

No other main effects or interactions reached statistical significance (all Fs(1, 109) $\leq$ 1.57, ps $\geq$ .21, η_p^2s $\leq$ .014).

3.1.7.2 Alerting Effect in reaction times – Analysis by congruency condition

As we had seen in section *3.1.5 – Conflict Effect in Reaction Times*, there was a significant interaction between the *Congruency* and *Cue* conditions, which would affect our interpretation of the Alerting Effect in RTs in the ANT. In order to look closer at this interaction, a 2x2x2x2x2 factorial ANCOVA was performed, which included the RTs in no-cue and double-cue trials as the DV. *Block* (block 1, block 2), *Cue* (no cue, double cue) and *Congruency* (congruent, incongruent) were entered in the analysis as within-subjects factors, *Group* (monolinguals, bilinguals) and *Gender* (male, female) as between-subjects factors, and *Age* and *Fluid Intelligence* as covariates.

The main effects of *Cue*, *Age*, *Fluid Intelligence* and *Gender*, as well as the interaction effects between *Block* and *Cue* and between *Block*, *Cue* and *Age* were all statistically significant, as it was expected, since this analysis includes the same DV and most of the same variables as the ANCOVA described in the previous section. For this reason, we will restrict the description of this analysis to the information added by the variable *Congruency*.

Main effect of Congruency

There was a significant main effect of *Congruency* on the RTs observed in the no-cue and double-cue trials, $F(1, 109) = 896$, $p < .001$, $\eta_p^2 = .89$, again with responses to incongruent trials being slower than responses to congruent trials.

Interaction between Congruency and Cue

More importantly, the interaction between *Congruency* and *Cue* was statistically significant, $F(1, 109) = 27.7$, $p < .001$, $\eta_p^2 = .20$. Pairwise comparisons conducted by means of Fisher's LSD test revealed that, even though there were significant Conflict Effects in both no-cue and double-cue trials (both *p*s < .001), as well as significant Alerting Effects in both congruent and incongruent trials (both *p*s < .001), the Alerting Effect was much larger in congruent trials ($M = 40.2$, $SD = 25.5$), than in incongruent ones ($M = 19.5$, $SD = 30.5$) (see Figure 13). It could be the case that the extra time needed to process conflict, in the incongruent trials, obscures the Alerting Effect values, which would seem more evident in the congruent trials, since participants have no extra cognitive load to deal with. Additionally, the congruence effect is more substantial for double-cue trials than for no-cue trials, suggesting that the introduction of conflict affects different cue conditions in different ways. This reflects, as has already been described earlier, the negative impact the alerting network has on the executive control network, with a larger Conflict Effect in cued trials (double-cue trials) than in no-cue trials, which also translates as a larger Alerting Effect in congruent trials than in incongruent trials.

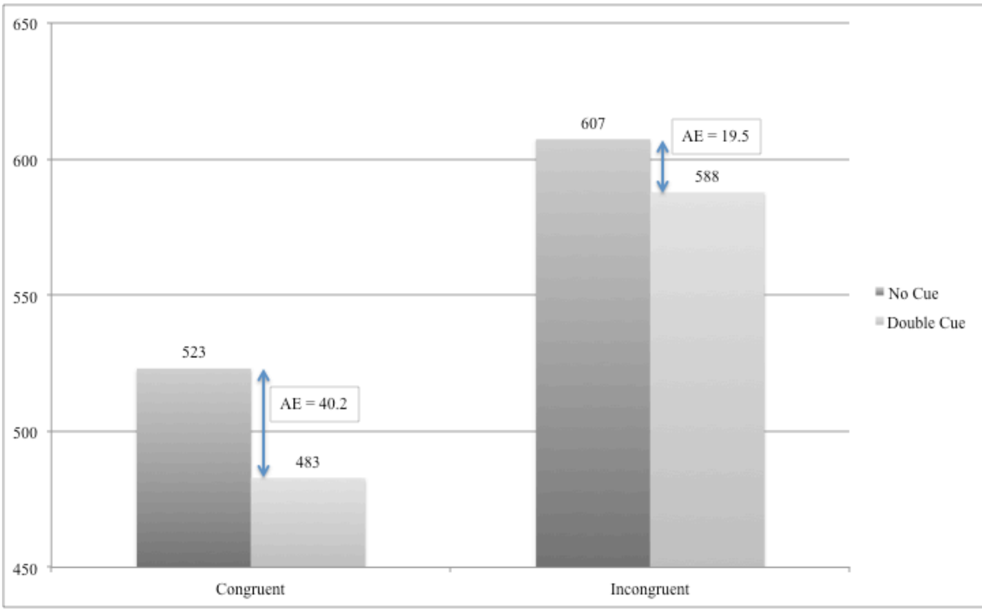

Figure 13. Mean reaction times in the no-cue and double-cue trials of the Attention Network Test, by congruency condition, with Alerting Effect (AE) scores.

Interaction between Congruency, Cue and Age

There was also a significant interaction between *Congruency*, *Cue* and *Age*, $F(1, 109) = 6.37$, $p = .013$, $\eta_p^2 = .055$. Comparisons between unstandardized beta weights from the parameter estimates showed that, even though the association between older age and slower RTs is more accentuated in incongruent trials ($B = 2.81$) than in congruent ones ($B = 1.95$), this relationship is much stronger in no-cue trials (incongruent: $B = 2.94$; congruent: $B = 1.69$) than in double-cue trials (incongruent: $B = 2.68$, congruent: $B = 2.21$).

On the other hand, the association between older age and slower RTs impacts the Alerting Effect differently depending on *Congruency*: in incongruent trials, the association between older age and slower RTs is stronger in no-cue trials than in double-cue trials, suggesting an association between older age and larger Alerting Effects; however, in congruent trials, the relationship between older age and slower

RTs has a stronger impact on double-cue trials instead, which indicates an association between older age and smaller Alerting Effects.

3.1.8 Alerting Effect in Accuracy Rates

Table 12 shows the accuracy rates observed in the no-cue and double-cue conditions of the ANT.

Table 12

Means (M) and Standard Deviations (SD) of Accuracy Rates in the No-Cue and Double-Cue Trials of the Attention Network Test, and Mean Scores for the Alerting Effect

	Block 1			Block 2			Total		
	No Cue	Double C.	**Alert. Ef.**	No Cue	Double C.	**Alert. Ef.**	No Cue	Double C.	**Alert. Ef.**
	M (*SD*)	*M* (*SD*)	***M***	*M* (*SD*)	*M* (*SD*)	***M***	*M* (*SD*)	*M* (*SD*)	***M***
Monolinguals	.987 (.02)	.980 (.03)	**.007**	.982 (.03)	.980 (.03)	**.002**	.985 (.02)	.980 (.02)	**.004**
Bilinguals	.983 (.03)	.983 (.03)	**-.001**	.988 (.03)	.984 (.03)	**.004**	.985 (.02)	.984 (.02)	**.002**
Total	.984 (.03)	.982 (.03)	**.002**	.986 (.03)	.983 (.03)	**.003**	.985 (.02)	.983 (.02)	**.003**

Notes: C. = cue, Alert. Ef. = Alerting Effect.

3.1.8.1 Alerting Effect in accuracy rates – Main analysis

A 2x2x2x2 factorial ANOVA was conducted to determine whether there was a significant Alerting Effect in ARs. The analysis included the arcsine-transformed ARs in no-cue and double-cue trials as the DV, *Block* (block 1, block 2) and *Cue* (no cue, double cue) as within-subjects factors, and *Group* (monolinguals, bilinguals) and *Task Order* (ANT first, Simon task first) as between-subjects factors.

No main effects were statistically significant (all Fs(1, 111) $\leq$ .81, ps $\geq$ .37, η_p^2s $\leq$ .007, showing a non-significant Alerting Effect in ARs, as well as non-significant differences between groups and between blocks.

Interaction between Block, Cue and Task Order

There was a significant interaction effect between *Block*, *Cue* and *Task Order*, $F(1, 111) = 4.62$, $p = .034$, $\eta_p^2 = .040$. Post-hoc comparisons performed using Fisher's LSD test revealed non-significant Alerting Effects in all *Block* by *Task Order* combinations (all ps $\geq$ .12). Similarly, there were no significant practice effects in any of the *Task Order* by *Cue* combinations (all ps $\geq$ .073), as well as no significant differences between task orders in any of the *Block* by *Cue* combinations (all ps $\geq$ .077).

No other interactions were statistically significant (all Fs(1, 111) $\leq$ 2.84, ps $\geq$ .095, η_p^2s $\leq$ .025.

3.1.8.2 Alerting Effect in accuracy rates – Analysis by congruency condition

Since the previous analysis showed no significant Alerting Effect in ARs, there is no justification to run an analysis by congruency condition.

3.1.9 Orienting Effect in Reaction Times

The Orienting Effect, calculated by subtracting the reaction times in spatial-cue trials from the RTs in centre-cue trials, is intended to tap into the functioning of the orienting network. It is expected that trials initiated by a cue appearing at the same location as the target stimulus (spatial-cue trials) be more easily processed than trials initiated by a centre cue (centre-cue trials), which does not allow the participant to predict where the target stimulus will show up. This difference in difficulty between the two types of trials should thus materialize in a difference in RTs, with the spatial-cue trials expected to produce faster responses than the centre-cue ones. Table 13 displays the RTs for the centre- and spatial-cue trials in the ANT.

Table 13

Means (M) and Standard Deviations (SD) of Reaction Times in the Centre-Cue and Spatial-Cue Trials of the Attention Network Test, and Mean Scores for the Orienting Effect

	Block 1			Block 2			Total		
	Centre C.	Spatial C.	**Orient. Ef.**	Centre C.	Spatial C.	**Orient. Ef.**	Centre C.	Spatial C.	**Orient. Ef.**
	M (*SD*)	*M* (*SD*)	***M***	*M* (*SD*)	*M* (*SD*)	***M***	*M* (*SD*)	*M* (*SD*)	***M***
Monolinguals	531 (58)	487 (57)	**43.4**	521 (58)	476 (58)	**45.4**	526 (57)	481 (56)	**44.4**
Bilinguals	547 (74)	505 (69)	**41.9**	539 (71)	491 (72)	**48.5**	543 (71)	498 (69)	**45.2**
Total	542 (69)	499 (66)	**42.4**	533 (67)	486 (68)	**47.5**	538 (67)	493 (65)	**44.9**

Notes: C. = cue, Orient. Ef. = Orienting Effect.

3.1.9.1 Orienting Effect in reaction times – Main analysis

A 2x2x2x2 factorial ANCOVA was conducted to determine whether there was a significant Orienting Effect in RTs. The analysis included the RTs in centre-cue and spatial-cue trials as the DV, *Block* (block 1, block 2) and *Cue* (centre cue, spatial cue) as within-subjects factors, *Group* (monolinguals, bilinguals) and *Gender* (male, female) as between-subjects factors, and *Age* and *Fluid Intelligence* as covariates.

Main effect of Cue (Orienting Effect)

The test revealed a significant main effect of *Cue* on RTs, $F(1, 109) = 213$, $p < .001$, $\eta_p^2 = .66$, showing an Orienting Effect, with RTs to spatial-cue trials being faster ($M = 493$, $SD = 65.2$) than RTs to centre-cue trials ($M = 538$, $SD = 66.8$).

Main effect of Group

There was a non-significant main effect of *Group* on reaction times, $F(1, 109) = .23$, $p = .64$, $\eta_p^2 = .002$, indicating no significant differences in RTs between monolinguals and bilinguals. More importantly, the interaction effect between *Group* and *Cue* was also non-significant, $F(1, 109) = .004$, $p = .95$, $\eta_p^2 < .001$, revealing no differences in Orienting Effect between monolinguals and bilinguals.

Main effect of Block

There was a significant main effect of *Block* on reaction times, $F(1, 109) = 11.5$, $p = .001$, $\eta_p^2 = .096$, showing a significant practice effect in RTs, with participants being faster in block 2 than in block 1. The interaction effect between *Block* and *Cue* was not statistically significant, though, $F(1, 109) = 1.76$, $p = .19$, $\eta_p^2 = .016$, revealing no significant differences in Orienting Effect between blocks.

Main effects of the individual-difference variables

The main effects of the covariates *Age* and *Fluid Intelligence* were statistically significant —*Age*: $F(1, 109) = 33.5$, $p < .001$, $\eta_p^2 = .24$; *Fluid Intelligence*: $F(1, 109) = 10.2$, $p = .002$, $\eta_p^2 = .085$. The main effect of *Gender*, however, was only near significant, $F(1, 109) = 3.11$, $p = .081$, $\eta_p^2 = .028$. The same interpretation given for the results on the whole data are also true for this data subset: younger age, higher *Fluid Intelligence* and male gender were associated with faster RTs.

Interaction between Block, Cue, Group and Gender

There was a significant interaction between *Block*, *Cue*, *Group* and *Gender*, $F(1, 109) = 4.30$, $p = .040$, $\eta_p^2 = .038$. Pairwise comparisons performed using Fisher's LSD method revealed significant Orienting Effects for all combinations of *Group*, *Gender* and *Block* (all *p*s < .001). The comparison between groups revealed near significant differences between female monolinguals and bilinguals (all *p*s ≥ .057 and ≤ .087), but no significant differences between male monolinguals and bilinguals (all *p*s ≥ .34). On a different perspective, the comparison between blocks showed females to have mostly significant practice effects, reducing their RTs between blocks 1 and 2 (all *p*s ≤ .006, except one $p = .060$), while males had mostly non-significant practice effects (all *p*s ≥ .33, except one $p = .031$). The most informative comparison, though, was the one between males and females, as it revealed significant differences in RTs between bilingual females and males, in all *Block* and *Cue* combinations (all *p*s < .019), in contrast with no significant differences between monolingual males and females (all *p*s ≥ .63). In all cases, females were slower than males, but only significantly so within the bilingual group.

3.1.9.2 Orienting Effect in reaction times – Analysis by congruency condition

As we had seen in section *3.1.5 – Conflict Effect in Reaction Times*, there was a significant interaction between the *Congruency* and *Cue* conditions, which could affect our interpretation of the Orienting Effect in RTs. Table 14 shows the RTs obtained in centre- and spatial-cue trials across the *Congruency* condition.

Table 14

Means (M) and Standard Deviations (SD) of Reaction Times in the Attention Network Test, by Congruency and (Orienting Network) Cue Conditions, with Mean Scores for the Orienting Effect

	Congruency					
	Congruent			Incongruent		
	Mon.	Bil.	**Total**	Mon.	Bil.	**Total**
Cue	*M* (*SD*)	*M* (*SD*)	***M* (*SD*)**	*M* (*SD*)	*M* (*SD*)	***M* (*SD*)**
Centre	471 (53)	489 (63)	**483 (60)**	583 (64)	601 (82)	**595 (77)**
Spatial	437 (52)	458 (63)	**451 (60)**	526 (63)	539 (78)	**535 (73)**
Orienting Effect	34	31	**32**	57	62	**60**

Notes: Mon. = monolinguals, Bil. = bilinguals.

A 2x2x2x2x2 factorial ANCOVA was performed, with the RTs in centre- and spatial-cue trials as the DV, *Block* (block 1, block 2), *Congruency* (congruent, incongruent) and *Cue* (centre cue, spatial cue) as within-subjects factors, *Group* (monolinguals, bilinguals) and *Gender* (male, female) as between-subjects factors, and *Age* and *Fluid Intelligence* as covariates.

The significant main effects and interactions already explored in the previous ANCOVA (main effects of *Block*, *Cue*, *Age* and *Fluid Intelligence* and interaction between *Block*, *Cue*, *Group* and *Gender*) were also significant in this analysis, as anticipated, and therefore only main effects and interactions related to the added variable *Congruency* will be described here.

Main effect of Congruency

There was a significant main effect of *Congruency*, $F(1, 109) = 985$, $p < .001$, $\eta_p^2 = .90$, as well as significant interaction effects between *Congruency* and *Age*, and

Congruency and *Fluid Intelligence*, which have already been described in the section on the Conflict Effect.

Interaction between Cue and Congruency

There was a significant interaction between *Cue* and *Congruency*, $F(1, 109) = 42.8$, $p < .001$, $\eta_p^2 = .28$, showing a significant effect of *Congruency* on the Orienting Effect. Post-hoc comparisons using Fisher's LSD test revealed significant Conflict Effects in both centre- and spatial-cue conditions (both *p*s < .001), as well as significant Orienting Effects in both congruent and incongruent conditions (both *p*s < .001). The interaction between these two factors seems to be related to the two-fold increase observed in the Orienting Effect, between congruency conditions (see Figure 14). This increase is associated with the fact that the congruence effect for the centre-cue trials is visibly more marked than the one for the spatial-cue trials. These results could suggest that the orienting (spatial) cue diminishes the impact of the introduction of conflict in the trial, while the merely alerting (centre) cue does not provide the same mitigating effect, causing the RTs to get significantly slower in those trials. In other words, the orienting network seems to have a positive impact on the executive control network, with participants benefitting more from the introduction of a spatial cue in incongruent trials than in congruent trials. This leads, on the other hand, to a larger Orienting Effect in incongruent trials than in congruent trials.

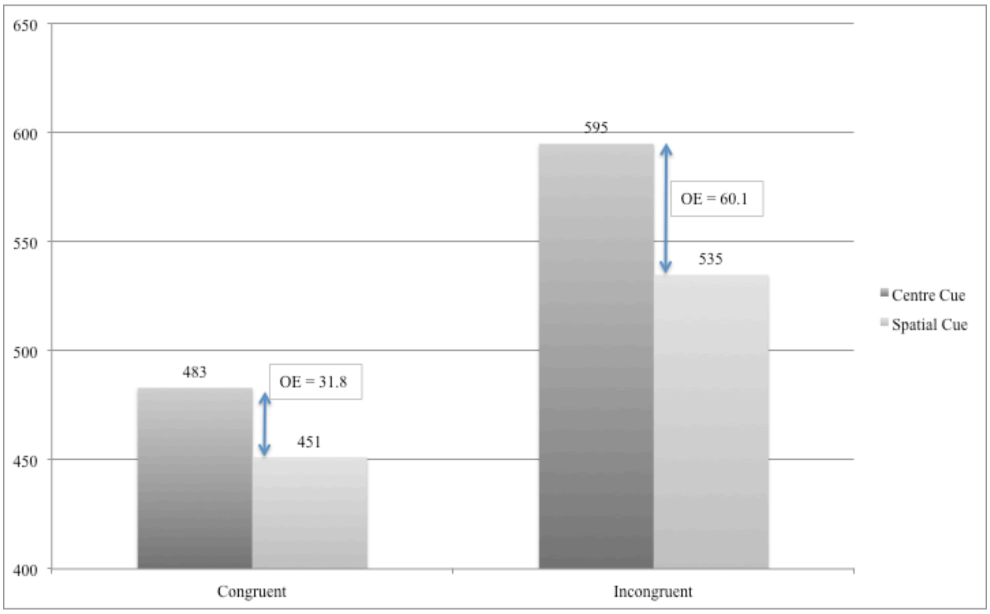

Figure 14. Mean reaction times in the centre-cue and spatial-cue trials of the Attention Network Test, by congruency condition, with Orienting Effect (OE) scores.

No other main effects or interactions were significant and/or pertinent to our analysis.

3.1.10 Orienting Effect in Accuracy Rates

Table 15 displays the ARs observed in centre-cue and spatial-cue trials, as well as the mean scores for the Orienting Effect in accuracy.

Table 15

Means (M) and Standard Deviations (SD) of Accuracy Rates in the Centre-Cue and Spatial-Cue Trials of the Attention Network Test, and Mean Scores for the Orienting Effect

	Block 1			Block 2			Total		
	Centre C.	Spatial C.	**OE**	Centre C.	Spatial C.	**OE**	Centre C.	Spatial C.	**OE**
	M (*SD*)	*M* (*SD*)	***M***	*M* (*SD*)	*M* (*SD*)	***M***	*M* (*SD*)	*M* (*SD*)	***M***
Mon.	.972 (.04)	.992 (.02)	**-.021**	.979 (.03)	.996 (.01)	**-.016**	.975 (.02)	.994 (.01)	**-.019**
Bil.	.981 (.04)	.991 (.02)	**-.010**	.979 (.03)	.990 (.02)	**-.011**	.980 (.03)	.991 (.01)	**-.011**
Total	.978 (.04)	.991 (.02)	**-.013**	.979 (.03)	.992 (.02)	**-.013**	.978 (.03)	.992 (.01)	**-.013**

Notes: C. = cue, OE = Orienting Effect, Mon. = monolinguals, Bil. = bilinguals.

3.1.10.1 Orienting Effect in accuracy rates – Main analysis

A 2x2x2x2 factorial ANOVA was conducted to determine whether there was a significant Orienting Effect in ARs. The analysis included the arcsine-transformed ARs in centre-cue and spatial-cue trials as the DV, *Block* (block 1, block 2) and *Cue* (centre cue, spatial cue) as within-subjects factors, and *Group* (monolinguals, bilinguals) and *Task Order* (ANT first, Simon task first) as between-subjects factors.

Main effect of Cue (Orienting Effect)

The test revealed a significant main effect of *Cue* on ARs, $F(1, 111) = 36.3$, $p < .001$, $\eta_p^2 = .25$, showing a significant Orienting Effect in accuracy, with responses to spatial-cue trials being more accurate ($M = .992$, $SD = .013$) than responses to centre-cue trials ($M = .978$, $SD = .027$).

Main effect of Group

There was a non-significant main effect of *Group* on accuracy, $F(1, 111) = .086$, $p = .77$, $\eta_p^2 = .001$, demonstrating no significant differences in ARs between monolinguals and bilinguals.

Interaction between Cue and Group

Nonetheless, the interaction effect between *Group* and *Cue* was statistically significant, $F(1, 111) = 5.04$, $p = .027$, $\eta_p^2 = .043$. Post-hoc comparisons using Fisher's LSD test revealed that, although monolinguals showed lower accuracy than bilinguals in centre-cue trials, they seem to have benefitted more from the spatial cue than bilinguals, showing conversely higher accuracy rates than bilinguals in spatial-cue trials (see Figure 15), which translates as a larger Orienting Effect in ARs for monolinguals than for bilinguals.

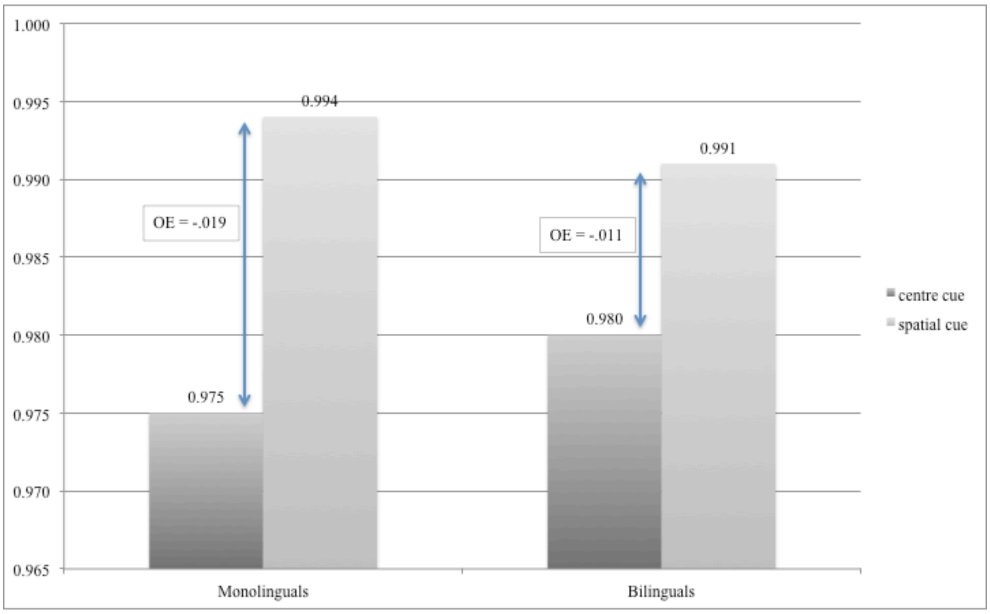

Figure 15. Mean accuracy rates in centre-cue and spatial-cue trials in the Attention Network Test, with Orienting Effect (OE) scores.

Main effect of Block

There was a non-significant main effect of *Block* on accuracy rates, $F(1, 111) = .013$, $p = .91$, $\eta_p^2 < .001$, showing no significant practice effect in ARs. The interaction effect between *Block* and *Cue* was also statistically non-significant, $F(1, 111) = .084$, $p = .77$, $\eta_p^2 = .001$, revealing no significant practice effect in the Orienting Effect between blocks.

Interaction between Group and Task Order

There was a significant interaction effect between *Group* and *Task Order*, $F(1, 111) = 5.59$, $p = .020$, $\eta_p^2 = .048$. Pairwise comparisons performed using Fisher's LSD test revealed a near significant difference in ARs in centre- and spatial-cue trials between monolinguals and bilinguals who took the ANT first ($p = .063$), in contrast with those who took the Simon task first ($p = .15$). The comparisons between task orders, on the other hand, revealed a significant difference in ARs in centre- and spatial-cue trials between bilinguals, depending on which task order they were assigned ($p = .034$), while no significant difference between task orders was found among monolinguals ($p = .17$).

Interaction between Block, Group and Task Order

There was also a significant interaction effect between *Block*, *Group* and *Task Order*, $F(1, 111) = 4.01$, $p = .048$, $\eta_p^2 = .035$. Pairwise comparisons performed using Fisher's LSD test revealed a significant difference in ARs between task orders, for monolingual participants, in block 1 ($p = .022$), a significant difference in ARs between monolinguals and bilinguals who took the ANT first, in block 1 ($p = .006$), as well as a significant difference in ARs between blocks for monolinguals who took the ANT first ($p = .024$). All remaining comparisons were non significant (all *p*s $\geq .077$). However, the more noteworthy nature of this interaction can be appreciated in Figure 16, which reveals that bilinguals were more accurate than monolinguals when the participants took the ANT at the beginning of the experimental session, while monolinguals were more accurate than bilinguals when the Simon task was taken first.

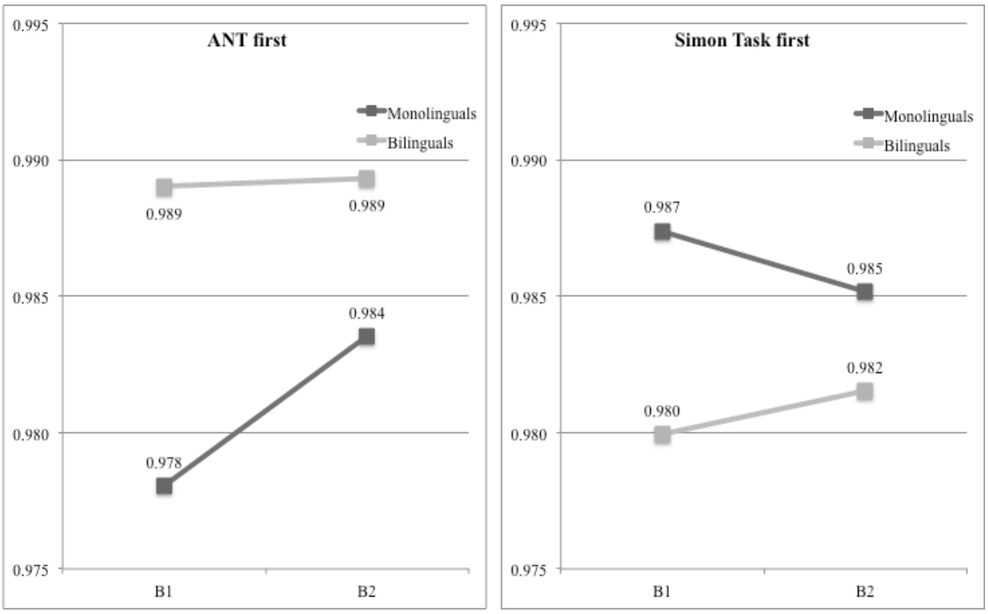

Figure 16. Mean accuracy rates in centre- and spatial-cue trials in the Attention Network Test, by group, block and task order.

No other interactions reached statistical significance (all Fs(1, 111) $\leq$ 3.09, ps $\geq$ .082, η_p^2s $\leq$ .027).

3.1.10.2 Orienting Effect in accuracy rates – Analysis by congruency condition

Next, we assess whether the *Congruency* condition had a significant impact on the Orienting Effect in accuracy in the ANT. Table 16 shows the ARs obtained in the centre- and spatial-cue trials across the *Congruency* condition.

Table 16

Means (M) and Standard Deviations (SD) of Accuracy Rates in the Attention Network Test, by Congruency and (Orienting Network) Cue Conditions, with Mean Scores for the Orienting Effect

	Congruency					
	Congruent			Incongruent		
	Mon.	Bil.	**Total**	Mon.	Bil.	**Total**
Cue	*M* (*SD*)	*M* (*SD*)	***M* (*SD*)**	*M* (*SD*)	*M* (*SD*)	***M* (*SD*)**
Centre	.997 (.01)	1.000 (.01)	**.999 (.01)**	.954 (.05)	.960 (.06)	**.958 (.05)**
Spatial	.999 (.01)	.998 (.01)	**.998 (.01)**	.989 (.02)	.983 (.03)	**.985 (.03)**
Orienting Ef.	-.002	.002	**.000**	-.035	-.023	**-.027**

Notes: Mon. = monolinguals, Bil. = bilinguals, Orienting Ef. = Orienting Effect.

A 2x2x2x2x2 factorial ANOVA was performed, with the arcsine-transformed ARs in centre- and spatial-cue trials as the DV, *Block* (block 1, block 2), *Congruency* (congruent, incongruent) and *Cue* (centre cue, spatial cue) as within-subjects factors, and *Group* (monolinguals, bilinguals) and *Task Order* (ANT first, Simon task first) as between-subjects factors.

Since this analysis only differs from the previous one in that it adds the variable *Congruency*, the main effects and interactions already explored in the previous ANOVA (and previous section) will not be described here, in order to avoid redundant information. For this reason, only the main effect and interactions including the variable *Congruency* will be described in this section.

Main effect of Congruency

The test revealed a significant main effect of *Congruency*, $F(1, 111) = 81.5$, $p < .001$, $\eta_p^2 = .42$, with participants being faster when responding to congruent than to incongruent trials, as predicted by the Conflict Effect.

Interaction between Cue and Congruency

Crucially, there was a statistically significant interaction between *Cue* and *Congruency*, $F(1, 111) = 26.2$, $p < .001$, $\eta_p^2 = .19$. Pairwise comparisons conducted using Fisher's LSD method revealed that the Orienting Effect in accuracy is only significant in incongruent trials ($p < .001$), but not so in congruent ones ($p = .80$) (see Figure 17).

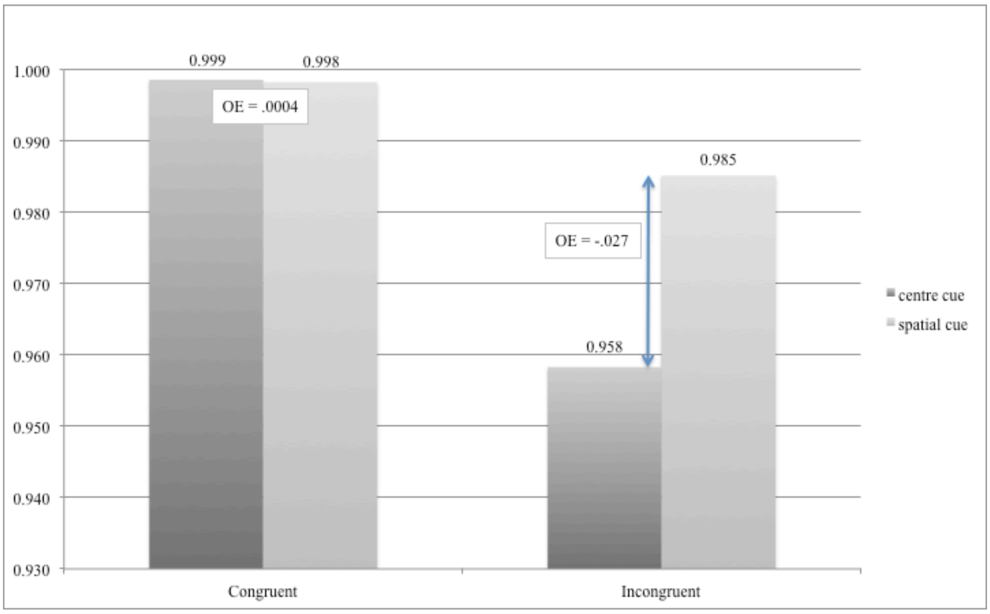

Figure 17. Mean accuracy rates in centre- and spatial-cue trials in the Attention Network Test, by congruency condition, with Orienting Effect (OE) scores.

These results show that the Orienting Effect in accuracy rates only materialises in the incongruent trials, as it is virtually non nexistent in the congruent trials. The addition of conflict decreases accuracy for spatial-cue trials, but significantly more so for centre-cue trials. In summary, both in RTs and ARs, the introduction of conflict is associated with a larger Orienting Effect. It seems that the orienting (spatial) cue lessens the impact of the presence of conflict in the trial, while the merely alerting (centre) cue does not deliver the same mitigating effect. As described earlier, this result reflects the positive impact the orienting network of attention has on the executive control network, with participants benefitting significantly from the introduction of a spatial cue, thus showing a smaller Conflict Effect in spatial-cue trials than in centre-cue trials.

Interactions between Congruency, Group and Task Order (and Block)

There was a statistically significant interaction between *Congruency*, *Group* and *Task Order*, $F(1, 111) = 4.79$, $p = .031$, $\eta_p^2 = .041$, as well as a significant interaction between *Congruency*, *Group*, *Task Order* and *Block*, $F(1, 111) = 5.46$, $p = .021$, $\eta_p^2 = .047$. However, the nature of these interactions has already been described in the section *3.1.6.1 Conflict Effect in accuracy rates – Main analysis*, and thus will not be described again here.

3.1.11 Sequential Congruency Effects in Reaction Times

In order to investigate the Sequential Congruency Effects in the Attention Network Test, the data were analysed by trial sequence, which is arrived by via a combination of the experimental features *Current Trial Congruency* (congruent, incongruent) and *Previous Trial Congruency* (congruent, incongruent). *Current Trial Congruency* corresponds to the variable referred to until now as *Congruency*; however, to avoid confusions, and because both *Previous Trial Congruency* and *Current Trial Congruency* involve similar levels (congruent, incongruent), this variable will be referred to, in this section, as *Current Trial Congruency*, in order to better distinguish it from *Previous Trial Congruency*.

The combination of these two variables results in four possibilities of trial sequence: *a)* previous-congruent trial, followed by current-congruent trial (CC), *b)* previous-congruent trial followed by current-incongruent trial (CI), *c)* previous-incongruent trial followed by current-congruent trial (IC), and *d)* previous-incongruent trial followed by current-incongruent trial (II). Sequential Congruency Effects, as we have seen them described in the literature, translate as faster reaction times for II than for CI and slower reaction times for IC than for CC, or, in other words, smaller Conflict Effects following an incongruent trials than following a congruent one.

Table 17 shows the mean reaction times obtained in the ANT, by trial sequence.

Table 17

Means (M) and Standard Deviations (SD) of Reaction Times in the Attention Network Test (ANT), by Trial Sequence

	Previous Trial Congruency						
	Previous Congruent			Previous Incongruent			**ANT Total**
Current Trial	Mon.	Bil.	**Total**	Mon.	Bil.	**Total**	***M* (*SD*)**
Congruency	*M* (*SD*)	*M* (*SD*)	***M* (*SD*)**	*M* (*SD*)	*M* (*SD*)	***M* (*SD*)**	
Current Congruent	464 (46)	485 (59)	**478 (56)**	479 (53)	498 (64)	**492 (61)**	**485 (58)**
Current Incongruent	571 (59)	592 (80)	**585 (74)**	570 (62)	581 (73)	**577 (69)**	**581 (71)**
Total	518 (51)	538 (68)	**532 (63)**	524 (56)	539 (67)	**534 (64)**	

Notes: Mon. = monolinguals, Bil. = bilinguals.

In order to establish the existence of Sequential Congruency Effects in our data, a 2x2x2x2x2 factorial ANCOVA was performed, with *Block* (block 1, block 2), *Previous Trial Congruency* (congruent, incongruent) and *Current Trial Congruency* (congruent, incongruent) as within-subjects factors, *Group* (monolinguals, bilinguals) and *Gender* (male, female) as between-subjects factors, and *Age* and *Fluid Intelligence* as covariates.

Since the only difference between this statistical analysis and the one performed for the Conflict Effect in RTs is the inclusion of the variable *Previous Trial Congruenc*y, we will refrain from describing any results reported earlier (which present the same levels of statistical significance there and here) and we will restrict the description of results to those related to the main effect and interactions of the added variable *Previous Trial Congruency*.

Main effect of Previous Trial Congruency

The test revealed a significant main effect of *Previous Trial Congruency* on reaction times, $F(1, 109) = 7.49$, $p = .007$, $\eta_p^2 = .064$, with participants presenting faster RTs in previous-congruent trials ($M = 531$, $SD = 63.1$) than in previous-incongruent ones ($M = 534$, $SD = 64.2$).

Interaction between Previous Trial Congruency and Group

There was also a statistically significant interaction effect between *Previous Trial Congruency* and *Group*, $F(1, 109) = 6.34$, $p = .013$, $\eta_p^2 = .055$. Post-hoc comparisons using Fisher's LSD method indicated that only monolinguals' RTs were affected by differences in *Previous Trial Congruency* ($p < .001$), presenting significantly faster RTs in previous-congruent trials than in previous-incongruent trials. *Previous Trial Congruency* alone seemed to have no effect on bilinguals' RTs ($p = .88$) (see Figure 18).

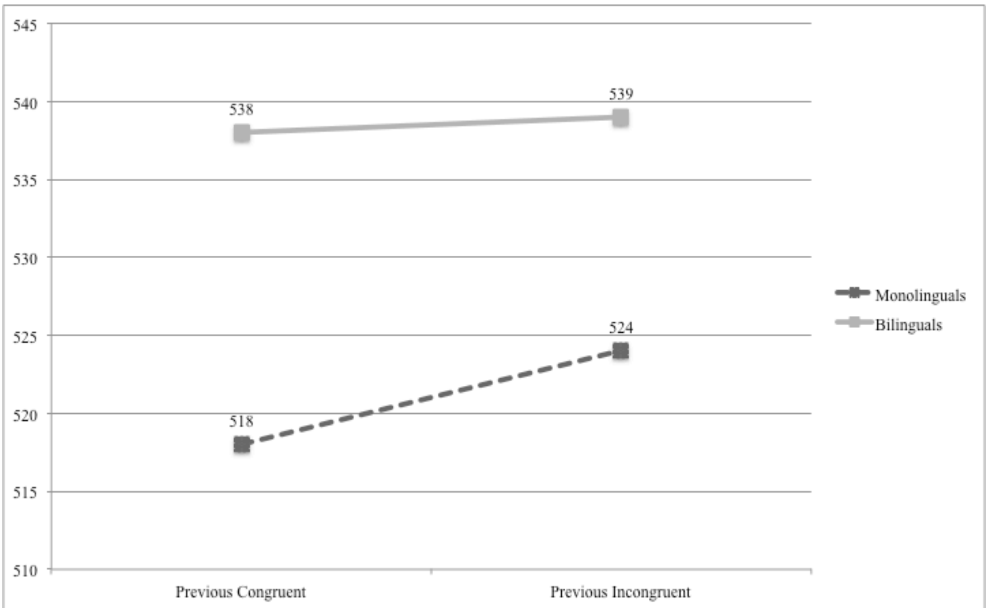

Figure 18. Mean reaction times in the Attention Network Test, by previous trial congruency and by group.

Interaction between Previous Trial Congruency and Current Trial Congruency (Sequential Congruency Effects)

The interaction between *Previous Trial Congruency* and *Current Trial Congruency* was statistically significant, $F(1, 109) = 56$, $p < .001$, $\eta_p^2 = .34$. Post-hoc comparisons using Fisher's LSD method showed that the main effect of each factor remained statistically significant within each of the levels of the other factor (all *p*s < .001). The interaction results from the fact that RTs to current-congruent trials are faster when the previous trial was also congruent, and RTs to current-incongruent trials are faster when the previous trial was also incongruent (see Figure 19). This interaction is what is usually referred to as Sequential Congruency Effects.

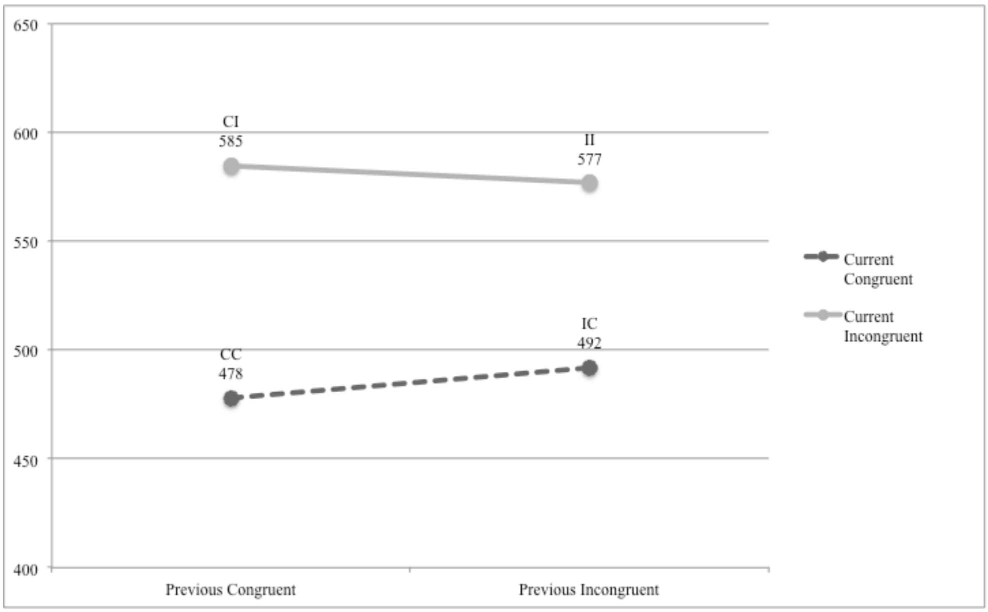

Figure 19. Mean reaction times in the Attention Network Test, by trial sequence condition, depicting the pattern associated with Sequential Congruency Effects. CI = congruent-incongruent, II = incongruent-incongruent, CC = congruent-congruent, IC = incongruent-congruent.

Interaction between Previous Trial Congruency, Current Trial Congruency and Age

There was a statistically significant interaction effect between *Previous Trial Congruency*, *Current Trial Congruency* and *Age*, $F(1, 109) = 4.60$, $p = .034$, $\eta_p^2 = .040$. Comparisons between unstandardized beta weights from the parameter estimates obtained as part of the ANCOVA showed a similar pattern to the Sequential Congruency Effects' pattern: the association of older age and slower RTs is stronger for CI ($B = 3.08$) than for II ($B = 2.82$) and stronger for IC ($B = 2.24$) than for CC ($B = 2.05$), and it is also stronger in current-incongruent trials ($B = 2.95$) than in current-congruent ones ($B = 2.14$). In sum, this interaction reveals an association between older age and larger Sequential Congruency Effects.

Interaction between Previous Trial Congruency, Current Trial Congruency and Fluid Intelligence

Finally, there was also a significant interaction effect between *Previous Trial Congruency*, *Current Trial Congruency* and *Fluid Intelligence*, $F(1, 109) = 5.72$, $p = .018$, $\eta_p^2 = .050$. Comparisons between unstandardized beta weights from the parameter estimates obtained as part of the ANCOVA showed this time a pattern that mirrors the Sequential Congruency Effects: the association of higher fluid intelligence and faster RTs is stronger for CI ($B = -1.43$) than for II ($B = -1.29$) and stronger for IC ($B = -.95$) than for CC ($B = -.72$), and it is also stronger in current-incongruent trials ($B = -1.36$) than in current-congruent ones ($B = -.84$).

In sum, this interaction reveals an association between higher fluid intelligence and smaller Sequential Congruency Effects, counteracting the association we have just seen between older age and larger Sequential Congruency Effects.

No other main effects or interactions were statistically significant (all Fs ≤ 2.17, ps $\geq .14$, η_p^2s $\leq .020$).

3.1.12 Sequential Congruency Effects in Accuracy Rates

Table 18 shows the average accuracy rates obtained in the ANT, by trial sequence (CC, CI, II, IC) and by group.

Table 18

Means (M) and Standard Deviations (SD) of Accuracy Rates in the Attention Network Test (ANT), by Trial Sequence

	Previous Trial Congruency						
	Previous Congruent			Previous Incongruent			**ANT**
Current Trial	Mon.	Bil.	**Total**	Mon.	Bil.	**Total**	**Total**
Congruency	*M* (*SD*)	*M* (*SD*)	***M* (*SD*)**	*M* (*SD*)	*M* (*SD*)	***M* (*SD*)**	***M* (*SD*)**
Current Congruent	.997 (.01)	.997 (.01)	**.997 (.01)**	.996 (.01)	.997 (.01)	**.997 (.01)**	**.997 (.01)**
Current Incongruent	.964 (.03)	.965 (.04)	**.964 (.04)**	.978 (.02)	.981 (.03)	**.980 (.03)**	**.972 (.03)**
Total	.980 (.02)	.981 (.02)	**.981 (.02)**	.987 (.01)	.989 (.02)	**.988 (.02)**	

Notes: Mon. = monolinguals, Bil. = bilinguals.

A 2x2x2x2x2 factorial ANOVA was conducted, in order to ascertain whether there were Sequential Congruency Effects in accuracy in the ANT. The test included the arcsine-transformed ARs as the DV, *Block* (block 1, block 2), *Previous Trial Congruency* (congruent, incongruent) and *Current Trial Congruency* (congruent, incongruent) as within-subjects factors, and *Group* (monolinguals, bilinguals) and *Task Order* (ANT first, Simon task first) as between-subjects factors.

Since the only difference between this statistical test and the one performed for the Conflict Effect in ARs is the inclusion of the variable *Previous Trial Congruenc*y, we will refrain from describing any results reported earlier (which present the same levels of statistical significance there and here) and we will restrict the description of results to those related to the main effect and interactions of the added variable *Previous Trial Congruency*.

Main effect of Previous Trial Congruency

There was a significant main effect of *Previous Trial Congruency* on ARs, $F(1, 111) = 21.4$, $p < .001$, $\eta_p^2 = .16$, with responses to previous-congruent trials being significantly less accurate (*M* = .981, *SD* = .018) than responses given to previous-incongruent trials (*M* = .988, *SD* = .016).

Interaction between Previous Trial Congruency and Current Trial Congruency (Sequential Congruency Effects)

Crucially, the interaction between *Previous Trial Congruency* and *Current Trial Congruency* was also significant, $F(1, 111) = 24.9$, $p < .001$, $\eta_p^2 = .18$. Fisher's LSD post-hoc comparisons indicated that the effect of *Previous Trial Congruency* was only significant for current-incongruent trials ($p < .001$), but not for current-congruent trials ($p = .99$). In current-incongruent trials, participants were more accurate when the previous trial was incongruent (II trials) than when it was congruent (CI trials).

These results can be observed in Figure 20, which does not fully depict the pattern usually associated with Sequential Congruency Effects, contrary to what was observed for the RT results: CI trials are less accurate than II trials, as expected, but the accuracy frequencies observed in CC and IC trials are indistinguishable from each other (the predicted pattern would have been CC trials showing higher accuracy rates than IC trials, mirroring the RT results). However, the Conflict Effect is still smaller following incongruent trials than following congruent ones, which is what defines Sequential Congruency Effects.

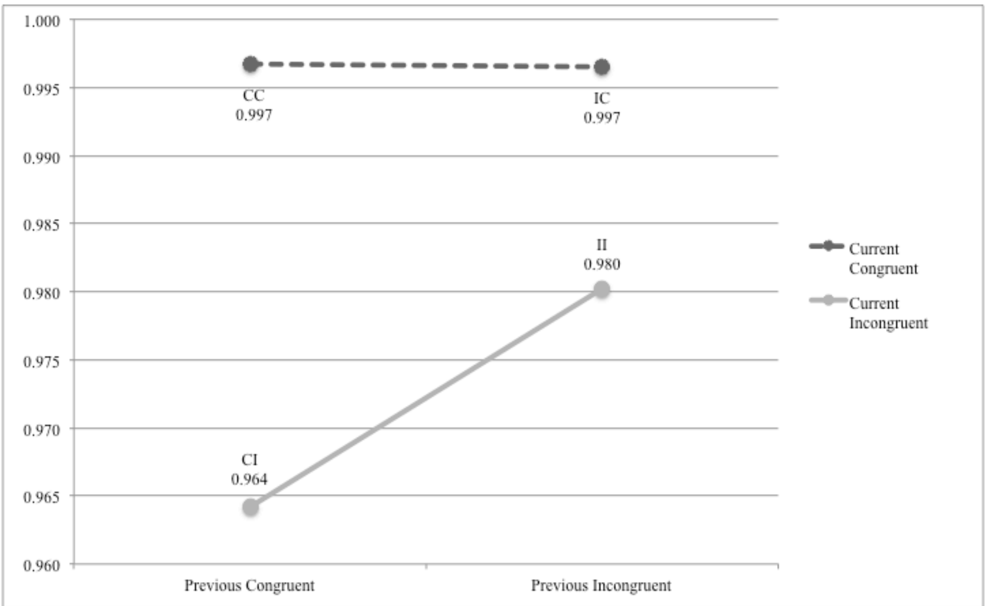

Figure 20. Mean accuracy rates in the ANT, by trial sequence condition. CC = congruent-congruent, IC = incongruent-congruent, CI = congruent-incongruent, II = incongruent-incongruent.

No other interactions with *Previous Trial Congruency* were statistically significant (all Fs(1, 111) ≤ 1.54, ps ≥ .22, η_p^2s ≤ .014).

3.1.13 Summary of Findings in the ANT

3.1.13.1 General results

The ANT results analysed in this section have indicated evidence of a significant Conflict Effect, with faster RTs and higher ARs to congruent than to incongruent trials. The Conflict Effect, both in reaction times and accuracy rates, was shown to differ significantly, contingent on *Cue* conditions, with smaller Conflict Effects in no-cue and spatial-cue conditions than in double-cue and centre-cue conditions, revealing that the executive network of attention is negatively impacted by the alerting network and positively impacted by the orienting network.

Our data show no evidence of an Alerting Effect in ARs, but they do show a significant Alerting Effect in RTs, with faster reaction times in double-cue than in no-cue trials. The Alerting Effect in RTs also differed depending on the congruency condition, with a larger Alerting Effect being associated with congruent trials, in contrast with a smaller, albeit significant, one in incongruent trials.

There were also significant Orienting Effects in reaction times and in accuracy rates. In both the RT and AR results, there were significant differences between Orienting Effects, depending on *Congruency* conditions: in the RT results, the Orienting Effect was larger in incongruent trials than in congruent trials; in the AR results, the Orienting Effect was only present in incongruent trials, and completely absent in congruent ones.

Our results show evidence of Sequential Congruency Effects in both RTs and ARs. There were significant differences in both RTs and ARs between previous-congruent and previous-incongruent trials, with previous-congruent trials presenting faster but less accurate responses. Both the RT and AR results show the pattern depicting Sequential Congruency Effects: smaller Conflict Effects following incongruent trials than following congruent ones.

There was also no evidence of a practice effect, as participants did not show a significant difference in either RTs or ARs between blocks, the only exception being in the subset comprising only the RTs in centre-cue and spatial-cue trials, where a practice effect was found.

The analyses identified *Age*, *Gender* and *Fluid Intelligence* as significant predictors of RTs. No significant predictors of accuracy in the ANT were identified. Younger age, male gender and high fluid intelligence were all associated with faster RTs. Older age was found to be associated with larger Conflict Effects, as well as with larger Sequential Congruency Effects. High fluid intelligence, on the other hand, was related to smaller Conflict Effects and also to smaller Sequential Congruency Effects. An association was also found between high fluid intelligence and larger Alerting Effects.

3.1.13.2 Bilingual advantage

No bilingual (or monolingual) advantage was found in overall RTs or ARs. Similarly, no differences between groups were identified in the analyses on the Conflict Effect, Alerting Effect or Sequential Congruency Effects, both in RTs and ARs.

There were only two main significant differences found between groups: *a)* there was a larger Orienting Effect in ARs for monolinguals than for bilinguals, and *b)* only monolinguals' RTs were affected by *Previous Trial Congruency*, with bilinguals showing no significant difference in their RTs associated with this variable.

3.1.13.3 Bilingualism-specific predictors

Analyses showed that none of the bilingualism-specific individual-difference variables —*Age of Onset of Active Bilingualism*, *Length of Active Bilingualism*, *Balancedness of Bilingual Language Use* and *Language-Switching Frequency*— were significant predictors of RTs in the ANT, when controlling for *Age*, *Gender* and *Fluid Intelligence*. Likewise, no variables specific to bilingualism were selected as good predictors of ARs.

3.2 Simon Task

Recapping what was already described in the Methodology chapter, the version of the Simon task used in the present study was presented in two blocks. In between blocks, the participants completed the Cattell – Culture Fair Intelligence Test. Both blocks comprised four experimental conditions, which were presented to the participants in one of four different sequences in block 1. That sequence was then presented in block 2, in the exact inverse order. The four conditions were: Centre-2 (2 differently coloured squares, displayed at the centre of the screen), Side-2 (2 differently coloured squares, displayed at each side of the screen), Centre-4 (4 differently coloured squares, displayed at the centre of the screen), and Side-4 (4 differently coloured squares, displayed at each side of the screen).

The following sections include the main RT and AR results, as well as results related to the Simon Effect, Working Memory Costs and Sequential Congruency Effects.

3.2.1 Preliminary Analyses – Counterbalancing

Preliminary analyses were performed to ensure that task order or sequence of experimental conditions within the task did not influence the results in any way.

Task Order

In the data collection sessions with the participants, there were two possible sequences of tasks: one in which the ANT preceded the Simon task and a second sequence in which the Simon task was taken first.

Experimental Condition Sequence

Within the Simon task, there were also four different sequences in which experimental conditions could be presented to the participants:

- Sequence A: Centre-2 → Side-2 → Centre-4 → Side-4 (block 1) / Side-4 → Centre-4 → Side-2 → Centre-2 (block 2)
- Sequence B: Centre-4 → Side-4 → Centre-2 → Side-2 (block 1) / Side-2 → Centre-2 → Side-4 → Centre-4 (block 2)
- Sequence C: Centre-2 → Centre-4 → Side-2 → Side-4 (block 1) / Side-4 → Side-2 → Centre-4 → Centre-2 (block 2)
- Sequence D: Centre-4 → Centre-2 → Side-4 → Side-2 (block 1) / Side-2 → Side-4 → Centre-2 → Centre-4 (block 2)

3.2.1.1 Effect of procedural variables in groups' reaction times

In order to determine if the participants' reaction times were influenced by *Task Order* and/or *Experimental Condition Sequence*, a 4x2x4x2 factorial ANOVA was performed, with the RTs as the DV, *Condition* (Centre-2, Side-2, Centre-4, Side-4) as a within-subjects factor, and *Task Order* (ANT first, Simon task first), *Experimental Condition Sequence* (sequence A, sequence B, sequence C, sequence D) and *Group* (monolinguals, bilinguals) as between-subjects factors.

Mauchly's test indicated that the assumption of sphericity had been violated ($\chi^2(5) = 75.3$, $p < .001$) for the main effect of *Condition*, hence degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .68$). The analysis revealed a significant main effect of *Condition*, $F(2.04, 201) = 252$, $p < .001$,

$\eta_p^2 = .72$, which will be explored in later analyses. No other main effects or interactions were statistically significant (all *F*s ≤ 1.70, *p*s ≥ .17, η_p^2s ≤ .017).

3.2.1.2 Effect of procedural variables in groups' accuracy rates

An analogous 4x2x4x2 factorial ANOVA was run with the AR results as the DV. The analysis showed a significant main effect of *Condition*, $F(3, 297) = 16.9$, $p < .001$, $\eta_p^2 = .15$, but no other main effects or interactions were statistically significant (all *F*s ≤ 1.84, *p*s ≥ .060, η_p^2s ≤ .053).

In summary, *Task Order* and *Experimental Condition Sequence* did not impact significantly either the reaction times or the accuracy rates observed in all the experimental conditions of the Simon task.

3.2.2 General Analyses – Reaction Times

3.2.2.1 Monolinguals versus bilinguals

Table 19 shows the mean reaction times, by experimental condition, by block and by group.

Table 19

Means (M) and Standard Deviations (SD) of Reaction Times in the Simon Task, by Condition, Block and Group

	Block 1					
	Monolinguals		Bilinguals		Total	
	M	(*SD*)	*M*	(*SD*)	*M*	(*SD*)
Centre-2	398	(71)	396	(66)	397	(67)
Side-2	448	(67)	438	(66)	441	(67)
Centre-4	524	(76)	534	(95)	531	(89)
Side-4	527	(70)	537	(90)	533	(83)
Total	**473**	**(55)**	**474**	**(64)**	**474**	**(61)**
	Block 2					
	Monolinguals		Bilinguals		Total	
	M	(*SD*)	*M*	(*SD*)	*M*	(*SD*)
Centre-2	380	(50)	373	(61)	375	(57)
Side-2	422	(53)	411	(62)	415	(59)
Centre-4	468	(65)	464	(69)	465	(67)
Side-4	489	(55)	502	(77)	498	(70)
Total	**438**	**(44)**	**437**	**(59)**	**437**	**(54)**
	Total					
	Monolinguals		Bilinguals		Total	
	M	(*SD*)	*M*	(*SD*)	*M*	(*SD*)
Centre-2	388	(53)	384	(57)	386	(55)
Side-2	435	(55)	424	(60)	428	(58)
Centre-4	496	(62)	498	(72)	497	(69)
Side-4	507	(58)	519	(78)	515	(72)
Total	**456**	**(47)**	**455**	**(58)**	**455**	**(55)**

The first step in our analysis was to determine if there were any differences in reaction times between monolinguals and bilinguals, as well as between blocks 1 and 2, overall in the Simon task, but also in each of the experimental conditions. We were also interested in knowing if any of the individual-difference variables (*Age*, *Gender*, *SES* and *Fluid Intelligence*) could be good predictors of RTs in the Simon task, in order to control for those in between-group comparisons. With these goals in view, a

2x4x2x2 factorial ANCOVA was performed, with the RTs as the DV, *Block* (block 1, block 2) and *Condition* (Centre-2, Side-2, Centre-4, Side-4) as within-subjects factors, and *Group* (monolinguals, bilinguals) and *Gender* (male, female) as between-subjects factors. *Age*, *SES* and *Fluid Intelligence* were also added to the model, as covariates.

Interaction between Fluid Intelligence and Group

Before performing the ANCOVA, I tested for the assumption of homogeneity of regression slopes, by computing a custom model with interaction terms between *Group* and each of the covariates. The interaction between *Group* and *Fluid Intelligence* came out as significant (p = .008); therefore, *Fluid Intelligence* was excluded from this analysis and any other further analyses on RTs, as its inclusion in the model would complicate the interpretation of the relationship between the factor *Group* and the dependent variable.

Nevertheless, this interaction seems to be informative, and thus a closer look at the nature of this interaction was in order. Simple linear regressions were performed, with each group's RTs as the DV and *Fluid Intelligence* as the IV (see Figure 21). The regressions showed that the monolinguals' RTs do not seem to change much depending on the participants' *Fluid Intelligence* scores, B = -.14, $t(37)$ = -.27, p = .79, with *Fluid Intelligence* not explaining any significant amount of variance in monolinguals' RTs in the Simon task, R^2 = .002. On the other hand, for bilinguals, faster RTs are associated with higher *Fluid Intelligence*, B = -1.72, $t(76)$ = -4.09, p < .001, with approximately 18.2% of the variance in the bilinguals' reaction times in the Simon task being accounted for by *Fluid Intelligence*, R^2 = .18.

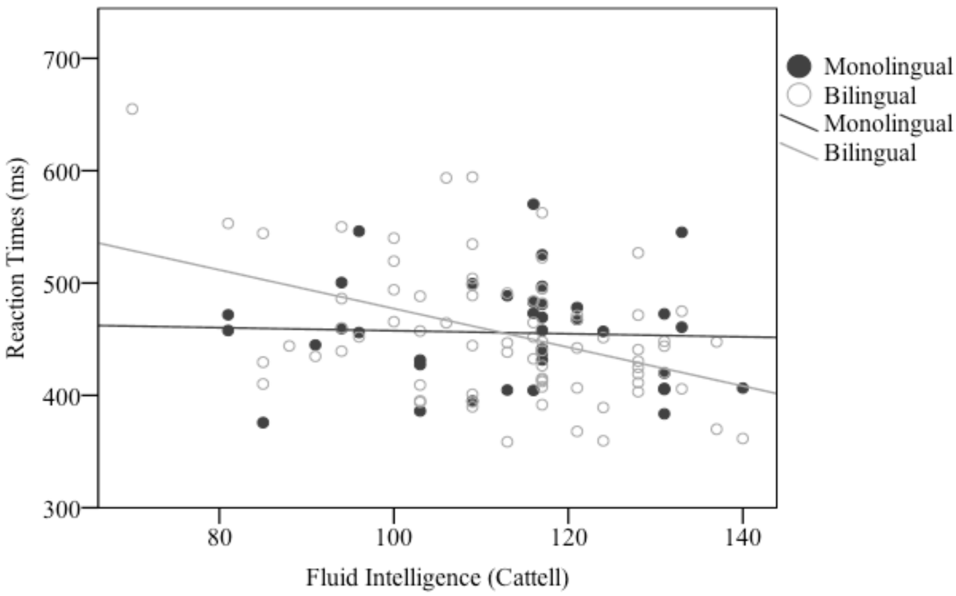

Figure 21. Mean reaction times in the Simon task, by fluid intelligence scores and by group.

Main effect of Condition

Mauchly's test indicated that the assumption of sphericity had been violated ($\chi^2(5) = 83.4$, $p < .001$) for the main effect of *Condition*, hence degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .66$). The test revealed a significant main effect of *Condition*, $F(1.99, 217) = 62$, $p < .001$, $\eta_p^2 = .36$, with significant differences in RTs between all experimental conditions (all ps $\leq .001$), according to post-hoc comparisons using Fisher's LSD test.

Participants responded faster to the Centre-2 condition ($M = 386$, $SD = 55.1$), followed by the Side-2 condition ($M = 428$, $SD = 58.2$), the Centre-4 condition ($M = 497$, $SD = 68.8$) and, finally, the Side-4 condition ($M = 515$, $SD = 72.1$) (see Table 19 and Figure 22). These differences were consistent with expectations: on the one hand, the amount of information participants had to deal with increased between the 2-square and the 4-square conditions —hence, the prediction that 4-square conditions would receive slower responses than 2-square conditions; on the other hand, the Side conditions added uncertainty of stimulus location, as well as conflicting information in incongruent trials, and so were expected to be harder and, thus, result in slower RTs than the Centre conditions.

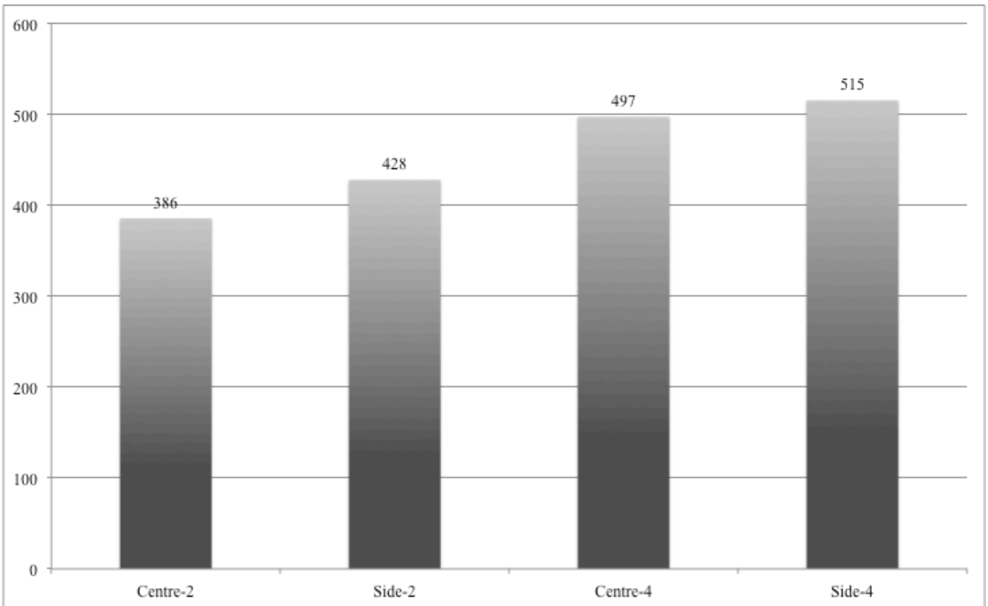

Figure 22. Mean reaction times obtained in the Simon task, by condition.

Main effect of Group

There was a non-significant main effect of *Group* on reaction times, $F(1, 109) = .31$, $p = .58$, $\eta_p^2 = .003$, indicating no significant overall differences in RTs between monolinguals and bilinguals.

Main effect of Block

There was a significant main effect of *Block* on reaction times, $F(1, 109) = 29.9$, $p < .001$, $\eta_p^2 = .22$, denoting a significant difference in RTs between blocks 1 and 2. In other words, a practice effect in RTs was observed, with significantly faster RTs in block 2 ($M = 437$, $SD = 54$), when compared with block 1 ($M = 474$, $SD = 60.8$).

Interaction between Condition and Block

There was a significant interaction effect between *Condition* and *Block*, $F(3, 327) = 3.41$, $p = .018$, $\eta_p^2 = .030$. Post-hoc comparisons using Fisher's LSD test revealed significant practice effects in all conditions (all *p*s < .001), as well as significant differences between conditions in both blocks (all *p*s < .001), except for the difference between the Centre-4 and Side-4 conditions, in block 1 only ($p = .87$) (see Figure 23).

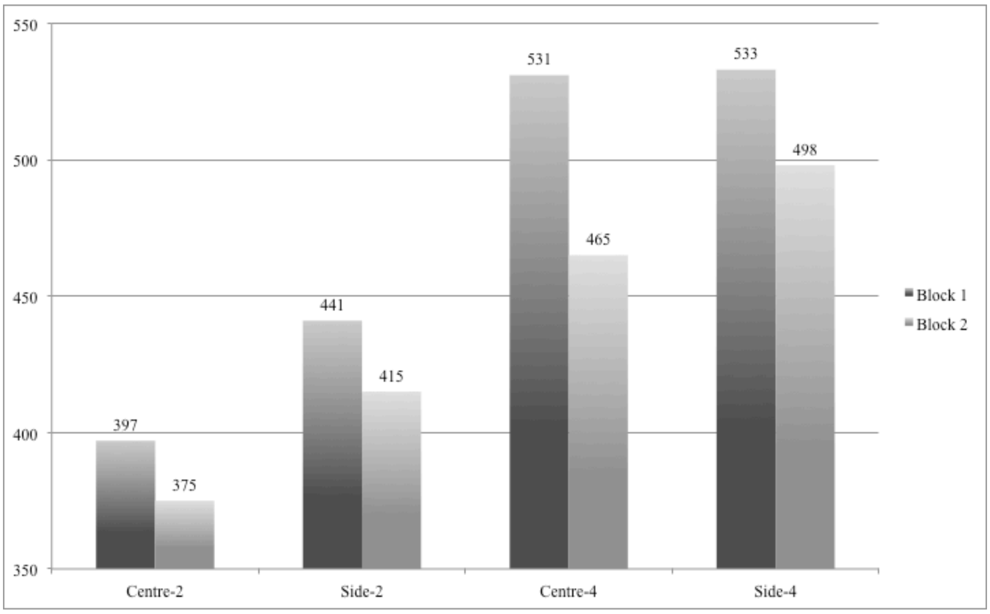

Figure 23. Mean reaction times obtained in the Simon task, by condition and by block.

The results by block allow us to see that the practice effect was not the same for all conditions, with the Centre-4 condition registering a much larger practice effect than all other conditions. It is this larger practice effect that allows for the Centre-4 condition to become significantly different from the Side-4 condition, in block 2. It is interesting to note that the reduction in reaction times with practice was much more pronounced in the condition that demanded an added use of working memory resources, but which did not include conflicting information (Centre-4 condition).

Main effects of the individual-difference variables

The analysis showed a significant main effect of *Age* on RTs, $F(1, 109) = 16.8$, $p < .001$, $\eta_p^2 = .13$, with younger age being associated with faster RTs. This covariate will thus be included in subsequent analyses related to RTs in the Simon task.

The main effect of *SES* on RTs was non-significant, $F(1, 109) = .029$, $p = .87$, $\eta_p^2 < .001$. Likewise, the main effect of *Gender* on RTs was also non-significant, $F(1, 109) = 2.53$, $p = .11$, $\eta_p^2 = .023$. Therefore, these two individual-difference variables will be dropped from any further analyses on reaction times in the Simon task.

Interaction between Condition and Age

There was a significant interaction between *Condition* and *Age*, $F(3, 327) = 2.85$, $p = .037$, $\eta_p^2 = .025$. Comparisons between the beta weights obtained in the parameter estimates showed that, in all cases, older age was associated with slower reaction times (see Figure 24). This association was stronger in the Side-4 condition ($B = 2.75$), followed by the Side-2 condition ($B = 2.34$), Centre-4 condition ($B = 1.57$) and, finally, Centre-2 condition ($B = 1.49$). In sum, older age seemed to be associated with slower reaction times in the Simon task, but more so when faced with uncertainty of stimulus location and presence of incongruence, as well as with greater working memory demands.

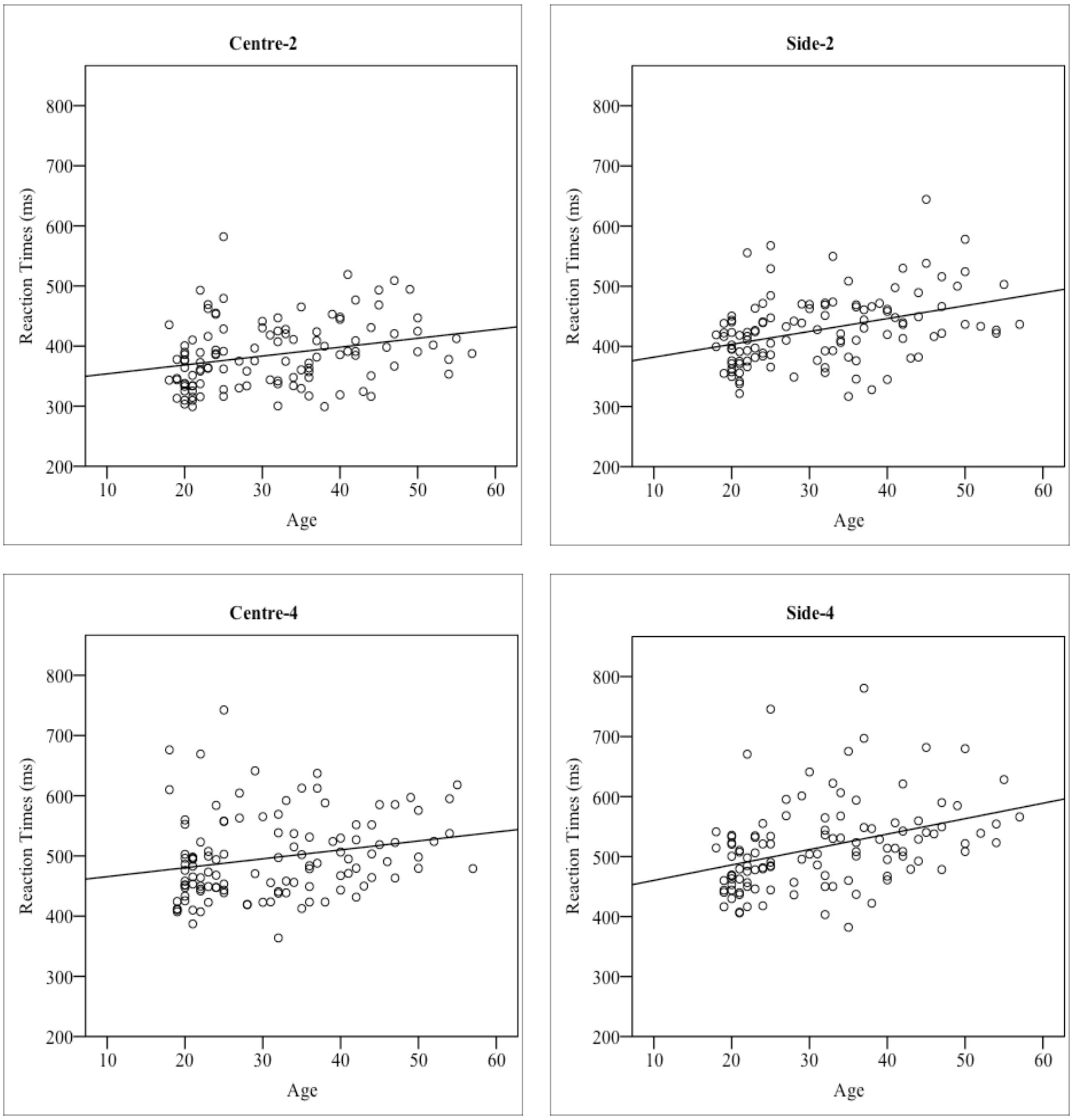

Figure 24. Mean reaction times in the four experimental conditions of the Simon task, by age.

No remaining main effects or interactions reached statistical significance (all *F*s ≤ 2.53, *p*s $\geq .11$, η_p^2s $\leq .023$).

3.2.2.2 Bilinguals' within-group analyses

So as to assess whether individual-difference variables specific to bilingualism had an impact on the reaction-time performance of bilinguals in the Simon task, multiple linear regressions were performed for models which included the independent variables: *Age*, *Gender*, *Fluid Intelligence*, *Age of Onset of Active Bilingualism*, *Length of Active Bilingualism*, *Balancedness of Bilingual Language Use* and *Language-Switching Frequency*. The RTs were used as the DV.

Since *Age of Onset of Active Bilingualism* and *Length of Active Bilingualism* are proxies of *Age*, and were thus strongly correlated with *Age* (*Age of Onset of Active Bilingualism* and *Age*: $r(113) = .62$, $p < .001$; *Length of Active Bilingualism* and *Age*: $r(113) = .32$, $p = .005$), we wanted to ascertain whether those variables would account for significant additional variance in bilinguals' RTs, after controlling for *Age*. In order to do so, we compared three models, all of which included *Age*, *Gender*, *Fluid Intelligence*, *Balancedness of Bilingual Language Use* and *Language-Switching Frequency*. We then added *Age of Onset of Active Bilingualism* to form the second model and *Length of Active Bilingualism* to form the third model. Extra sum of squares comparisons revealed that neither one of the larger models were significantly better than the first (both F_{extra}s $\leq .33$, *p*s > .050), and so *Age of Onset of Active Bilingualism* and *Length of Active Bilingualism* were dropped from this and any further analyses on RTs.

Table 20 shows the summary of the multiple linear regression analysis of the smaller model, which included *Age*, *Gender*, *Fluid Intelligence*, *Balancedness of Bilingual Language Use* and *Language-Switching Frequency* as IVs and the RTs as the DV.

Table 20

Summary of Multiple Regression Analysis for Variables Predicting Reaction Times for the Bilingual Group in the Simon Task

Variable	*B*	*SE B*	β
Age	1.73	.62	.29**
Gender	-8.31	7.19	-.12
Fluid Intelligence	-1.61	.42	-.40**
Balancedness of Bil. Lang. Use	.19	.46	.05
Language-Switching Frequency	3.13	5.47	.07

Notes: R^2 = .28. *p < .05, **p < .01. Bil. Lang. Use = Bilingual Language Use.

The analysis selected two significant predictors of reaction times for bilinguals: *Age*, B = 1.73, t(71) = 2.78, p = .007, with younger age being associated with faster RTs; and *Fluid Intelligence*, B = -1.61, t(71) = -3.80, p < .001, with higher *Fluid Intelligence* scores being associated with faster RTs. This model accounted for 27.7% of the variance in bilinguals' reaction times, R^2 = .28, F(5, 71) = 5.44, p < .001.

None of the bilingualism-specific variables were thus selected as good predictors of RTs in the Simon task, when controlling for *Age*, *Gender* and *Fluid Intelligence*, and therefore no further analyses will be performed on the bilingual group's results alone.

3.2.3 General Analyses – Accuracy Rates

3.2.3.1 Monolinguals versus bilinguals

Table 21 shows the mean accuracy rates obtained in the Simon task, by experimental condition, by block and by group.

Table 21

Means (M) and Standard Deviations (SD) of Accuracy Rates in the Simon Task, by Condition, Block and Group

	Block 1					
	Monolinguals		Bilinguals		Total	
	M	(*SD*)	*M*	(*SD*)	*M*	(*SD*)
Centre-2	.967	(.08)	.982	(.03)	.977	(.05)
Side-2	.963	(.04)	.974	(.04)	.971	(.04)
Centre-4	.965	(.04)	.976	(.04)	.973	(.04)
Side-4	.963	(.05)	.964	(.04)	.963	(.05)
Total	**.965**	**(.03)**	**.974**	**(.03)**	**.971**	**(.03)**
	Block 2					
	Monolinguals		Bilinguals		Total	
	M	(*SD*)	*M*	(*SD*)	*M*	(*SD*)
Centre-2	.987	(.03)	.985	(.03)	.986	(.03)
Side-2	.974	(.03)	.970	(.04)	.971	(.04)
Centre-4	.955	(.05)	.961	(.05)	.959	(.05)
Side-4	.948	(.05)	.953	(.06)	.951	(.06)
Total	**.966**	**(.03)**	**.967**	**(.03)**	**.967**	**(.03)**
	Total					
	Monolinguals		Bilinguals		Total	
	M	(*SD*)	*M*	(*SD*)	*M*	(*SD*)
Centre-2	.977	(.04)	.983	(.02)	.981	(.03)
Side-2	.969	(.03)	.972	(.03)	.971	(.03)
Centre-4	.960	(.04)	.968	(.04)	.966	(.04)
Side-4	.956	(.04)	.958	(.04)	.957	(.04)
Total	**.966**	**(.03)**	**.971**	**(.03)**	**.969**	**(.03)**

A 2x4x2x2 factorial ANCOVA was performed, with the arcsine-transformed accuracy rates as the DV, *Block* (block 1, block 2) and *Condition* (Centre-2, Side-2, Centre-4, Side-4) as within-subjects factors, *Group* (monolinguals, bilinguals) and *Gender* (male, female) as between-subjects factors, and *Age*, *SES* and *Fluid Intelligence* as covariates. As with the RT analysis, we were interested in determining if accuracy changed between conditions, groups and/or blocks. We were also interested in ascertaining whether any of the individual-difference variables were significant predictors of accuracy in the Simon task.

Main effect of Condition

The test revealed a significant main effect of *Condition*, $F(3, 324) = 3.89$, $p = .009$, $\eta_p^2 = .035$. Post-hoc comparisons using Fisher's LSD test indicated that nearly all differences in ARs between experimental conditions were statistically significant (all *p*s $\leq .046$), except for the difference between the Side-2 and the Centre-4 conditions, which did not differ significantly in regards to accuracy ($p = .18$) (see Figure 25).

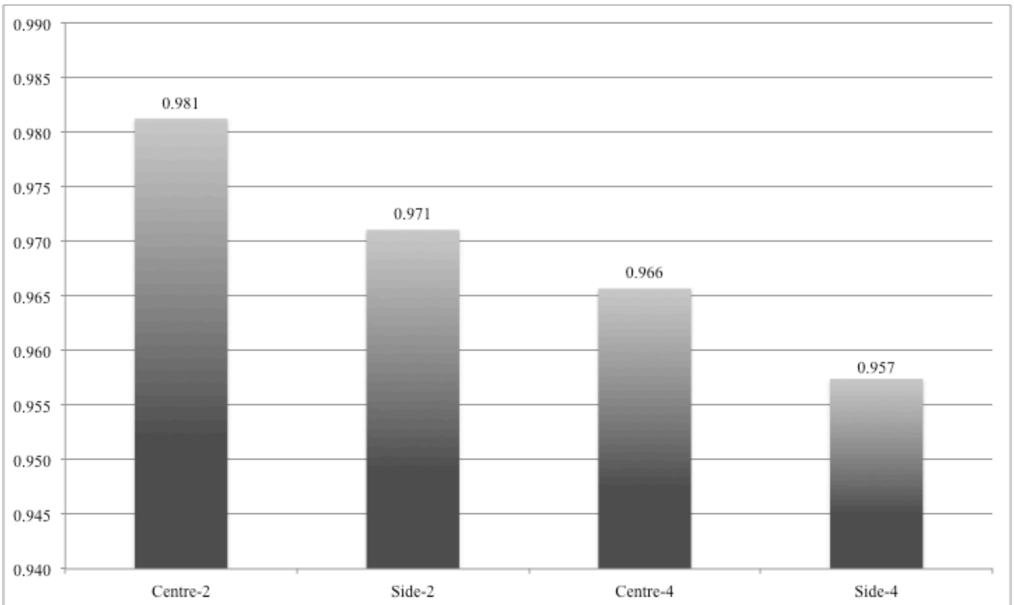

Figure 25. Mean accuracy rates obtained in the Simon task, by experimental condition.

These results mirror the RT ones: if reaction times increase with difficulty associated with the experimental condition (see Figure 22), accuracy rates decrease with difficulty: participants responded more accurately to the Centre-2 condition ($M = .981$, $SD = .03$), followed by the Side-2 condition ($M = .971$, $SD = .03$), the Centre-4 condition ($M = .966$, $SD = .04$) and, finally, the Side-4 condition ($M = .957$, $SD = .04$).

Once again, these differences were consistent with what was anticipated: the 4-square conditions were expected to trigger less accurate responses than the 2-square conditions, given that those conditions presented higher working memory demands; on the other hand, the Side conditions added conflicting information to the tasks, and so were expected to be harder and, thus, trigger lower ARs than the Centre conditions. Moreover, these results reveal that an increase in working memory load seems to be more taxing on performance than the addition of conflict, since the difference, both in RTs and in ARs, between the Centre-2 and the Centre-4 conditions is greater than the difference between the Centre-2 and the Side-2 conditions.

Main effect of Group

There was a non-significant main effect of *Group* on accuracy rates, $F(1, 108) = .63$, $p = .43$, $\eta_p^2 = .006$, indicating no significant difference in overall ARs between monolinguals and bilinguals.

Main effect of Block

There was a significant main effect of *Block* on accuracy rates, $F(1, 108) = 4.16$, $p = .044$, $\eta_p^2 = .037$, denoting a significant difference in accuracy between blocks 1 and 2. In fact, an inverse practice effect in ARs was observed, with ARs actually diminishing significantly in block 2 ($M = .967$, $SD = .03$), when compared with block 1 ($M = .971$, $SD = .03$).

Main effects of the individual-difference variables

Apart from a near-significant main effect of the covariate *Age*, $F(1, 108) = 3.21$, $p = .076$, $\eta_p^2 = .029$, where older age appeared associated with higher accuracy, none of the main effects or interactions involving any of the individual-difference variables were statistically significant (all Fs ≤ 1.17, ps ≥ .28, η_p^2s ≤ .011). Therefore, all individual-difference variables will be dropped from any further analyses on accuracy rates in the Simon task.

3.2.3.2 Relation of reaction times to accuracy rates in the Simon task

Overall RTs and overall ARs in the Simon task were correlated, $r(113) = .26$, $p = .004$, indicating a weak but significant association between higher accuracy rates and slower RTs (see Figure 26).

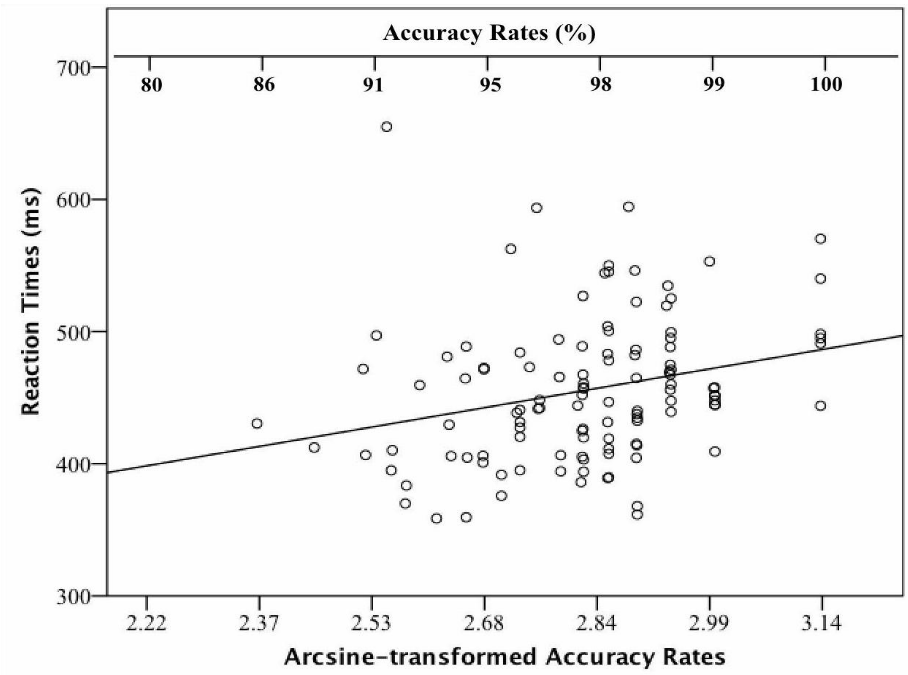

Figure 26. Mean reaction times by mean accuracy rates in the Simon task. This graph depicts a correlation performed on the RTs and the arcsine-transformed ARs, and thus both an arcsine-transformation scale and a regular percentage scale are provided for the AR scores.

3.2.3.3 Bilinguals' within-group analyses

So as to assess whether individual-difference variables specific to bilingualism had any bearing on bilinguals' performance in terms of accuracy, multiple linear regressions were performed, with the arcsine-transformed ARs as the DV, and *Age*, *Gender*, *Fluid Intelligence*, *Age of Onset of Active Bilingualism*, *Length of Active Bilingualism*, *Balancedness of Bilingual Language Use*, and *Language-Switching Frequency* as independent variables.

Age of Onset of Active Bilingualism and *Length of Active Bilingualism* are proxies of *Age*, and therefore strongly correlated with *Age*. In order to ascertain if those variables would account for significant additional variance in bilinguals' ARs, after controlling for *Age*, we compared three models, all of which included *Age*, *Gender*, *Fluid Intelligence*, *Balancedness of Bilingual Language Use* and *Language-Switching Frequency*. We then added *Age of Onset of Active Bilingualism* to form the second model and *Length of Active Bilingualism* to form the third model. Extra sum of squares comparisons revealed that neither one of the larger models were significantly better than the first (both F_{extra}s $\leq .24$, *p*s $> .050$), and so *Age of Onset of Active Bilingualism* and *Length of Active Bilingualism* were dropped from this and any further analyses on accuracy rates.

The multiple linear regression performed for the smaller model, which included *Age*, *Gender*, *Fluid Intelligence*, *Balancedness of Bilingual Language Use* and *Language-Switching Frequency* as IVs, and the arcsine-transformed ARs as the DV, revealed that none of the variables were selected as significant predictors of accuracy in the Simon task (all *p*s $\geq .15$) (see Table 22). Hence, no further analyses of ARs looking at the bilingual group alone will be undertaken, as none of the bilingualism-specific individual-difference variables were selected as good predictors of ARs.

Table 22

Summary of Multiple Regression Analysis for Variables Predicting Accuracy Rates for the Bilingual Group in the Simon Task

Variable	*B*	*SE B*	β
Age	.002	.002	.103
Gender	-.015	.022	-.082
Fluid Intelligence	-.00009	.001	-.008
Balancedness of Bil. Lang. Use	.001	.001	.091
Language-Switching Frequency	.025	.017	.216

Notes: R^2 = .048. *p < .05, **p < .01. Bil. Lang. Use = Bilingual Language Use.

3.2.4 Simon Effect in Reaction Times

In this section, we will be looking at the conflict effect in the Simon task, commonly referred to as the Simon Effect. According to the *dimensional overlap model* (Kornblum, 1994; Kornblum, Hasbroucq, & Osman, 1990), this effect reflects the increase in reaction time observed in trials where there is an overlap of the irrelevant stimulus dimension (location of the coloured square on the screen: left or right) with the response dimension (location of the response key: left or right), when the relevant stimulus dimension is colour. The need to ignore the irrelevant information and inhibit a response that would agree with the wrong stimulus slows reaction times, making responses to incongruent trials slower than responses to congruent trials. The difference between the two is what is usually referred to as the Simon Effect.

In the following analyses of the conflict effect in the Simon task, the data analysed will be restricted to the results obtained in the Side-2 and Side-4 conditions, which were the only conditions where conflict was introduced. Data were analysed including *Condition* as a within-groups factor —recall that the Side-2 and Side-4 conditions differed only in the number of colours that appeared on the screen, which involved a difference in the number of rules participants had to memorize and recall in order to complete the task: 2 colours/rules in the Side-2 condition, and 4 colours/rules in the Side-4 condition. The difference between the Side-2 and the Side-4 conditions was, therefore, a difference in working memory load.

Similarly to the procedure followed in previous sections, data analyses will be presented by looking at potential differences between groups and conditions, as well as possible practice effects. Table 23 shows the reaction times exhibited by the participants in the two conditions that demanded participants dealt with conflicting information:

Table 23

Means (M) and Standard Deviations (SD) of Reaction Times in the Side-2 and Side-4 Experimental Conditions of the Simon Task, by Congruency Condition, and with Mean Scores for the Simon Effect

	Side-2								
	Congruent			Incongruent			Simon Effect		
	Mon.	Bil.	**Total**	Mon.	Bil.	**Total**	Mon.	Bil.	**Total**
	M (*SD*)	*M* (*SD*)	***M* (*SD*)**	*M* (*SD*)	*M* (*SD*)	***M* (*SD*)**	*M* (*SD*)	*M* (*SD*)	***M* (*SD*)**
Block 1	428 (72)	425 (73)	**426 (72)**	469 (69)	451 (66)	**457 (67)**	41 (49)	26 (42)	**31 (44)**
Block 2	410 (63)	396 (68)	**401 (67)**	435 (55)	426 (66)	**429 (63)**	25 (55)	30 (52)	**29 (53)**
Total	419 (58)	411 (64)	**413 (62)**	452 (57)	439 (60)	**443 (59)**	33 (38)	28 (35)	**30 (36)**
	Side-4								
	Congruent			Incongruent			Simon Effect		
	Mon.	Bil.	**Total**	Mon.	Bil.	**Total**	Mon.	Bil.	**Total**
	M (*SD*)	*M* (*SD*)	***M* (*SD*)**	*M* (*SD*)	*M* (*SD*)	***M* (*SD*)**	*M* (*SD*)	*M* (*SD*)	***M* (*SD*)**
Block 1	527 (74)	529 (90)	**528 (85)**	527 (75)	544 (97)	**539 (90)**	0 (54)	15 (57)	**10 (56)**
Block 2	488 (64)	494 (83)	**492 (77)**	489 (59)	511 (82)	**504 (76)**	1 (57)	17 (58)	**12 (58)**
Total	507 (60)	511 (78)	**510 (72)**	508 (62)	527 (84)	**521 (72)**	1 (40)	16 (44)	**11 (43)**

Notes: Mon. = monolinguals, Bil. = bilinguals.

A 2x2x2x2 factorial ANCOVA was performed, with the RTs in the Side-2 and Side-4 conditions as the DV, *Block* (block 1, block 2), *Condition* (Side-2, Side-4) and *Congruency* (congruent, incongruent) as within-subjects factors, and *Group* (monolinguals, bilinguals) as a between-subjects factor. *Age* was also included as a covariate.

Main effect of Condition

There was a significant main effect of *Condition* on the RTs, $F(1, 112) = 262$, $p < .001$, $\eta_p^2 = .70$, with responses to the Side-2 condition being significantly faster (M = 428, SD = 58.2) than those to the Side-4 condition (M = 515, SD = 72.1).

Main effect of Group

There was a non-significant main effect of *Group* on the RTs obtained in the Side conditions, $F(1, 112) = .004$, $p = .95$, $\eta_p^2 < .001$, denoting no significant differences between monolinguals and bilinguals.

Interaction between Condition and Group

However, there was a significant interaction effect between *Condition* and *Group*, $F(1, 112) = 4.75$, $p = .031$, $\eta_p^2 = .041$. Fisher's LSD post-hoc comparisons revealed that bilinguals were faster than monolinguals in the Side-2 condition, while the inverse happened in the Side-4 condition, with monolinguals being faster than bilinguals (see Figure 27). In other words, the difference between the Side-2 and the Side-4 conditions was larger for bilinguals than for monolinguals. The difference between conditions remained statistically significant for both groups (both *p*s < .001), and the difference between monolinguals and bilinguals remained non-significant across both Side conditions (both *p*s ≥ .27).

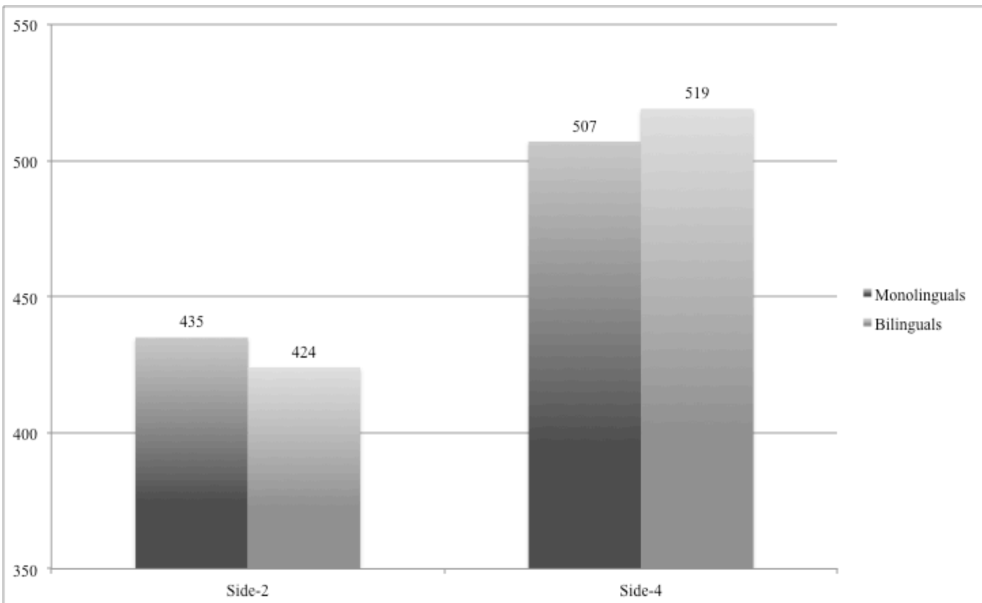

Figure 27. Mean reaction times in the Side-2 and Side-4 conditions of the Simon task, by group.

Main effect of Block

There was a significant main effect of *Block* on the RT results in the Side conditions, $F(1, 112) = 66.8$, $p < .001$, $\eta_p^2 = .37$, again with block 2 obtaining faster RTs than block 1.

Main effect of Congruency (Simon Effect)

The main effect of *Congruency* was also significant, $F(1, 112) = 47.5$, $p < .001$, $\eta_p^2 = .30$, showing evidence of a Simon Effect in RTs in the Side conditions, with responses to congruent trials being faster ($M = 460$, $SD = 59.8$) than responses to incongruent trials ($M = 481$, $SD = 61.7$).

Interaction between Condition and Congruency

There was, however, a significant interaction between *Condition* and *Congruency*, $F(1, 112) = 18.2$, $p < .001$, $\eta_p^2 = .14$. Pairwise comparisons using Fisher's LSD method revealed significant Simon Effects in both conditions (Side-2 condition: $p < .001$; Side-4 condition: $p = .041$), as well as a significant difference between conditions in both congruent and incongruent trials (both *p*s < .001). The interaction translates as a larger Simon Effect in the Side-2 condition ($M = 29.5$, $SD = 35.5$) than in the Side-4 condition ($M = 11.1$, $SD = 42.8$) (see Figure 28), which would be expected, as it is known that slower-RT conditions usually present smaller Simon Effects (Burle, Possamaï, Vidal, Bonnet, & Hasbroucq, 2002; De Jong, Liang, & Lauber, 1994; Hommel, 1993; Lammertyn, Notebaert, Gevers, & Fias, 2007; Rubichi & Pellicano, 2004).

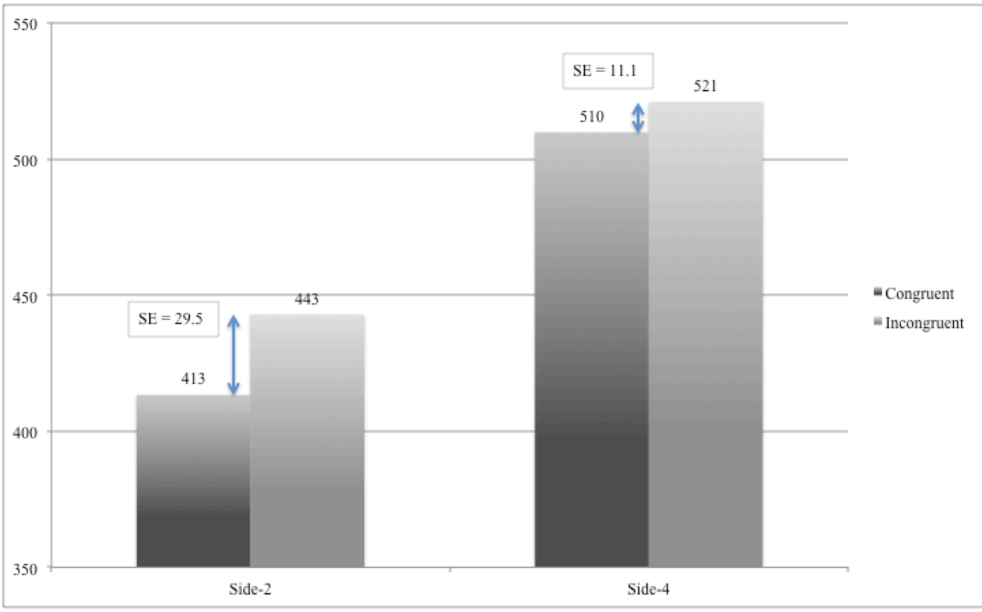

Figure 28. Mean reaction times in the Side-2 and Side-4 conditions of the Simon task, with mean scores for the Simon Effect (SE).

Interaction between Condition, Congruency and Group

The interaction effect between *Condition*, *Congruency* and *Group* was near significant, $F(1, 112) = 3.78$, $p = .054$, $\eta_p^2 = .033$. Pairwise comparisons using Fisher's LSD test showed no Simon Effect for monolinguals in the Side-4 condition ($p = .86$), in contrast with a significant Simon Effect in the Side-2 condition ($p < .001$). The bilingual group, on the other hand, displayed significant Simon Effects in both conditions (both ps $\leq .001$) (see Figure 29).

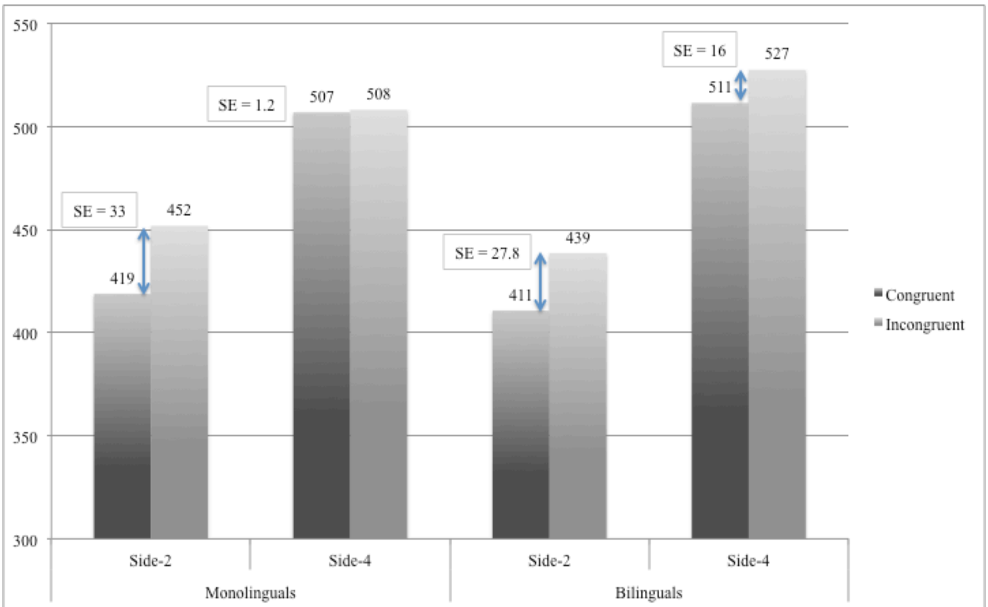

Figure 29. Mean reaction times in the Side-2 and Side-4 conditions of the Simon task, by congruency and by group, with mean scores for the Simon Effect (SE).

The lack of Simon Effect in the monolinguals' results in the Side-4 condition is not completely unexpected. A reduction in the magnitude of the Simon Effect between the Side-2 and the Side-4 conditions was predictable, as it is known that the Simon Effect decreases in size in slower-RT experimental conditions (De Jong et al., 1994; Hommel, 1993; Lammertyn et al., 2007; Rubichi & Pellicano, 2004). Such a reduction in the size of the Simon Effect can be seen in the bilinguals' results, which show a decrease from a Simon Effect of 27.8 ms in the Side-2 condition to 16 ms in the Side-4 condition (11.8 ms difference). However, the monolinguals' Simon Effect suffered a much more pronounced decrease from 33 ms in the Side-2 condition to 1.2 ms in the Side-4 condition (31.8 ms difference). Given that the decrease of the Simon Effect over time is usually explained as reflecting a decay of the irrelevant information with slower RTs (Burle et al., 2002; De Jong et al., 1994), it could potentially be argued that monolinguals may have an advantage over bilinguals in this instance, as the irrelevant information seems to decay faster for them than for bilinguals, which would explain why they stop showing a Simon Effect at a faster RT than bilinguals.

Main effect of Age

There was also a significant main effect of *Age* on the RTs in the Side conditions, $F(1, 112) = 22.2$, $p < .001$, $\eta_p^2 = .17$, with younger ages being associated with faster reaction times.

Interaction between Congruency and Age

Additionally, the interaction between *Congruency* and *Age* was also significant, $F(1, 112) = 5.67$, $p = .019$, $\eta_p^2 = .048$. A comparison between unstandardized beta weights from the parameter estimates showed that the association of older age and slower RTs is stronger in incongruent ($B = 2.66$) than in congruent trials ($B = 2.05$). In other words, the older the age, the greater the susceptibility to the Simon Effect.

3.2.5 Simon Effect in Accuracy Rates

Table 24 displays the accuracy rates obtained by all participants in conditions Side-2 and Side-4 of the Simon task.

Table 24

Means (M) and Standard Deviations (SD) of Accuracy Rates in the Side-2 and Side-4 Experimental Conditions of the Simon Task, by Congruency Condition, and with Mean Scores for the Simon Effect

	Side-2								
	Congruent			Incongruent			Simon Effect		
	Mon.	Bil.	**Total**	Mon.	Bil.	**Total**	Mon.	Bil.	**Total**
	M (*SD*)	*M* (*SD*)	***M* (*SD*)**	*M* (*SD*)	*M* (*SD*)	***M* (*SD*)**	*M* (*SD*)	*M* (*SD*)	***M* (*SD*)**
Block 1	.976 (.05)	.983 (.05)	**.980 (.05)**	.951 (.08)	.967 (.05)	**.961 (.06)**	-.025 (.10)	-.016 (.07)	**-.019 (.08)**
Block 2	.983 (.04)	.982 (.04)	**.982 (.04)**	.965 (.06)	.959 (.05)	**.961 (.05)**	-.018 (.07)	-.024 (.07)	**-.022 (.07)**
Total	.979 (.03)	.982 (.04)	**.981 (.03)**	.958 (.06)	.963 (.04)	**.961 (.05)**	-.021 (.07)	-.020 (.05)	**-.020 (.06)**
	Side-4								
	Congruent			Incongruent			Simon Effect		
	Mon.	Bil.	**Total**	Mon.	Bil.	**Total**	Mon.	Bil.	**Total**
	M (*SD*)	*M* (*SD*)	***M* (*SD*)**	*M* (*SD*)	*M* (*SD*)	***M* (*SD*)**	*M* (*SD*)	*M* (*SD*)	***M* (*SD*)**
Block 1	.955 (.08)	.969 (.05)	**.964 (.06)**	.971 (.05)	.959 (.06)	**.963 (.06)**	.017 (.08)	-.010 (.07)	**-.001 (.07)**
Block 2	.943 (.06)	.962 (.06)	**.955 (.06)**	.954 (.07)	.943 (.08)	**.947 (.08)**	.011 (.08)	-.019 (.08)	**-.001 (.08)**
Total	.949 (.05)	.965 (.05)	**.960 (.05)**	.962 (.04)	.951 (.05)	**.955 (.05)**	.014 (.05)	-.014 (.06)	**-.005 (.06)**

Notes: Mon. = monolinguals, Bil. = bilinguals.

A 2x2x2x2 factorial ANOVA was performed to ascertain if there were any differences in ARs between groups, conditions or blocks, in congruent and incongruent trials. The test included the arcsine-transformed ARs obtained in the Side conditions as the DV, *Block* (block 1, block 2), *Condition* (Side-2, Side-4) and *Congruency* (congruent, incongruent) as within-subjects factors, and *Group* (monolinguals, bilinguals) as a between-subjects factor.

Main effect of Condition

The analysis found a significant main effect of *Condition* on accuracy, $F(1, 113) = 14$, $p < .001$, $\eta_p^2 = .11$, with responses to the Side-2 condition being on average more accurate (*M* = .97, *SD* = .03) than responses to the Side-4 condition (*M* = .96, *SD* = .04).

Main effect of Congruency (Simon Effect)

There was a significant main effect of *Congruency* in ARs, $F(1, 113) = 6.32$, $p = .013$, $\eta_p^2 = .053$, with responses to congruent trials being more accurate (*M* = .97, *SD* = .04) than responses to incongruent trials (*M* = .96, *SD* = .04), revealing a Simon Effect.

Interaction between Congruency and Condition

There was a significant interaction effect between *Condition* and *Congruency*, $F(1, 113) = 10.6$, $p = .002$, $\eta_p^2 = .086$. Fisher's LSD pairwise comparisons showed that the Simon Effect was, in fact, only present in the Side-2 condition ($p < .001$), and completely absent from the Side-4 condition ($p = .92$).

Main effect of Group

The main effect of *Group* on ARs was not statistically significant, $F(1, 113) = .27$, $p = .60$, $\eta_p^2 = .002$, revealing no significant differences between monolinguals and bilinguals.

Interaction between Congruency and Group

However, there was a near significant interaction between *Congruency* and *Group*, $F(1, 113) = 3.22$, $p = .076$, $\eta_p^2 = .028$. Pairwise comparisons using Fisher's LSD test revealed that monolinguals had a non-significant Simon Effect ($p = .66$), while bilinguals presented a significant Simon Effect ($p < .001$).

Interaction between Condition, Congruency and Group

There was also a near significant interaction between *Condition*, *Congruency* and *Group*, $F(1, 113) = 2.92$, $p = .090$, $\eta_p^2 = .025$. Post-hoc comparisons were conducted, using Fisher's LSD test. These comparisons indicated no significant difference between congruent and incongruent trials —i.e. no Simon Effect— for monolinguals in the Side-4 condition ($p = .11$), while that same difference was significant for bilinguals ($p = .037$) (see Figure 30). However, both groups displayed a significant Simon Effect in the Side-2 condition (both $p \leq .030$).

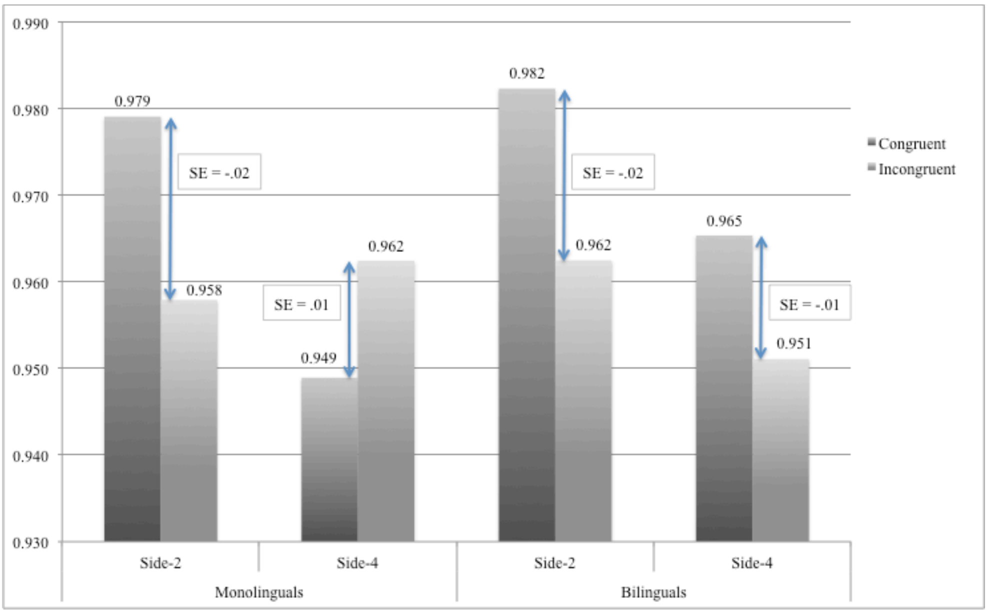

Figure 30. Mean accuracy rates in the Side-2 and Side-4 conditions of the Simon task, by congruency and by group, with mean scores for the Simon Effect (SE).

This lack of Simon Effect in ARs in the monolingual group, in the Side-4 condition, echoes what was observed for the Simon Effect in RTs, which was also non-existent for this group in this condition (see Figure 29).

Main effect of Block

Contrary to what was observed for RTs, there was no significant main effect of *Block* on ARs, $F(1, 113) = 2.42$, $p = .12$, $\eta_p^2 = .021$, revealing a lack of practice effect in ARs.

Interaction between Block and Condition

There was a significant interaction effect between *Block* and *Condition*, $F(1, 113) = 4.77$, $p = .031$, $\eta_p^2 = .041$. Pairwise comparisons performed using Fisher's LSD method revealed that the difference in ARs between the Side-2 and Side-4 conditions was statistically significant in block 2 ($p < .001$), but not in block 1 ($p = .15$). Additionally, there was a significant difference between blocks 1 and 2 in the Side-4 condition ($p = .022$) but not in the Side-2 condition ($p = .76$). The difference between blocks in the Side-4 condition, however, translates into an inverse practice effect, with accuracy decreasing with time and practice (see Figure 31).

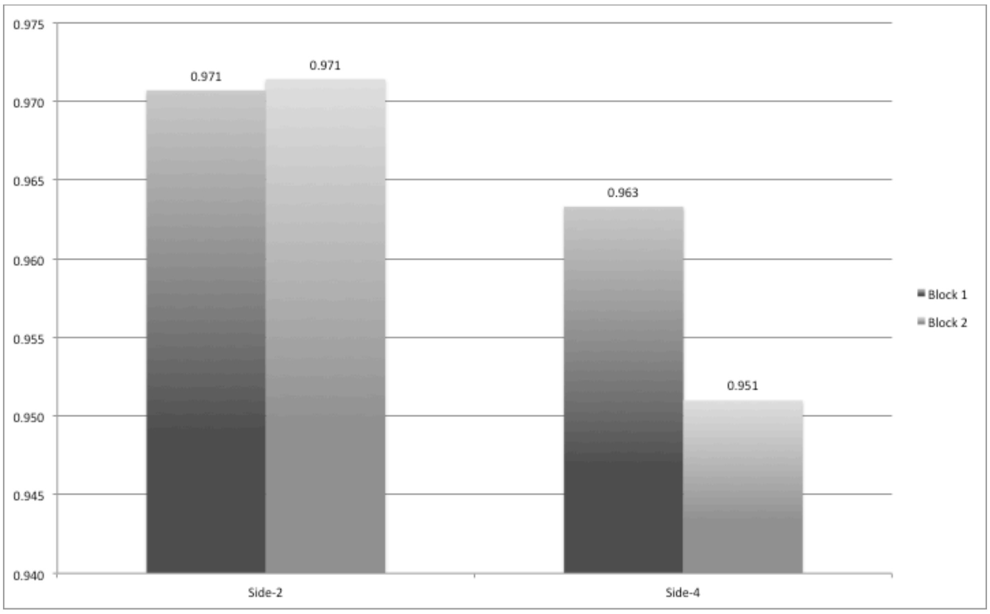

Figure 31. Mean accuracy rates in the Side-2 and Side-4 conditions of the Simon task, by block.

Interaction between Block, Condition and Group

Additionally, there was also a near significant interaction between *Block*, *Condition* and *Group*, $F(1, 113) = 3.61$, $p = .060$, $\eta_p^2 = .031$. Pairwise comparisons performed using Fisher's LSD method revealed that the interaction between *Condition* and *Block* differs across groups (see Figure 32): the tendency to get lower accuracy rates in block 2 than in block 1 does not materialise for monolinguals, in the Side-2 condition. Monolinguals seem to improve in accuracy between blocks, while bilinguals decrease slightly. Additionally, the monolingual group's differences in accuracy between the Side-2 and Side-4 conditions were not significant in block 1 ($p = .99$), but were significant in block 2 ($p = .002$). Bilinguals, on the other hand, present significant differences in accuracy between conditions in both blocks (both ps $\leq .015$).

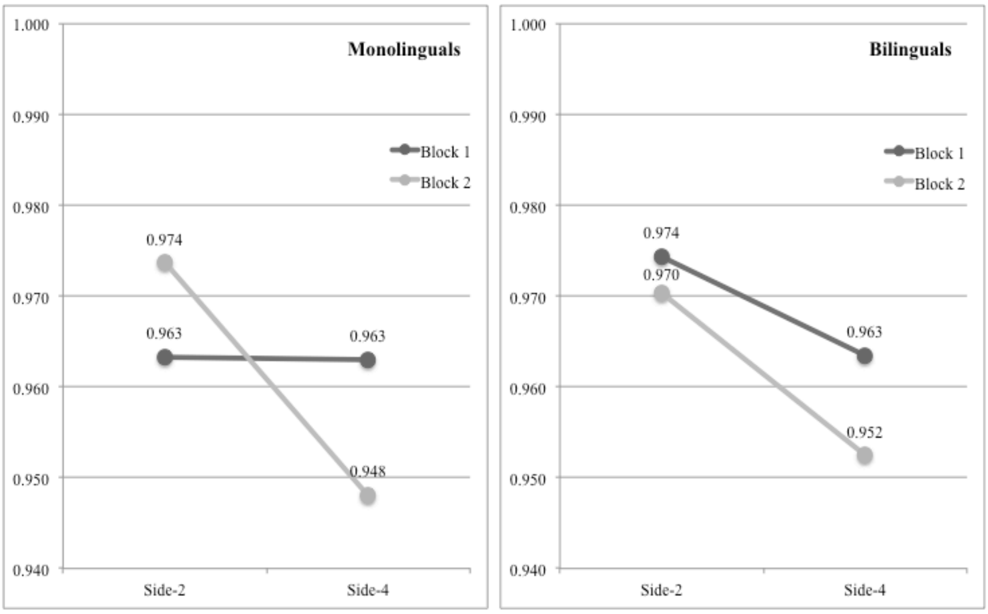

Figure 32. Mean accuracy rates in the Side-2 and Side-4 conditions of the Simon task, by block, presented separately by group.

There were no significant differences in accuracy between groups in any of the *Block* by *Condition* combinations (all ps $\geq .14$), as well as no significant differences between blocks 1 and 2 in any of the *Condition* by *Group* combinations (all ps $\geq .056$).

No other main effects or interactions were statistically significant (all *F*s ≤ .33, *p*s ≥ .57, η_p^2s ≤ .003).

3.2.6 Working Memory Costs in Reaction Times

I next investigate Working Memory (WM) Costs in the Simon task, by comparing participants' reaction times (and accuracy rates, in the next section) in the 2-square conditions with those in the 4-square conditions, both averaged across Centre/Side conditions, but also including a *Stimulus Location* (centre, side) factor. By increasing the amount of rules the participants had to remember and recall during the task from 2 to 4, the 4-square conditions presented an increase in working memory load when compared with the 2-square conditions. For this reason, a comparison between these two types of experimental conditions will allow us to pinpoint the existence of any Working Memory Costs. On the other hand, the inclusion of *Stimulus Location* as a factor allows us to account for any impact of the uncertainty of stimulus location (always in the centre vs. left or right side of the screen) on the results.

Table 25 contains the Working Memory Costs, calculated as the difference in RTs between the 2-square conditions and the 4-square conditions. Mean reaction times in all conditions are also reproduced here from the *3.2.2 General Analyses – Reaction Times* section, for ease of access, although they are displayed differently to aid the comparison between the relevant experimental conditions.

Table 25

Means (M) and Standard Deviations (SD) of Reaction Times in All Experimental Conditions of the Simon Task, by Block, Group and Stimulus Location (Centre, Side), and Working Memory Costs Scores

	Centre								
	Centre-2			Centre-4			WM Costs		
	Mon.	Bil.	**Total**	Mon.	Bil.	**Total**	Mon.	Bil.	**Total**
	M (*SD*)	*M* (*SD*)	***M* (*SD*)**	*M* (*SD*)	*M* (*SD*)	***M* (*SD*)**	*M* (*SD*)	*M* (*SD*)	***M* (*SD*)**
Block 1	398 (71)	396 (66)	**397 (67)**	524 (76)	534 (95)	**531 (89)**	126 (93)	137 (82)	**134 (86)**
Block 2	380 (50)	373 (61)	**375 (57)**	468 (65)	464 (69)	**465 (67)**	89 (67)	91 (58)	**90 (61)**
Total	388 (53)	384 (57)	**386 (55)**	496 (61)	498 (72)	**497 (69)**	109 (68)	113 (58)	**112 (61)**
	Side								
	Side-2			Side-4			WM Costs		
	Mon.	Bil.	**Total**	Mon.	Bil.	**Total**	Mon.	Bil.	**Total**
	M (*SD*)	*M* (*SD*)	***M* (*SD*)**	*M* (*SD*)	*M* (*SD*)	***M* (*SD*)**	*M* (*SD*)	*M* (*SD*)	***M* (*SD*)**
Block 1	448 (67)	438 (66)	**441 (67)**	527 (70)	537 (90)	**533 (83)**	79 (60)	99 (76)	**92 (71)**
Block 2	422 (53)	411 (62)	**415 (59)**	489 (55)	502 (77)	**498 (70)**	66 (43)	91 (55)	**83 (52)**
Total	435 (55)	424 (60)	**428 (58)**	507 (58)	519 (78)	**515 (72)**	73 (43)	95 (55)	**88 (53)**

Notes: WM Costs = Working Memory Costs, Mon. = monolinguals, Bil. = bilinguals.

In order to ascertain the existence of significant Working Memory Costs in the Simon task, a 2x2x2x2 factorial ANCOVA was performed, which included the RTs as the DV, *Block* (block 1, block 2), *Stimulus Location* (centre, side), and *Working Memory Load* (2 squares, 4 squares) as within-subjects factors, *Group* (monolinguals, bilinguals) as a between-subjects factor, and *Age* as a covariate.

Main effect of Working Memory Load (WM Costs)

There was a significant main effect of *WM Load* on the RTs, $F(1, 112) = 355$, $p < .001$, $\eta_p^2 = .76$, with responses to trials involving a stimulus in one of only 2 different colours being significantly faster than responses to trials involving a stimulus in one of

4 different colours. In other words, there were significant Working Memory Costs in the Simon task.

Main effect of Stimulus Location

The main effect of *Stimulus Location* was statistically significant, $F(1, 112) = 105$, $p < .001$, $\eta_p^2 = .48$, revealing a significant difference in RTs between Centre and Side conditions. Centre conditions presented faster RTs than Side conditions.

Interaction between WM Load and Stimulus Location

The interaction between *Stimulus Location* and *WM Load* was statistically significant, $F(1, 112) = 29.2$, $p < .001$, $\eta_p^2 = .21$. Post-hoc comparisons using Fisher's LSD test revealed a significant difference between Centre and Side conditions across both levels of *WM Load* (both *p*s < .001), as well as significant WM Costs across both Centre and Side conditions (both *p*s < .001). Figure 33 reveals the nature of this interaction: Working Memory Costs are greater in Centre conditions than in Side conditions, which seems mainly due to an increase in RTs in the 2-square conditions, between Centre-2 and Side-2 trials. The difference between Centre and Side conditions is thus more apparent when the WM Load is lower. In contrast, when the WM Load is higher (4-square conditions), the difference in RTs diminishes considerably.

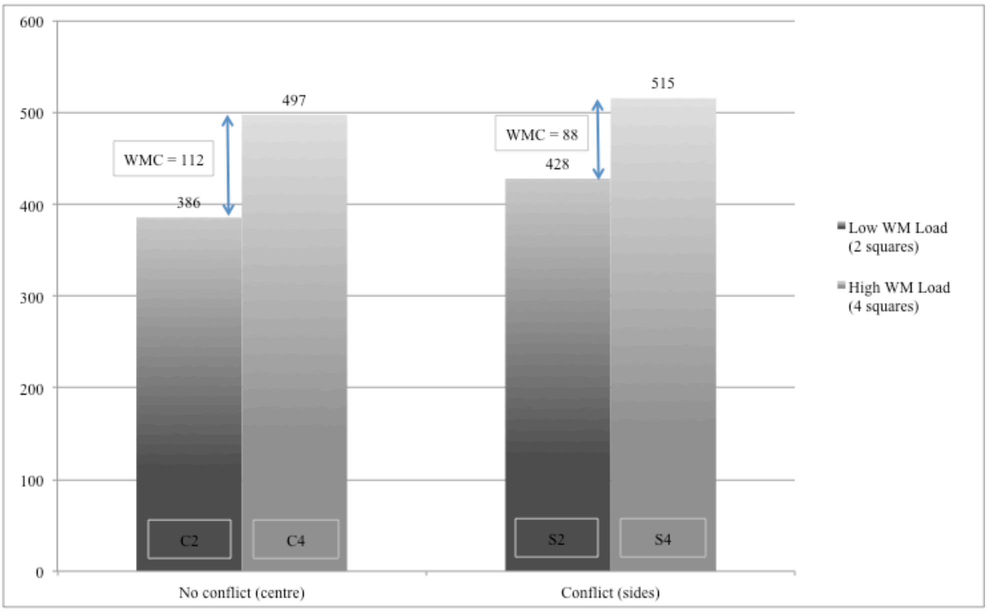

Figure 33. Mean reaction times in the Simon task, by stimulus location and by working memory (WM) load conditions, with mean scores for Working Memory Costs (WMC). C2 = Centre-2, C4 = Centre-4, S2 = Side-2, S4 = Side-4.

Main effect of Block

There was a significant main effect of *Block* in the RTs, $F(1, 112) = 100$, $p < .001$, $\eta_p^2 = .47$, revealing a significant practice effect in RTs, with faster RTs being obtained with practice in the task.

Interactions between Block, WM Load and Stimulus Location

The interaction effect between *Block* and *WM Load* was significant, $F(1, 112) = 21.9$, $p < .001$, $\eta_p^2 = .16$. Pairwise comparisons performed using Fisher's LSD method revealed significant WM Costs in both blocks (both *p*s < .001), as well as significant practice effects in both 2-square and 4-square conditions (both *p*s < .001).

The interaction effect between *Block* and *Stimulus Location* was also significant, $F(1, 112) = 4.18$, $p = .043$, $\eta_p^2 = .036$. Pairwise comparisons performed using Fisher's LSD method revealed significant differences between Centre and Side conditions in both blocks (both *p*s < .001), as well as significant practice effects in both Centre and Side conditions (both *p*s < .001).

There was also a significant interaction between *Block*, *WM Load* and *Stimulus Location*, $F(1, 112) = 11.5$, $p = .001$, $\eta_p^2 = .093$. Post-hoc comparisons conducted using Fisher's LSD test revealed that the interaction between *WM Load* and *Stimulus Location* differs across blocks (see Figure 34): the tendency to get slower RTs in high *WM Load* conditions is stronger for Side conditions than for Centre conditions, but this pattern differs between blocks, with block 1 showing a non-significant difference between the Centre-4 and Side-4 conditions ($p = .68$).

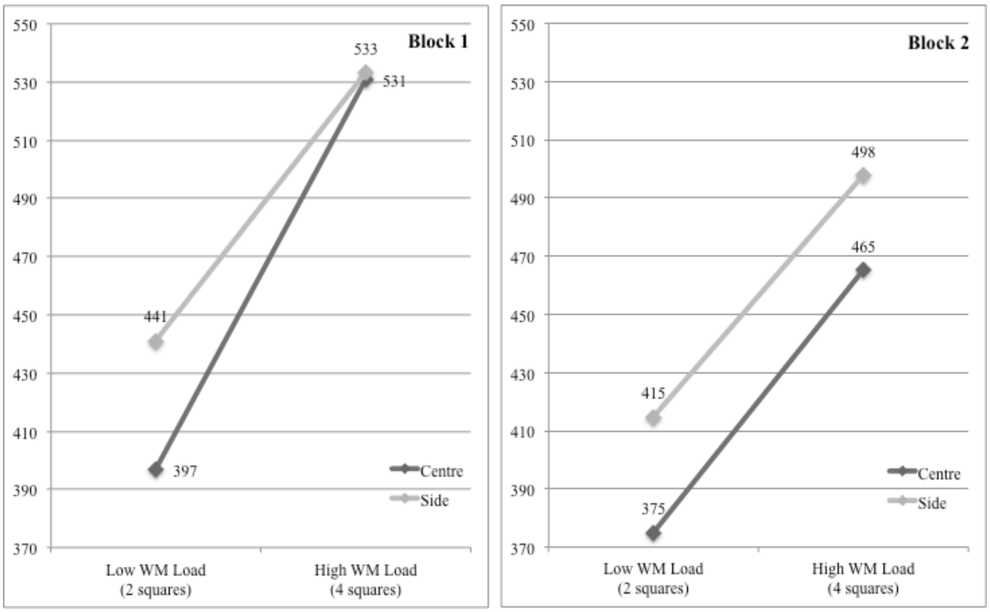

Figure 34. Mean reaction times in the Simon task, by Working Memory (WM) load and stimulus location conditions, separately for blocks 1 and 2.

It is interesting that the larger WM Costs were found in the Centre conditions, in block 1 ($M = 134$). These larger WM Costs seem to be linked to the slow RTs observed in the Centre-4 trials, which did not differ significantly from the RTs in the Side-4 condition in the same block (1). It could be argued that the extra demand of having to memorise four colours and four rules to go with those colours was so taxing to participants that the difference between Centre-4 and Side-4 is not even statistically significant. It is only in block 2 that, after some time and practice, participants seem to have memorised the rules and are then able to respond more quickly to the Centre-4 than to the Side-4 condition.

Main effect of Group

The main effect of *Group* was non-significant, $F(1, 112) = .012$, $p = .91$, $\eta_p^2 < .001$, indicating no significant differences between monolinguals and bilinguals.

Main effect of Age

There was a statistically significant main effect of *Age* on the RTs, $F(1, 112) = 16.5$, $p < .001$, $\eta_p^2 = .13$, with older age being associated with slower RTs.

Interaction between Age and Stimulus Location

There was also a statistically significant interaction effect between *Age* and *Stimulus Location*, $F(1, 112) = 10.8$, $p = .001$, $\eta_p^2 = .088$. A comparison between unstandardized beta weights from the parameter estimates showed that the association of older age and slower RTs is stronger in the Side conditions ($B = 2.35$) than in the Centre conditions ($B = 1.49$).

No other interactions were statistically significant (all Fs ≤ 2.47, ps $\geq .12$, η_p^2s $\leq .022$).

3.2.7 Working Memory Costs in Accuracy Rates

Table 26 shows the accuracy rates obtained by participants in all conditions, but, more significantly, it presents the Working Memory Costs associated with both the Centre and Side conditions, for both blocks and also for both groups of participants.

Table 26

Means (M) and Standard Deviations (SD) of Accuracy Rates in All Experimental Conditions of the Simon Task, by Block and by Group

	Centre								
	Centre-2			Centre-4			WM Costs		
	Mon.	Bil.	**Total**	Mon.	Bil.	**Total**	Mon.	Bil.	**Total**
	M (*SD*)	*M* (*SD*)	***M* (*SD*)**	*M* (*SD*)	*M* (*SD*)	***M* (*SD*)**	*M* (*SD*)	*M* (*SD*)	***M* (*SD*)**
Block 1	.967 (.08)	.982 (.03)	**.977 (.05)**	.965 (.04)	.976 (.04)	**.973 (.04)**	-.001 (.09)	-.005 (.04)	**-.004 (.06)**
Block 2	.987 (.03)	.985 (.03)	**.986 (.03)**	.955 (.05)	.961 (.05)	**.959 (.05)**	-.032 (.05)	-.024 (.05)	**-.027 (.05)**
Total	.977 (.04)	.983 (.02)	**.981 (.03)**	.960 (.04)	.968 (.04)	**.966 (.04)**	-.017 (.06)	-.015 (.03)	**-.016 (.04)**
	Side								
	Side-2			Side-4			WM Costs		
	Mon.	Bil.	**Total**	Mon.	Bil.	**Total**	Mon.	Bil.	**Total**
	M (*SD*)	*M* (*SD*)	***M* (*SD*)**	*M* (*SD*)	*M* (*SD*)	***M* (*SD*)**	*M* (*SD*)	*M* (*SD*)	***M* (*SD*)**
Block 1	.963 (.04)	.974 (.04)	**.971 (.04)**	.963 (.05)	.964 (.04)	**.963 (.05)**	-.000 (.05)	-.011 (.04)	**-.007 (.05)**
Block 2	.974 (.03)	.970 (.04)	**.971 (.04)**	.948 (.05)	.953 (.06)	**.951 (.06)**	-.026 (.05)	-.018 (.06)	**-.020 (.06)**
Total	.969 (.03)	.972 (.03)	**.971 (.03)**	.956 (.04)	.958 (.04)	**.957 (.04)**	-.013 (.04)	-.014 (.04)	**-.014 (.04)**

Notes: WM Costs = Working Memory Costs, Mon. = monolinguals, Bil. = bilinguals.

In order to determine whether there were significant Working Memory Costs in accuracy rates in the Simon task, a 2x2x2x2 factorial ANOVA was performed, which included the arcsine-transformed ARs as the DV, *Block* (block 1, block 2), *Stimulus Location* (centre, side), and *Working Memory Load* (2 squares, 4 squares) as within-subjects factors, and *Group* (monolinguals, bilinguals) as a between-subjects factor.

Main effect of Working Memory Load (WM Costs)

There was a significant main effect of *WM Load* on the ARs, $F(1, 113) = 34.4$, $p < .001$, $\eta_p^2 = .23$, with responses to 2-square conditions being significantly more accurate than responses to 4-square conditions (see Figure 35). In other words, there were significant Working Memory Costs in the Simon task.

Main effect of Stimulus Location

The main effect of *Stimulus Location* was also statistically significant, $F(1, 113) = 14.8$, $p < .001$, $\eta_p^2 = .12$, revealing a significant difference in ARs between Centre and Side conditions (see Figure 35). Centre conditions presented higher accuracy rates than Side conditions.

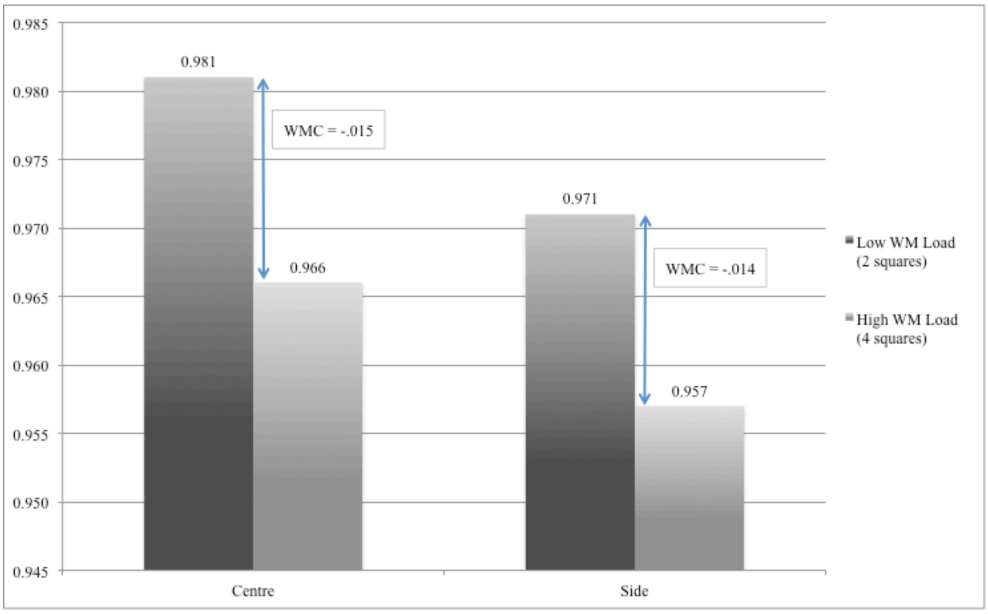

Figure 35. Mean accuracy rates in the Simon task, by working memory (WM) load and stimulus location conditions, with mean scores for Working Memory Costs (WMC).

Main effect of Block

There was a non-significant main effect of *Block* on the ARs, $F(1, 113) = 1.86$, $p = .18$, $\eta_p^2 = .016$, revealing no practice effect in accuracy.

Interaction between Block and WM Load

There was a significant interaction between *Block* and *WM Load*, $F(1, 113) = 13.5$, $p < .001$, $\eta_p^2 = .11$. Pairwise comparisons performed using Fisher's LSD test showed significant WM Costs in block 2 ($p < .001$), but no significant WM Costs in block 1 ($p = .099$) (see Figure 36).

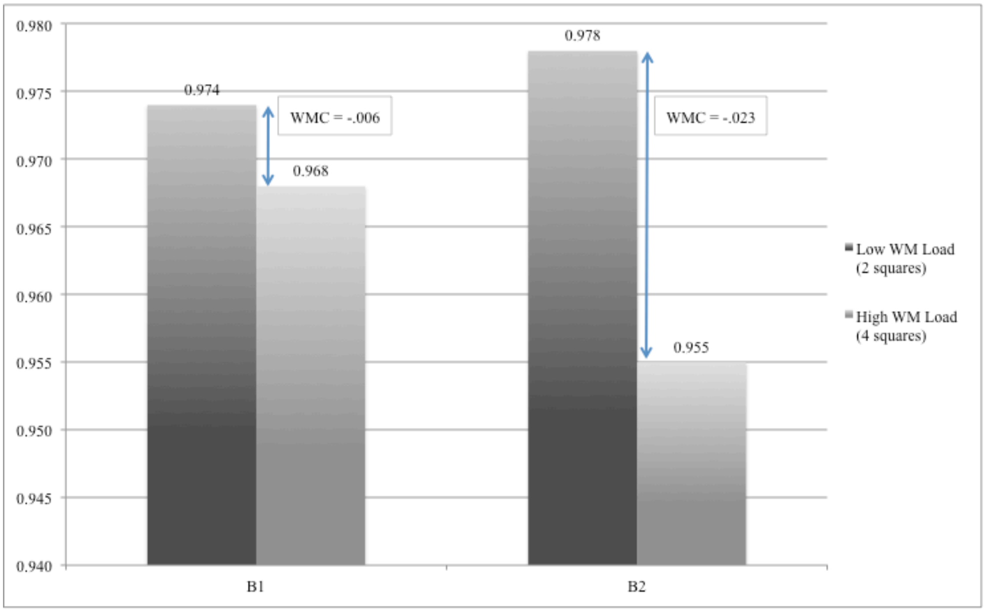

Figure 36. Mean accuracy rates in the Simon task, by working memory (WM) load and by block, with mean scores for Working Memory Costs (WMC).

Main effect of Group

There was a non-significant main effect of *Group* on the ARs, $F(1, 113) = 1.07$, $p = .30$, $\eta_p^2 = .009$, revealing no significant differences between monolinguals and bilinguals.

No other interactions were statistically significant (all Fs ≤ 2.38, ps $\geq .13$, η_p^2s $\leq .021$).

3.2.8 Sequential Congruency Effects in Reaction Times

To examine the Sequential Congruency Effects in the Simon task, the results were analysed by trial sequence: previous-congruent trial – current-congruent trial (CC), previous-congruent trial – current-incongruent trial (CI), previous-incongruent trial – current-congruent trial (IC), and previous-incongruent trial – current-incongruent trial (II). Given the nature of the experimental conditions, only the Side-2 and Side-4 conditions were included in these analyses, as these conditions are the only ones that include congruency effects. Table 27 shows the average reaction times obtained in the Simon task, by trial sequence, block and group.

Table 27

Means (M) and Standard Deviations (SD) of Reaction Times in the Simon Task, by Trial Sequence, Block and Group

	Block 1						
	Previous Congruent			Previous Incongruent			**Total B1**
	Mon.	Bil.	**Total**	Mon.	Bil.	**Total**	
	M (*SD*)	*M* (*SD*)	***M* (*SD*)**	*M* (*SD*)	*M* (*SD*)	***M* (*SD*)**	***M* (*SD*)**
Current Cong.	456 (70)	452 (74)	**453 (73)**	495 (72)	497 (75)	**496 (73)**	**475 (67)**
Current Inc.	512 (68)	508 (73)	**509 (71)**	481 (64)	481 (76)	**481 (72)**	**496 (67)**
Total B1	485 (63)	481 (68)	**482 (66)**	488 (63)	489 (70)	**489 (68)**	
	Block 2						
	Previous Congruent			Previous Incongruent			**Total B2**
	Mon.	Bil.	**Total**	Mon.	Bil.	**Total**	
	M (*SD*)	*M* (*SD*)	***M* (*SD*)**	*M* (*SD*)	*M* (*SD*)	***M* (*SD*)**	***M* (*SD*)**
Current Cong.	434 (60)	427 (64)	**429 (63)**	460 (66)	459 (83)	**460 (77)**	**446 (63)**
Current Inc.	469 (52)	474 (75)	**472 (68)**	454 (59)	462 (71)	**460 (67)**	**466 (63)**
Total B2	453 (49)	452 (65)	**452 (60)**	457 (56)	461 (68)	**459 (64)**	
	Total						
	Previous Congruent			Previous Incongruent			**Total**
	Mon.	Bil.	**Total**	Mon.	Bil.	**Total**	
	M (*SD*)	*M* (*SD*)	***M* (*SD*)**	*M* (*SD*)	*M* (*SD*)	***M* (*SD*)**	***M* (*SD*)**
Current Cong.	444 (51)	440 (62)	**441 (59)**	477 (61)	478 (72)	**478 (68)**	**460 (60)**
Current Inc.	490 (57)	491 (69)	**491 (65)**	468 (57)	471 (64)	**470 (62)**	**481 (62)**
Total	469 (51)	466 (63)	**467 (59)**	472 (55)	475 (65)	**474 (62)**	

Notes: Mon. = monolinguals, Bil. = bilinguals, Cong. = congruent, Inc. = incongruent, B1 = block 1, B2 = block 2.

In order to determine whether there were significant Sequential Congruency Effects in RTs, a 2x2x2x2x2 factorial ANCOVA was performed, which included the RTs in the Side conditions as the DV, *Block* (block 1, block 2), *Condition* (Side-2, Side-4), *Previous Trial Congruency* (congruent, incongruent) and *Current Trial Congruency* (congruent, incongruent) as within-subjects factors, and *Group* (monolinguals, bilinguals) as a between-subjects factor. *Age* was also included as a covariate.

This analysis is extremely similar to the analysis conducted on the section on the Simon Effect (see *3.2.4 Simon Effect in Reaction Times*), the only difference being the inclusion, in the present analysis, of the within-subjects factor *Previous Trial Congruency*. For this reason, the results on the main effects of *Block*, *Current Trial Congruency* (identified in the analysis on the Simon Effect as *Congruency*), *Condition*, *Group* and *Age*, as well as the interactions between *Current Trial Congruency* and *Age*, between *Condition* and *Group*, and between *Condition* and *Current Trial Congruency* will not be described here, so as to avoid unnecessary repetition of information.

Main effect of Previous Trial Congruency

There was a significant main effect of *Previous Trial Congruency* on the RTs, $F(1, 112) = 11.9$, $p = .001$, $\eta_p^2 = .096$, revealing that participants responded significantly faster following previous-congruent trials ($M = 467$, $SD = 58.7$) than following previous-incongruent ones ($M = 474$, $SD = 61.5$).

Interaction between Previous Trial Congruency and Current Trial Congruency (Sequential Congruency Effects)

There was also a significant interaction between *Previous Trial Congruency* and *Current Trial Congruency*, $F(1, 112) = 162$, $p < .001$, $\eta_p^2 = .59$. Post-hoc comparisons using Fisher's LSD method revealed that the current-trial Simon Effect was larger following previous-congruent trials than following previous-incongruent trials. This pattern can be appreciated in Figure 37. It matches the pattern associated with Sequential Congruency Effects —faster RTs in II than in CI and slower RTs in IC than in CC—, but it differs from the conventional pattern inasmuch as the RTs in IC are slower than those in II.

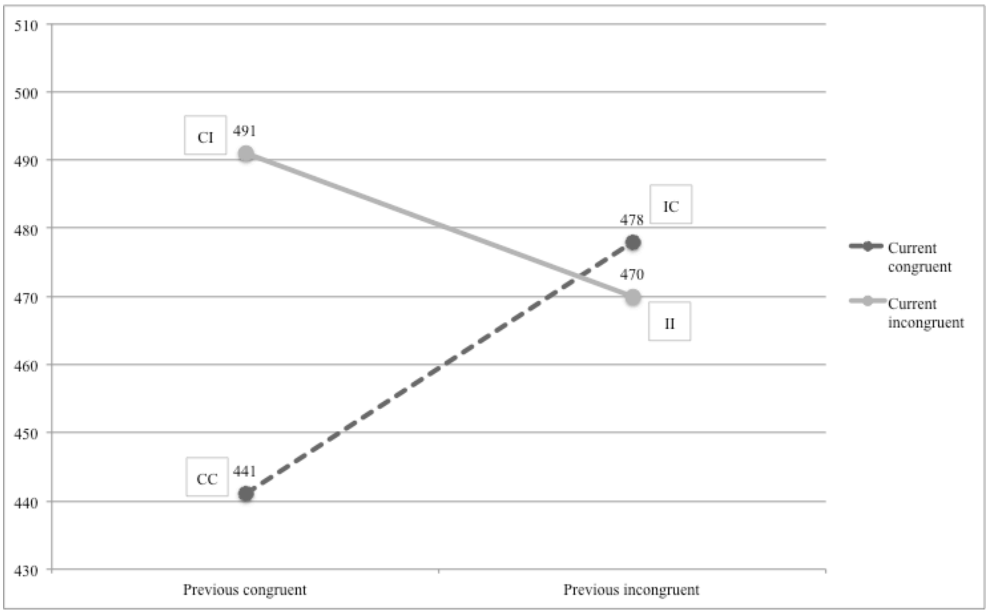

Figure 37. Mean reaction times in the Simon task, by trial sequence condition. CI = congruent-incongruent, IC = incongruent-congruent, II = incongruent-incongruent, CC = congruent-congruent.

Interaction between Previous Trial Congruency, Current Trial Congruency and Block

The interaction between *Previous Trial Congruency*, *Current Trial Congruency* and *Block* was also statistically significant, $F(1, 112) = 4.46$, $p = .037$, $\eta_p^2 = .038$. Post-hoc comparisons performed using Fisher's LSD method revealed larger Sequential Congruency Effects in block 1 than in block 2. Additionally, as can be seen in Figure 38, when the previous trial is congruent, there is a conventional (and significant) Simon Effect in both blocks (both *p*s < .001), with faster RTs to current-congruent than to current-incongruent trials. Nevertheless, when the previous trial is incongruent, the Simon Effect is inversed (block 1), with significantly faster RTs in current-incongruent than in current-congruent trials ($p < .001$), or it disappears (block 2) ($p = .55$).

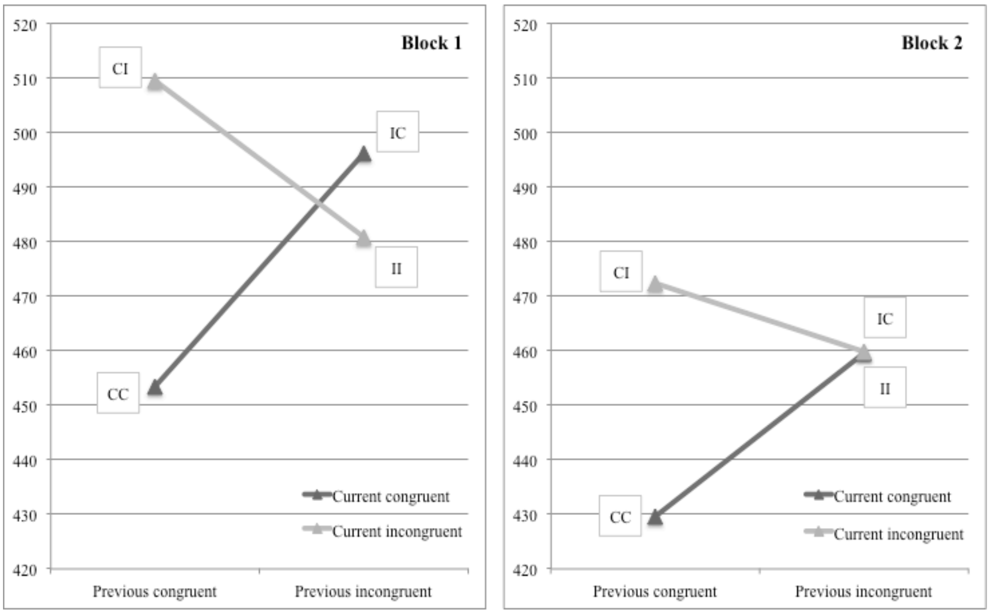

Figure 38. Mean reaction times in the Side conditions of the Simon task, revealing the interaction between previous trial congruency and current trial congruency, separately for blocks 1 and 2. CC = congruent-congruent, CI = congruent-incongruent, IC = incongruent-congruent, II = incongruent-incongruent.

Interaction between Previous Trial Congruency, Current Trial Congruency and Condition

The interaction effect between *Previous Trial Congruency*, *Current Trial Congruency* and *Condition* was statistically significant, $F(1, 112) = 8.80$, $p = .004$, $\eta_p^2 = .073$. Pairwise comparisons conducted using Fisher's LSD test revealed larger Sequential Congruency Effects in the Side-2 condition than in the Side-4 condition. Additionally, as shown in Figure 39, when the previous trial is congruent, there is an expected (and significant) Simon Effect (both *p*s < .001), in both conditions, with faster RTs to current-congruent than to current-incongruent trials. However, when the previous trial is incongruent, the Simon Effect is inversed and non-significant (both *p*s $\geq .077$).

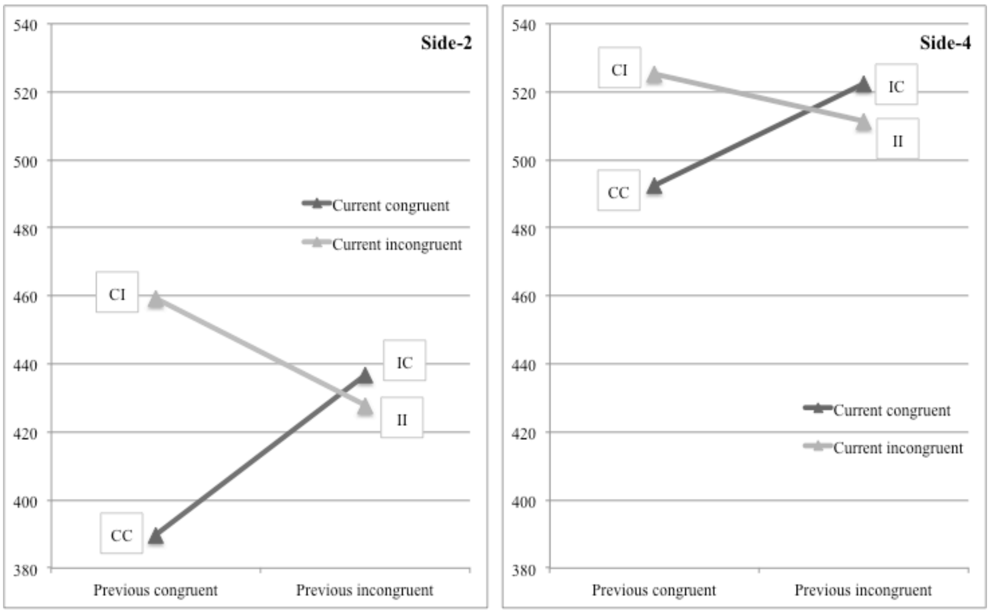

Figure 39. Mean reaction times in the Simon task, revealing the interaction between previous trial congruency and current trial congruency, separately for the Side-2 and Side-4 conditions. CC = congruent-congruent, CI = congruent-incongruent, IC = incongruent-congruent, II = incongruent-incongruent.

Interaction between Previous Trial Congruency, Current Trial Congruency and Age

The interaction between *Previous Trial Congruency*, *Current Trial Congruency* and *Age* was statistically significant as well, $F(1, 112) = 5.25$, $p = .024$, $\eta_p^2 = .045$. A comparison between unstandardized beta weights from the parameter estimates showed an association of older age and slower RTs that was stronger in CI trials ($B = 2.90$), followed by II trials ($B = 2.40$), IC trials ($B = 2.32$), and finally CC trials ($B = 1.82$). These values showed the expected Sequential Congruency Effect, varying depending on *Age*, which seems to have a stronger impact on current-incongruent than on current-congruent trials. This pattern repeats the results found in the same 3-way interaction in the Attention Network Test (see section *3.1.11 Sequential Congruency Effects in Reaction Times*).

As we had already seen from the significant interaction between *Current Trial Congruency* and *Age* (see section *3.2.4 Simon Effect in Reaction Times*), *Age* has a higher impact on RTs in current-incongruent trials than in current-congruent trials. For this reason, older age is associated with a greater susceptibility to the Simon Effect. The present 3-way interaction adds to our understanding of the effect of *Age* in the RTs, as its CI-II-IC-CC pattern implies an association between older age and larger Sequential Congruency Effects.

No other interactions were statistically significant (all Fs$(1, 112) \leq 2.97$, ps $\geq .087$, η_p^2s $\leq .026$).

3.2.9 Sequential Congruency Effects in Accuracy Rates

Table 28 shows the average accuracy rates obtained in the Simon task, by trial sequence, block and group. As with the RT analysis, these results correspond only to the Side-2 and Side-4 experimental conditions.

Table 28

Means (M) and Standard Deviations (SD) of Accuracy Rates in the Simon Task, by Trial Sequence, Block and Group

	Block 1						
	Previous Congruent			Previous Incongruent			**Total B1**
	Mon.	Bil.	**Total**	Mon.	Bil.	**Total**	
	M (*SD*)	*M* (*SD*)	***M* (*SD*)**	*M* (*SD*)	*M* (*SD*)	***M* (*SD*)**	***M* (*SD*)**
Current Cong.	.982 (.05)	.988 (.03)	**.986 (.04)**	.952 (.07)	.966 (.06)	**.961 (.07)**	**.973 (.04)**
Current Inc.	.948 (.08)	.946 (.07)	**.947 (.07)**	.973 (.05)	.980 (.05)	**.978 (.05)**	**.962 (.05)**
Total B1	.964 (.05)	.966 (.04)	**.965 (.04)**	.962 (.05)	.973 (.04)	**.970 (.04)**	
	Block 2						
	Previous Congruent			Previous Incongruent			**Total B2**
	Mon.	Bil.	**Total**	Mon.	Bil.	**Total**	
	M (*SD*)	*M* (*SD*)	***M* (*SD*)**	*M* (*SD*)	*M* (*SD*)	***M* (*SD*)**	***M* (*SD*)**
Current Cong.	.973 (.05)	.978 (.04)	**.977 (.05)**	.951 (.06)	.966 (.05)	**.961 (.06)**	**.969 (.04)**
Current Inc.	.945 (.08)	.928 (.08)	**.934 (.08)**	.977 (.05)	.977 (.04)	**.977 (.05)**	**.954 (.05)**
Total B2	.959 (.05)	.952 (.05)	**.954 (.05)**	.963 (.04)	.971 (.04)	**.968 (.04)**	
	Total						
	Previous Congruent			Previous Incongruent			**Total**
	Mon.	Bil.	**Total**	Mon.	Bil.	**Total**	
	M (*SD*)	*M* (*SD*)	***M* (*SD*)**	*M* (*SD*)	*M* (*SD*)	***M* (*SD*)**	***M* (*SD*)**
Current Cong.	.979 (.03)	.983 (.03)	**.982 (.03)**	.952 (.05)	.966 (.05)	**.961 (.05)**	**.971 (.04)**
Current Inc.	.946 (.07)	.938 (.06)	**.941 (.06)**	.976 (.03)	.979 (.03)	**.978 (.03)**	**.958 (.04)**
Total	.962 (.04)	.959 (.04)	**.960 (.04)**	.963 (.04)	.972 (.03)	**.969 (.03)**	

Notes: Mon. = monolinguals, Bil. = bilinguals, Cong. = congruent, Inc. = incongruent, B1 = block 1, B2 = block 2.

So as to determine whether there were significant Sequential Congruency Effects in ARs, a 2x2x2x2x2 factorial ANOVA was performed, which included the arcsine-transformed ARs in the Side conditions as the DV, *Block* (block 1, block 2), *Condition* (Side-2, Side-4), *Previous Trial Congruency* (congruent, incongruent) and *Current Trial Congruency* (congruent, incongruent) as within-subjects factors, and *Group* (monolinguals, bilinguals) as a between-subjects factor.

This analysis is very similar to the analysis conducted in the section on the Simon Effect (see *3.2.5 Simon Effect in Accuracy Rates*), the only difference between the two being the inclusion, in the present analysis, of the within-subjects factor *Previous Trial Congruency*. For this reason, the results on the main effects of *Block*, *Current Trial Congruency* (identified in the analysis on the Simon Effect as *Congruency*), *Condition*, and *Group*, as well as the interactions between *Current Trial Congruency* and *Group*, between *Current Trial Congruency* and *Condition*, and between *Current Trial Congruency*, *Condition* and *Group* will not be described here, so as to avoid unnecessary repetition of information.

Main effect of Previous Trial Congruency

There was a non-significant main effect of *Previous Trial Congruency* on the ARs, $F(1, 113) = 2.54$, $p = .11$, $\eta_p^2 = .022$.

Interaction between Previous Trial Congruency and Group

There was a near significant interaction effect between *Previous Trial Congruency* and *Group*, $F(1, 113) = 3.29$, $p = .072$, $\eta_p^2 = .028$. Post-hoc comparisons using Fisher's LSD method indicated that only bilinguals' ARs were affected by differences in *Previous Trial Congruency* ($p = .004$), presenting significantly more accurate responses following previous-incongruent trials than following previous-congruent trials. *Previous Trial Congruency* alone seemed to have no effect on monolinguals' ARs ($p = .89$) (see Figure 40). There were no significant differences between monolinguals and bilinguals either in previous-congruent or previous-incongruent trials (both ps $\geq .16$).

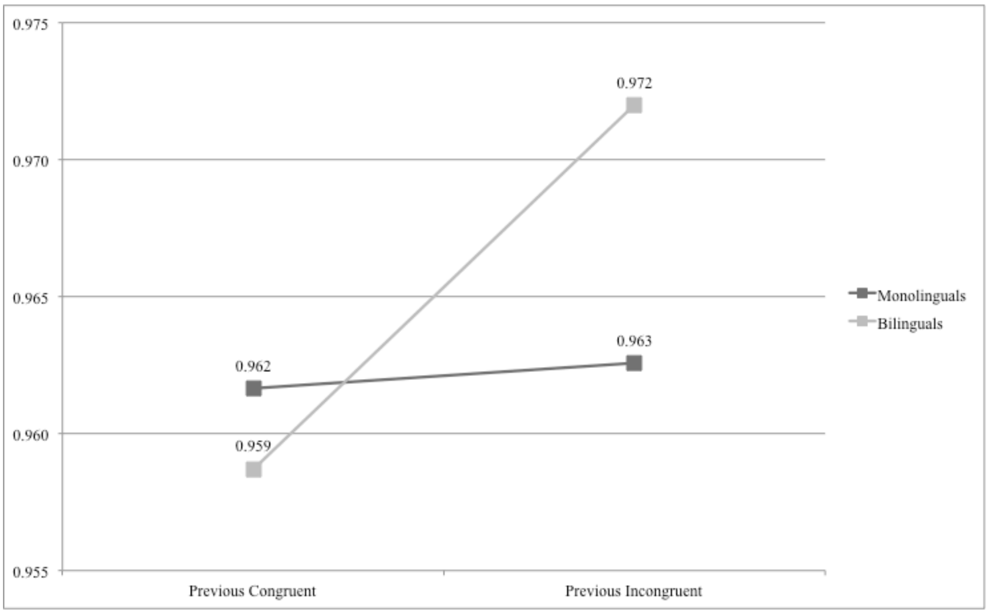

Figure 40. Mean accuracy rates in the Simon task, by previous trial congruency and by group.

Interaction between Previous Trial Congruency and Current Trial Congruency (Sequential Congruency Effects)

There was a statistically significant interaction between *Previous Trial Congruency* and *Current Trial Congruency*, $F(1, 113) = 68.7$, $p < .001$, $\eta_p^2 = .38$. Pairwise comparisons using Fisher's LSD test revealed the expected Sequential Congruency Effects, with a higher current-trial Simon Effect following previous-congruent trials than following previous-incongruent trials. This pattern can be appreciated in Figure 41. It matches the pattern associated with Sequential Congruency Effects —higher ARs in II than in CI and lower ARs in IC than in CC—, but it differs from the traditional pattern inasmuch as the ARs in IC are lower than those in II.

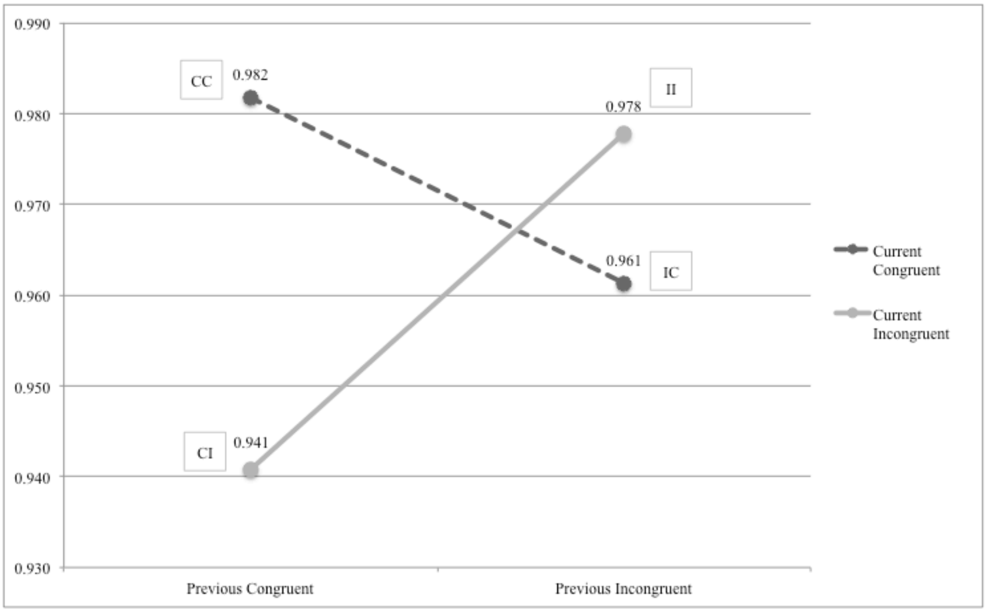

Figure 41. Mean accuracy rates in the Simon task, by trial sequence condition. CC = congruent-congruent, II = incongruent-incongruent, IC = incongruent-congruent, CI = congruent-incongruent.

No other interactions were statistically significant (all Fs(1, 113) ≤ 2.48, ps ≥ .12, η_p^2s ≤ .021).

3.2.10 Summary of Findings in the Simon Task

3.2.10.1 General results

The Simon task results analysed in this section have shown significantly different RTs and ARs by experimental condition, with participants responding faster and more accurately to the Centre-2 condition, followed by the Side-2 condition, the Centre-4 condition and, finally, the Side-4 condition (there was one exception: no significant difference in ARs between the Side-2 and Centre-4 conditions). In both RTs and ARs, this was the expected outcome, with difficulty increasing (bringing about slower RTs and lower ARs) in higher working memory load conditions, as well as in Side conditions.

The data showed evidence of a significant Simon Effect, with faster RTs and higher ARs to congruent than to incongruent trials. The Simon Effect in reaction times was significant in both the Side-2 and the Side-4 conditions (it was also larger in the Side-2 condition than in the Side-4 condition); however, in the AR results, the Simon Effect was only significant in the Side-2 condition, and not in the Side-4 condition.

There were also significant Working Memory Costs both in reaction times and in accuracy rates, with faster and more accurate responses to 2-square conditions than to 4-square conditions. WM Costs in RTs were greater between Centre conditions than between Side conditions. WM Costs in ARs were only statistically significant in block 2, but not in block 1. The absence of a significant difference between the RTs observed in the Centre-4 and Side-4 conditions in block 1 (but a significant difference in block 2) seems to suggest that WM load is initially more taxing for RT performance than the introduction of conflict.

There were significant differences between RTs following previous-congruent and previous-incongruent trials (not taking into consideration *Current Trial Congruency*), with faster responses following previous-congruent trials. In the RT results of both Side conditions, the Simon Effect only materializes in trials preceded by a congruent trial, whereas responses following previous-incongruent trials show either inverse or non-significant Simon Effects. The main effect of *Previous Trial Congruency* on ARs was not significant. However, *Previous Trial Congruency* seemed to affect the ARs of the two groups of participants differently: bilinguals were more accurate in trials preceded by an incongruent trial than in trials preceded by a congruent trial; monolinguals, however, showed no differences in ARs depending on *Previous Trial Congruency*.

Our results show evidence of Sequential Congruency Effects in both RTs and ARs. Both the reaction time and accuracy rate results show the pattern depicting Sequential Congruency Effects: faster and more accurate responses to II than to CI and slower and less accurate responses to IC than to CC, with larger Simon Effects following previous-congruent trials than following previous-incongruent trials.

There was evidence of practice effects in the overall RTs and ARs, with participants showing faster reaction times in block 2 than in block 1, but lower accuracy rates. When looking exclusively at the Side conditions, a practice effect was observed in RTs, showing the same pattern as before. However, there was no significant practice effect in ARs, in the Side-2 condition, while the Side-4 condition presented an inversed practice effect, again with less accurate responses in block 2 than in block 1.

The analyses identified *Age* as a significant predictor of RTs. No significant predictors of accuracy in the Simon task were identified. Younger age was associated with faster RTs. Older age was found to be associated with larger Simon Effects, as well as with larger Sequential Congruency Effects. This association of older age and slower RTs was stronger in the Side-4 condition, followed by conditions Side-2, Centre-4, and finally Centre-2.

Fluid Intelligence was shown to interact with *Group*: for bilinguals, faster RTs were associated with higher fluid intelligence, but the same association was not found for monolinguals.

3.2.10.2 Bilingual advantage

No bilingual (or monolingual) advantage was found in RTs or in ARs. A non-significant difference between groups in the control condition (Centre-2) shows that there were no inherent differences in response speed between monolinguals and bilinguals on a straightforward RT task. Similarly, no differences between groups were identified in the analyses on the Simon Effect, Working Memory Costs or Sequential Congruency Effects, both in RTs and ARs.

There was, however, one main significant difference found between groups: in both RTs and ARs, monolinguals showed no Simon Effect in the Side-4 condition, in contrast with a significant Simon Effect in the Side-2 condition; bilinguals, on the other hand, showed significant Simon Effects in both conditions.

3.2.10.3 Bilingualism-specific predictors

Analyses showed that none of the bilingualism-specific individual-difference variables —*Age of Onset of Active Bilingualism*, *Length of Active Bilingualism*, *Balancedness of Bilingual Language Use* and *Language Switching Frequency*— were significant predictors of RTs in the Simon task, when controlling for *Age*, *Gender* and *Fluid Intelligence*. Likewise, no variables specific to bilingualism were selected as good predictors of ARs.

4 Discussion

A substantial amount of research has been done, particularly in the last two decades, on the impacts of bilingualism on executive functions. We set out to contribute to this area of research by investigating the bilingual advantage hypothesis, according to which the continuous experience of managing two linguistic systems leads to cognitive gains, particularly in cognitive control functions related to conflict monitoring and resolution (Abutalebi & Green, 2007; Bialystok, 2001, 2007; D. W. Green, 1998). We compared the performance of a group of bilingual participants with a control group of monolinguals in two tasks measuring different mechanisms of conflict monitoring and resolution —the Simon task and the Attention Network Test. Our objectives in this study were manifold:

(a) To investigate whether a bilingual advantage was to be found in conflict control tasks requiring both interference control and suppression of a prepotent response. We wanted to test both of these inhibition mechanisms, so as to better ascertain if the bilingual advantage, if it were to be found, was limited to one of these inhibition functions, or if it was more robust in one function than the other. In order to test this hypothesis, we used the versions of the Attention Network Test (interference control) and the Simon task (interference control and suppression of prepotent response) used in two experiments that we are replicating here: Bialystok et al.'s (2004, study 2) and Costa et al.'s (2009, experiment 2, version 1).

(b) To ascertain whether the supposed bilingual advantage stems from an improved inhibition control mechanism or from a more efficient monitoring function, or a combination of both. A bilingual advantage in inhibitory control would be supported by a reduced susceptibility to interference, observable through faster RTs in incongruent trials and, consequently, smaller Conflict Effects. According to suggestions in the literature (Costa et al., 2009; Costa et al., 2008; Hilchey & Klein, 2011), a bilingual advantage in monitoring instead of (or additionally to) a bilingual advantage in inhibitory control would be supported by results showing faster overall RTs in high conflict-monitoring conditions. Also for this reason, Costa et al.'s (2009, experiment 2, version 1) version of the ANT was ideal, as it had been adapted by the original authors to increase monitoring demands. We also chose to measure and analyse Sequential Congruency Effects, following the suggestion by Hilchey and Klein (2011) that, if a bilingual advantage in conflict monitoring exists, bilinguals may show reduced sequential congruency effects when compared with monolinguals, as evidence of enhanced conflict adaptation. Additionally, Bialystok et al.'s (2004, study 2) version of the Simon task included increased working memory demands on some of the conditions, which would also allow us to determine if there was a possibility of the bilingual advantage being extended to other executive functions, such as working memory.

(c) To investigate whether monolinguals and bilinguals differed in measures of the alerting and orienting networks of attention. Since there seems to be a fairly interconnected relationship between the three networks of attention (Callejas et al., 2004; Posner, 1994), it would be reasonable to expect differences between groups in the Alerting and Orienting Effects, additionally to a difference in the Conflict Effect. In order to do so, we measured and compared the performance of monolinguals and bilinguals on all three networks of attention and analysed the relations between them.

(d) Following proposals offered by several authors regarding the need for a better control of confounding variables (Hilchey & Klein, 2011; Morton & Harper, 2007; Paap & Greenberg, 2013; Peal & Lambert, 1962; Valian, 2015), we controlled for the most relevant individual-difference variables in our study, and analysed their impact on the participants' performance. For this reason, we collected data on *Age*, *Gender*, *Fluid Intelligence*, *Education Level*, and *Socio-Economic Status*, which, whenever relevant, were added to the statistical analyses as covariates. We also matched groups for proficiency in English, immigration status, length of immigration experience, frequency of music playing, frequency of video game playing, frequency of physical exercising, and frequency of meditation.

(e) Finally, to explore more about the potential effects of confounding variables specific to bilingualism, as there is evidence showing that the hypothesised bilingual advantage in conflict control might be restricted by specific features of the bilingual experience (see Valian, 2015, for a review). To gain a more thorough understanding of the possible impact of the individual specificities of our participants' bilingual experience on their performance in the conflict control tasks, data was collected and analysed on *Age of Onset of Active Bilingualism*, *Length of Active Bilingualism*, *Balancedness of Bilingual Language Use*, and *Language-Switching Frequency*.

4.1 Results Related to the Hypotheses of a Bilingual Advantage in Conflict Control and Monitoring

Conflict Effects and overall RTs

Our data showed significant Conflict Effects, in both RTs and ARs, in the Simon task as well as in the ANT (with the exception of the Simon task's Side-4 condition, which did not show a Simon Effect in ARs). However, no significant differences between groups were found in the magnitude of the Conflict Effect (ANT) or the Simon Effect. This evidence contrasts with the results obtained in the Simon task by Bialystok et al.'s (2004) study 2, whose adapted version we used here, but corroborates Costa et al.'s (2009) findings in their experiment 2 (version 1 of the ANT), whose task version was also used here, and therefore weakens the hypothesis according to which bilinguals would have a cognitive advantage in conflict processing and resolution, as the bilinguals in our sample do not show any evidence of being able to process conflict in a faster or more efficient way than monolinguals. Moreover, it is important to stress the fact that our results reveal no bilingual advantage either in interference control or in suppression of a prepotent response, both key inhibition control functions in which we would expect to find an advantage for bilinguals if they were to have a more efficient inhibition control system.

There is one result we obtained in the Simon task that was unusual: the monolingual group showed no Simon Effect in the Side-4 condition of the Simon task, both in RTs and in ARs, in contrast with a significant Simon Effect in the Side-2 condition, while bilinguals showed significant Simon Effects in both conditions. A reduction in the magnitude of the Simon Effect between the Side-2 and the Side-4 conditions is, however, predictable, as it is known that the Simon Effect decreases in size in slower-RT experimental conditions (De Jong et al., 1994; Hommel, 1993; Lammertyn et al., 2007; Rubichi & Pellicano, 2004). A similar absence of the Simon Effect was reported by Bialystok et al. (2004), although in their case it was the bilingual group showing that result. Since the decrease of the Simon Effect over time is usually explained as reflecting a decay of the irrelevant information with slower RTs (Burle et al., 2002; De Jong et al., 1994), it could be argued that monolinguals may have an advantage over bilinguals in this instance, as the irrelevant information seems to decay faster for them than for bilinguals, which would explain why they stop showing a Simon Effect at a faster RT than bilinguals.

In overall reaction times and accuracy rates, in the two tasks, again there were no significant differences between groups. Bilinguals were not overall faster or more accurate than monolinguals —or vice versa. Neither of the two studies replicated here (Bialystok et al., 2004, study 2; Costa et al., 2009, experiment 2, version 1) reported a bilingual advantage in overall ARs, but they both found a significant advantage for bilinguals in overall RTs, with the exception of the control condition (condition Centre-2 of the Simon task), where no significant differences were found between groups. Bialystok et al. (2004) offered as an explanation for the overall-RT advantage that "the executive processes involved in attention and selection across these conditions are the same, and it is these central executive components, rather than just inhibition, for example, that are enhanced through the experience of lifelong bilingualism" (p. 302). Costa et al. (2009), on the other hand, had predicted that their high-monitoring condition would elicit an overall bilingual advantage in RTs, which they suggested "could be the result of a more efficient monitoring processing system, in charge of evaluating the need of involving conflict resolution processes or not when a given trial is presented" (pp. 141-142). A significant difference between groups in overall reaction times could thus have been interpreted as a more efficient monitoring mechanism in bilinguals, but our results do not support this hypothesis, leading us to the conclusion that bilingualism does not seem to lead to benefits in conflict monitoring. Our results, and corresponding conclusions, are in line with the findings of Kousaie and Phillips (2012b), Paap and Greenberg (2013), and Prior and MacWhinney (2010), who also reported no significant differences between groups in global RTs for the Stroop, Simon, or flanker tasks.

Additionally, we highlight the fact that the adapted versions of the tasks used allowed us to compare the two groups of speakers in: (1) a control condition, without conflicting information (Centre-2 condition of the Simon task); (2) a condition with a higher working memory load, but without conflicting information (Centre-4 condition of the Simon task); (3) a condition that required interference control, with high demands on conflict-monitoring control (ANT); (4) a condition that required interference control and suppression of a prepotent response, with high demands on conflict-monitoring control (Side-2 condition of the Simon task); and (5) a condition that required interference control and suppression of a prepotent response, with high demands on conflict-monitoring control, and with additional increased demands on working memory (Side-4 condition of the Simon task). In none of these conditions did our results show any significant differences between monolinguals and bilinguals. Both groups performed similarly in all conditions, regardless of the inhibition mechanism(s) needed to complete the task and regardless of how demanding the condition was on conflict monitoring and/or working memory abilities.

Our results are not unique, as a growing number of studies have also reported no differences between monolinguals and bilinguals in conflict monitoring or control. Of these, some used the ANT task (Antón et al., 2014) or the flanker task (Kousaie & Phillips, 2012b; Paap & Greenberg, 2013; Paap et al., 2014), several used the Simon task (Clare et al., 2014; Gathercole et al., 2014; Kirk et al., 2013; Kousaie & Phillips, 2012b; Morton & Harper, 2007; Paap & Greenberg, 2013; Paap et al., 2014; Rosselli et al., 2015), and others used other conflict control tasks (Duñabeitia et al., 2014; Goldman et al., 2014; Kousaie & Phillips, 2012a, 2012b; Paap & Greenberg, 2013; Paap & Liu, 2014). However, most of these studies were performed with children, younger adults or older adults, but not with a comprehensive sample of participants of all (adult) ages, as we did, except for Gathercole and colleagues (2014), who tested participants from six age groups between 3 and 60 years old, and also Rosselli et al.

(2015), who tested a group of adults between the ages of 18 and 45. Our results thus replicate many other authors' findings, while also extending them to a less studied population: adults of ages between 18 and 57 years old.

Sequential Congruency Effects

Our data showed evidence of Sequential Congruency Effects in both RTs and ARs, in both the ANT and the Simon task, with results displaying the typical pattern: faster responses to II than to CI and slower responses to IC than to CC, with larger Conflict Effects following previous-congruent trials and smaller Conflict Effects following previous-incongruent trials.

Non-significant differences were found between monolinguals and bilinguals in the magnitude of the Sequential Congruency Effects, both in RTs and ARs, in both tasks. There was, however, a significant interaction between *Group* and *Previous Trial Congruency* in the ANT, showing that bilinguals' RTs were unaffected by whether the previous trial was congruent or not, while monolinguals exhibited faster responses when the previous trial was congruent than when it was incongruent. This may be a type I error, given the very small RT difference between types of trials: monolinguals' mean RT to trials following previous-congruent trials was 518 ms, and for trials following previous-incongruent trials it was 524 ms. (Bilinguals' were 538 ms and 539 ms, respectively.) However, if this difference is actually real, then we interpret it as possible evidence that monolinguals experience higher conflict interference in incongruent trials preceded by incongruent trials (II trials), when compared with bilinguals. As can be observed in Figure 42, the main reason why monolinguals' RTs are affected by *Previous Trial Congruency* seems to be the fact that they exhibit similar RTs in current-incongruent trials, regardless of whether those trials are preceded by a congruent or an incongruent trial. However, if the first-order sequencing effects were present, as would be expected, the monolingual group should exhibit (as does the bilingual group) faster RTs to incongruent trials following an incongruent (II trials) than following a congruent trial (CI trials). According to the conflict monitoring theory, an incongruent trial triggers a high level of cognitive control, which leads to lower conflict interference in the following trial, and thus faster RTs (Botvinick et al., 2001; Botvinick et al., 1999; Egner & Hirsch, 2005; Kerns et al., 2004). Our monolingual group, however, seemed to experience a similar level of conflict interference in both cases. Nevertheless, this interpretation was not fully backed by our findings, since the interaction between *Group*, *Previous Trial Congruency* and *Current Trial Congruency* was not statistically significant.

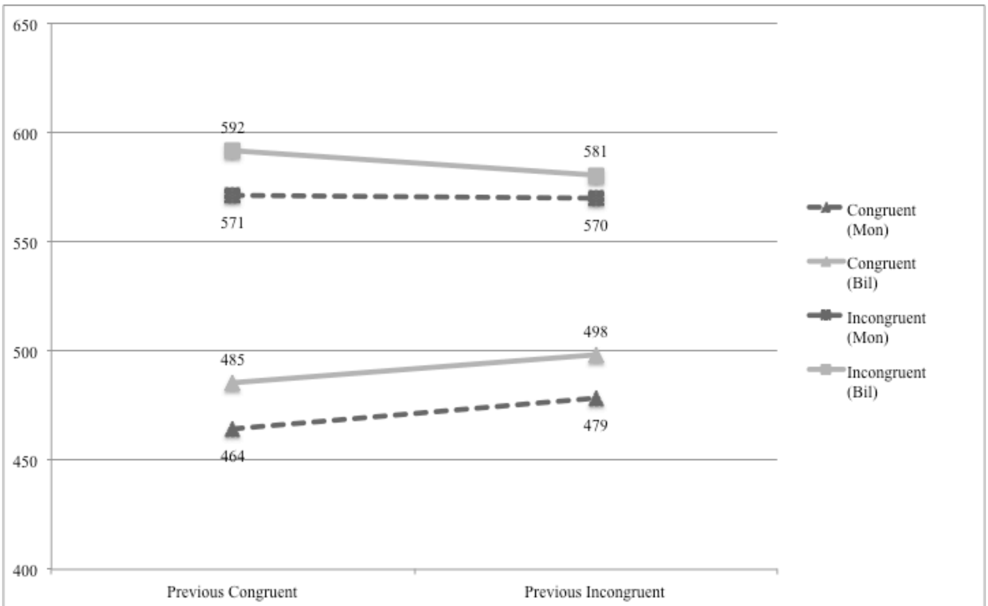

Figure 42. Mean reaction times in the Attention Network Test, by previous trial congruency, current trial congruency, and group.

The same interaction between *Previous Trial Congruency* and *Group* in RTs was not significant in the Simon task. However, still in the Simon task, the interaction between *Previous Trial Congruency* and *Group* in ARs was statistically significant, with bilinguals showing higher accuracy rates in trials preceded by an incongruent trial than in trials preceded by a congruent trial, while monolinguals' ARs were not affected by *Previous Trial Congruency*. If, according to the conflict monitoring theory, an incongruent trial triggers a high level of cognitive control, which leads to lower conflict interference in the subsequent trial, and thus faster RTs and higher accuracy rates, again it could be argued that our monolingual group's ARs seem to reflect a higher level of conflict interference in trials preceded by incongruent trials than what would be expected.

Our results in this respect are not robust enough to ascertain that in fact monolinguals show more susceptibility to conflict interference than bilinguals, as a significant interaction between *Previous Trial Congruency* and *Group* only materialised for reaction times in the ANT but not in the Simon task, and it only materialised for accuracy rates in the Simon task but not in the ANT. More critically, it was not corroborated by a significant interaction between *Previous Trial Congruency*, *Current Trial Congruency* and *Group*, which is the crucial interaction to look at. Moreover, the significant differences we found between monolinguals and bilinguals pointed not at a bilingual advantage, but at a monolingual "disadvantage" of sorts. In other words, it is not that our bilingual sample shows a better performance than expected —it is the monolingual group who does not show certain RT and AR benefits in previous-incongruent trials as it would be expected to. This is an unusual finding because it does not replicate the robust findings on Sequential Congruency Effects in the literature (i.e., faster RTs and higher ARs in II trials than in CI trials), which makes us believe that these results are more likely given to chance.

We initially decided to include analyses on the Sequential Congruency Effects, following Hilchey and Klein's (2011) suggestion that, since conflict monitoring has a significant role in modulating cognitive control on a trial-by-trial basis, a difference in performance between monolinguals and bilinguals on Sequential Congruency Effects could be interpreted as evidence of one group benefitting from more efficient conflict-monitoring processes or mechanisms than the other group. Our results do not support this hypothesis. Even though there were two significant interactions between *Previous Trial Congruency* and *Group* (one in RTs, the other in ARs; one in the ANT, the other in the Simon task), we do not interpret them as evidence of a bilingual advantage in conflict monitoring, particularly because this interaction was not visible in both tasks, but more importantly because it was not corroborated by a significant interaction between *Previous Trial Congruency*, *Current Trial Congruency* and *Group*, which is what the hypothesis would predict.

Alerting and orienting networks of attention

Our results in the ANT also show an Alerting Effect in RTs, as well as Orienting Effects both in RTs and ARs. However, no Alerting Effect was found in ARs. No significant differences were found between monolinguals and bilinguals in the magnitude of the Alerting and the Orienting Effects in RTs, revealing no difference between groups in these two networks of attention. We did find one significant difference between groups: monolinguals exhibited a larger Orienting Effect in ARs than bilinguals. However, given that our ARs were very much at ceiling (the Orienting Effect for monolinguals was of -.02%, while the bilinguals' was -.01%), we consider this to be a type I error.

Our results are inconsistent with Costa et al.'s (2008), who found a significantly smaller Alerting Effect for bilinguals than for monolinguals, but no difference between groups in the Orienting Effect, as well as Marzecová, Asanowicz, Krivá, and Wodniecka's (2013), who reported a significantly larger Alerting Effect for bilinguals than for monolinguals, but no difference between groups in the Orienting Effect. However, our findings replicate Antón and colleagues' (2014), Costa et al.'s (2009), Morales Castillo's (2014), Paap and Greenberg's (2013), Poarch and van Hell's (2012), Tao et al.'s (2011), and Yang, Yang, and Lust's (2011) findings, who also reported no bilingual (or monolingual) advantage in either the Alerting or the Orienting Effects.

Given that the Alerting Effect measures the RT benefit of presenting a temporal cue concerning the upcoming target display, no difference between the two groups of participants ought to be interpreted as evidence that the two groups benefitted equally from the introduction of such cue. Likewise, given that the Orienting Effect measures the RT benefit of preceding the target with a spatial cue to its location, our results show that the two groups benefitted equally from a spatial cue, as both perform similarly.

It is known that the three networks of attention —executive, alerting, and orienting— are very closely connected and interrelated, and that a benefit or deficit in one of them might have a significant impact on the others (Callejas et al., 2004). For this reason, since we did not obtain a bilingual advantage in the Conflict Effect, it did not surprise us to find no advantage in either the Alerting or the Orienting Effects. Both our RT and AR results showed that the alerting network had an inhibitory effect on the executive network of attention (with a larger Conflict Effect in temporally cued trials), and that the orienting network, on the other hand, had a positive effect on the executive network of attention (with a smaller Conflict Effect in spatially cued trials) (see Figures 7 and 12), in line with what other authors have found (Callejas et al., 2004; Funes & Lupiáñez, 2003; Posner, 1994). Concerning the negative effect of the alerting network on the executive network, Posner (1994) proposed that the alerting network, prompted by an alerting cue, inhibits the usual response of the executive network, which would be to give a fast answer, thus forcing it to slow down and increase attention on the target. As for the positive effect of the orienting network on the executive network, Callejas et al. (2004) suggested that this could be due to the fact that the asterisk in spatially cued trials appears exactly in the same place as the target stimulus, thus helping to focus attention and facilitating interference control.

Additionally, our results also showed a significant impact of congruency on both the Alerting and the Orienting Effects: participants showed smaller Alerting Effects but larger Orienting Effects in incongruent trials than in congruent trials (see Figures 13 and 14). This interconnectedness of the networks of attention supports the view that a bilingual advantage in conflict processing would also impact the participants' performance on the Alerting and Orienting Effects.

Overall, these results provide evidence against a bilingual advantage in attentional control. By investigating the performance of the two groups of participants in tasks assessing the three hypothesised networks of attention, and by analysing the relationships between the networks across groups, we conclude that the performance in the three networks of attention does not differ significantly between monolinguals and bilinguals.

Working Memory Costs

Bialystok and colleagues (2004) reported a significant difference between monolinguals and bilinguals in Working Memory Costs, calculated as the difference in RTs between two sets of conditions of the Simon task, one of which was more demanding on working memory than the other. Bialystok et al. (2004) interpreted their results as indicative of the fact that the bilingual advantage was not circumscribed to conflict control, but that it also reached other areas of executive control. Our data do not replicate that bilingual advantage, even though we used the same version of the Simon task in our study. We found significant Working Memory Costs both in RTs and ARs, with faster and more accurate responses to 2-square conditions than to 4-square conditions, but no significant difference in this effect between monolinguals and bilinguals. Hence, our results do not corroborate the idea that there is a bilingual advantage in other executive functions, namely in working memory, with or without conflict interference, replicating other authors' findings (Engel de Abreu, 2011; Gutiérrez-Clellen et al., 2004).

4.2 Individual-Difference and Bilingualism-Specific Variables

In our study, the possibility that group differences in individual-difference variables could account for group differences in conflict monitoring and control is not relevant, since we did not find significant differences between the performance of monolinguals and bilinguals in conflict control tasks. Nevertheless, individual-difference variables can also provide information about what other factors may predict performance in conflict control tasks on a person-by-person basis, independently of whether the participant is monolingual or bilingual. This is what we will be looking into in this section.

Individual-difference variables

Socio-Economic Status did not appear to have a significant impact on our sample's performance on the conflict control tasks. We believe that was due to the fact that our participants were initially matched for this variable, but also because they measured quite high on it. There is research showing how socio-economic status relates most strongly to brain structure among the most disadvantaged children (Noble et al., 2015), with small differences in income among children from lower income families being associated with large differences in brain surface area, whereas small differences in income among children from higher income families were associated with small differences in brain surface area. Since a larger proportion of brain surface area is usually associated with better performance in executive control tasks, it would be expected for significant differences in performance to occur more often among the lowest levels of *SES* than among the highest levels (Farah & Noble, 2005; Noble et al., 2005). Since our participants' average *SES* was 2.42, on a scale of 1 ("Very high SES") to 5 ("Medium low SES"), and with 54.8% of participants ranking in "High" or "Very High" SES levels, it is very probable that the differences in *SES* between participants were too small and the level at which the participants ranked was too high on the *SES* scale to translate into significant differences in performance on the tasks.

The same applies to *Education Level*: participants presented an average level of education of 2.76, on a scale of 1 ("High School, Certificate or Diploma") to 5 ("PhD"), with the average participant having a Bachelor's degree with Honors, a Postgraduate Diploma or a Postgraduate Certificate. Thirty-six percent of the participants had Masters or PhD degrees, and 100% of participants had completed High School. As with *SES*, it is possible that, in order to fully appreciate the impact *Education Level* may have on performance in conflict control tasks, we would need participants from all levels of education, particularly the lowest levels. Since our participants all have considerably high levels of education, the differences in *Education Level* between the participants may not be sufficient to impact performance in conflict control tasks.

Our analyses found *Age* to be a significant predictor of RTs in both the ANT and the Simon task, with younger age being associated, in both tasks, with faster reaction times. This is in line with previous research showing a generalized age-related increase in processing times in reaction-time tasks, as well as in other types of processing-speed tasks (see Deary, Johnson, & Starr, 2010, for a review), which has generally been taken to mean a cognitive decline (Deary et al., 2010; Salthouse, 1994). We also found older age to be associated with larger Conflict Effects and larger Sequential Congruency Effects in both tasks, which indicates that the increase in RTs with increased age may not just be due to an overall slowing down in processing speed, as it is more pronounced in trials with conflict interference, thus indicating an association between older age and decreased abilities in interference control, suppression of a prepotent response, and conflict monitoring.

Fluid Intelligence was also found to be a significant predictor of RTs in both tasks, with higher *Fluid Intelligence* being associated with faster RTs. In the Simon task, however, we had to exclude *Fluid Intelligence* from the analyses, as the test of assumption of homogeneity of regression slopes revealed a significant interaction between *Group* and *Fluid Intelligence*, with monolinguals' RTs not affected by *Fluid Intelligence*, while, for bilinguals, faster RTs were associated with higher *Fluid Intelligence*. Additionally, high *Fluid Intelligence* was also associated, in our results, with smaller Conflict Effects and smaller Sequential Congruency Effects. These significant effects reveal that *Fluid Intelligence* plays an important role in the processing of information in general, and, more critically, in the processing of conflict, for both monolinguals and bilinguals, but maybe more so for bilinguals. These results replicate Rosselli and colleagues' (2015) findings that non-verbal intelligence is a better predictor of executive function performance than bilingualism.

Contrary to what would be expected, our sample did not show an association between older *Age* and declining *Fluid Intelligence*, as previous literature has reported and predicted (Horn & Cattell, 1967; Jones & Conrad, 1933; Schretlen et al., 2000). It could be argued that, by not including participants over the age of 57 years old, our sample is too limited to be able to pick up a significant relation between age and fluid intelligence. However, an association between older age and lower fluid intelligence scores has been found in several studies that used samples of participants of up to 60 years of age. Jones and Conrad (1933), for instance, collected Army Alpha scores for 1191 participants between the ages of 10 and 60 years of age. The authors describe the intelligence developmental curve obtained as:

> involving linear growth to about 16 years, with a negative acceleration beyond 16 to a peak between the ages of 18 and 21. A decline follows which is much more gradual than the curve of growth but which by the age of 55 involves a recession to the 14 year level. (Jones & Conrad, 1933, p. 223)

Similarly, Horn and Cattell (1967) used a sample of 297 participants between the ages of 14 and 61 (with the bulk of the sample being between 15 and 51 years old), and found that the mean level of fluid intelligence was systematically higher in younger participants relative to older participants. Our results do not replicate these authors', as there was no significant correlation between the two variables, $r(113) = -.11$, $p = .25$. It could also be argued that our participants enjoyed very high *Fluid Intelligence* scores (monolinguals: 113.1, bilinguals: 112.7), which could have enhanced their performance in the tasks. However, previous studies that used the Cattell – CFIT showed similar or even higher scores (Bialystok, Craik, & Ruocco, 2006; Emmorey et al., 2008; Luk et al., 2010; Luk, De Sa, et al., 2011), indicating that our sample was not unusually intelligent. One possible explanation for this non-significant relation between *Age* and *Fluid Intelligence* in our results is the fact that our participants had a very high education level, which is known as one of the most important factors in the preservation of cognitive abilities (Bennett et al., 2003; Stern, 2002).

Finally, *Gender* was also a significant predictor of RTs in the ANT, with male participants being faster than female participants, but showed no impact on the Conflict Effect or on the Sequential Congruency Effects. Also, the same significant effect was not present in the Simon task. These results indicate that *Gender* does not seem to play a significant role in conflict monitoring and control.

Controlling for the variables *Socio-Economic Status*, *Education Level*, *Age*, *Fluid Intelligence*, and *Gender* allowed us to identify the potential sources of confounding effects, and demarcate those effects in our analyses, by including these variables as covariates. Additionally, we matched our groups of participants for *Handedness*, *Immigration Status*, *Length of Immigration Experience* and frequency of *Music Playing*, *Video-Game Playing*, *Exercise*, and *Meditation*, in an attempt to minimise as much as possible the potential influence of external variables in our results. Apart from *Age*, *Fluid Intelligence*, and *Gender*, none of the other variables seemed to be significant predictors of performance in conflict control tasks.

Bilingualism-specific variables

Following Hulstijn's (2012) suggestion that L2 proficiency should be objectively measured, we matched our monolingual and bilingual speakers on their level of proficiency in English (L1 for the monolinguals, L2 for the bilinguals). By limiting our sample to highly proficient bilinguals, we sought to include in our study only bilinguals who had had the relevant bilingual experience that would qualify them as probable candidates for a conflict control advantage, as predicted by the bilingual advantage hypothesis. Controlling for L2 proficiency also allowed us to focus our analyses on other features of the bilingual experience, which have been less studied, such as *Age of Onset of Active Bilingualism*, *Length of Active Bilingualism*, *Balancedness of Bilingual Language Use* and *Language-Switching Frequency*. Having chosen to include only highly proficient bilinguals in this study, our results and conclusions can therefore only be extended to bilinguals with a similar high proficiency in their L2.

Our data also showed that, after controlling for *Age*, *Fluid Intelligence*, and *Gender*, there were no significant effects of *Age of Onset of Active Bilingualism*, *Length of Active Bilingualism*, *Balancedness of Bilingual Language Use*, or *Language-Switching Frequency* on the bilingual participants' performance. Our results replicate the findings of other authors who reported no impact of features of the bilingual experience on performance on cognitive control tasks (Von Bastian, Souza, and Gade, 2015, as cited in Paap et al., 2014; Paap, Johnson, et al., 2015). Nevertheless, the fact that our participants had high *English Proficiency*, *SES* and *Education Level* may have obscured the contribution of these variables, which might only be visible among individuals with lower levels of *English Proficiency*, *SES* and *Education Level*.

4.3 Reassessing the Bilingual Advantage Hypothesis

Following a rise in the number of studies that have found no evidence in support of a bilingual advantage in conflict control, several authors have emphasized the needs to: revisit and advance our understanding of executive functions and corresponding mechanisms; reassess the tasks used to measure executive control, to ensure we fully understand what aspect of cognition is being measured and what that measurement means; use two or more measures of the same component of executive functioning, selecting when possible tasks that have demonstrated convergent validity in previous studies; control more effectively for confounding variables, including those related to enriching life experiences that may bring about cognitive benefits; and investigate more thoroughly the features of bilingual experience that might restrict or boost a potential bilingual advantage (Hilchey & Klein, 2011; Paap & Greenberg, 2013; Paap, Johnson, et al., 2015; Valian, 2015).

Our study has investigated the bilingual advantage hypothesis in two different tasks measuring conflict control, with reasonable numbers of participants per language group. We have endeavoured to put in place an objective and standardized controlling of confounding variables, and gathered and analysed data on enriching activities that could have an impact on executive functions, as well as on different features of the bilingual experience. We found no evidence in support of a bilingual advantage in cognitive control. Our results support and extend the findings of recent studies (Antón et al., 2014; Duñabeitia et al., 2014; Paap & Greenberg, 2013; Von Bastian, Souza, and Gade, 2015, as cited in Paap, Johnson, et al., 2015).

Some evidence makes it enticing to retain the bilingual advantage hypothesis: evidence showing important anatomical brain changes for bilinguals, namely in grey matter volume (Abutalebi, Canini, et al., 2015), white matter volume (Luk, Bialystok, et al., 2011), and cortical thickness (D. Klein et al., 2014; Mårtensson et al., 2012), and evidence showing that bilinguals may benefit from a cognitive reserve brought about by bilingual experience, which seems to substantially delay the onset of some neurodegenerative diseases (Alladi et al., 2013; Bialystok, Craik, et al., 2014; Bialystok et al., 2007; Bialystok et al., 2012; Craik et al., 2010; Woumans et al., 2014). However, none of these results lead to a conclusion in favour of a bilingual advantage *specifically* in conflict control.

As Paap and Greenberg (2013) point out, we should take the substantial amount and relevance of null and negative results obtained in this area of research as an invitation to question the assumptions that brought us here. The bilingual advantage, if one exists, may not lie in more efficient conflict control mechanisms. Or, if it does, the benefits may be limited to tasks dependent on linguistic representations, for instance. It may also be the case that bilingualism brings about not an advantage, but a substantial difference —bilinguals may perform similarly to monolinguals in certain executive control tasks, but using different strategies or pathways. In fact, there is evidence showing that bilinguals seem to activate different neural networks than the ones used by monolinguals, in non-verbal task-switching tasks (Garbin et al., 2010; Rodríguez-Pujadas et al., 2013), and interference tasks (Ansaldo et al., 2015; Luk et al., 2010), without necessarily exhibiting different behaviours. These different cognitive strategies could, then, function as potentiators of performance advantages in certain cognitive tasks. Bilingualism might impact cognition in ways that not necessarily manifest as an advantage in processing speed. Bilinguals may perform not necessarily better or faster in certain conflict control tasks —they may perform differently. If neuroimaging studies continue to reveal evidence showing a significant difference between monolinguals and bilinguals in the way their neural resources are being used —or in which resources are being used— then further research will be needed to identify the sources as well as the consequences of such group differences.

Language processing experience instead of bilingualism: suggestion of a new direction for future research

There is much more to bilingualism than inhibiting one language while using the other(s): bilinguals have larger vocabulary sets from which to choose, they have to deal with very different syntactic rules, as well as word-formation rules, they have different word orders per language to take into consideration and apply correctly, and they also have to deal with different challenges related to the semantic and pragmatic dimensions of each language, not to mention dealing with different phonetic and phonological representations. Additionally, most bilinguals also have to cope with added demands for monitoring of social and contextual cues, as well as all the added challenges of living a bi-cultural life. In the bilingual advantage hypothesis framework, it is reasonable to expect that the constant inhibiting of one language in order to use another should generate a cognitive advantage. But what about all the additional factors just described? Wouldn't the added linguistic demands and challenges be potential triggers for cognitive benefits on their own? What we are suggesting here is that it might be the additional language processing demands of dealing with an extra linguistic system that may lead to cognitive change and, potentially, to a cognitive advantage.

If we take overall intense and rich language processing as the important factor instead of bilingual language control, then it follows that the potential trigger of cognitive benefits would be critically high and demanding language processing experience in general, instead of conflict control and monitoring mechanisms involved in bilinguals' control of their languages. Also, by "overall language processing experience", we mean all language processing experience, regardless of which language is being used, and of how many languages the speaker has access to. This implies, of course, that monolinguals also have access to extended experiences requiring intense and rich language processing, but also that some bilinguals may learn a second language without the kind of intense language processing that could lead to cognitive gains. This leads us back to the notion of language proficiency, but not just L2 proficiency —overall language proficiency instead. Such a hypothesis would explain results like Rosselli et al.'s (2015), who investigated the performance of balanced and unbalanced bilinguals, and high- and low-proficiency bilinguals and monolinguals, on verbal and non-verbal tasks, specifically on working memory, updating, shifting and inhibition tasks. The participants did not differ in education level. The authors found that highly proficient monolinguals performed better than low proficiency monolinguals and bilinguals, and similarly to highly proficient bilinguals. Their results indicate that language proficiency —a speaker's linguistic knowledge and ability to successfully use her language(s) according to contextual needs— might be a good predictor of executive functions, and a better one than bilingualism. Rosselli et al.'s (2015) findings suggest that language proficiency in general —regardless of whether it refers to L1 or to L2— might have a more significant impact on cognitive control than bilingualism, which is basically what we are proposing here.

The term *language proficiency*, however, may not be the best term to define what we are referring to in our proposal of a cognitive advantage led by an intense and rich language processing experience. In our view, what may make a difference, and impact executive functions significantly is continued rich experience in language processing, of which greater levels of language proficiency is a by-product. But what would characterise a critically high and demanding language processing experience? Following Hulstijn's (2011) notion of *higher language cognition*, where the speaker is able to process both oral and written language containing high- and low-frequency linguistic items, a speaker who arrives at a high level of language proficiency has only been able to do so through continuous experience processing high- but also low-frequency linguistic items, regular but also complex syntactic structures, predictable but also ambiguous semantic interpretations. Critically, it is a level of language proficiency that derives from sustained experience of complex language processing, and therefore could potentially be a good measure of it.

Learning a second language can be an example of sustained experience of complex language processing, depending on how the language is used and at what level of structural complexity. As was said earlier, learning a second language is not just about adding new lemmas to our mental lexicon or incorporating new phonological representations of already stored lemmas: different languages have different structural rules across a variety of domains, specifically morphological and syntactic rules. Adding a new language to our repertoire increases demands in terms of the number of linguistic items to store and choose from, but more importantly it also increases the levels of structural-rule complexity we have to deal with as speakers. In sum, bilingualism entails an increase of language processing demands, but whether these demands reach a critical level of potentially impacting cognitive control may depend on the intensity of the language processing experience, but also on the level of linguistic complexity involved in that language processing. As mentioned earlier, a bilingual speaker may acquire functional competence in a second language without language processing experience that would require significantly complex and intense processing. Similarly, a monolingual speaker can achieve different levels of proficiency in her own native language, depending on the intensity and complexity of the linguistic experience she has had. A frequent use of language to express complex thought, for instance, may be seen as an example of language processing experience that could be qualified as rich and complex. There is plentiful evidence supporting an association between reading comprehension or academic achievement and cognitive control. De Beni, Palladino, Pazzaglia, and Cornoldi (1998), for instance, reported that lower performance in reading comprehension was associated with lower performance in a working memory test and also more intrusion (false alarm) errors, suggesting that poor readers have more difficulty inhibiting irrelevant information than more skilled readers. St Clair-Thompson and Gathercole (2006) found a link between executive control measures and academic achievement in English and mathematics, both of which require strong reading skills, as well as a successful use of language to express complex thought. Locascio, Mahone, Eason, and Cutting (2010) found that reading comprehension difficulties were linked to executive dysfunction, and Foy and Mann (2013) reported a close association between verbal inhibitory executive function skills and early reading ability.

The next logical question is: what would be the mechanism linking rich language processing to enhanced cognitive control? In the bilingual advantage hypothesis, it is assumed that continued experience in bilingual language control leads to benefits in non-verbal conflict control, because bilingual language control seems to use neural substrates that have been identified as having a main role in domain-general cognitive control. In a similar way, we suggest that continued and complex language processing experience may lead to benefits in non-verbal conflict control, given that important aspects of language processing seem to make use of neural areas identified in the literature as having a prominent role in domain-general conflict control.

Here, we draw from work developed by authors Novick, Trueswell, and Thompson-Schill (Novick, Trueswell, & Thompson-Schill, 2005; Novick, Trueswell, & Thompson‑Schill, 2010), who have investigated the existence of a consistent link between cognitive control and the left inferior frontal gyrus (LIFG), also known as Broca's area (more specifically, Brodmann areas 44 and 45). The LIFG has long been known to psycholinguistics to have a primary role in language processing, specifically in what concerns phonological, syntactic and semantic processing (for a comprehensive review and meta-analysis of research done on the left hemisphere language areas of the brain, see Vigneau et al., 2006). This area of the brain seems also to have a prominent role in domain-general cognitive control, specifically in tasks involving inhibitory control (Jonides & Nee, 2006; Nelson, Reuter-Lorenz, Sylvester, Jonides, & Smith, 2003; Swick, Ashley, & Turken, 2008; Tops & Boksem, 2011). Moreover, the LIFG area has been consistently associated with tasks that require processing of competing semantic representations, a process that requires the intervention of conflict control mechanisms (Badre & Wagner, 2002, 2007; Moss et al., 2005; Rodd, Johnsrude, & Davis, 2010; Thothathiri, Kim, Trueswell, & Thompson-Schill, 2012; Whitney, Kirk, O'Sullivan, Ralph, & Jefferies, 2011). The importance of general cognitive control mechanisms for the syntactic and semantic processing of sentences (Novick et al., 2005), and the described apparent overlapping in the LIFG of verbal and non-verbal conflict control processes, led Novick and colleagues (2005; 2010) to suggest that "the role of LIFG, including Broca's area, in language processing is the same as the one it appears to play in general complex cognitive tasks: to regulate and control behavior in the face of competing representations" (2010, p. 918).

This conclusion that the LIFG underlies a general conflict resolution mechanism that is shared by verbal and non-verbal tasks is supported by several studies. January, Trueswell, and Thompson-Schill (2009), for instance, used functional magnetic resonance imaging to investigate the neural circuitry used by participants performing a Stroop task and a syntactic ambiguity resolution task. The authors reported a within-subject co-localization in neural responses to syntactic and non-syntactic conflict. Similarly, Ye and Zhou (2008) found that general mechanisms of conflict control were involved in the reanalysis process needed to resolve conflict between competing sentential representations. In another study, Ye and Zhou (2009) compared the performance of participants in a Stroop task, in a flanker task, and in a sentence comprehension task, and found that the LIFG, alongside other neural areas, was more activated for implausible sentences, which give rise to incompatible sentential representations, triggering conflict resolution mechanisms. This evidence seems to support the hypothesis that general cognitive control functions are shared by the language-processing system, via the LIFG.

In the hypothesis of a bilingual advantage in conflict control, it is argued that extensive and repeated control of two linguistic systems leads to cognitive advantages in conflict control. We suggest here that extensive high-complexity language processing experience, which involves the repeated use of neural resources with an important role in conflict control, such as the LIFG, might lead to a performance advantage in non-verbal conflict control tasks. The fact that variation in cognitive control and parsing functions are both modulated by LIFG led Novick et al. (2010) to question if great disparities in cognitive control ability could capture differences in language processing performance. We raise the inverse question: can significant disparities in language processing experience predict significant differences in conflict control? If so, then this hypothesis may resolve some of the inconsistency in results found in the literature. For instance, results reported in studies only containing highly proficient monolingual and bilingual participants, such as the present one, that did not find a bilingual advantage in conflict control (Blumenfeld & Marian, 2014; Kousaie & Phillips, 2012a; Paap & Greenberg, 2013), could be due to the fact that all participants involved were matched for language proficiency, which may entail that all participants have a similarly rich and intense language processing experience. Also, if intense and rich language processing experience mediates the relationship between bilingualism and cognitive control, studies on the bilingualism advantage would need to measure and control for language processing experience, by controlling for language proficiency in objective standardised ways, that would include all language skills.

In sum, we suggest that: (a) assuming that language processing and general conflict control make use of the same neural substrate (the LIFG), (b) assuming that the benefits of an enhanced language processing experience would transfer to non-verbal tasks, and translate as an advantage in conflict control, (c) it follows that individuals who have had a continued intensive language processing experience may present a performance advantage on tasks measuring conflict control, when compared to individuals who have not had a similar language processing experience.

If I could follow up this thesis' study, I would recruit more participants from lower SES levels and lower education levels, but more importantly, I would measure language proficiency in a more comprehensive way, by including more than one measuring instrument, including grammaticality/acceptability judgements, cloze, and reading comprehension tasks, which can better capture more complex language processing. Participants with all levels of language proficiency would be invited to participate in the study. Bilingual participants would be assessed separately for their two languages. Additionally to all the background measures, participants' performance would be measured on non-verbal conflict control tasks, as well as on verbal conflict control tasks, such as phonological or semantic judgement tasks (Snyder, Feigenson, & Thompson-Schill, 2007), proactive interference tasks (Jonides, Smith, Marshuetz, Koeppe, & Reuter-Lorenz, 1998), or lexical decision tasks (Grindrod, Bilenko, Myers, & Blumstein, 2008). I would then be in a better position to investigate: (a) whether rich language processing experience is a good predictor of performance in cognitive control tasks; (b) whether rich language processing experience is a significant mediator between bilingualism and cognitive control.

4.4 Conclusions

The bilingual advantage hypothesis assumes that bilinguals develop cognitive control gains from their extensive experience in controlling two languages, which should manifest as an advantage in conflict control and resolution, mainly visible through a diminished susceptibility to conflict effects (Abutalebi & Green, 2007; Bialystok, 2001; D. W. Green, 1998). Additionally, another hypothesis has also been advanced, according to which the bilingual advantage may be extended to other executive functions, such as conflict monitoring (Costa et al., 2009; Costa et al., 2008; Hilchey & Klein, 2011) or working memory (Bialystok et al., 2004). Further predictions may be derived from these hypotheses, specifically that, in order to benefit fully from an advantage in conflict control, bilinguals should present some critical traits, namely: a lengthy experience as a bilingual, preferably from early age, and a high proficiency in both their languages (Bialystok, 2001).

Wanting to contribute to this area of research, we designed a study in which we replicated two experiments that had found bilingual advantages in inhibition control and/or in conflict monitoring on both a Simon task (Bialystok et al., 2004, study 2) and an Attention Network Test (Costa et al., 2009, experiment 2, version 1). Both tasks were versions adapted by the original authors, which we fully reproduced in our study.

By limiting our sample to highly proficient bilinguals, with extensive length of immigration experience, and therefore an also extensive exposure to the L2, and by controlling for the most pertinent individual-difference and bilingual-specific variables, we sought to limit our study to bilinguals who were comparable to our study's monolinguals in their life experiences, but also who had the greatest probabilities of exhibiting cognitive advantages derived from extensive and intensive use of two linguistic systems, as predicted by the bilingual advantage hypothesis.

Our data across both tasks, and across all measures analysed, consistently failed to find a bilingual advantage, either in inhibition control, in conflict monitoring, in attentional control, or in working memory.

In order to extend our understanding of the commonalities and differences between monolinguals and bilinguals in cognitive control, we second Paap, Johnson, and Sawi's (2015) roadmap for further research, which encourages researchers to start with a theory of bilingualism and of the executive control mechanisms to be investigated, ensure that the design of the study and the selection of participants is strongly led by that theoretical underpinning, use varied tasks and measures with demonstrated convergent validity, include large numbers of participants per language group, and measure and control for relevant individual-difference and bilingualism-specific variables.

More critically, we believe that the bilingual advantage, if one exists, may not reside in more efficient mechanisms of conflict control. We find it limiting to think of language control as the best (and only) candidate within bilingualism to trigger cognitive changes and potential advantages in executive functioning. Bilingualism involves numerous extremely demanding intellectual abilities, which might, individually or in combination, be sufficient to trigger significant cognitive change. This impact of bilingualism on cognition may also be of a different nature than an advantage in processing speed. Bilingualism may lead to cognitive changes that could potentiate the formation of a cognitive reserve, for instance, without immediate behavioural advantages. A bilingual advantage in cognition may not be ruled out just yet, but it is time to question the assumptions behind the current leading hypothesis of a bilingual advantage in inhibition and conflict control.

With this aim in mind, we present a proposal according to which intense and rich language processing experience may be a better predictor of cognitive control than bilingualism, and that it may, in fact, act as a mediator in the relationship between bilingualism and cognitive control. We draw on research by Novick, Trueswell, and Thompson-Schill (2005; 2010) showing a consistent link between cognitive control and language processing, by an activation of the same neural area —the left inferior frontal gyrus. We also leave a suggestion of how this hypothesis could be tested.

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Appendices

Appendix A: Pre-Screening Questionnaire

In order to determine if you qualify as a participant for this study, please reply to the following questions:

1. What is your native language?

2. What is your native country?

3. For how long have you been living in New Zealand and how old are you?

4. Did you live in any other English-speaking country before you came to New Zealand? Where and for how long?

5. How fluent would you say you are on a scale of 1 (very poor) to 7 (native-like) in each of your languages, including your native language?

6. If your native language is not English, can you please estimate, in terms of percentages, how often you currently use each one of your languages per day (in all daily activities combined, including reading, writing, listening and speaking)?

   (e.g., native language: 30%, language 2: 50%, language 3: 20%, language 4: 0%)

7. Which of your languages do you speak regularly (every day or almost every day)? For how long have you spoken them regularly?

Appendix B: Language History Questionnaire

Instructions

When you are ready, please press “Continue” below to start this questionnaire.

Please note that sometimes when you click on an answer, you will be automatically taken to the next question.

If you wish to change the answer you gave to a question, click “Go Back” and correct your answer.

1. Country of origin: ____

2. Length of residence in country of origin: (Please fill in with digits, not text.)

   _________ years, _________ months

3. Length of residence in New Zealand: (Please fill in with digits, not text.)

   _________ years, _________ months

4. Other countries in which you resided for (approximately) a year or longer (If too many, indicate the countries in which you lived the longest):

   (Please indicate country, length of residence and how old you were when you went to live there. Please use digits for number values.)

Country:	Length of residence:	Age:
1. ___________________	_____ years, _____ months	_____
2. ___________________	_____ years, _____ months	_____
3. ___________________	_____ years, _____ months	_____
4. ___________________	_____ years, _____ months	_____

5. What is your native language? (Please write the name of one language only.)

____

6. Do you know any other languages?

_____ Yes

_____ No

Participants who answered "No" would go straight to the Socio-Economic Status Questionnaire (see Appendix C)

7. Please specify which language(s) you know besides your native language:

Second language 1: _______________________

Second language 2: _______________________

Second language 3: _______________________

8. Rate your abilities in each one of the languages you know.

Please use the following scale (write down the number in the table):

1 = Very poor 2 = Poor 3 = Fair 4 = Functional 5 = Good

6 = Very good 7 = Native-like

Languages	Reading	Writing	Speaking	Listening
(language 1)	_____	_____	_____	_____
(language 2)	_____	_____	_____	_____
(language 3)	_____	_____	_____	_____
(language 4)	_____	_____	_____	_____

9. Please specify the age at which you started learning each one of your languages in the following situations:

(Using digits, write age underneath any situation that applies. For those languages to which you were exposed from birth, please write "0" to indicate you started acquiring that language ever since you were a baby or that you were born in or moved into a country where that language was spoken when you were still a baby.)

Languages	At home	In school	After arriving in a country where that language was spoken
(language 1)	_____	_____	_____
(language 2)	_____	_____	_____
(language 3)	_____	_____	_____
(language 4)	_____	_____	_____

10. How did you learn your languages up to this point?

(Please use the following scale, writing down the corresponding number in the table.)

1 = Only 2 = Mainly 3 = Mostly 4 = Occasionally 5 = Never

Languages	Through formal classroom instruction	Through interaction with people	Other (Specify:)
(language 1)	_____	_____	_____
(language 2)	_____	_____	_____
(language 3)	_____	_____	_____
(language 4)	_____	_____	_____

11. For the languages which you have learned in a classroom environment, please provide the schooling level(s) at which you were taught those languages (click all that apply), as well as the total number of years you spent on formally learning each language.

Languages	Schooling level(s)						Number of years studying
	Preschool	Primary School	Intermediate or Secondary School	University	Private language school	Private language tutor	
(language 1)	______	______	______	______	______	______	______
(language 2)	______	______	______	______	______	______	______
(language 3)	______	______	______	______	______	______	______
(language 4)	______	______	______	______	______	______	______

12. Do you use any of your second languages regularly (every day or nearly every day)?

_____ Yes

_____ No

Participants who answered "No" would go straight to question 13.

12a. Please specify the age at which you started using each language on a regular basis (every day or nearly every day) and the mode of usage of each language.

Languages	Age at which you started using the language on a regular basis	Mode of usage
(language 1)	______	___ Mainly reading and writing ___ Mainly speaking and listening ___ All modes
(language 2)	______	___ Mainly reading and writing ___ Mainly speaking and listening ___ All modes
(language 3)	______	___ Mainly reading and writing ___ Mainly speaking and listening ___ All modes
(language 4)	______	___ Mainly reading and writing ___ Mainly speaking and listening ___ All modes

13. Estimate, in terms of percentages, how often you currently use each one of your languages per day (in all daily activities combined, including reading, writing, listening and speaking):

(Please make sure the overall sum of the percentages totals 100%.)

(Example: Language 1 – 30%, Language 2 – 50%, Language 3 – 20%, Language 4 – 0%)

Languages										
(language 1)	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
(language 2)	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
(language 3)	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
(language 4)	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

14. Thinking about your typical week, estimate, in terms of hours per week, how often you are engaged in the following activities with each of your languages. (Please use digits when indicating number of hours weekly spent on each activity/language.)

Activities	(language 1)	(language 2)	(language 3)	(language 4)
Listen to Radio/Watching TV:	_____	_____	_____	_____
Reading for fun:	_____	_____	_____	_____
Reading for work:	_____	_____	_____	_____
Writing emails to friends or family and writing in social networks (e.g. Facebook):	_____	_____	_____	_____
Writing articles/papers/reports:	_____	_____	_____	_____
Speaking with coworkers and speaking at meetings and conferences:	_____	_____	_____	_____
Speaking with family:	_____	_____	_____	_____
Speaking with friends:	_____	_____	_____	_____

15. Do you ever switch between languages (when talking to someone, feeling the need to switch to another language either because someone else has joined the conversation or because you need to pause the conversation for a moment and address someone else)?

_____ Yes

_____ No

Participants who answered "No" would go straight to question 18.

15a. How often are you in situations in which you have to switch between languages?

_____ Rarely

_____ Occasionally

_____ Sometimes

_____ Frequently

_____ Very frequently

16. Between which languages do you usually have to switch? (Check all that apply.)

___ language 1 and language 2

___ language 1 and language 3

___ language 1 and language 4

___ language 2 and language 3

___ language 2 and language 4

___ language 3 and language 4

17. How often do you switch between languages in each of the following situations?

Situations	Rarely	Occasionally	Sometimes	Frequently	Very frequently
At work, during meetings or work-related conversations.	_____	_____	_____	_____	_____
With friends or coworkers, in non-work-related conversations.	_____	_____	_____	_____	_____
With family members, at home.	_____	_____	_____	_____	_____
Other. (Please specify:)	_____	_____	_____	_____	_____

18. If there is anything else that you feel is interesting or important about your language background or language use, please comment below.

Appendix C: Socio-Economic Status Questionnaire

PART A

1. Use this ladder to show where you would place yourself in New Zealand society, from lowest to highest status.

___ (highest)
___
___
___
___
___
___
___
___
___ (lowest)

2. Please indicate your highest educational qualification:

_____ Less than high school

_____ High school

_____ Certificate

_____ Diploma

_____ Bachelor's degree, Graduate Diploma or Graduate Certificate

_____ Postgraduate Diploma, Postgraduate Certificate or Bachelor’s degree with Honours

_____ Masters

_____ Doctorate

_____ Other (Specify): ____

3. Which of the following best describes your current main daily activities and/or responsibilities?

(Mark all that apply.)

_____ Working full time

_____ Working part-time

_____ Unemployed or laid off

_____ Looking for work

_____ Keeping house or raising children full-time

_____ Retired

_____ Studying full time

_____ Studying part-time

4. With regard to your current or most recent job activity:

4a. What kind of work do/did you do?

(For example: I teach children at a school, I help preparing meals at a restaurant.)

____

4b. What is/was your job title?

(For example: registered nurse, personnel manager, supervisor of order department, grinder operator.)

____

4c. Please indicate your current total income per annum (including loans, scholarships and benefits, etc.).

_____ Loss

_____ Zero income

_____ NZ$1 – NZ$5,000

_____ NZ$5,001 – NZ$10,000

_____ NZ$10,001 – NZ$15,000

_____ NZ$15,001 – NZ$20,000

_____ NZ$20,001 – NZ$25,000

_____ NZ$25,001 – NZ$30,000

_____ NZ$30,001 – NZ$35,000

_____ NZ$35,001 – NZ$40,000

_____ NZ$40,001 – NZ$50,000

_____ NZ$50,001 – NZ$60,000

_____ NZ$60,001 – NZ$70,000

_____ NZ$70,001 – NZ$80,000

_____ NZ$80,001 – NZ$90,000

_____ NZ$90,001 – NZ$100,000

_____ NZ$100,001 – NZ$110,000

_____ NZ$110,001 – NZ$120,000

_____ NZ$120,001 – NZ$130,000

_____ NZ$130,001 – NZ$140,000

_____ NZ$140,001 – NZ$150,000

_____ NZ$150,001 +

5. How many people are currently living in your household, including yourself?

_____

5a. Of these people, how many are dependents (not contributing to the household's income)? _____

6. Is the home where you live:

_____ owned?

_____ owned but paying mortgage?

_____ rented?

_____ a student flat?

_____ occupied without payment of money or rent?

_____ Other? (Specify:) ______________________________________

7. Do you share income with anyone else?

_____ Yes

_____ No

Participants who answered “No” would go straight to Part B of the questionnaire.

8. Please indicate your household’s current total income per annum (including loans, scholarships and benefits, etc.).

_____ Loss

_____ Zero income

_____ NZ$1 – NZ$5,000

_____ NZ$5,001 – NZ$10,000

_____ NZ$10,001 – NZ$15,000

_____ NZ$15,001 – NZ$20,000

_____ NZ$20,001 – NZ$25,000

_____ NZ$25,001 – NZ$30,000

_____ NZ$30,001 – NZ$35,000

_____ NZ$35,001 – NZ$40,000

_____ NZ$40,001 – NZ$50,000

_____ NZ$50,001 – NZ$60,000

_____ NZ$60,001 – NZ$70,000

_____ NZ$70,001 – NZ$80,000

_____ NZ$80,001 – NZ$90,000

_____ NZ$90,001 – NZ$100,000

_____ NZ$100,001 – NZ$110,000

_____ NZ$110,001 – NZ$120,000

_____ NZ$120,001 – NZ$130,000

_____ NZ$130,001 – NZ$140,000

_____ NZ$140,001 – NZ$150,000

_____ NZ$150,001 +

PART B

The following questions do not refer to your present situation, but to the context in which you lived as a child.

Please answer the questions as a way of describing, in the best way possible, your main caretaker’s household, between the time you were born and up until you were 10 years of age.

(Note: Your main caretakers would have been your parents, guardians, or any adult responsible for you when you were a child.)

1. Use this ladder to show where you would place the household where you spent your childhood (first 10 years of your life) in the society of the country where you were living at the time, from lowest to highest status. (If you lived in more than one country during that time, please use the country where you spent the most time as the reference one.)

___ (highest)
___
___
___
___
___
___
___
___
___ (lowest)

2. Until you were 10 years old, what was the highest educational qualification obtained by your main FEMALE caretaker?

_____ Less than high school
_____ High school
_____ Certificate
_____ Diploma
_____ Bachelor's degree, Graduate Diploma or Graduate Certificate
_____ Postgraduate Diploma, Postgraduate Certificate or Bachelor’s degree with Honours
_____ Masters
_____ Doctorate
_____ Other (Specify): ____

3. Until you were 10 years old, what was the highest educational qualification obtained by your main MALE caretaker?

_____ Less than high school

_____ High school

_____ Certificate

_____ Diploma

_____ Bachelor's degree, Graduate Diploma or Graduate Certificate

_____ Postgraduate Diploma, Postgraduate Certificate or Bachelor’s degree with Honours

_____ Masters

_____ Doctorate

_____ Other (Specify): ____

4. Which of the following best describes your FEMALE caretaker’s main daily activities and/or responsibilities (during the first 10 years of your life)? (Mark all that apply.)

_____ Working full time

_____ Working part-time

_____ Unemployed or laid off

_____ Looking for work

_____ Keeping house or raising children full-time

_____ Retired

_____ Studying full time

_____ Studying part-time

5. Which of the following best describes your MALE caretaker's main daily activities and/or responsibilities (during the first 10 years of your life)? (Mark all that apply.)

_____ Working full time

_____ Working part-time

_____ Unemployed or laid off

_____ Looking for work

_____ Keeping house or raising children full-time

_____ Retired

_____ Studying full time

_____ Studying part-time

6. With regard to your caregiver's main job activity:

6a. What kind of work did they do during the first 10 years of your life?

(For example: Teach children at a school, Help preparing meals at a restaurant.)

Main female caretaker: ____

Main male caretaker: ____

6b. What were their job titles?

(For example: registered nurse, personnel manager, supervisor of order department, grinder operator.)

Main female caretaker: ____

Main male caretaker: ____

7. During the first 10 years of your life, how many people lived in your household, including yourself? _____

   7a. Of these people, how many were dependents (not contributing to the household's income), including yourself? _____

8. During the first 10 years of your life, was the home where you lived:

   _____ owned?

   _____ owned but paying mortgage?

   _____ rented?

   _____ occupied without payment of money or rent?

   _____ Other? (Specify:) ____________________________________

Appendix D: Questionnaire on Activities with an Impact on Executive Functions

1. Have you ever played a musical instrument?

_____ Yes

_____ No

Participants who answered "No" would go straight to question 2.

1a. Which of these options better describes your situation?

_____ I play a musical instrument at present.

_____ I used to play a musical instrument, but it has been over a year since I last played.

1b. What musical instrument(s) do/did you play?

____

1c. For how long have you played a musical instrument?

(Please fill in with digits, not text.)

_____ years, _____ months

1d. How often do/did you play?

_____ Rarely (less than once a week)

_____ Occasionally (one or two times a week)

_____ Sometimes (three or four times a week)

_____ Frequently (five or six times a week)

_____ Very frequently (everyday)

1e. How many hours do/did you play per week?

_____ Up to 5 hours per week.

_____ Between 6 and 8 hours per week.

_____ Between 9 and 11 hours per week.

_____ Between 12 and 14 hours per week.

_____ More than 15 hours per week.

1f. Please rate your own skills as a musical player.

_____ Very poor

_____ Poor

_____ Regular

_____ Good

_____ Very good

2. Have you ever played video games?

_____ Yes

_____ No

Participants who answered “No” would go straight to question 3.

2a. Which of these options better describes your situation?

_____ I play video games at present.

_____ I used to play video games, but it has been over a year since I last played.

2b. What type of video games do/did you play?

Examples: action, adventure, role-playing, simulation, strategy, etc.

____

2c. For how long have you played video games?

(Please fill in with digits, not text.)

_____ years, _____ months

2d. How often do/did you play video games?

_____ Rarely (less than once a week)

_____ Occasionally (one or two times a week)

_____ Sometimes (three or four times a week)

_____ Frequently (five or six times a week)

_____ Very frequently (everyday)

2e. How many hours do/did you play video games per week?

_____ Up to 5 hours per week.

_____ Between 6 and 8 hours per week.

_____ Between 9 and 11 hours per week.

_____ Between 12 and 14 hours per week.

_____ More than 15 hours per week.

2f. Please rate your own skills as a video-game player.

_____ Very poor

_____ Poor

_____ Regular

_____ Good

_____ Very good

3. Have you ever engaged in any other activity that involves rapid and frequent response to visual stimuli?

_____ Yes

_____ No

Participants who answered "No" would go straight to question 4.

3a. Which of these options better describes your situation?

_____ I engage in an activity that requires rapid and frequent response to visual stimuli at present.

_____ I used to engage in an activity that required rapid and frequent response to visual stimuli, but it has been over a year since I last did.

3b. What type of activity do/did you engage in which involves(/ed) rapid response to visual stimuli?

____

3c. For how long have you engaged in that activity?

(Please fill in with digits, not text.)

_____ years, _____ months

3d. How often do/did you engage in that activity?

_____ Rarely (less than once a week)

_____ Occasionally (one or two times a week)

_____ Sometimes (three or four times a week)

_____ Frequently (five or six times a week)

_____ Very frequently (everyday)

3e. How many hours do/did you engage in that activity per week?

_____ Up to 5 hours per week.

_____ Between 6 and 8 hours per week.

_____ Between 9 and 11 hours per week.

_____ Between 12 and 14 hours per week.

_____ More than 15 hours per week.

3f. Please rate your own skills in the same activity.

_____ Very poor

_____ Poor

_____ Regular

_____ Good

_____ Very good

4. Do you exercise or engage in physical sports?

_____ Yes

_____ No

Participants who answered "No" would go straight to question 5.

4a. What type of exercise/sports do you usually do?

____

4b. For how long have you exercised/played physical sports?

(Please fill in with digits, not text.)

_____ years, _____ months

4c. How often do you exercise/play sports?

_____ Rarely (less than once a week)

_____ Occasionally (one or two times a week)

_____ Sometimes (three or four times a week)

_____ Frequently (five or six times a week)

_____ Very frequently (everyday)

4d. How many hours do you exercise/play physical sports per week?

_____ Up to 5 hours per week.

_____ Between 6 and 8 hours per week.

_____ Between 9 and 11 hours per week.

_____ Between 12 and 14 hours per week.

_____ More than 15 hours per week.

4e. Did you exercise/play a physical sport some time today?

_____ Yes

_____ No

Participants who answered "No" would go straight to question 5.

4e1. HOW LONG AGO TODAY have you exercised/played physical sports?

(Please fill in with digits, not text.)

_____ hours, _____ minutes

4e2. What type of exercise/sports did you do TODAY?

____

4e3. FOR HOW LONG did you exercise/play physical sports today?

(Please fill in with digits, not text.)

_____ hours, _____ minutes

5. Have you ever practiced meditation?

_____ Yes

_____ No

Participants who answered "No" would finish the questionnaire.

5a. Which of these options better describes your situation?

_____ I practice meditation at present.

_____ I used to practice meditation, but it has been over a year since I last meditated.

5b. For how long have you practiced meditation?

(Please fill in with digits, not text.)

_____ years, _____ months

5c. How often do/did you meditate?

_____ Rarely (less than once a week)

_____ Occasionally (one or two times a week)

_____ Sometimes (three or four times a week)

_____ Frequently (five or six times a week)

_____ Very frequently (everyday)

5d. How many hours do/did you meditate per week?

_____ Up to 5 hours per week.

_____ Between 6 and 8 hours per week.

_____ Between 9 and 11 hours per week.

_____ Between 12 and 14 hours per week.

_____ More than 15 hours per week.

5e. Please rate how successful you are at meditating.

_____ Very unsuccessful

_____ Unsuccessful

_____ Average

_____ Successful

_____ Very successful

6. Which one are you?

_____ Right-handed

_____ Left-handed

_____ Ambidextrous

Thank you for participating in our study, by taking these questionnaires.

To finish, please press “Continue.”

Appendix E: Information Sheet for Participants

INFORMATION SHEET FOR PARTICIPANTS

Thank you for showing an interest in this project. Please read this information sheet carefully before deciding whether or not to participate. If you decide to participate we thank you. If you decide not to take part there will be no disadvantage to you of any kind, and we thank you for considering our request.

What is the aim of the project?

This study aims at a better understanding of the impact of long-term, active bilingualism (knowledge and frequent use of at least two languages) in non-verbal aspects of cognition.

What type of participants is being sought?

We are seeking non-New Zealand born adults who speak at least two languages. The participants would have learned their second language at any age, and they speak both (or all) of their languages frequently (every day or almost every day) as well as fluently (without any significant effort). This bilingual experience, characterized by a frequent usage of both languages, must have had a length of no less than 5 years.

We are also seeking non-new Zealand born monolingual participants, who have moved to New Zealand as teenagers or adults and have been living in the country for a number of years.

What will participants be asked to do?

Should you agree to take part in this project, you will be asked to answer a questionnaire on your personal language, culture and social backgrounds. You will also be asked to take an English language task and three tasks that will aim at measuring specific aspects of cognition related to divergent and convergent thinking, the ability to deal with conflicting information, and the ability to direct and control attention.

The questionnaire and three of the tasks will be presented on a computer screen. One of the tasks will be paper and pencil.

The questionnaire comprises questions regarding your language history, your socio-economical situation and questions about activities that you might practice regularly. Most of these questions will demand a simple tick mark selecting one of a number of given answers. In some cases, you will be asked to submit a short written answer, by using the keyboard.

The English language task is structured in sentences and small texts, with blank spaces that you are expected to complete with one of several possible answers supplied.

In one of the cognitive tasks, which will be given in paper format, you will be given instructions to solve four different types of visual puzzles, by choosing the odd element out, the correct pattern to follow a sequence of given patterns or by identifying similarities between figures, for example.

For the two tasks that aim at measure cognitive ability, you will be asked to press one of two buttons depending of the type of stimulus that you will see appearing on the screen. Different forms, like squares or arrows will be shown on the screen and you'll be expected to press a right-hand button or a left-hand button depending on the colour or place the form takes.

Individual times are always variable, but we expect that the whole process, with short breaks in between, should last between 60 and 80 minutes.

To avoid any discomfort, there will be short breaks in between tasks, when the participants can relax and get away from the computer screen.

If you decide to take part in this project, you will be asked to return at a later time (in two or three months time) for a second session of different cognitive tasks, that will aim to look at working memory, creativity, and the ability to understand and predict other people's interpretation of reality. This second session will be of similar length and will involve similar methods.

Please be aware that you may decide not to take part in the project without any disadvantage to yourself of any kind.

Can participants change their mind and withdraw from the project?

You may withdraw from participation in the project at any time and without any disadvantage to yourself of any kind.

What data or information will be collected and what use will be made of it?

The data that we will be collecting are data regarding your personal language history, your present and past socio-economical situation, your English language ability, your problem solving skills, and your response times and error rates in conflict monitoring and resolution tasks.

At your second session, the data we will be collecting will be response times, error rates and eye movements.

Participants will not be audiotaped or videotaped.

The data collected will be statistically analysed, separately (per task, not per participant) and collectively, in order to look for patterns and possible correlations that will bring light and increase the knowledge there is on the relationship between the acquisition of a second language to a high level of proficiency and use and other aspects of human cognition, mainly nonverbal ones.

This data will be collected as part of a doctoral research program, and only the researchers will have access to your individual data.

The results of the project may be published and will be available in the University of Otago Library (Dunedin, New Zealand) but every attempt will be made to preserve your anonymity.

You are most welcome to request a copy of the results of the project should you wish.

The data collected will be securely stored in such a way that only those mentioned below will be able to gain access to it. At the end of the project any personal information will be destroyed immediately except that, as required by the University's research policy, any raw data on which the results of the project depend will be retained in secure storage for five years, after which they may be destroyed.

What if participants have any questions?

If you have any questions about our project, either now or in the future, please feel free to contact either:

Célia Mendes

Department of Psychology

University Telephone Number: 3 4795117

email address: celia.mendes@otago.ac.nz

Dr. Tamar Murachver

Department of Psychology

University Telephone Number: 3 4798351

email address: tamar@psy.otago.ac.nz

Dr. Mele Taumoepeau

Department of Psychology

University Telephone Number: 3 4794029

email address: mele@psy.otago.ac.nz

Prof. Jeff Miller

Department of Psychology

University Telephone Number: 3 4797997

email address: miller@psy.otago.ac.nz

This study has been approved by the Department of Psychology. If you have any concerns about the ethical conduct of the research you may contact the HoD Psychology (ph 03 479 7644) or the Human Ethics Committee Administrator (ph 03 479 8256). Any issues you raise will be treated in confidence and investigated and you will be informed of the outcome.

Appendix F: Participant Basic Information Form

Basic Information Form ID Number: _________________

Full name: ____

Date of birth: ________/________/_________ Gender: F ____ M ____

Email: ____

Contact number: __________________________________

Mobile phone: ____________________________________

Ethnicity: What ethnic groups do you identify with?

____

____

Appendix G: Participant Consent Form

CONSENT FORM FOR PARTICIPANTS

I have read the Information Sheet concerning this project and understand what it is about. All my questions have been answered to my satisfaction. I understand that I am free to request further information at any stage.

I know that:

1. My participation in the project is entirely voluntary;
2. I am free to withdraw from the project at any time without any disadvantage;
3. Personal identifying information will be destroyed at the conclusion of the project but any raw data on which the results of the project depend will be retained in secure storage for five years, after which they may be destroyed;
4. I will be reimbursed for my time and travel expenses with a voucher (NZD $20.00 value) per session;
5. The results of the project may be published and will be available in the University of Otago Library (Dunedin, New Zealand) but every attempt will be made to preserve my anonymity.

I agree to take part in this project.

....

(Signature of participant) (Date)

This study has been approved by the Psychology Department. If you have any concerns about the ethical conduct of the research you may contact the Head of Department of Psychology (Ph. 03 479 7644) or the Human Ethics Committee Administrator (ph. 03 479 8256). Any issues you raise will be treated in confidence and investigated and you will be informed of the outcome.