THE UNIVERSITY *of* EDINBURGH

**Do bilinguals have a cognitive advantage?**

**Examining effects of bilingualism and language use on executive control**

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## Declaration

I hereby declare that the work presented in this thesis is my own. Contributions of others are clearly acknowledged at the beginning of the chapters. No part of this thesis has been submitted for any other degree. References and author contributions are provided when chapters are based on my publications.

Angela de Bruin

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## Contents

## Abstract

The daily practice of bilingual language control has been argued to affect both lexical processing and non-verbal executive control in bilingual speakers. On the one hand, bilingualism may slow down lexical processing in both languages. On the other hand, bilinguals have been said to show cognitive advantages compared to monolinguals, for example on inhibition and switching tasks. However, this ‘bilingual advantage’ is hotly debated, can often not be replicated, and language groups have been poorly matched on background variables in previous studies. Furthermore, I examined the reliability of the literature and found evidence for the existence of a publication bias (Chapter 3). This overrepresentation of positive studies compared to studies with null or negative findings hinders a reliable interpretation of the actual effects of bilingualism.

The current thesis therefore aimed to examine possible effects of bilingualism on both lexical processing and executive control. Specifically, I investigated the effects of an understudied, but important feature of bilingualism: language use.

Effects of bilingualism have been argued to be largest in older adults. Chapter 4 presents a study discussing inhibition and possible effects of age across various tasks. I show that inhibitory control and age effects depend on task-specific features, including the type of interference, type of stimuli, and processing speed.

Next, I present a study (Chapter 5 and 6) examining the relation between bilingualism and both lexical processing and executive control in older adults. Importantly, bilingual and monolingual groups were matched on background variables including immigrant status. I furthermore compared a group of active to inactive bilinguals to assess effects of language use. On a lexical processing task, bilinguals had a disadvantage compared to monolinguals. This effect was modulated by language use, implying that not only language proficiency but also actual language use are needed to explain lexical effects of bilingualism. However, the non-verbal executive control tasks showed no consistent effects of bilingualism or language use on inhibition or task switching. Thus, this study did not replicate positive effects on executive control in older adults.

Between-subject comparisons remain problematic as groups can never be matched perfectly. Furthermore, these designs cannot assess a causal effect of bilingualism. Therefore, I conducted another study using behavioural and EEG measurements to test for causal effects of language switching on task switching (Chapter 7). When young bilinguals completed a language-switching task prior to a verbal task-switching paradigm, they showed larger switching costs than after a monolingual naming task. However, this effect of language switching was not found for non-verbal task switching. Language switching may thus have a negative impact on verbal switching, but these effects did not extend to non-verbal executive control.

Together, these studies suggest that bilingualism and language use affect lexical processing, but there was no evidence for effects of bilingualism and language use on non-verbal executive control in younger or older adults. In combination with other failed replications and the biased literature, this questions the reliability of cognitive benefits associated with bilingualism. However, executive control is not a unity and its manifestation depends on task-specific features. This task impurity, together with the degree to which participant groups are matched, may explain the inconsistency with which effects of bilingualism on executive control have been observed.

## Lay summary

More than half of the world's population speaks a second language. Many of these bilinguals use their two languages seemingly effortlessly. Yet, speaking two languages is not as easy as it appears. Bilinguals constantly need to select the appropriate language, choose the right words in that target language while suppressing the equivalent in the non-target language, and in some circumstances quickly have to switch between their languages.

This constant language control may lead to differences between bilinguals and monolinguals in other aspects too. On the one hand, it has been found that bilinguals are slower and less accurate than monolinguals when they have to name pictures or do vocabulary tests ('lexical tasks'). On the other hand, the practice with language inhibition and language switching may make bilinguals better at non-verbal inhibition or switching too ('non-verbal cognitive control tasks'). Especially this latter finding, also dubbed the 'bilingual advantage', has received much media attention and is often presented as common knowledge. However, in many previous studies assessing effects of bilingualism on non-verbal control tasks, bilinguals and monolinguals did not only differ in the number of languages that they speak. They often also differed in socio-economic status, education, or the country of origin. Thus, it is unclear whether effects of bilingualism are truly related to being bilingual.

In my thesis, I therefore assessed effects of bilingualism on both lexical control and on non-verbal cognitive control in more detail. Furthermore, I wanted to investigate an aspect of bilingualism that is often neglected: actual language use. Is *knowing* two languages enough to affect lexical and non-verbal cognitive control or do you need to *use* your two languages?

Across a series of studies, I examined this question in both younger and older adults. The bilingual and monolingual groups were matched on various background variables, including education and immigrant status. I firstly found that bilingualism has a negative impact on verbal tasks. Bilinguals were slower than monolinguals to match pictures with corresponding words. Importantly, this effect depends on actual language use. Bilinguals who used two languages on a regular basis had a larger disadvantage on this lexical task than bilinguals who mainly used one language only. Similarly, bilinguals were slower at verbal task switching after they had to switch between their two languages. In contrast, I did not find these effects on non-verbal control tasks. Bilinguals did not differ from monolinguals on tasks measuring inhibition of irrelevant information or on non-verbal switching tasks. There was also no effect of language use. Furthermore, while language switching affected verbal task switching, it did not have any consequences for non-verbal switching.

This suggests that bilingualism indeed has a negative impact on lexical tasks and that this effect is largest for bilinguals actively using two languages on a regular basis. However, I did not obtain evidence for a positive effect of bilingualism or

language use on non-verbal cognitive control tasks. This challenges the 'bilingual advantage' and shows that cognitive effects of bilingualism are less stable than often assumed.

# Chapter 1. Literature review

Parts of this chapter (as indicated in footnotes) are based on:

de Bruin, A., & Della Sala, S. (2016). The importance of language use when studying the neuroanatomical basis of bilingualism. *Language, Cognition and Neuroscience, 31*(3), 335-339.

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Sixty years ago, learning two languages was argued to just confuse children and therefore bilingualism was believed to be detrimental to their intellectual functioning (e.g., Saer, 1923; Jones & Stewart, 1951, cited in Peal & Lambert, 1962). Peal and Lambert (1962) were among the first to counter-argue this belief. They criticised the lack of control in earlier studies and the many differences between bilinguals and monolinguals on background variables such as socio-economic status. When controlling for these background variables, they did not observe any adverse effects of bilingualism on intelligence tests. Rather, they discovered that bilinguals outperformed monolinguals.

The current views on effects of bilingualism are very different from those expressed before 1962. Bilinguals are now argued to have a cognitive advantage over monolinguals on non-verbal executive control tasks assessing, amongst others, suppression of task-irrelevant information or the ability to switch between two tasks. This advantage has been found for children (e.g., Bialystok & Martin, 2004), young adults (e.g., Costa, Hernández, & Sebastián-Gallés, 2008), and older adults (e.g., Bialystok, Craik, Klein, & Viswanathan, 2004). At the same time, bilingualism has been linked to disadvantages on lexical tasks. For instance, bilinguals have shown slower responses on picture naming tasks compared to monolinguals (e.g., Gollan, Montoya, Fennema-Notestine, & Morris, 2005).

The finding that bilinguals may have an advantage on non-verbal executive control tasks has received much media attention (see Figure 1.1), giving the impression that the bilingual advantage is now accepted as common knowledge and is no longer matter of debate. Several recent studies, however, have not been able to replicate these findings (e.g., Paap & Greenberg, 2013; Gathercole et al., 2014) and it has been estimated that 80% of recent studies do not show a cognitive advantage of bilingualism (Paap, Johnson, & Sawi, 2015). Furthermore, bilingual and monolingual groups have not always been matched on background variables such as immigration status or education, raising the possibility that a positive effect may not truly be related to bilingualism. The 'bilingual advantage' is therefore hotly debated at the moment.


*Figure 1.1.* Overview of several media headlines describing the 'bilingual advantage'.[1]

The work presented in this thesis aimed to examine effects of bilingualism on both lexical processing and non-verbal executive control in more detail. In this chapter, I will firstly review studies assessing the link between bilingualism and lexical processing, inhibitory control, task switching, (working) memory, dementia, and neuronal mechanisms. While this chapter merely provides an overview of

[1] Top left: C. Schwartz (8 July 2011); Newsweek. Top right: E. Zolfagharifard (13 January 2015); Dailymail.com. Bottom left: Unknown author (1 August 2013); Huffington Post. Bottom right: K. Fox (12 June 2011); The Guardian.

effects described in the literature, the second chapter will evaluate these studies more critically.

### 1.1. Bilingual language control

It is estimated that more than half of the world's population speaks more than one language (Grosjean, 2010). These bilinguals differ in many features. Some acquired a second language from birth while others started learning a language after retirement. Some bilingual speakers are fully fluent in both languages while others are less proficient in their second language. Some bilinguals continuously switch between their languages, whilst others only use one language at a time. Furthermore, some bilinguals may use both languages on a daily basis while others only or predominantly use one language. Despite the large variety of bilinguals, much of the work on bilingualism and executive control has focused on bilinguals who acquired two languages at an early age, up to a high proficiency level, and who use both on a regular basis.

Although these balanced, early bilinguals often appear to use their languages effortlessly, this requires great language control. For example, a Dutch-English bilingual firstly has to ensure that the right word is selected in the appropriate language. When describing a dog in Dutch, the word *hond* needs to be activated while the non-target word *dog* should not be selected. In other circumstances, however, *hond* may not be appropriate and *dog* has to be selected instead. This not only requires activating the correct words in the correct language, but also continuous monitoring of the language environment. Bilinguals need to consider the language(s) spoken by their conversation partners as well as the general environment. For example, even though two Dutch native speakers may want to converse in Dutch, it may not be the appropriate language when surrounded by English speakers. Furthermore, language switching demands additional language control. Bilinguals may switch between conversations depending on the person they are talking to. When both speak the same languages, switching may also take place within a conversation or even at the sentence level.

Many studies have shown that the two languages of a bilingual are always active, even if only one is needed (e.g., Hermans, Bongaerts, De Bot, & Schreuder, 1998; Dijkstra, Grainger, & Van Heuven, 1999). For example, in an eye-tracking study, Russian-English bilinguals were instructed to ‘pick up the marker’ while being presented with pictures of various items, including a marker and a stamp (*marka* in Russian). Even though the experiment was conducted in English, Russian-English bilinguals still looked at the image of a stamp as its Russian name (*marka)* shares phonological features with *marker* (Marian, Spivey, & Hirsch, 2003). Similarly, Chinese-English bilinguals showed greater difficulty indicating that an English word pair was unrelated when the Chinese equivalent contained a character repetition (e.g., Thierry & Wu, 2004).

Several theories have been presented aiming to explain how bilinguals control their two languages while both are simultaneously activated. One of the most prominent models is the Inhibitory Control (IC) model developed by Green

(1998). This model posits that inhibition is needed to select the correct target word. In language production, the concept needs to be selected first. This is followed by selection of the lemma: the word representation that includes its syntactic properties. This then leads to the activation of the selected word form. Green argues that lemmas have associated language tags both for the first language (L1) and second language (L2). After concept selection, the lemmas with the L1 as well as L2 tag become active. However, to select the correct response, the lemma with the incorrect language tag needs to be suppressed. As this suppression occurs after both lemmas become activated, the language inhibition is argued to be reactive rather than proactive. Based on this reactive inhibition, the IC model posits two main predictions. Firstly, it takes time to overcome reactive inhibition. Secondly, the amount of inhibition depends on language proficiency. Indeed, language-switching studies often observe asymmetrical switching costs (e.g., Meuter & Allport, 1999). Naming in a weaker L2 requires more inhibition of the proficient L1 while less inhibition of the L2 is needed during L1 naming. As it takes time to overcome this inhibition, switching back to L1 takes more time than switches to L2. Further studies have suggested that the inhibition mechanisms involved in language production and switching may overlap with domain-general mechanisms used in non-verbal inhibition and switching (e.g., Abutalebi & Green, 2007; De Bruin, Roelofs, Dijkstra, & FitzPatrick, 2014; De Baene, Duyck, Brass, & Carreiras, 2015).

This inhibition account is one of the most prominent theories to explain bilingual language control, but several others have been suggested that do not require inhibition. Some of these posit that only items in the target language are considered for selection and thus there is no competition with the non-target language (e.g., Costa & Caramazza, 1999). Highly proficient bilinguals may achieve selection of the appropriate target word by making the lexical representations of the target words *more* available rather than by making the non-target representations *less* available ('language-specific selection threshold hypothesis'; Costa & Santesteban, 2004).

While the mechanisms behind bilingual language control have been debated, the concept of inhibitory control being needed to select and control languages has formed the basis of studies addressing effects of bilingualism on both lexical as well as non-verbal control performance. On the one hand, interference from the inappropriate but active language could lead to disadvantages on lexical tasks for bilinguals. On the other hand, the bilinguals' daily practice with verbal inhibition has been claimed to lead to advantages on non-verbal tasks.

## 1.2. Lexical effects of bilingualism

In lexical tasks, bilinguals have often been found to show a disadvantage compared to monolinguals. In terms of vocabulary size, bilinguals usually know fewer words in each of their languages than monolinguals. For example, Bialystok and Feng (2009) used a test of receptive vocabulary (PPVT) and found that monolingual children recognised 105 words, while bilinguals only scored 96 items correct. Similarly, in production tasks, bilinguals produce fewer items than monolinguals. In verbal fluency tasks, this has mainly been observed in category fluency requiring participants to name as many items within a category (e.g., animals or fruits) as possible within one minute. Bilingual participants often score lower on this task than monolinguals (e.g., Rosselli et al., 2000). However, in letter fluency tasks requiring participants to name words starting with a certain letter, this bilingual-monolingual difference is sometimes smaller (e.g., Gollan, Montoya, & Werner, 2002) or absent (e.g., Rosselli et al., 2000). Bilinguals furthermore show more tip of the tongue experiences (Gollan & Acenas, 2004). Besides lower accuracy, bilinguals also show longer reaction times (RTs) when naming pictures in their dominant as well as their second language (e.g., Gollan et al., 2005; Ivanova & Costa, 2008). These effects have been observed for all age groups, including children (e.g., Bialystok & Feng, 2009); young adults (e.g., Bialystok, Craik, & Luk, 2008); and older adults (e.g., Rosselli et al., 2000). I will discuss the mechanisms behind this lexical disadvantage in more detail in Chapter 5.

### 1.3. Bilingualism and executive control

As the other side of the coin, bilinguals have been argued to show an advantage on non-verbal executive control tasks, predominantly on those concerning inhibition or switching. Following Miyake et al. (2000), executive control is often thought of as divided in three subcomponents: shifting, updating, and inhibition. These three components were found after a factor analysis on several frequently used tasks. Shifting (often referred to as 'task switching' in the bilingualism literature) refers to the ability to switch between multiple tasks. Updating concerns the monitoring of incoming information and is related to working memory by replacing old information with new information needed to perform the task. Lastly, inhibition reflects the ability to suppress (automatic) responses or distracting information. The components were described to be “moderately correlated with one another, but […] clearly separable” (p. 49). Correlations among the three components ranged from .42 to .63, suggesting that there is some overlap between shifting, updating, and inhibition. In an updated model (Miyake & Friedman, 2012), the component of inhibition is excluded and only shifting and updating are left. Instead, this model now has a ‘common executive function’. The inhibition component correlates almost perfectly with this common executive function. It can be argued that this nearly perfect correlation suggests that this common component in fact equals inhibition (thus suggesting that inhibition is present in all tasks).

Based on the original 2000 model, effects of bilingualism have mainly been studied on tasks assumed to measure inhibition and switching/shifting. I will discuss effects of bilingualism on these two components separately, starting with inhibition.

### 1.3.1. Inhibitory control tasks

Inhibition is used as a general term but refers to different types of inhibitory control. Interference suppression, i.e., the ability to ignore irrelevant and misleading information, is tested most often in respect to bilingualism. This has been measured in various tasks, including the Simon (arrow) task, flanker task, attentional network task (ANT), anti-saccade task, and Stroop task. In the Simon task (see Figure 1.2), participants are presented with stimuli associated with a left or right button press and presented on the left or right side of the screen. This leads to congruent trials (button corresponds with presentation side) and incongruent trials (mismatch button and presentation side). Incongruent trials usually elicit longer RTs than congruent trials and this difference (the Simon cost) is taken as an indication of inhibitory control. The Simon arrow task (also called Spatial Stroop) is similar to this task but uses arrows pointing left or right instead. In this way, it avoids the random assignment of colours or shapes to button presses and lowers working memory demands.

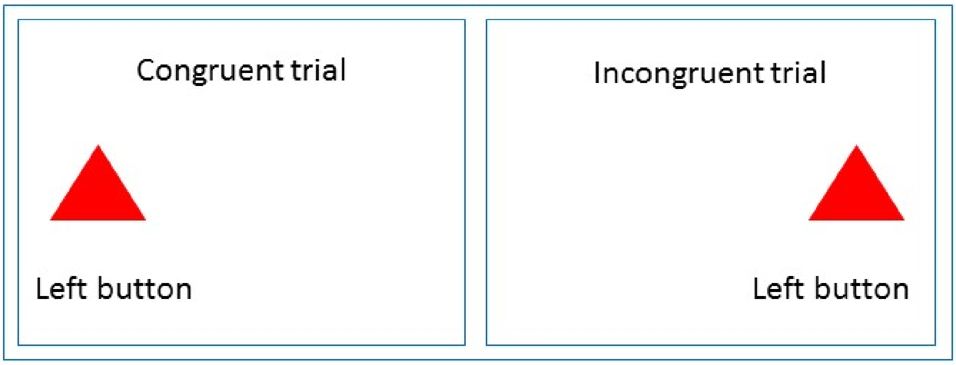


*Figure 1.2.* Example of a Simon task trial. In the left trial, the response button corresponds with the presentation side (congruent) while there is a mismatch in the trial on the right (incongruent).

Similarly, in the flanker task, participants see a central arrow surrounded by flanker arrows pointing in the same (congruent) or opposite (incongruent) direction. The

ANT is similar to the flanker task but also includes measures of alerting and orienting. The arrow presentation can be preceded by an alerting cue. The difference between trials with and without an alerting cue is used as an indicator of alerting. The cue could also provide information about the spatial position of the arrow stimulus. The difference in RTs after a spatial cue versus after a cue without spatial information is defined as orienting. A distinction between interference suppression and response inhibition can be made in an anti-saccade task. Response inhibition reflects the ability to withhold a habitual response (e.g., a button press). In an anti-saccade task, participants have to focus on a centrally presented face. Stimuli are flashed on one side of the fixation point. If the eyes in the face are green, participants have to respond towards the stimulus presentation; if the eyes are red, participants have to respond to the opposite side. The difference between red-eye and green-eye trials is defined as response inhibition. The eyes in the face could furthermore look at the direction of the stimulus (‘to-target’) or in the opposite direction (‘away-target’). The most conflicting trials are thus trials that show a mismatch between eye colour and gaze (‘green-away’ and ‘red-to’). Interference suppression is defined as the difference between high and low conflict trials (e.g., ‘green-away’ minus ‘green-to’). While these tasks are all non-verbal, Stroop tasks have been used both verbally and non-verbally. In a verbal version, participants usually see colour names in conflicting font colours. They have to name the font colour while ignoring the colour name. Non-verbal Stroop tasks are similar and can, for instance, use a pair of two digits with the smaller digit being presented in a larger font.

These tasks, as well as various others, have been used to examine effects of bilingualism on inhibitory control in children, younger adults, and older adults. Appendix A1 gives an overview of published studies using the above-described tasks to examine effects of bilingualism on inhibitory control. To exclude potential effects of language materials, I did not include verbal Stroop tasks.

**Children**

Several studies have found a bilingual advantage for children on the Simon task (e.g., Martin-Rhee & Bialystok, 2008); the flanker task (e.g., De Abreu, Cruz-Santos, Tourinho, Martin, & Bialystok 2012); ANT (Kapa & Colombo, 2013); and the anti-saccade task (e.g., Bialystok & Viswanathan, 2009). Even seven-month old pre-verbal bilingual infants may show a bilingual advantage (Kóvacs & Mehler, 2009).

Comparing response inhibition to interference suppression has suggested that the bilingual advantage is only found on the latter type of inhibition. Using an anti-saccade task, Bialystok and Viswanathan (2009) found that bilinguals showed smaller interference costs, but no difference was found regarding response inhibition. Similar results with no bilingual effects on response inhibition, but faster overall performance in an interference suppression task were found by Martin-Rhee and Bialystok (2008).

However, other studies observed mixed results or no advantages for bilingual children in inhibitory control tasks. Several studies have found bilingual effects on some but not all (parts of the) tasks. Bialystok, Barac, Blaye, and Poulin-Dubois (2010) for example, found a bilingual advantage on three inhibitory control tasks, but not on the ANT. Poulin-Dubois, Blaye, Coutya, and Bialystok (2011) also tested bilingual children on a battery of tasks including three inhibition tasks. Only the Stroop task showed an effect of bilingualism, with bilingual children being more accurate than monolingual children. Two studies with Welsh-English bilinguals and English monolinguals also showed mixed effects (Gathercole et al., 2010; Gathercole et al., 2014). Bilingual children came from Welsh only, English only, or Welsh and English homes. Results on a tapping task (where participants were asked to reverse the tapping pattern that the experimenter had demonstrated) and a Stroop task were mixed (Gathercole et al., 2010). A bilingual advantage was obtained for some bilingual groups in some parts of the tapping and Stroop tasks, but this effect was not consistent across tasks, groups, or age range. It also depended on the testing language, socio-economic status, language use, and vocabulary.

Other studies did not find bilingual advantages at all. Duñabeitia et al. (2014) tested 252 bilingual and 252 monolingual children on a verbal Stroop task and a non-verbal number-size congruency task. In a series of analyses, no language group differences were obtained on incongruent trials, interference effects, or overall RTs. Another large study with 360 children also observed no effect of bilingualism on the

ANT task (Antón et al., 2014). Other studies have also shown no bilingual effects in children on the Simon task (Morton & Harper, 2007; Namazi & Thordardottir, 2010), or ANT task (Ladas, Carroll, & Vivas, 2015).

**Young adults**

Young adults have been argued to be the age group in which effects of bilingualism are observed least often (e.g., Kroll & Bialystok, 2013). Costa et al. (2008) found an effect of bilingualism in young adults using the ANT. Bilinguals showed overall faster RTs during the experiment than monolinguals. The conflict cost was smaller for bilinguals than monolinguals (in the first two blocks, but not in the last block) and bilinguals were aided more by alerting cues. No differences were found in terms of orienting. Other studies have also shown smaller conflict costs or smaller overall RTs for bilinguals in a Simon (Linck, Hoshino, & Kroll, 2008); ANT (Pelham & Abrams, 2014; Marzecová, Asanowicz, Krivá, & Wodniecka, 2013a); flanker (Luk, De Sa, & Bialystok, 2011, but only for early bilinguals); and Stroop task (Hernández, Costa, Fuentas, Vivas, & Sebastián-Gallés, 2010; Bialystok, Poarch, Luo, & Craik, 2014). This 'advantage' for bilinguals in interference suppression may lead to disadvantages on other tasks. In negative priming studies, information that needed to be inhibited on one trial becomes relevant in the next trial. Bilinguals have shown larger costs than monolinguals in this paradigm, suggesting that they had to overcome a larger amount of inhibition from the previous trial (e.g., Treccani, Argyri, Sorace, & Della Sala, 2009; Prior, 2012).

When multiple tasks or measurements are included, results are often mixed. For example, Bialystok et al. (2008) tested young and old bilinguals and monolinguals on three different measures of executive control: Simon arrow, verbal Stroop, and Sustained Attention to Response Task (SART). In the Simon arrow paradigm, young adults showed no effect of bilingualism. In the Stroop task, young bilinguals showed a smaller Stroop effect than monolinguals. The third task, SART, measured response inhibition and did not show an effect of bilingualism.

A bilingual effect may furthermore depend on task demand and is often only or mainly found in tasks with higher levels of conflict. Costa, Hernández, Costa-Faidella, and Sebastián-Gallés (2009) used a flanker task with high monitoring and low monitoring conditions. In low monitoring conditions, the percentage of incongruent trials was either very high (92%) or very low (8%). In the high monitoring conditions, incongruent and congruent trials were distributed more evenly (25% or 50% incongruent trials). The low monitoring condition did not show differences between bilinguals and monolinguals. The high monitoring condition showed an overall advantage for bilinguals, with faster RTs on both congruent and incongruent trials. In the 50% condition, this effect was present for all three blocks, whereas in the 75% condition the bilingual advantage disappeared after block 1. Whereas Costa et al. (2008) found a smaller interference cost for bilinguals than monolinguals, this effect was largely absent in the 2009 study. Only in the first block of the 75% condition, bilinguals showed a smaller interference cost than monolinguals. Similarly, Bialystok (2006) observed an effect of bilingualism on a

Simon arrow task in the more demanding high switch condition, but not in the low switch condition.

Yet there is also a large number of studies that have found no inhibitory effects of bilingualism in younger adults at all, for example on the flanker task (e.g., Luk, Anderson, Craik, Grady, & Bialystok, 2010), anti-saccade task (e.g., Bialystok, Craik, & Ryan, 2006), or Simon task (e.g., Bialystok et al., 2005a; Yudes, Macizo & Bajo, 2011; Salvatierra & Rosselli, 2011). Importantly, these null effects have also been found in studies with large sample sizes. Paap and Greenberg (2013) tested over 200 participants on four different tasks (flanker, anti-saccade, Simon, and colour/shape switching) and none of the tasks showed a bilingual advantage.

**Older Adults**

Bialystok and colleagues published a seminal paper in 2004 in which they showed that middle-aged (30-54 years) and older (60-88 years) bilinguals have an advantage on a Simon task compared to monolinguals of the same age. Both middle-aged and old bilinguals showed a smaller Simon effect than the monolinguals. This bilingual advantage was largest in the oldest age group, suggesting that bilinguals also have a smaller age-related decline than monolinguals. Besides an advantage on the Simon effect specifically, bilinguals were faster than monolinguals on both congruent and incongruent trials. These bilingual advantages were replicated across three experiments. The second experiment showed that the bilingual advantage on the Simon effect was most pronounced in the most difficult condition, namely the condition with four instead of two colours. The third experiment, however, showed that the bilingual advantage can be unstable across blocks. The bilingual advantage in terms of faster RTs and smaller Simon effects disappeared in the last block, suggesting that practice can diminish the differences between bilinguals and monolinguals.

Studies testing multiple age groups have often observed effects of bilingualism in older adults in the absence of an effect in the group of younger adults. For example, Bialystok et al. (2006) observed overall faster RTs for older bilinguals compared to monolinguals on an anti-saccade task, while this was not found in the younger group. Similarly, Bialystok et al. (2008) found a smaller Simon effect for older but not younger bilinguals.

Comparable with the other age groups, other studies did not observe a bilingual advantage in older adults. Kousaie & Phillips (2012a) did not find differences between monolingual and bilingual older adults performing a Stroop task. Similarly, Kirk, Fiala, Scott-Brown, and Kempe (2014) did not observe a bilingual advantage on the Simon task testing immigrant and non-immigrant older bilinguals.

Appendix A1 presents an overview of 48 published studies that used the common tasks to measure inhibitory control in bilinguals (Simon, flanker/ANT, anti-saccade, and non-verbal Stroop tasks). In total, 91 comparisons of bilingual-monolingual groups on interference costs were reported. Of these 91 analyses, 25 (27%) showed a positive effect of bilingualism. Four showed a monolingual advantage (4%), the other 62 (68%) showed no difference between the two language groups on interference costs. Overall RT analyses were reported in 84 instances. Twenty-two cases (26%) showed a positive effect of bilingualism; 2 a monolingual advantage (2%); and 60 no effect of language group (71%). For children, more studies showed an effect on overall RTs (30%) than on interference costs (11%). For younger adults, the opposite was found (16% on overall RTs, 27% on interference costs). Positive effects of bilingualism were found most often for middle-aged/older adults (60% on interference costs, 54% on overall RTs). However, this group also included relatively few studies (15 analyses across 9 studies for interference costs and 13 for overall RTs).

Thus, 27% of the studies showed a positive effect of bilingualism on interference costs and 26% on overall RTs. It is important to note that most studies only showed an effect on one of these two measurements. In only ten analyses, an effect was found on both interference costs and overall RTs; five of these analyses came from Bialystok et al. (2004). The published literature thus suggests that the majority of studies and analyses does not show an effect of bilingualism. This is consistent with Paap et al.'s (2015) estimation that over 80% of recent studies do not show an effect of bilingualism. If an effect occurs, it is most likely to be found in older adults. Furthermore, a bilingual effect may be more likely to be found in high demanding task conditions. Lastly, bilingual advantages have mainly been observed on interference suppression and are unlikely to be related to response inhibition.

However, the nature of bilingual effects is not consistent across studies and they can be found on either interference costs or on overall RTs. This will be discussed in more detail in Chapter 2.

### 1.3.2. Task switching

Besides inhibition tasks, studies have also examined effects of bilingualism on the ability to switch between two non-verbal tasks. Commonly, participants have to categorise stimuli according to a specific criterion. For example, in a colour/shape switching task (see Figure 1.3), they are asked to indicate the colour or shape of an object with a button press. In the blocked condition, all stimuli have to be categorised according to colour or shape only. In a mixed condition, shape and colour have to be used interchangeably. This condition thus consists of switch trials (switching between colour and shape) and non-switch trials (two consecutive trials have the same criterion). The RT difference between switch and non-switch trials is defined as the switching cost. Most studies have also analysed mixing costs (the difference between mixed non-switch trials only and blocked trials), which is often taken as an indication of more global mechanisms needed to maintain two competing tasks in a mixed condition (Rubin & Meiran, 2005). Besides the colour/shape switching task, studies have also used the Wisconsin Card Sorting task. In this task, the participant again has to match objects based on colour and shape. Rather than receiving instructions, they receive feedback about their performance. Without being informed, the rules change after a certain number of cards and participants have to identify this change of rules. Commonly, the number of errors is taken as a measurement of switching performance. Task switching abilities in bilinguals have also been tested in an auditory task (Test of Everyday Attention, TEA, subtest Elevator Task with Reversal). In this task, participants have to count tones. When they hear a high tone, they have to count upwards while they have to count downwards after a low tone, thus requiring them to switch counting direction.

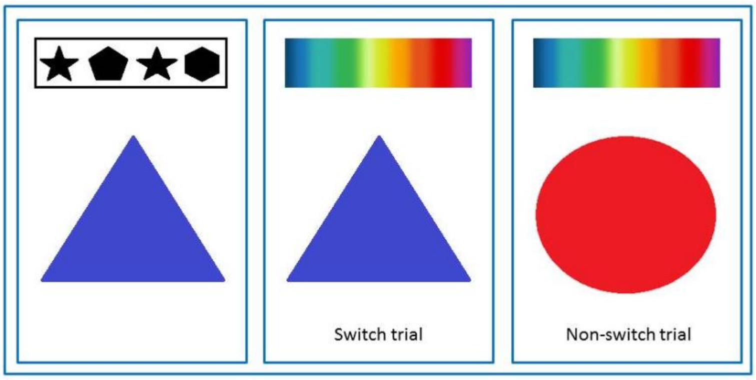


*Figure 1.3.* Example of a colour/shape switching task. Participants have to indicate the colour or shape of these objects according to the cue. The cue on the first trial (left) requires a shape decision. Trial 2 (middle) indicates a colour decision and thus requires a switch from shape to colour. Trial 3 (right) is a non-switch trial as it is a colour decision preceded by a colour trial.

One of the most-cited studies that found a bilingual advantage on task-switching paradigms is that by Prior and MacWhinney (2010). They observed smaller switching costs for bilinguals than monolinguals but no such difference on mixing costs. Similar results were observed by Prior and Gollan (2011), yet they noted that the effects of bilingualism could depend on language-switching behaviour. While a group of frequently switching Spanish-English bilinguals showed smaller switching costs than monolinguals, this was not found for the low switching group of Mandarin-English bilinguals. Smaller switching costs for bilinguals have not only been found in these groups of younger adults, but also for children (e.g., Bialystok & Viswanathan, 2009) and older adults (e.g., Gold, Kim, Johnson, Kryscio, & Smith, 2013a). Using the TEA, Bak, Vega-Mendoza, and Sorace (2015) suggested that these switching advantages can not only be found in the visual but also in the auditory domain.

However, other studies with large sample sizes have challenged the bilingual switching advantages (e.g., Paap & Greenberg, 2013; Paap & Sawi, 2014). Across three different experiments, Hernández, Martin, Barceló, and Costa (2013) did not observe any group differences in switching costs in their omnibus analysis with 292 participants.

Appendix A2 gives an overview of 22 studies examining non-verbal task-switching performance. Of the 33 switching measurements, 11 (33%) reported a positive effect of bilingualism. Not all studies reported mixing costs, but of the 14 that did, 2 (14%) showed a bilingual advantage. Similarly, for overall response times, of the 14 studies that reported this analysis, 2 (14%) showed a bilingual advantage. As most of these studies have been conducted with younger adults, there are not enough data from children or older adults to make a reliable age comparison.

Concluding, relatively few studies have looked at task-switching performance, especially in groups of older adults and children. There is no evidence for a bilingual advantage on mixing costs or overall response times in switching tasks. Although there is some evidence to support smaller switching costs for bilinguals, the majority of studies reported no differences between bilinguals and monolinguals.

### 1.3.3. Characteristics of bilingualism

Although initial studies often only included early and proficient bilinguals, recent studies have compared different types of bilinguals (e.g., different age of acquisition (AoA) or proficiency). Some studies have also examined effects of language-switching behaviour or have compared balanced to unbalanced bilinguals. Appendix A1 and A2 offer some details about the type of participants tested on inhibitory control and task-switching tasks (if these details were given). They suggest that the effects of age of acquisition and proficiency are mixed. For example, while Luk et al. (2011) only found a bilingual advantage for early but not late bilinguals on the flanker task, Pelham and Abrams (2014) found this effect for both early and late bilinguals on the ANT. Similarly for proficiency, while Linck et al. (2008) found advantages for Spanish learners on the Simon task, Poarch and Van Hell (2012) used the same task and found an effect for trilinguals, but not for language learners. Other studies have found effects for both early and late bilinguals but on different components. Tao, Marzecová, Taft, Asanowicz, & Wodniecka (2011), for example, found advantages for early but not late bilinguals on overall RTs on the ANT and positive effects for both bilingual groups on interference costs. Bak et al. (2015) observed switching advantages for early childhood bilinguals on the TEA, but selective attention effects for late childhood and early adulthood bilinguals. This could suggest that early bilingualism mainly affects switching abilities while later bilingualism places a greater demand on inhibitory control and therefore has an impact on inhibition components.

Examining effects of language switching, Verreyt, Woumans, Vandelanotte, Szmalec, & Duyck (2016) compared unbalanced bilinguals (who used one language more often than the other) to balanced switching and balanced non-switching bilinguals (this study did not include a monolingual control group). Balanced switching bilinguals showed faster RTs on a Simon and flanker task than unbalanced and balanced non-switching bilinguals, with no difference between the latter two groups. Similarly, using a task-switching paradigm, Prior and Gollan (2011) only observed smaller switching costs for a group of switching bilinguals. However, Von Bastian, Souza, & Gade (2016) assessed whether different dimensions of bilingualism (AoA, proficiency, and usage) affected performance on nine different cognitive abilities each measured through multiple tasks. They did not observe effects of AoA, proficiency, or language use. Bak, Nissan, Allerhand, & Deary (2014) also only observed small differences when they compared the impact on cognitive ageing of the active use of two languages versus low use of a second language. Furthermore, Keijzer and Schmid (2016) assessed effects of the individual bilingual's language use on various tasks and observed mixed results too. Their participants' code-switching behaviour did not correlate significantly with either Simon or Stroop costs. However, participants who used their two languages in a more separated manner (i.e., one language at home, one language outside the home) showed the smallest Simon costs.

These studies suggest that language switching and language use may affect executive control, but the results are mixed. Furthermore, while age of acquisition and proficiency of bilingual participants are often described, the actual language use is often not mentioned at all or described in very little detail. Green and Abutalebi (2013) presented their Adaptive Control Hypothesis which suggests that different types of language use can have differential impacts on executive control. According to this hypothesis, a bilingual needs different types of language use in three contexts. In the single-language context, the two languages are used separately in different contexts (e.g., one at home, one at work). The dual-language context requires use of two languages in the same context but with different speakers. This places a high demand on language control as the speaker needs to select the right language per conversation partner and can only switch at certain times (e.g., switching may occur within a conversation but is unlikely to happen within an utterance). In a dense code-switching context, the two languages can not only be used in the same context but also with the same conversation partners. In this context, language switching occurs not only frequently but also freely within both conversations and utterances and as such places lower demands on language control and monitoring. Consequently, Green and Abutalebi suggest that dual-language use should have a higher impact on executive control than dense code-switching.

Chapter 5, 6, and 7 will further discuss language use and examine its effects on both lexical processing and non-verbal executive control. These effects will be studied both by comparing bilingual groups with different types of language use as well as by manipulating language use within bilingual individuals.

### 1.4. Bilingualism and memory

Although most studies initially focused on inhibition and switching tasks, effects of bilingualism have also been studied in (working) memory tasks. However, a concrete hypothesis or theory regarding memory effects of bilingualism is lacking. In a 2009 overview, Bialystok described that “It is not clear *a priori* whether bilingualism should affect the development and functioning of memory in general, and working memory in particular” (p. 6). The findings are generally mixed (or, as described in Bialystok’s overview in 2009: ‘indifferent’). A full review of findings on memory tasks is beyond the scope of this thesis. However, it is interesting to note that, similar to inhibition and switching, the findings have been suggested to depend on the age group, the nature of the task (verbal compared to non-verbal materials) as well as the complexity of the task. For example, in Wodniecka, Craik, Luo, and Bialystok (2010), a bilingual advantage, if observed, was mainly found in older adults, non-verbal tasks, and more demanding task conditions. However, a recent meta-analysis (Von Bastian et al., 2015) concluded that there are no overall effects of bilingualism on working memory (average effect size of .06 across all conditions).

### 1.5. Bilingualism and dementia

In addition to studies examining effects of bilingualism on executive control performance in children, younger adults, and healthy older adults, other studies have investigated if and how bilingualism may affect clinical groups and cognitive decline. These studies are based on the concept of *cognitive reserve*, referring to the finding that factors such as education may 'protect' against cognitive decline. These types of mental activity have been argued to enhance plasticity and therefore to allow for healthy cognitive functioning despite the presence of pathology (e.g., Robertson, 2013). Bilingualism has been argued to be one such type of mentally stimulating activities. Bak et al. (2014) indeed found a positive effect of bilingualism against cognitive decline after controlling for childhood IQ. Assessing cognitive performance after a stroke furthermore showed normal cognition in a larger proportion of bilinguals than monolinguals (Alladi et al., 2016).

Most studies assessing bilingual-monolingual differences in clinical populations have focussed on dementia. The methodological approach to examine effects of bilingualism on dementia onset can be divided in two subtypes. In *retrospective studies,* the age of dementia onset is generally retrospectively determined through the family/carers' recall of the patient's first symptoms. The age at the first visit to a memory clinic is often included as a second measurement. In *prospective studies*, cohorts of bilinguals and monolinguals are tested multiple times in a longitudinal design. This allows for a baseline measurement at the beginning of the study, when all participants are free of dementia. The diagnosis of dementia is generally conducted by neurologists during one of the testing moments.

#### 1.5.1. Retrospective studies examining the link between bilingualism and dementia onset

The first study testing the link between bilingualism and dementia onset was conducted by Bialystok, Craik, and Freedman in 2007. Comparing 184 dementia patients (91 monolinguals, 93 bilinguals), they observed that the bilingual group on average showed a 4.1 year delay in the onset of dementia symptoms compared to monolinguals. Furthermore, bilinguals were on average 3.2 years older than monolinguals during their first visit to the memory clinic. Scores at the *Mini-Mental State Examination (MMSE),* a test of cognitive impairment, were similar for the two language groups. Similar findings were observed in a consecutive study (Craik, Bialystok, & Freedman, 2010), with a 4.3 year delay in diagnosis and a 5.1 year delay in symptom onset for bilinguals compared to monolinguals. Furthermore, in patient groups matched on age, education, and MMSE scores, the bilingual group showed greater brain atrophy in the temporal horn (an area associated with dementia) than the monolingual group. This suggests that bilingual patients were able to maintain a similar level of cognitive functioning as monolinguals despite more pathology (Schweizer, Ware, Fischer, Craik, & Bialystok, 2012).

One of the major problems with these studies concerns the confounding variable of immigrant status. While most bilinguals in these studies were immigrants, most monolinguals were non-immigrants. Although the findings were similar when re-analysed with non-immigrants only, these analyses were based on small sample sizes. Other studies have therefore attempted to address the possible link between bilingualism and dementia onset in non-immigrant cohorts. Alladi et al. (2013) tested 648 bilingual and monolingual non-immigrant dementia patients in India. Bilinguals on average showed a 4.5 year delay in the onset of dementia compared to monolinguals and this effect was found for various dementia subtypes. Similarly, but with a smaller sample size, Woumans et al. (2015a), observed a 4.8 year delay in onset for Belgian bilinguals versus monolinguals.

However, other retrospective studies did not observe significant effects of bilingualism on the onset of dementia. Clare et al. (2014) found no significant differences in bilinguals and monolinguals living in Wales. Furthermore, in a study with Spanish-English bilinguals, degree of bilingualism was associated with age of diagnosis in participants with low levels of education but not with high education (Gollan, Salmon, Montoya, & Galasko, 2011). Another Canadian study (Chertkow et al., 2010) observed a five-year delay for bilinguals in the immigrant sub-group. The subgroup with non-immigrants showed a trend towards a positive effect of speaking *more* than two languages in French native speakers. However, this effect was not significant and not found for English native speakers.

#### 1.5.2. Prospective studies examining the link between bilingualism and dementia onset

To date, two prospective studies have suggested that bilingualism may delay the onset of dementia. Kavé, Eyal, Shorek, and Cohen-Mansfield (2008) tested performance of multilingual Israeli participants on two cognitive screening tests (including the MMSE). Multilingual participants performed better than bilinguals and trilinguals, suggesting that the number of languages one speaks can affect cognitive performance. However, as the majority of older adults in Israel speaks a second language, this study could not assess a bilingual effect compared to monolinguals. In a sample with 264 monolinguals and 700 bilinguals, Wilson, Boyle, Yang, James, and Bennett (2015) found a lower risk of developing mild cognitive impairment for bilinguals than monolinguals, without differences in cognitive decline.

Most prospective studies, however, show a different pattern of results. In a recent study (Lawton, Gasquoine, & Weimer, 2015), 1789 Hispanic Americans were tested every 12 to 15 months for ten years. During this time, 81 participants developed dementia. The proportions of bilinguals and monolinguals developing dementia did not differ. Furthermore, there was no significant difference in the age of onset between bilinguals and monolinguals; if anything, monolinguals were diagnosed at a slightly later age than bilinguals. These findings were not affected by immigrant status. Another longitudinal study spanning 23 years tested Spanish immigrants in New York. In the 282 participants who developed dementia, there was no association between bilingualism and cognitive decline or dementia (Zahodne, Shofield, Farrell, Stern, & Manly, 2014). Similarly, no effects of bilingualism or language use on the onset of dementia were found in prospective studies comparing large samples of native and non-native English speakers in New York (Sanders, Hall, Katz, & Lipton, 2012), Canadian bilinguals, language learners, and monolinguals (Yeung, John, Menec, & Tyas, 2014) and second-generation Japanese-American bilinguals (Crane et al., 2010).

In summary, results from the retrospective studies suggest that bilingualism could delay the onset of dementia. Effects may be modulated by factors such as education (e.g., Gollan et al., 2011) and immigration (e.g., Chertkow et al., 2010, although Alladi et al., 2013, and Woumans et al., 2015a, showed effects of bilingualism in non-immigrant samples). Contrary to the retrospective studies, most prospective studies have not found evidence for a link between bilingualism and the onset of dementia. Prospective studies have been argued to be methodologically more robust than retrospective studies as they follow participant groups longitudinally. This may exclude possible confounds such as recall bias when patients and/or caregivers are asked to retrospectively estimate the onset of symptoms. Moreover, only including participants who visited memory clinics may lead to a selection bias (i.e., some people may be more likely to visit a memory clinic than others and there may be differences in the time between symptom onset and visiting a clinician). At the same time, prospective studies have not always included monolingual control groups and have often tested first- or second-generations of immigrants (e.g., Crane et al., 2009). Furthermore, this type of studies too may suffer from selection biases (i.e., there may be differences between those who do and do not decide to participate) and, despite a large initial sample size, the number of participants who develop dementia throughout the study cannot be controlled for and is often small. Moreover, a bias may occur in the selection of age groups as many studies do not include younger participants. Frontotemporal dementia, which has been linked to the strongest effects of bilingualism (Alladi et al., 2013), is often found in younger age groups and may therefore remain undetected. Thus, larger sample sizes, long follow-up times, and larger age ranges are needed to reach a more careful assessment of the relation between bilingualism and dementia onset (cf., Fuller-Thomson, 2015).

### 1.6. Neuronal mechanisms

Bilingual-monolingual differences have not only been studied in behavioural tasks, but also in neuroimaging studies examining potential neuronal differences between the various language groups. I will first discuss electroencephalography (EEG) and magnetoencephalography (MEG) studies, functional magnetic resonance imaging (fMRI) studies, and structural studies, followed by an evaluation of the alignment between behavioural and neuroimaging findings.

### 1.6.1. EEG and MEG studies on bilingualism and executive control

In one of the first MEG studies, young bilingual and monolingual participants completed a Simon task (Bialystok et al., 2005a). In terms of behavioural results, Chinese-English bilinguals, but not French-English bilinguals, showed faster overall RTs than monolinguals in all conditions including the control task. However, no behavioural bilingual effects were observed on the Simon cost. Bilinguals and monolinguals furthermore recruited similar brain regions in congruent and incongruent trials. The only difference between language groups was established in the association between RTs and brain activity. For monolinguals, fast RTs were associated with the middle frontal regions. For both groups of bilinguals, fast RTs were associated with increased activity in a larger network, including the superior and inferior frontal regions, superior and middle temporal regions, and cingulate regions. These correlations between RTs and brain activity were found for both congruent and incongruent trials and were interpreted as bilinguals using different brain mechanisms in conflict tasks compared to monolinguals.

EEG studies have observed differences between bilinguals and monolinguals on various event-related potential (ERP) components, but often in an inconsistent way. For example, Kousaie and Phillips (2012b) compared young bilinguals and monolinguals on a Simon, Stroop, and flanker task. No behavioural effects of language group were observed. Each task showed an effect of language group on an ERP component, but these findings were not consistent. The N2 component was analysed as a measurement of conflict monitoring and was smaller for bilinguals than monolinguals in the Stroop task, but no such effect was found in the Simon or flanker task. The P3, interpreted as reflecting stimulus categorisation, had a smaller amplitude for bilinguals in the Simon task, but peaked later for monolinguals in the Stroop and flanker task. The ERN component, taken to reflect error processing, was larger for monolinguals in the Stroop task, but smaller for monolinguals in the flanker task. Taking these three tasks together, there are some language group differences, but these are found on various components and in different directions. In combination with the absence of a behavioural effect, they do not show clear differences (let alone *advantages*) for bilinguals compared to monolinguals.

Bilingual effects also vary across EEG studies. Kousaie and Phillips (2012b) observed a smaller N2 component for bilinguals on the Stroop task. Using a similar verbal Stroop task, Heidlmayr, Hemforth, Moutier, and Isel (2015) also found a reduced negativity for bilinguals compared to monolinguals. However, this difference was not observed for the N2, but rather around the N400. Similar to Kousaie and Phillips, no behavioural differences were observed. While these two studies found smaller negativities for bilinguals than monolinguals, other studies have observed the exact opposite. Coderre and Van Heuven (2014a) found increased negative components for bilinguals than monolinguals in some conditions of a verbal Stroop task. Using a different paradigm measuring various types of inhibition, Morales, Yudes, Gómez-Ariza, and Bajo (2015), also found increased ERP peaks for bilinguals compared to monolinguals accompanied by a behavioural difference, specifically on the N2 and P3a. Similarly, Fernandez, Tartar, Padron, and

Acosta (2013) found increased N2 amplitudes for bilinguals compared to monolinguals on a go/no-go task. This furthermore correlated with L2 proficiency: More proficient bilinguals showed a larger N2 amplitude. However, no behavioural differences were observed: Both language groups were equally successful at withholding a motor response. Contrary to other studies, the authors suggest that bilinguals may use *more* inhibition than monolinguals when inhibiting a habitual response during a no-go trial.

Taking these EEG studies together, the results suggest that bilinguals and monolinguals differ in some ways on executive control tasks. The differences, however, vary within and between studies. Effects have been found on different components with different timings such as the N2 (Kousaie & Phillips, 2012b; Fernandez et al., 2013; Morales et al., 2015), a later negative component (Coderre & Van Heuven, 2014a; Heidlmayr et al., 2015), and the P3 (Kousaie & Phillips, 2012b; Morales et al., 2015). In some studies, these differences refer to a larger peak for bilinguals, while in others they concern reduced amplitudes for bilinguals. While some studies observe these ERP differences accompanied by some behavioural effects (Coderre & Van Heuven, 2014a; Morales et al., 2015), others did not observe behavioural differences (Kousaie & Phillips, 2012b; Fernandez et al., 2013; Heidlmayr et al., 2015).

### 1.6.2. fMRI studies on bilingualism and executive control

Similar brain regions may be activated in both executive control tasks and language control tasks (such as language switching) in bilinguals (e.g., De Bruin et al., 2014; De Baene et al., 2015). More generally, Abutalebi and Green (2007) proposed a network of brain regions involved in both cognitive and language control. This includes the prefrontal cortex, anterior cingulate cortex (ACC), basal ganglia, and inferior parietal lobe. This model largely concerns language control in bilinguals only. However, more recent fMRI studies aimed to examine bilingual-monolingual differences in brain regions activated during non-verbal executive control tasks. Several of these have examined non-verbal task-switching performance. Testing younger adults, Garbin et al. (2010) found a reduced switching cost for bilinguals over monolinguals accompanied by different brain activation patterns. Bilinguals mainly showed activation in the left inferior frontal gyrus (IFG). Increased activation in this area as well as the striatum was related to smaller switching costs. Compared to bilinguals, monolinguals showed increased activation in the right IFG and anterior cingulate cortex (ACC). Using a similar paradigm, Rodríguez-Pujades et al. (2013) found increased activation for bilinguals in the left IFG and left caudate compared to monolinguals. No differences were found in the right IFG, ACC, or right caudate, and participant groups did not differ on behavioural switching costs.

On these tasks, older adults have been found to over-recruit the frontoparietal network compared to younger adults (e.g., Madden, 2007). Gold et al. (2013a) identified seven brain regions that showed increased activity in older people on a non-verbal task-switching paradigm and that were related to diminished behavioural performance: Bilateral dorsolateral prefrontal cortex (DLPFC) and ventrolateral prefrontal cortex (VLPFC), bilateral supramarginal gyrus (SMG), and ACC. Older adults showed more activity in these areas than young adults. Activation in three of these areas (left DLPFC, left VLPFC, and ACC) was furthermore modulated by language group, with bilinguals showing less activity than monolinguals. This language group effect was only obtained for old, but not for young adults. Older bilinguals also showed a (non-significant) behavioural advantage compared to monolinguals in terms of switching costs. Older bilinguals thus had lower activity in these areas than monolinguals, while outperforming them behaviourally. This suggests that older people indeed over-recruit brain areas related to executive control and that this over-recruitment can be diminished by bilingualism.

Studies using inhibition tasks have also observed differences in brain activation between bilinguals and monolinguals. In groups of older adults performing a Simon task (Ansaldo, Ghazi-Saidi, & Adrover-Roig, 2015), no behavioural differences were observed. However, bilinguals showed more activation in the left inferior parietal lobule, while monolinguals had increased activation in the right middle frontal gyrus (MFG). The authors argue that while monolinguals showed the additional recruitment in frontal areas often observed in older adults, this shift was not required in the bilingual group to process the Simon task.

In groups of younger adults completing a flanker task, Luk et al. (2010) also observed different patterns of brain activation. On the one hand, monolinguals mainly activated the left temporal pole and superior parietal cortex during incongruent trials. On the other hand, bilinguals showed increased activation in a large network including bilateral frontal, temporal, and subcortical regions during incongruent trials. However, again no behavioural differences were observed between monolinguals and bilinguals. Despite the absence of behavioural differences, the authors argue that bilinguals process the flanker task differently than monolinguals in terms of brain activation. Using a similar task paradigm, Abutalebi et al. (2012) compared performance across two sessions. RTs showed no difference between bilinguals and monolinguals across the sessions and even a slight bilingual disadvantage in the first session. Comparing the two sessions, however, bilinguals showed decreased RTs in session 2 compared to 1, while this effect was not found for monolinguals. The second session, furthermore, showed less ACC activation during conflict trials for bilinguals than monolinguals. Testing groups of bilingual and monolingual children as well as L2 learners on a Simon and Stroop task, Mohades et al. (2014) found increased activation for both bilinguals and L2 learners in the left superior temporal gyrus and right MFG on the Simon task. On the Stroop task, increased activation for both bilingual groups was found on the ACC. However, it should be noted that bilinguals showed a behavioural *disadvantage* compared to monolinguals.

Thus, differences between bilinguals and monolinguals in fMRI studies have mainly been observed in frontal areas (bilateral IFG, DLPFC, and VLPFC), and the ACC. It is noteworthy that these areas are similar to the ones proposed by Abutalebi and Green (2007). If differences in activation in the ACC are observed, these effects typically point to increased activation for monolinguals (Garbin et al., 2010; Abutalebi et al., 2012; Gold et al., 2013a). Mohades et al. (2014) form an exception with increased activation for bilinguals who also showed a behavioural disadvantage compared to monolinguals. Findings regarding frontal areas are more inconsistent. While Garbin et al. (2010) and Rodríguez-Pujades et al. (2013) observe increased activation in the left frontal areas for bilinguals in young adults, Gold et al. (2013a) observe decreased activation in left frontal areas for older bilinguals (see Table 1.1). Furthermore, while all discussed studies showed differences in brain activation, the majority showed no effect of bilingualism or even a disadvantage.

### 1.6.3. Structural studies on bilingualism and executive control

Differences in grey and white matter between bilinguals and monolinguals have been studied too. It has been suggested (e.g., with taxi drivers, Maguire et al., 2000) that experience can change brain plasticity and can increase grey matter volume in experience-related areas. In a recent paper, García-Pentón, Fernández García, Costello, Duñabeitia, and Carreiras (2016) reviewed studies examining effects of bilingualism on grey and white matter. Overall they conclude that "the picture is still too blurry and definitely less clear than expected, with very few data points and not enough consistent findings across studies." (p.45).

Effects of bilingualism on grey matter density have been found in various areas, including the inferior parietal lobule (Mechelli et al., 2004; Abutalebi, Canini, Della Rosa, Green, & Weekes, 2015), cerebellum (Pliatsikas, Moschopoulou, & Saddy, 2015), left anterior inferior temporal gyrus, bilateral temporal pole, bilateral orbito-frontal cortex (Abutalebi et al., 2014), bilateral ACC (Abutalebi et al., 2015), left putamen (Abutalebi et al., 2013), and left caudate nucleus (Zou et al., 2012). In four further studies (Grogan et al., 2012; Ressel et al., 2012; Gold, Johnson, & Powell, 2013b; Olsen et al., 2015) no differences were observed in grey matter. Thus, although grey matter differences have been found in some areas also indicated in fMRI studies (e.g., the striatum and ACC), these findings all differ across studies. Apart from the inferior parietal lobule, no area was linked to bilingual-monolingual differences in more than one study.

In terms of white matter, differences have been found more consistently and predominantly occur in two areas: The corpus callosum (Luk et al., 2011; Gold et al., 2013b; Pliatsikas et al., 2014; Mohades et al., 2012); and the inferior fronto-occipital fasciculus (IFOF, Luk et al., 2011; Gold et al., 2013b; Cummine & Boliek, 2013; Pliatsikas et al., 2014; Mohades et al., 2012). However, even though similar areas have been observed consistently, the direction of the effect is unclear. In some studies, bilinguals show increased connections in the corpus callosum (e.g., Luk et al., 2011; Pliatsikas et al., 2015) while others observe lower values (e.g., Mohades et al., 2012; Gold et al., 2013b). Similarly, for the IFOF, some observe increased (e.g., Luk et al., 2011; Mohades et al., 2012; Pliatsikas et al., 2014) and others decreased (e.g., Cummine & Boliek, 2013; Gold et al., 2013b) white matter for bilinguals.

Structural studies have also been used to test for effects of second-language learning. Stein et al. (2012) followed participants learning German in Switzerland. At the end of their five month stay, second-language learners showed an increased grey matter density in the left IFG and left anterior temporal lobe that correlated with their L2 proficiency. Changes in white matter have also predominantly been found within or in connections between frontal regions (Schlegel, Rudelson, & Peter, 2012; Mårtensson et al., 2012), the striatum (Schlegel et al., 2012; Hosoda, Tanaka, Nariai, Honda, & Hanakawa, 2013), superior temporal gyrus (Mårtensson et al., 2012; Hosoda et al., 2013), and hippocampus (Mårtensson et al., 2012).

### 1.6.4. Alignment and valence ambiguity

Neuroimaging studies are a valuable method to investigate the biological mechanisms that underlie language and cognition (Vaughn, Greene, Nunez, & Hernandez, 2015; Van Heuven & Coderre, 2015). They can inform us about the locations in the brain that could be associated with bilingualism. Identifying structural differences between bilinguals and monolinguals in the brain is an interesting question on its own and is often also posed separate from the 'bilingual advantage' question. Still, in other cases, neuroimaging data have been used as a means to provide evidence towards models of bilingualism and cognition. *Differences* in structures or brain areas activated do not imply a bilingual advantage or more efficient processing per se. We should therefore be careful in our interpretation of these studies for three main reasons. Firstly, there is no direct mapping between the location of a brain area and cognitive processes. Finding a difference in a certain brain area therefore does not necessarily provide information about the cognitive process involved (cf., Duñabeitia & Carreiras, 2015). Language and cognitive control have been associated with a wide range of brain areas (cf., Abutalebi & Green, 2007) that include much of the frontal, parietal, and subcortical areas of the brain. Finding a difference in one of these areas can therefore not easily be assigned to a specific cognitive process. Furthermore, similar brain areas may be involved in language control and non-verbal cognitive control (e.g., Abutalebi & Green, 2007). Thus when bilingual-monolingual differences are observed in these frontal, parietal, and subcortical regions, we do not know whether these relate to cognitive control, language control, or both.

Secondly, even when similar effects are observed, these are sometimes found in combination with a behavioural effect and other times in the absence of behavioural differences. Thus, an alignment between brain studies and behavioural findings is often lacking (cf., Paap et al., 2015). A difference in neuroimaging studies suggests that bilinguals and monolinguals use different neuronal mechanisms to process a task or that they have differences in anatomical structures in areas related to language and cognitive control. However, in the absence of a behavioural difference, does this also mean that they process executive control tasks more efficiently? Neuroimaging studies are often included in overviews of studies supporting the existence of a bilingual advantage. However, the alignment issue is not always addressed carefully enough. Kroll and Bialystok (2013, p. 499), for example wrote that "Executive function advantages for bilinguals have been demonstrated in behavioural evidence as well as neuroimaging using MEG (Bialystok et al., 2005)." The behavioural data referred to, however, show no reliable behavioural effect of bilingualism (a difference was only found in one of the two bilingual groups and was also found in the baseline condition). The MEG data can at best be argued to show a *difference* between the two language groups. Luk et al. (2010) also reach a conclusion that was not supported by their actual data (namely a difference in brain activation, but no effect of bilingualism on RTs). They conclude that "[this] suggests that bilinguals can recruit this control network for interference suppression more effectively than monolinguals, consistent with their tendency to show less interference in terms of RTs" (p. 356). Yet, the measurement of interference (an interaction between trial and language group) in their paper shows an *F* value smaller than 1. Therefore, bilinguals cannot be argued to have shown a tendency to show less interference in terms of RTs in this paper.

Lastly, the ERP components, brain areas, or structures related to the bilingual-monolingual differences differ across studies. Differences have been observed in many different areas and components, but not always in the same areas, components, or directions in more than one study. Table 1.1 shows that some areas/structures yield more consistent results than others. For instance, the ACC has relatively consistently shown increased activation for monolinguals while grey matter in the IPL has been associated with increases for bilinguals. For other regions, the findings are discrepant. For instance, whereas Gold et al. (2013b) found decreased connectivity values in the corpus callosum (CC) for bilinguals, Luk et al. (2011) found increased values in the CC for bilinguals compared to monolinguals. In both studies, bilinguals and monolinguals showed no differences on neuropsychological tests including executive control tasks (Treccani & Mulatti, 2015). Despite the absence of behavioural differences and despite the opposing directions in neuroanatomical data, both studies interpret these findings as showing the brain mechanisms underlying cognitive benefits for bilinguals. The interpretation of these data is thus ambiguous (also referred to as 'valence ambiguity', Paap et al., 2015) when some researchers interpret increased neural values as positive and others judge them to be negative.

Neuroimaging data alone are not going to solve the debate on the behavioural bilingual advantage, but comparing results across different approaches will hopefully lead to a better and more detailed understanding of the cognitive processes involved in bilingual language processing as well as the potential impact of bilingual language processing on cognitive processes[2].

[2] This paragraph is based on de Bruin, A., & Della Sala, S. (2016). The importance of language use when studying the neuroanatomical basis of bilingualism. *Language, Cognition and Neuroscience, 31*(3), 335-339.

Table 1.1

*Overview of studies showing increases for monolinguals or bilinguals in terms of activation observed in fMRI experiments, grey matter, or white matter. This overview is only meant as a comparison of opposite effects across studies and as such only includes (comparable) areas that have been observed in multiple studies. Abbreviations refer to the following regions: ACC = anterior cingulate cortex; CC = corpus callosum; DLPFC = dorsolateral prefrontal cortex; IFG = inferior frontal gyrus; IFOF = inferior fronto-occipital fasciculus; IPL = inferior parietal lobule; MFG = middle frontal gyrus; SPC = superior parietal cortex; VLPFC = ventrolateral prefrontal cortex.*

| | **Monolinguals show increase** | **Bilinguals show increase** |
|---|---|---|
| **fMRI studies** | | |
| ACC | Garbin et al. (2010)<br>Abutalebi et al. (2012)<br>Gold et al. (2013a) | Mohades et al. (2014), accompanied by a behavioural disadvantage |
| Left frontal areas | lDLPFC & lVLPFC (Gold et al., 2013a) | lIFG (Garbin et al., 2010; Luk et al., 2010; Rodríguez-Pujades et al., 2013)<br>lMFG (Luk et al., 2010) |
| Right frontal areas | rIFG (Garbin et al., 2010)<br>rMFG (Ansaldo et al., 2015) | rMFG (Luk et al., 2010; Mohades et al. (2014) |
| Left parietal | lSPC (Luk et al., 2010) | lIPL (Ansaldo et al., 2015) |
| **Grey matter** | | |
| IPL | | Mechelli et al. (2004)<br>Abutalebi et al. (2015) |
| **White matter** | | |
| CC | Mohades et al. (2012)<br>Gold et al. (2013b) | Luk et al. (2011)<br>Pliatsikas et al. (2015) |
| IFOF | Gold et al. (2013b) | Luk et al. (2011) |

| | | |
|---|---|---|
| | Cummine & Boliek (2013) | Mohades et al. (2012)<br>Pliatsikas et al. (2014) |

### 1.7. Summary

In summary, possible advantageous effects of bilingualism have been tested in multiple domains, including inhibitory control, task switching, working memory, onset of dementia, and neuronal mechanisms. In all domains, the effects of bilingualism are at best inconsistent. An analysis of commonly used inhibition tasks showed that less than one-third of published analyses showed a positive effect of bilingualism. The exact nature of this effect is unclear as findings were reported on interference costs or overall RTs, but rarely on both within one study. However, effects appear to be found most often in more demanding tasks and in groups of older adults. For task-switching studies, no overall effects of bilingualism were seen in mixing costs or overall RTs. Similar to inhibitory control studies, approximately one-third of the analyses showed an effect of bilingualism on switching costs. Regarding the onset of dementia, the outcome of studies appears to depend on the method used. While many retrospective studies have suggested that bilingualism can delay the onset of dementia, most prospective studies have not found such an effect. Lastly, inconsistent effects of bilingualism have been found in neuroimaging studies too. Although most studies found some type of bilingual-monolingual effect, they differ in terms of ERP components and brain regions. Furthermore, in the absence of a behavioural finding it is difficult to interpret the link between bilingualism and cognition in these studies.

The current literature thus shows that effects of bilingualism are not consistently observed. Their presence may depend on task difficulty, age groups, and the methodology used. In the next chapter, I will discuss some issues related to these published studies, including the theoretical frameworks used and the quality of matching participant groups on background variables.

# Chapter 2. Evaluation of the literature on bilingualism and executive control

Parts of this chapter (as indicated in footnotes) are based on:

De Bruin, A., Bak, T. H., & Della Sala, S. (2015). Examining the effects of active versus inactive bilingualism on executive control in a carefully matched non-immigrant sample. *Journal of Memory and Language*, *85*, 15-26.

*Author contribution: All authors contributed to the study concept and design. Data collection and analysis were performed by A. de Bruin. A. de Bruin drafted the manuscript and T. H. Bak and S. Della Sala provided critical revisions.*

De Bruin, A., & Della Sala, S. (2015). The decline effect: How initially strong results tend to decrease over time. *Cortex, 73*, 375-377.

*Author contribution: A. de Bruin drafted the manuscript and S. Della Sala provided critical revisions.*

De Bruin, A., & Della Sala, S. (2016). The importance of language use when studying the neuroanatomical basis of bilingualism. *Language, Cognition and Neuroscience, 31*(3), 335-339.

*Author contribution: A. de Bruin drafted the manuscript and S. Della Sala provided critical revisions.*

Chapter 1 offered an overview of published studies examining effects of bilingualism on lexical tasks, executive control tasks (predominantly inhibition and task switching), onset of dementia, and neuronal mechanisms. Effects of bilingualism are often inconsistent and can vary within as well as between studies. In behavioural tasks, the effects can be observed in interference costs, switching costs, or overall RTs. The inconsistency with which effects of bilingualism have been observed and the varying appearances when effects are found have also led to changes in theoretical interpretations. Furthermore, the quality of studies on this topic has been criticised heavily in the past few years. This chapter will firstly discuss theoretical frameworks on bilingualism and executive control as well as the change in interpretations. This will be followed by a discussion of some of the main points of criticism on the current literature, including issues with biases and ill-matched participant groups.

## 2.1. Changing perspectives on the nature of a bilingual advantage

### 2.1.1. Early frameworks: inhibition

The initial framework (predominantly tested by Bialystok and colleagues) focused on a bilingual advantage on inhibition in particular. This framework argued that if the two languages of a bilingual are always active, this daily practice in verbal inhibitory control should lead to an advantage on non-verbal inhibition tasks too. In 2004, Bialystok and colleagues published three studies that specifically looked at (different aspects of) inhibition. Bialystok and Senman (2004) tested children on several executive control tasks and concluded that the bilingual advantage observed "is attributed to the advanced inhibitory control that comes with bilingualism" (p. 562). Another statement says that "past research with similar children has consistently shown the superiority of bilinguals in solving tasks requiring inhibition of attention" (p. 577). Bialystok and Martin (2004) made a further division between *response inhibition* and *interference suppression*. Their results suggest that bilingual children only had an advantage in interference suppression, but not in response inhibition. According to their conclusions, "bilinguals have better inhibitory control for ignoring perceptual information than monolinguals do." (p. 325). A similar conclusion was reached by Craik and Bialystok in two reviews in 2005 and 2006. Again, these reviews concluded that "the bilingual advantage is attributable to greatly increased practice in suppressing a coherent set of internal representations and their links to inputs and responses." (2005, p. 223). In 2009, Bialystok again stated that the explanation for the bilingual advantage in executive control "is the need to resolve the conflict from jointly activated languages and the involvement of the frontal executive system to resolve that conflict" (p. 61). These early studies thus focus on inhibition and attribute the bilingual advantage to enhanced inhibition in particular.

### 2.1.2. Later frameworks: general monitoring/flexibility

If bilinguals indeed have an advantage in inhibition in particular, this advantage should only appear on conflict trials (also called incongruent trials, i.e., the trials that actually require inhibition). Enhanced performance should then be reflected in decreased Simon or flanker costs for bilinguals. However, as discussed in Chapter 1, effects of bilingualism are not only found on interference costs, but also on overall RTs (congruent and incongruent trials together, e.g., Bialystok et al., 2004). In other studies, effects are not found on interference costs at all but only for overall RTs (e.g., Bialystok, 2006; Bialystok & DePape, 2009).

From 2007 onwards (see Figure 2.1), Bialystok's papers more concretely acknowledge a potentially broader effect of bilingualism. In 2010, Bialystok et al. noted that "Early speculation pointed to advanced inhibitory control as the mechanism (e.g., Bialystok, 2001), but that explanation may be too narrow" (p. 487). In 2010, they furthermore published a paper mentioning 'beyond inhibition' in the title (Bialystok, 2010) and concluded that there is no specific component leading to a bilingual advantage.

The strongest claims appeared in 2012 and 2013, where Bialystok clearly differentiated herself from earlier claims regarding an advantage on inhibition in particular.

She argued that (Bialystok, Craik, & Luk, 2012, p. 245):

> "Inhibitory control was suggested as the relevant mechanism in early studies (Bialystok et al., 2004; Green, 1998) and continues to be endorsed by some researchers (Kroll et al., 2008; Philipp et al., 2009). One problem with this account, however, is the recurrent finding in congruent trials (for which

> there is no conflict) as well as incongruent trials. Minimally, therefore, inhibition alone is insufficient to explain bilingual processing differences."

This view was further established by Kroll and Bialystok (2013). Here, they argued that we should not try to link bilingualism to one component of executive control only, as individual executive control tasks always include multiple components (e.g., a Stroop task is not a pure measurement of inhibition only). They also admitted that their initial approach might have been wrong in this respect:

> "Early research on the cognitive consequences of bilingualism did attempt to reduce the observations to differences in known components. Thus, an initial hypothesis was that bilinguals were better than monolinguals at inhibiting interference because of their practice in inhibiting attention to the non-target language (e.g., Bialystok, 2001). However, the limitations of this explanation were apparent very early. […] Our point is that the relations between complex task performance and complex individual characteristics cannot be reduced to unitary relationships." (p. 500)

Rather than looking at specific types of executive control, they advocated using a more holistic approach to tasks. This approach is related to Miyake and Friedman (2012) advocating a more general approach with a core executive control component rather than three separate subcomponents (inhibition, shifting, and updating). Indeed, Bialystok and Kroll stressed that

> "Recently, Miyake and Freedman *[sic]* (2012) acknowledged what they call the 'unity and diversity' of executive control, with a common core shared by the component processes and unique features of different parts of the system." (Kroll & Bialystok, p. 500)

Yet, while they acknowledge that effects of bilingualism may be more complex, a more specific framework is lacking.

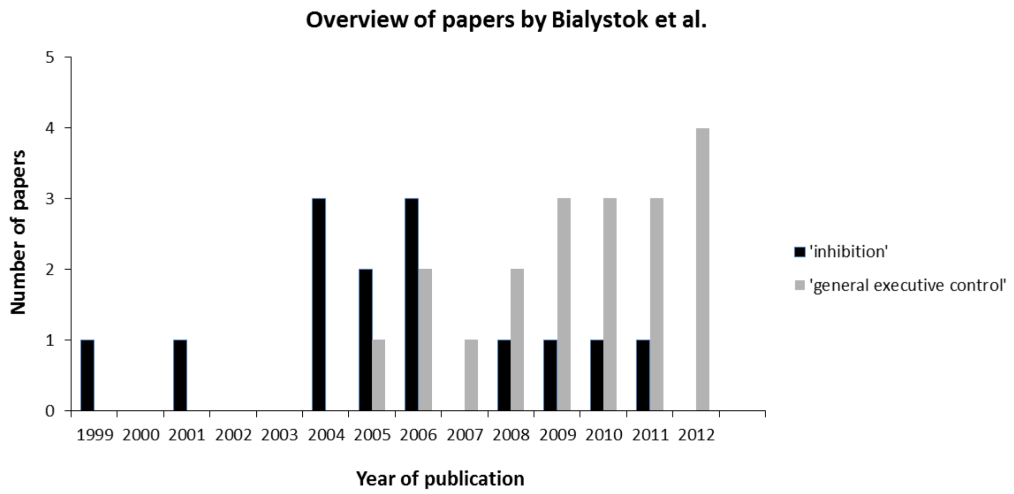


*Figure 2.1.* Overview of papers published by Bialystok between 1999 and 2012 on the topic of bilingualism and executive control (see Appendix B1 for the list of included papers). 'Inhibition' papers are those papers that interpret effects as a bilingual advantage on inhibition/interference suppression in particular. 'General executive control' papers are those papers that do not focus on inhibition in particular, but rather interpret effects as improved monitoring/coordination/mental flexibility (this includes a wide variety of theories and explanations, but all are broader than inhibition). Studies testing the onset of dementia, lexical control, task switching, or working memory are not included in this overview.

Work by Bialystok and colleagues has thus shifted from a focus on inhibitory control to a broader approach examining effects of bilingualism on executive control as a whole. This change in theoretical framework appeared in work of other research groups too. Costa et al. (2009) found that bilinguals only had an advantage in the high monitoring versions of a flanker task (with a relatively equal distribution of congruent and incongruent trials), but not in low monitoring conditions (with a high or low percentage of incongruent trials). While an effect of bilingualism on the flanker effect was absent in most task versions, an advantage was found on congruent and incongruent trials together. They therefore argued that bilinguals are enhanced in conflict *monitoring* rather than conflict *resolution*. This could be the result of the bilingual's practice in monitoring the circumstances to select the most appropriate language in a given context and dialogue. They furthermore argue that, if bilinguals are enhanced in conflict monitoring, this advantage should show in both congruent and incongruent trials; in mixed, but not blocked contexts; and in high, but not low demanding conditions.

Hilchey and Klein (2011) presented a review of studies on bilingualism and executive control discussing effects of bilingualism on inhibition specifically versus on global RTs. Their BICA ('bilingual inhibitory control advantage') hypothesis proposes that bilinguals are enhanced in inhibitory control specifically. An effect of bilingualism should then be observed on interference costs (e.g., Simon or flanker effect). Their BEPA ('bilingual executive processing advantage') hypothesis suggests that bilinguals have an advantage on global RTs. According to this hypothesis, bilinguals should be enhanced on both congruent and incongruent trials in a conflict task. Based on a review of 31 studies across 13 papers, Hilchey and Klein concluded that a bilingual advantage on interference effects (i.e., inhibitory control) appears to be elusive in children and young adults. In older adults, these effects can be "surprisingly large […] despite not being consistently observed" (p. 644). In contrast, they conclude that a bilingual advantage on global RTs appeared "strikingly often" (p. 641). This overview thus suggests that a bilingual advantage may not concern inhibitory control, but rather a more global processing advantage.

In summary, the research on bilingualism and executive control has seen a shift in theoretical frameworks. The initial framework hypothesised that effects of bilingualism should appear on inhibitory control in particular. Driven by the finding that bilingual effects do not always appear on interference costs but also/only on overall RTs, new frameworks have been suggested. These approaches suggest that the bilingual advantage may concern conflict monitoring (e.g., Costa et al., 2009), coordination of multiple tasks (e.g., Bialystok, 2011), or executive processing (e.g., Hilchey & Klein, 2011). Some of these frameworks posit concrete hypotheses. For instance, according to the conflict monitoring approach, bilingual advantages should occur in high but not low demanding conflict conditions. Other recent 'theories', however, are less specific and argue that a bilingual advantage should occur on cognitive flexibility in general (e.g., Kroll & Bialystok, 2013).

## 2.2. Issues affecting the literature on bilingualism and executive control

### 2.2.1. Lack of theoretical framework

While new data (e.g., the finding that bilingual effects occur on overall RTs) can enforce changes in theoretical frameworks, we should ensure that new theories are concrete and allow for the formulation of specific hypotheses. Terms such as ‘cognitive flexibility’ are not concise and any type of bilingual effect on any type of executive control task could be interpreted as supporting increased flexibility. Considering the inconsistency with which effects are observed, a more concrete theoretical model is needed to both predict and interpret effects of bilingualism. Several researchers have therefore criticised the lack of a clear theoretical framework. For example, in her commentary entitled ‘What is the theory?’, Debra Jared (2015) argues that the current literature is more task- than theory-driven. She states that without an underlying theoretical framework, it becomes difficult to choose appropriate tasks and to interpret effects. Many studies find an effect of bilingualism on some but not all tasks or in some participant groups but not others. Some find an effect on interference costs and others on overall RTs. In some instances, these effects are found in accuracy and in other cases in response times. Thus, even though multiple studies may find some effects of bilingualism, these effects are rarely found on the same tasks or analyses. How do we interpret these findings? Do all effects support a bilingual advantage, even though they are not consistent across studies? Without a theoretical framework, these outcomes are difficult to interpret (cf., Treccani & Mulatti, 2015, for a similar argument).

### 2.2.2. Replications and decline effect

Another key issue affecting this field is the failure to replicate effects of bilingualism. Several studies with large sample sizes (e.g., Paap & Greenberg, 2013; Antón et al., 2014; Duñabeitia et al., 2014) have not observed any effects of bilingualism on various executive control tasks. Paap et al. (2015) estimated that more than 80% of studies conducted after 2011 do not show a bilingual effect on inhibition or switching tasks. Furthermore, they noticed that effects of bilingualism were predominantly found in studies with smaller sample sizes. A similar conclusion is drawn by Hilchey, Saint-Aubin, & Klein (2015). In 2011, Hilchey and Klein still concluded that their review showed limited evidence for an inhibitory effect of bilingualism, but 'robust' evidence for a global bilingual advantage. In their updated review, however, they conclude that the evidence for a global advantage has evaporated since their initial review. This change in conclusions is compatible with an analysis by Klein (2015), who compared RTs on Simon and flanker tasks between bilinguals and monolinguals. Large bilingual-monolingual differences were predominantly found in earlier studies, but less so in recent publications. Indeed, when we examine the support for a bilingual advantage, we see a decline in studies supporting this effect[3]. Figure 2.2 shows an overview of studies on bilingualism and executive control published between 2004 and 2015. Publications were found through a PubMed and Scopus search using the keywords 'bilingual executive', 'bilingual cognitive', and 'bilingual advantage' and included a wide range of

[3] This overview has been published in de Bruin, A., & Della Sala, S. (2015). The decline effect: How initially strong results tend to decrease over time. *Cortex, 73*, 375-377.

executive control tasks (see Appendix B2 for the list of included publications). Based on the overall conclusions presented in these papers, I classified them as ‘supporting’ or ‘challenging’ a bilingual advantage, or as ‘mixed’ if no conclusion was drawn[4]. The pattern of supporting versus challenging studies has indeed changed over time. Whereas earlier studies largely supported a bilingual advantage, recent years (especially 2014) have shown an upsurge in studies challenging this view, either with mixed results or by showing no bilingual advantage.

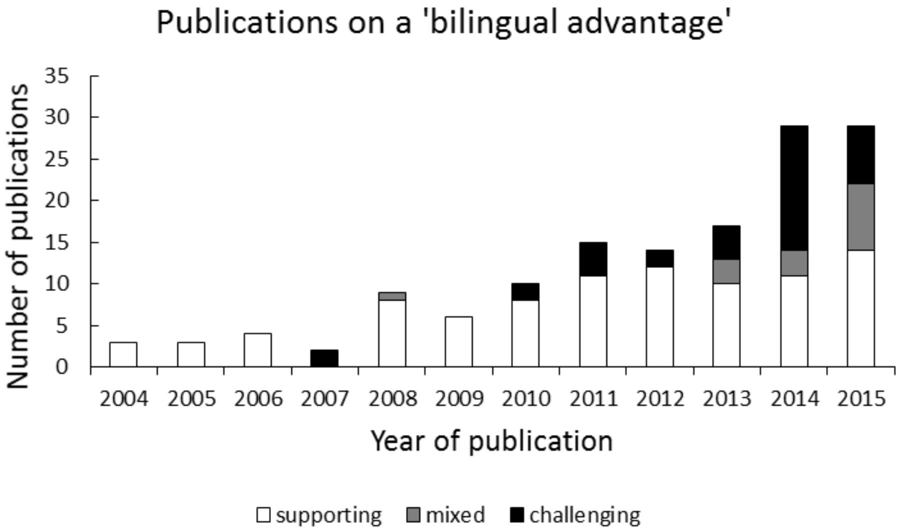


*Figure 2.2.* Overview of 141 studies examining bilingualism and executive control published between 2004 and 2015. The types (‘supporting’, ‘mixed’, ‘challenging’) are based on the overall conclusions of the paper rather than on results of individual tasks.

[4] Contrary to Paap et al.’s overview based on individual tasks and comparisons, I based this classification on overall conclusions. Some papers were classified as ‘supporting’ even if the results included null effects. Figure 2.2 is therefore likely to give an exaggerated impression of the actual effects of bilingualism.

A decrease in positive evidence after a strong initial finding is not uncommon in science and is dubbed the 'decline effect'. In many research fields, initial studies have shown large effects whereas later studies struggle to replicate these findings or only find effects in restricted circumstances. For example, the decline effect accounts for the lack of confirmation of a widely used treatment for autism (Carter et al., 2011, linked to the decline effect by Ozonoff, 2011), of the link between depression and left-hemisphere lesion in stroke (Carson et al., 2000), of the link between type D personality and mortality rates (Coyne & De Voogd, 2012), and has been observed in several clinical (Ioannidis, 2006) and experimental psychology studies (Francis, 2012).

Several explanations for this decline effect have been suggested (cf., Schooler, 2011, and Lehrer, 2010). One common statistical explanation is regression to the mean: If initial measurements show an inflated effect size due to errors, statistical self-correction will lead to results closer to the average in subsequent measurements. Changes in methodology and research practices could also contribute to a decline effect. Whereas initial findings are often reported with smaller sample sizes, follow-up studies tend to include more participants. Considering that larger studies have been associated with smaller effect sizes (McMahon, Holly, Harrington, Roberts, & Green, 2008), this could explain part of the decline in effect sizes. Furthermore, due to publication pressure, studies are often reported with only one experiment without self-replication. Especially in combination with selectively reporting only those experiments that work, replication in follow-up studies may prove to be difficult.

In the literature on bilingualism and executive control, the attempt to establish the boundaries of a bilingual advantage may also have led to an increase in null effects and mixed results. Recent studies have examined the limits of a bilingual effect through the use of different types of tasks, different methodologies, and different populations that often do not show an effect of bilingualism. This is likely to have increased the amount of null results as well as mixed results in the past years.

### 2.2.3. Publication bias

Another reason to explain this decline effect could be the presence of a publication bias: Studies with positive results are more likely to be published than studies with null or negative results. It is difficult to publish null effects or small effect sizes when a new hypothesis is tested for the first time. Initial effects are therefore usually positive and large. However, when a theory becomes more established, challenging studies may become more interesting and easier to publish. The overview in the first chapter as well as the discussion in the second chapter are largely or only based on published studies. In the field of bilingualism too, there is a large amount of studies that have been conducted but not (yet) published. Even in published studies, there is some evidence for file drawing (i.e., leaving out tasks that do not show the required finding). For example, Prior and MacWhinney (2010) only discuss the results of their task-switching paradigm but leave out the flanker and Simon tasks that did not show an effect of bilingualism. In Chapter 3, I will discuss evidence for the presence of a publication bias in the field of bilingualism and executive control.

The decline effect, publication bias, and difficulties replicating earlier findings of bilingualism do not mean that the effect does not exist. Rather, it explains how evidence for a phenomenon can change over time and how initially strong findings are likely to be challenged in later studies. However, it should encourage researchers to critically evaluate published findings. The interpretation of the current literature is biased if we only have access to positive studies. For research to progress, it is essential to unbiasedly report all results regardless of the outcome[5].

#### 2.2.4. Interpretation of the data

Data are often over-interpreted by researchers (cf., Boutron, Dutton, Ravaud, & Altman, 2010) and the bilingualism literature is no exception in this respect. Bialystok et al. (2008), for example, state in the abstract that “bilinguals performed better on executive control tasks” (p. 859). In this study, old and young bilinguals were tested on three different executive control tasks. The first task, SART, showed no group differences. The Stroop task showed some differences, but inconsistently across young and old adults. The Simon task showed no advantage for young adults

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[5] Paragraph 2.2.2 and 2.2.3 are largely based on de Bruin, A., & Della Sala, S. (2015). The decline effect: How initially strong results tend to decrease over time. *Cortex, 73*, 375-377.

and only an advantage on the Simon effect for older adults. Bialystok et al. (2008) acknowledge in the discussion session that bilinguals only showed some advantages, that the effect sizes are small to medium, and that the data show "some deviation and anomalies" (p. 869). Still, the main message of the paper is that bilinguals show enhanced cognitive control. Similarly, Wodniecka et al. (2010) conclude in the abstract that "older bilingual adults did show such an advantage [on working memory, AdB], especially on non-verbal tasks" (p. 575). Again, looking at the data, an effect of bilingualism was only found in some of the working memory tasks and, if present, only in certain parts of those tasks (i.e., the most difficult task versions).

In their review, Paap et al. (2015) point out the importance of testing for interactions. Rather than just stating that an effect was found in one condition but not in the other, this needs to be confirmed by the presence of a significant interaction. The pattern of an interaction matters too. This is supported by Wagenmakers (2015), who emphasises that the pattern of an interaction has to be examined before conclusions are drawn about the nature and direction of an effect. If bilinguals are better at interference suppression, the bilingual-monolingual difference on interference costs should be driven by the conflict trials (i.e., the incongruent trials) and not purely by non-conflict trials (i.e., congruent trials). This is not always the case. For example, in Schroeder and Marian (2012), bilinguals are argued to be better at interference suppression in a Simon task than monolinguals: "Results from the experimental condition suggested that bilinguals exhibited more efficient inhibitory control than monolinguals" (p. 597). However, this effect is purely driven by monolinguals being faster on congruent trials than bilinguals. On the incongruent trials, there is no difference between the two language groups.

Thus, effects of bilingualism are over-interpreted in several papers. Yet, more extremely, even null effects have been interpreted as possibly showing beneficial effects of bilingualism. In their review paper, Kroll and Bialystok (2013) argue that "not observing a bilingual effect for young adults does not mean that there are no consequences of their language experience". (p. 503). Arguing that a bilingual effect exists even if it cannot be observed in experiments is, of course, extremely problematic for data interpretation. In another statement, they furthermore argue that

> "The considerable literature that reports group differences between monolingual and bilingual participants is greatly more informative than the attempted replications that fail to find significance […]. Failures to replicate are important because they require that additional complexity be assumed to provide a comprehensive account of the larger body of evidence. But unless all conditions have been accounted for and all other explanations have been exhausted, it is misleading to call into question the reliability of the phenomena themselves." (p. 502, 503)

The latter argument also applies to studies that *do* find a bilingual advantage as will be discussed in the next paragraph.

### 2.2.5. Matching language groups on background variables

An important issue in between-group comparisons, and thus concerning most studies on bilingualism and executive control, is the extent to which groups are matched on background variables. To truly study bilingualism, bilingual and monolingual groups should only differ in the number of languages that they speak. In many studies, especially the earlier ones, this is not the case. Bilingual and monolingual groups have, for example, been found to differ on socio-economic status, education, genetics, country of origin, and immigrant status (see Table 2.1 for several examples).

**Socio-economic status and education**

Especially in earlier studies, socio-economic status (SES) was often not explicitly controlled for. Even though this issue was already criticised by Peal and Lambert in 1962, Morton and Harper (2007) were among the first in recent years to re-emphasise the need for well-matched participant groups. They argued that participant groups in several Canadian studies (e.g., Bialystok & Martin, 2004) had different backgrounds and were not matched on education and socio-economic status. They furthermore pointed out that immigrant Canadians (dominating the bilingual group) on average have more years of education than non-immigrant Canadians (the monolingual group). When Morton and Harper matched bilingual and monolingual children on SES, they found no effects of language group. However, they did observe a correlation between Simon costs and SES: Those with higher SES showed smaller Simon costs. This study emphasises the need to control for background variables and minimise differences between bilingual and monolingual groups.

Although more recent studies often measure education and SES, this does not always mean that groups are matched on these scores. In several cases, the degree of matching also alters the outcome on executive control tasks. For example, Prior and Gollan (2011) initially found Spanish-English bilinguals to respond more slowly than monolinguals on a task-switching task. After including SES as a covariate, these bilinguals responded equally fast overall and showed smaller switching costs than monolinguals. However, the use of ANCOVA is problematic in this case as this analysis assumes that the covariate and the language groups are independent (cf., Miller & Chapman, 2001). This is not the case when one group scores higher than the other on the covariate, as in the example with SES, and results of this analysis then become unreliable.

**Immigrant status**

Another factor, which is confounded even more often, is immigrant status. Many studies have compared bilinguals and monolinguals living in or originating from different countries (see Table 2.1 for several examples). In many other studies, immigrant status is not mentioned explicitly, but the large variety of L2s in most papers suggests that bilingual immigrants are often compared to monolingual non-immigrants. This could lead to differences in cultural, ethnical and genetic background, education, and lifestyle.

Indeed, several studies have suggested that immigrants, independent of bilingualism, show increased cognitive control and less cognitive decline when compared to non-immigrants (e.g., Kopec, Williams, To, & Austin, 2001; Hill, Angel, Balistreri, & Herrera, 2012). This could be due to several factors. Immigrants could be argued to have greater flexibility or a more outgoing personality. Moving to a new country is inherently linked to adapting to new circumstances, which could then in turn lead to increased cognitive flexibility.

Cultural background has also been shown to relate to executive control. The Asian culture, for example, has been linked to faster development in children (e.g., Sabbagh, Xu, Carlson, Moses, & Lee, 2006). Indeed, Yang, Yang, and Lust (2011) found a cognitive advantage for Korean monolingual children raised in Korea as compared to monolingual Korean and American children raised in the USA. Carlson and Choi (2009) furthermore demonstrated how the entanglement of bilingualism and cultural differences can lead to misunderstandings. They found a bilingual advantage for Korean-English bilinguals living in the USA when compared to 'matched' American monolinguals. When compared to Korean monolinguals, however, there was no bilingual advantage. Other differences between immigrants and non-immigrants might occur in healthiness, which has been labelled the 'healthy immigrant effect'. Fuller-Thompson, Nuru-Jeter, Richardson, Raza, and Minkler (2013), for instance, found that white Hispanic immigrants in the USA had

26% lower chance of functional limitations than the white non-immigrant inhabitants of the USA. It could be possible that healthy people are more likely to migrate and thus to become bilingual (Fuller-Thompson & Kuh, 2014).

It should, however, be noted that not only studies showing a positive effect of bilingualism have confounded bilingualism with immigrant status. Several studies not showing effects of bilingualism have also tested bilingual participants from an immigrant background (e.g., Paap & Greenberg, 2013), mismatched groups on background variables such as urban vs. rural environment (e.g., Kirk et al., 2014), or have compared migrant monolingual participants to local bilinguals (e.g., Clare et al., 2014).

When the confound of immigrant status is avoided by comparing non-immigrant monolinguals and bilinguals, effects are mixed. Several studies have found positive effects for healthy adults (e.g., Costa et al., 2008; Bak et al., 2014; Woumans, Ceuleers, Van der Linden, Szmalec, & Duyck, 2015b) and dementia patients (Alladi et al., 2013, Woumans et al., 2015a). Yet other studies with non-immigrant samples did not observe a cognitive effect of bilingualism in children (e.g., Antón et al., 2014), younger adults (e.g., Kousaie & Philips, 2012b, although some differences were found in the ERP data), healthy older adults (e.g., Kousaie & Philips, 2012a; Kirk et al., 2014), and dementia patients (e.g., Chertkow et al., 2010; Lawton et al., 2015)[6].

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[6] This paragraph is partly based on de Bruin, A., Bak, T. H., & Della Sala, S. (2015). Examining the effects of active versus inactive bilingualism on executive control in a carefully matched non-immigrant sample. *Journal of Memory and Language*, *85*, 15-26.

### Genetic differences

Recently, it has been suggested that bilingual and monolingual language groups from different countries of origin may also show genetic differences related to executive control performance. Hernandez, Greene, Vaughn, Francis, and Grigorenko (2015) collected genetic data from Caucasian monolinguals and Hispanic Spanish-English bilinguals. In the bilingual group, 69% carried the A1 allele, while this was only the case in 31% of the monolinguals. This allele has been linked to cognitive flexibility. Hernandez and colleagues note that their sample of Hispanic bilinguals commonly has a lower SES than the Caucasian monolingual control group. They suggest that those bilinguals with the A1 allele may be more likely to gain higher levels of education and become more proficient in English. Although speculative, this could suggest that those with increased cognitive flexibility are more likely to be bilingual rather than vice versa.

Table 2.1

*Overview of background differences between bilingual and monolingual groups with examples from the literature*[7].

| **Background differences** | **Examples** |
|---|---|
| Socio-Economic Status (SES) | Morton & Harper (2007): Children with higher SES perform better than children with lower SES on a Simon task. No effect of bilingualism when language groups are matched on SES. |
| Country of origin | Bialystok et al. (2004): Bilinguals from India compared to monolinguals from Canada show inhibitory advantage.<br><br>Bialystok & Viswanathan (2009): Immigrant bilinguals from Canada and non-immigrant bilinguals from India compared to non-immigrant monolinguals from Canada. Bilinguals show enhanced performance on an anti-saccade task. |
| Immigrant status | Bialystok et al. (2008): 20/24 bilinguals are immigrants. All monolinguals are non-immigrants. Bilinguals show some advantages on inhibition tasks.<br><br>De Abreu et al. (2012): Portuguese bilingual immigrants living in Luxembourg compared to monolingual non-immigrants in Portugal. Bilinguals perform faster on a flanker task.<br><br>Gold et al. (2013a): 75% of bilinguals are immigrants vs. 15% of monolinguals. Bilinguals are faster at task switching than monolinguals.<br><br>Craik et al. (2010): 79% of bilinguals are immigrants vs. 32% of monolinguals. Bilinguals show a delayed onset of dementia. |
| Genetic differences | Hernandez et al. (2015): Genetic differences between bilinguals and monolinguals that are related to cognitive flexibility. |

[7] This table is based on de Bruin, A., & Della Sala, S. (2016). The importance of language use when studying the neuroanatomical basis of bilingualism. *Language, Cognition and Neuroscience, 31*(3), 335-339.

**Confounds may also mask effects of bilingualism**

These confounds, and particularly the association between bilingualism and immigrant status, could lead to advantages that are linked to bilingualism but potentially not caused by language differences. At the same time, ill-matched groups could also hide a bilingual effect. There are many other activities that have been linked to enhanced executive control, including playing video games (e.g., Bialystok, 2006) and music training (e.g., Bialystok & DePape, 2009). Thus not only bilinguals, but also monolinguals have access to many activities that could enhance their executive control performance (cf., Valian, 2015). When we do not match participant groups on these activities and their general lifestyle, these background differences may mask the presence of a bilingual advantage.

In other instances, the 'monolingual' group has received some form of second language training. For example, Paap and Greenberg (2013) classified participants as monolingual if their L2 proficiency was rated as intermediate or lower. Similarly, in Mor, Yitzhaki-Amsalem, and Prior (2014), both Hebrew 'monolinguals' and Hebrew-Russian bilinguals had studied English as a second language. If some degree of second language training is enough to enhance executive control, a 'bilingual' advantage cannot be found in these studies.

Effects of confounds can thus go in two directions. They may result in an advantage for 'bilinguals' that is not related to bilingualism. At the same time, they could also mask an effect of bilingualism. We should therefore aim to match our language groups on background variables while keeping the one main difference:

the number of languages spoken. Chapter 6 therefore discusses a study comparing bilingual to monolingual non-immigrants that are matched on SES, education, background, and lifestyle.

### 2.2.6. Causality

Despite aiming to minimise any background differences, these can never fully be controlled in a between-group comparison. Furthermore, the question of causality remains. Does bilingualism lead to enhanced executive control performance, or are those with better cognitive skills more likely to become bilingual? People with better cognitive skills may be more likely to learn a second language and may be better at language learning (cf., Kempe, Kirk, & Brooks, 2015). For example, non-verbal intelligence and working memory have been found to predict the success of L2 learning (Brooks & Kempe, 2013). This does not appear to affect studies with early bilinguals to a great extent, as many infants are raised bilingually from birth and do not *choose* to become bilingual. However, general cognitive functioning may still affect the level of proficiency that is reached.

A few studies have examined whether bilingualism/second language learning can have a causal effect on executive control. Although still using a between-group comparison and thus not addressing causality as such, Bak et al. (2014) found positive effects of bilingualism against cognitive ageing after controlling for childhood IQ. Furthermore, Bak, Long, Vega-Mendoza, and Sorace (2016) observed a positive effect on the Test of Everyday Attention after one week of language learning. These effects were found in various age groups. Still, another study did not observe positive effects on switching or inhibition tasks after one year of learning (Duñabeitia, 2016) and more studies need to be conducted to assess causal effects of language learning.

The issue of causality will be discussed from a different angle in Chapter 7. Across several experiments, I examined effects of language use and switching on both verbal and non-verbal task-switching performance within a group of bilinguals.

### 2.2.7. Task impurity

Another issue hindering the interpretation of the current literature concerns the type of executive control tasks used. One of the crucial problems regards the nature of executive control tasks. A task-switching paradigm, for example, is usually considered to reflect switching. A bilingual advantage on such a task is claimed to be a switching advantage. In a task-switching paradigm, however, not only switching plays a role. Inhibitory control is also involved, for instance when participants need to suppress the irrelevant feature of a stimulus (e.g., shape when a colour decision is required). In the updated executive control framework, Miyake and Friedman (2012) no longer consider inhibition to be the third component (besides updating and shifting), but now argue for a 'common factor', defined as the ability to maintain task goals and information needed to reach this goal as well as the ability to use this information. The common factor of this model, however, correlated perfectly with the previously called inhibition-specific factor, suggesting that inhibition may be the underlying component in both shifting and updating processes. Thus, even though we often assume that a specific task measures a specific component of executive control, this is often not the case. For this reason, several bilingualism researchers have argued that we need to understand more about the mechanisms involved in the various executive control tasks before we use these tasks to analyse effects of bilingualism (cf., Valian, 2015).

Furthermore, even executive control tasks that have been assumed to measure similar aspects of executive control do not always correlate. Paap and Greenberg (2013) only found a correlation of $r$ = -0.01 between the Simon and flanker effects, two tasks that have been argued to measure inhibitory control[8]. Similarly, Duñabeitia et al. (2014) observed low correlations between their two types of verbal and numerical Stroop tasks ($r$ = .07 for the Stroop effect, $r$ = .05 for facilitation, and $r$ = .14 for inhibition). Kousaie and Phillips (2012b) compared three inhibitory control tasks (Simon, flanker, and Stroop) and observed different ERP components and different effects of bilingualism for each of the three tasks. Thus, even when we assume that two or more tasks measure the same mechanisms, the low correlations suggest that task-specific mechanisms may overrule domain-general effects. This problem has also been referred to as task impurity: An executive control task does not only measure executive functions but also includes non-executive components (such as type of stimuli or processing speed) that affect

[8] The absence of a correlation between two inhibitory control tasks seems to contradict the correlations found by Miyake et al. (2000). However, it should be noted that their overview of tasks did not include Simon or flanker tasks, two paradigms that have often been studied in bilingualism research.

performance (Jurado & Rosselli, 2007). Although Simon and flanker tasks may appear to tap into a common mechanism and have a similar set-up in terms of incongruent and congruent trials, they also differ in many other aspects. Possibly the most striking difference is the type of interference. In a flanker task, this interference is caused by flanker arrows surrounding a target arrow. The interference is thus found in the periphery. In the Simon task, however, there is only one stimulus and the interference is related to the match between presentation side and button side. In this light, it is perhaps also not surprising that effects of bilingualism are inconsistent across tasks. In Chapter 4, I will discuss this issue of task impurity in more detail by comparing three types of tasks assumed to measure inhibition[9].

### 2.3. Summary

The theoretical explanation behind effects of bilingualism on executive control has changed over the years. Initially, effects of bilingualism were argued to be related to inhibition, but researchers now state that these advantages are more generic and related to conflict monitoring or more holistic terms such as mental flexibility. However, there are several issues that affect the interpretation of the current literature. Firstly, the changing theoretical framework has been criticised for being too vague to allow for concrete hypotheses and interpretations. Secondly, seminal papers have often not been replicated. Especially recent years have seen a relative

[9] This paragraph is partly based on de Bruin, A., Bak, T. H., & Della Sala, S. (2015). Examining the effects of active versus inactive bilingualism on executive control in a carefully matched non-immigrant sample. *Journal of Memory and Language*, *85*, 15-26.

decline in the number of studies supporting the bilingual advantage. This could be related to the third issue of publication bias. Fourthly, when bilingual effects are found (and even when they are not found), their implications are often interpreted too strongly. Ill-matched language groups pose a fifth problem. Bilinguals and monolinguals often differ in SES, education, and immigrant status. On the one hand, alleged effects of bilingualism may be due to background differences. On the other hand, other experiences may enhance executive control in monolinguals and may thus mask effects of bilingualism. Together with the issue of causality, this is a problem that is inherent to between-subject designs. Lastly, due to task impurity, we often do not know what exactly is measured in 'executive control tasks'. This may further hinder the finding and interpretation of bilingual effects.

The next chapters present work examining effects of bilingualism and language use on lexical processing and non-verbal executive control. Several issues presented in the current chapter will be discussed in more detail. Chapter 3 will firstly discuss evidence for the presence of a publication bias. Chapter 4 will further discuss inhibitory control and the issue of task impurity. As effects of bilingualism have been argued to occur predominantly in older adults, this chapter will focus on effects of cognitive ageing on inhibitory control. Chapter 5 and 6 will describe work examining effects of bilingualism and language use on respectively lexical processing and non-verbal executive control performance in carefully matched language groups. In Chapter 7, I will discuss two behavioural and one EEG study aimed to avoid between-group comparisons and test direct effects of language use on task-switching performance in bilinguals only. Lastly, the general discussion will come back to several issues discussed in the current chapter and will provide my interpretation of the field's current position and future.

# Chapter 3. Cognitive advantage in bilingualism: An example of publication bias?

This chapter is based on:

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*Author contribution: All authors contributed to the study concept and design. Data collection and analysis were performed by A. de Bruin. Abstract classification was performed by A. de Bruin and B. Treccani. A. de Bruin drafted the manuscript and B. Treccani and S. Della Sala provided critical revisions.*

De Bruin, A., Treccani, B., & Della Sala, S. (2015). The connection is in the data: We should consider them all. *Psychological Science, 26*(6), 947-949.

*Author contribution: A. de Bruin drafted the manuscript, and B. Treccani and S. Della Sala provided critical revisions.*

### 3.1. Introduction

Chapter 1 and 2 provided an overview and evaluation of published studies on bilingualism and executive control. In Chapter 2, I furthermore discussed that the evidence for a positive effect of bilingualism has diminished over the years. One of the factors underlying this so-called 'decline effect' may be publication bias: Studies with null or negative results are less likely to be published than positive results. The presence of a publication bias has been suggested for many different research fields, including neuroimaging, animal studies, psychology, genetics, and clinical research (for an overview, see Ioannidis, Munafo, Fusar-Poli, Nosek, & David, 2014). Especially in clinical research, (publication) biases have been thoroughly examined and criticised (e.g., Easterbrook, Gopalan, Berlin, & Matthews, 1991; Dickersin, Min & Meinert, 1992; Ioannidis & Trikalinos, 2007). For example, Easterbrook et al. (1991) tracked research projects approved by an ethics committee between 1984 and 1987. Of the 285 studies that had been analysed by the time of the survey, 52% were published. 68% of published or presented papers had significant results and 25% had null findings. Examining the percentage of publications per result type showed that 60% of studies with a significant finding were published and 85% were published and/or presented at a meeting. In contrast, 34% of studies with null results were published and 56% were published and/or presented. Furthermore, the average impact factor of the journal in which the article was published was higher for significant findings than null results. In many cases, the authors stated that the null effect was the reason for not writing up or submitting the paper. Lack of publication was due to editorial rejection in only 9% of the cases. In recent years, psychology too has been argued to be affected by questionable research practices and biases (e.g., Bakker, Van Dijk, Wicherts, 2012; Francis, 2012; Ferguson & Heene, 2012). Many of these claims are based on the finding that the number of psychology papers observing a positive effect exceeds the number of papers that is expected to report positive findings, especially considering that studies often contain small sample sizes that are not large enough to detect small to medium effect sizes (cf., Bakker et al., 2012). Francis (2014) examined 44 articles published in *Psychological Science* between 2009 and 2012. He used the 'test for excess significance' to estimate the probability to observe effects similar to or larger than the ones observed in the article. A low value indicates that this probability is low and thus that the article may be affected by bias (e.g., only successful experiments or analyses are included). In 82% of the examined psychology papers, bias appeared to play a role.

I suspected that a similar publication bias may also affect the field of bilingualism and executive control. This suspicion was partly based on experiences from our own research group. In 2009, Treccani et al. published a study reporting an effect of bilingualism in a spatial negative priming task. This effect, supporting the theories of enhanced inhibitory control in bilinguals, was obtained in one experiment. Three other tasks (Simon, colour negative priming, and spatial cueing tasks, see Table 3.1), however, were administered at the same time and to the same participants and did not show any differences between bilinguals and monolinguals. The only experiment that was submitted for publication was the one showing an effect of bilingualism. Similarly, another study from our research group (using the same spatial negative priming paradigm that was successful in Treccani et al., 2009) failed to replicate the observed effect of bilingualism. Due to the same file drawer bias (cf., Spellman, 2012), this study was not submitted either.

Table 3.1

| **N bilinguals** | **N monolinguals** | **Task** | **Index** | **Bilingual mean (SD)** | **Monolingual mean (SD)** | **p** |
|---|---|---|---|---|---|---|
| 27<br>(*M* age: 27.7) | 23<br>(*M* age: 28.7) | Spatial negative priming task | Spatial Negative priming [2] | RT: 38 ms (21.60)<br>PE: 1.0% (2.31) | RT: 32 ms (21.66)<br>PE: 1.4% (2.90) | RT: 0.426<br>PE: 0.655 |
| 29*<br>(*M* age: 28.1) | 29*<br>(*M* age: 26.2) | Colour negative priming task[1] | Colour Negative priming [3] | RT: 13 ms (65.38)<br>PE: 2.6% (8.35) | RT: 32 ms (47.58)<br>PE: 1.3% (6.94) | RT: 0.205<br>PE: 0.523 |
| 29*<br>(*M* age: 28.1) | 29*<br>(*M* age: 26.2) | Simon task | Simon effect[4] | RT: 31 ms (22.84)<br>PE: 3.0% (2.75) | RT: 23 ms (19.47)<br>PE: 2.7% (3.47) | RT: 0.143<br>PE: 0.664 |
| 29*<br>(*M* age: 28.1) | 29*<br>(*M* age: 26.2) | Spatial cueing task | Inhibition of Return effect[5] | RT: 31 ms (22.79)<br>PE: -0.59% (3.63) | RT: 28 ms (21.04)<br>PE: -0.16% (1.79) | RT: 0.603<br>PE: 0.568 |

*Overview of four unpublished experiments that did not find an effect of bilingualism (the p for each of the bilingual vs. monolingual comparisons are reported in the last column). RT = reaction time; PE = percentage of errors.*

1. A colour flanker task in which the flanker colour in a given trial might be the target colour in the following trial.
2. Difference between trials in which the target was presented in the position of the previous-trial distractor and trials in which both the target and distractor appeared in previously vacant locations.
3. Difference between trials in which the target colour was the same as the colour of the previous-trial flankers and trials in which neither the target colour nor the distractor colour had been presented in the previous trial.
4. Difference between incongruent and congruent trials.
5. Difference between invalid and valid trials (i.e., trials in which the target appeared in the uncued and cued locations respectively) with a 450 ms cue–target interval.

*: These participants are the same as the participants in Treccani et al. (2009).

I then wondered if the claim that bilinguals have a cognitive advantage is a correct reflection of all research in this field. Recently, Paap (2014) has raised the concern that the literature on bilingualism and executive control might be affected by a confirmation bias to report positive results only. To investigate whether and to what extent studies showing a bilingual advantage are more likely to be published than data challenging the bilingual-advantage hypothesis, I compared the publication rates of conference abstracts. I classified conference abstracts on the basis of their outcomes and assessed which abstracts were subsequently published in a journal.

## 3.2. Methods

I searched for conference abstracts on bilingualism and executive control in 169 conferences (31 different national and international meetings) organised between 1999 and 2012. The topics of these conferences included bilingualism, psycholinguistics, cognitive neuroscience, psychology, and psychiatry (see Table 3.2 for an overview of all conferences).

Table 3.2

*Overview of the different conferences that were researched.*

| Conference | Year |
|---|---|
| American Aging Society | 2005 - 2011 |
| Architectures and Mechanisms for Language Processing (AMLaP) | 2002 – 2004; 2007 - 2011 |
| Association for Psychological Science (APS) | 2003 - 2012 |
| Boston University Conference on Language Development (BUCLD) | 2008 - 2012 |
| Canadian Society for Brain, Behaviour, and Cognitive Science (CSBBCS) | 2004 - 2012 |
| Cognitive Science Society (CogSci) | 2003 - 2012 |
| Cognitive Neuroscience Society (CNS) | 2003 - 2012 |
| CUNY Sentence Processing Conference | 2006 - 2012 |
| European Brain and Behavior Society (EBBS) | 2003 - 2009 |
| European Congres of Psychology (ECP) | 2009 |
| European Federation of Neurological Societies (EFNS) | 2005 - 2011 |
| European Society for Cognitive and Affective Neuroscience (ESCAN) | 2012 |
| European Society for Cognitive Psychology (ESCOP) | 2007; 2009; 2011 |
| FENS Forum of Neuroscience | 2002; 2004; 2006; 2008; 2010; 2012 |
| International Association for the Study on Child Language (IASCL) | 2005; 2008; 2011 |
| International Conference on Cognitive Neuroscience (ICON) | 2011 |
| International Conference on Models of Interaction in Bilinguals (ICMIB) | 2009 |
| International Neuropsychological Society (INS) | 2003 - 2010 |
| International Symposium on Bilingualism (ISB) | 2003; 2007; 2009; 2011 |
| International Symposium of Psycholinguistics (ISP) | 2011 |
| Midwestern Psychological Association (MPA) | 2004; 2005; 2006; 2010; 2011; 2012 |
| Neurobilingualism | 2009 |
| Neurobiology of Language (NBL) | 2009 – 2012 |
| Nordic Conference on Bilingualism | 2009; 2012 |
| Psychonomics | 1999 – 2012 |
| Society for Neuroscience (SNF) | 2000 – 2012 |
| Society for Psychophysiological Research (SPR) | 2004-2012 |
| Society for Research in Child Development (SRCD) | 2005; 2007; 2009; 2011 |

| | |
|---|---|
| Workshop on Bilingualism | 2005 – 2008; 2011 |
| Workshop on Neurobilingualism | 2010 |
| Bilingual & Multilingual Interaction | 2012 |

I identified 128 abstracts (presented at 52 different conferences) that focussed on bilingualism and executive control. I included all abstracts that investigated the relationship between bilingualism and executive control in any age group, either with non-linguistic control tasks (116 abstracts; both standard executive control tasks, e.g., the Simon task, or tasks with a clear executive control component, e.g., working memory updating tasks) or with linguistic control tasks (12 abstracts, e.g., homograph interference task). I included executive control tasks with linguistic stimuli to get a complete overview of the publication bias in the general field of bilingualism and executive control. Conference abstracts looking at effects of bilingualism in lexical tasks without a clear executive control component (e.g., word learning or picture naming tasks) were not included. A total of 24 conference abstracts could not be classified because the abstract did not contain enough information about the results (15 abstracts), the study was lacking a (monolingual) control group (8 abstracts), or because the abstract was a review of previous studies (1 abstract). Two authors classified independently the remaining 104 abstracts according to their reported results. Any disagreement, which occurred in 11 cases, was resolved by discussion.

### 3.2.1. Classification

Abstracts were classified into four categories (see Appendix C1 for an overview of all abstracts and their classifications):

1. Studies only reporting data that support the bilingual advantage ('yes' studies).
2. Studies reporting mixed data that, on the whole, support the bilingual-advantage hypothesis ('mixed-yes' studies). These studies do not report a bilingual advantage in all tasks/analyses, but their results are still compatible with the prevalent idea of bilinguals showing enhanced abilities in executive control (they report no bilingual advantage in experimental conditions where an effect of bilingualism was not expected). This includes effects (a) for high executive control conditions (e.g., in flanker tasks involving strong interference effects), but not for low executive control conditions (e.g., in flanker tasks involving weaker interference effects; 5 studies); (b) for executive control tasks where a bilingual advantage was expected (e.g., domain-general control tasks such as Simon tasks), but not in other tasks where no bilingual advantage was expected (tasks in which performance depends on expertise in a particular field such as music, or tasks tapping executive functions that are not directly related to language control, e.g., the impulse-delay task; 6 studies); (c) for high proficiency bilinguals, but not low proficiency bilinguals (1 study) or for switching balanced bilinguals, but not for non-switching balanced bilinguals (1 study); (d) for unimodal, but not

bimodal bilinguals (i.e., people proficient in one spoken language and one sign language; 1 study).

3. Studies reporting mixed data that partly challenge the bilingual advantage ('mixed-no' studies). These studies report some results that support the bilingual advantage, but also report tasks where a bilingual advantage was expected, but not found or data indicating that the bilingual advantage in some tasks could have other explanations than the mere knowledge or use of two languages. This includes studies that show (a) a bilingual advantage in some executive control tasks, but not in other (parts of the) tasks where an effect of language group was expected too (20 studies); (b) a bilingual advantage for certain language groups, but not others (5 studies); (c) some (inconsistent) effects of language group in neuroimaging or electrophysiological data, but no bilingual advantage in behavioural data (6 studies); (d) a bilingual advantage for some age groups but not others (1 study); (e) a bilingual advantage that could be explained by other factors such as the socio-economic status of participants (1 study).
4. Studies reporting results that fully challenge the bilingual advantage ('no' studies): Studies that do not show any difference between monolinguals and bilinguals and studies that demonstrate a bilingual disadvantage.

The classification was based on the results and conclusions reported in the *conference abstracts*. In some cases, the study described in the abstract ended up being published in a journal and the conclusions drawn by the author in the abstract do not match those drawn in the published paper. For example, the abstract by Luk, Anderson, Craik, Grady, and Bialystok (2009; see Appendix C1) does not discuss the absence of a bilingualism effect on RTs, but only focuses on the bilingual ‘advantage’ observed in fMRI data. Based on this abstract, I have classified their study as belonging to group 1 (‘yes’ studies). These authors also describe this study in a published paper (Luk et al., 2010), in which they mention the absence of an RT effect. Based on this paper, a classification in group 3 (‘mixed-no’) would have been more appropriate. To avoid differences between published and unpublished studies, however, I based the categorisation on conference abstracts only.

After classifying the abstract, I identified whether the results presented in the conference abstract had been published in a journal. I classified a paper as being published if, on the 20th of February 2014, it had been accepted for publication by an international scientific journal. Either papers that had already appeared in a journal issue or in-press papers were classified as published. I did not include book chapters or published conference proceedings. I also classified an abstract as published if the results were part of a paper with additional experiments or participants. If two conference abstracts from the same research group, which reported different studies (e.g., Paap et al., 2010, and Paap et al., 2012), were later combined to form one journal publication, both abstracts were classified as being published. However, when two abstracts presented at different conferences reported exactly the same study findings, only the first conference presentation was deemed suitable for inclusion.

I also identified three factors that could potentially confound the results: year of conference presentation, number of participants per language group, and number of executive control tasks administered in the study. The number of participants per group was included rather than the total number of participants as some studies included many different groups (e.g., different language combinations) or multiple tasks, thus leading to very high numbers of participants.

### 3.2.2. Meta-analysis

I also performed a meta-analysis of the published studies that provided suitable data and assessed the presence of a publication bias by means of a funnel plot. Of the 50 identified published papers from this conference abstracts-assessment, I included 41 papers (see Appendix C2) in the meta-analysis. I contacted the authors if the paper did not provide the required descriptive statistics. Nine studies could not be included in the analysis, because I could not obtain the descriptive statistics, the paper focussed on neuroimaging data only, or the author did not allow inclusion of their study’s results in the analysis. I included all behavioural executive control tasks described in the papers, but did not include neuroimaging data, and only analysed bilingual-monolingual differences on the critical dependent variables (e.g., if the paper focussed on RTs, the meta-analysis only includes RT, but not accuracy results). For tasks that reported overall RTs as well as conflict costs (e.g., Simon or flanker task), I only included the conflict costs as this was the focus of most studies. If the study compared multiple bilingual or monolingual groups, those groups were included separately. In total, the meta-analysis contained 176 comparisons. I used MetaXL 2.0 software and the metafor software package in R (Viechtbauer, 2010) for the statistical analysis.

## 3.3. Results

### 3.3.1. Conference abstracts

Of the 104 abstracts included in the analysis, 40 abstracts (38%) found a bilingual advantage or results supporting the bilingual-advantage theories. A total of fourteen studies found mixed results supporting the bilingual advantage theories (13%). Thirty-three studies showed mixed results partly challenging the bilingual advantage theories (32%). Seventeen studies (16%) found no differences between monolinguals or bilinguals (13 studies) or a monolingual advantage (4 studies). In total, 52 studies were published in 50 papers (50% of all conference abstracts, see Appendix C2). Sixty-eight per cent of the 'yes' studies were published, compared to 50% of the mixed-yes studies, 39% of the mixed-no studies, and 29% of the no studies. On the whole, 63% of the studies supporting the bilingual advantage were published compared to only 36% of the challenging studies (see Table 3.3 and Figure 3.1).

Table 3.3

*Overview of the number of abstracts either fully or partially supporting or challenging the bilingual advantage that were presented at international conferences (1999-2012). The number and percentage of studies that ended up in publications are also presented. See paragraph 3.2.1 for a description of the four result types ('yes', 'mixed-yes', 'mixed-no', 'no').*

| Result type | N abstracts | N published | % published |
|---|---|---|---|
| 1. Bilingual advantage ('yes') | 40 | 27 | 68 |
| 2. Mixed data supporting bilingual advantage theory ('mixed-yes') | 14 | 7 | 50 |
| 3. Mixed data (partly) challenging bilingual advantage theory ('mixed-no') | 33 | 13 | 39 |
| 4. No bilingual advantage ('no') | 17 | 5 | 29 |
| - *Bilingual disadvantage* | *4* | *2* | *50* |
| - *No differences between monolinguals and bilinguals* | *13* | *3* | *23* |
| Results supporting the bilingual advantage (1+2) | 54 | 34 | 63 |
| Results challenging the bilingual advantage (3+4) | 50 | 18 | 36 |

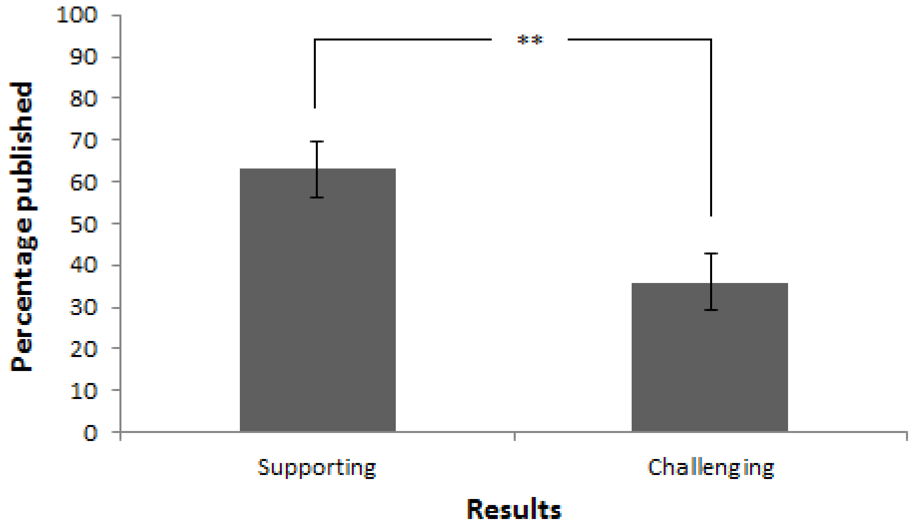


*Figure 3.1.* Percentage of conference papers supporting or challenging the bilingual advantage that were published in an international scientific journal. Error bars show +/- standard error of the mean (s.e.m.). **: $p < .01$.

A binary logistic regression analysis showed a significant difference between the publication outcomes (published or unpublished) of bilingual-advantage challenging and supporting abstracts (Wald $\chi^2(1) = 7.36$, $p = .007$, $\eta_p^2 = .073$). When all four result types were included, the analysis still showed a significant effect of result type on publication (Wald $\chi^2(3) = 8.86$, $p = .031$, $\eta_p^2 = .089$).

There were no significant differences between the bilingual-advantage supporting and challenging abstracts in terms of year of conference presentation and number of participants per group (see Table 3.4). Challenging abstracts, however, reported more executive control tasks than supporting abstracts. Not all abstracts included information on the number of executive control tasks and number of participants per group. Among the abstracts supporting the bilingual advantage, 9 studies did not report information on the number of participants and 3 abstracts lacked detail on the number of tasks. Among the abstracts challenging the bilingual advantage, 15 studies did not include information on the number of participants and 3 abstracts on the number of tasks. These analyses, therefore, include the majority of studies, but not all studies, and the results should be interpreted with caution.

Table 3.4

*Means (and standard deviations) of the year of the conference at which the analysed studies (either supporting or challenging the bilingual advantage) were presented, number of participants per language group, and number of tasks administered in the study.*

| | **Results** | | **Significant difference?** |
|---|---|---|---|
| | Supporting | Challenging | |
| Year of conference presentation | 2008.9 (1.97) | 2009.2 (2.76) | No ($t(103) = .50$, $p = .620$) |
| Number of participants per group | 31.1 (23.76) | 28.3 (16.21) | No ($t(79) = .60$, $p = .554$) |
| Number of tasks | 1.6 (1.29) | 2.2 (1.25) | Yes ($t(97) = 2.35$, $p = .021$) |

### 3.3.2. Meta-analysis

The meta-analysis of the published studies showed an effect of bilingualism with an average standardised mean difference of 0.30 (95% confidence interval, CI, 0.23 to 0.37, $z$ = 8.21, $p$ < .0001; see Appendix C3 for the forest plot). The funnel plot (Figure 3.2) is a scatter plot that can show whether the meta-analysis is affected by publication bias. In this plot, the standardised bilingual-monolingual mean differences (i.e., the bilingualism effects per individual study) are plotted on the x-axis against the standard error (i.e., a measure of precision per individual study) on the y-axis. This plot shows a clear asymmetry. Studies with larger standard errors showed a larger standardised mean difference than studies with smaller standard errors. In the absence of a publication bias, the funnel plot should have been symmetrical with studies with larger standard errors resulting in a similar amount of relatively high and low standardised mean differences. Studies with larger standard errors should then scatter widely at the bottom of the graph (cf., Sterne, Becker, & Egger, 2005). Instead we observe that less precise studies (with larger standard errors) more often show large effects than small effects, which suggests that studies with small effect sizes might not have been published. The observed asymmetry in the funnel plot was further supported by Egger's linear regression test, which showed a significant asymmetry ($z$ = 4.80, $p$ < .0001).

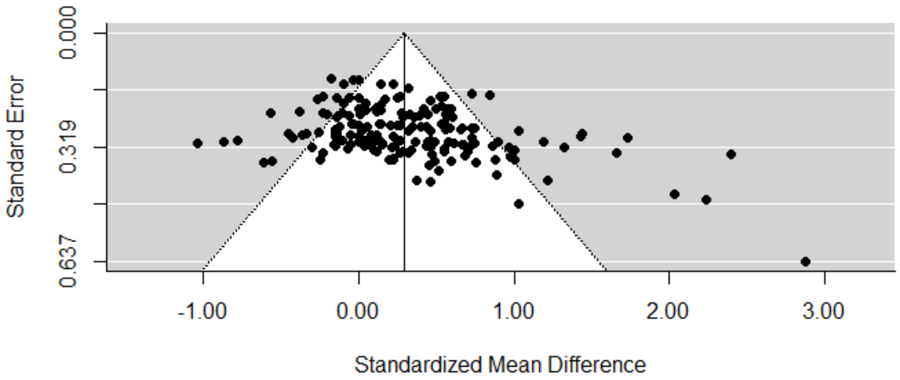


*Figure 3.2.* Funnel plot of the meta-analysis of published papers.

I also calculated the power of the analysed null effect studies to detect the various effect sizes reported in published positive papers. Power was calculated for studies concerning the Simon effect, flanker effect, and task-switching costs. On the whole, null effect studies had a medium-to-high probability of detecting the positive effects reported by published studies using the same tasks. For example, in the Simon task used by Bialystok et al. (2004), the bilingualism effect size (Cohen's *d*) ranged from 1.08 to 2.99. Using G*Power 3.1.8. (Faul, Erdfelder, Lang, & Buchner, 2007) with an alpha level of .05 (two tails), I calculated the probability to detect this effect, that is, the statistical power (1-β) of the null effect abstracts included in this overview that used a Simon task and provided sufficient information (i.e., they provided the number of participants per group; 12 studies; see Appendix C1 for full references). All studies using Simon tasks analysed here had very high probability to detect such a large effect (average of .87 to detect *d* of 1.08, and .99 to detect *d* of 2.99). The effect sizes for Simon effects reported by two other published positive studies (i.e., Bialystok et al., 2008, and Salvatierra & Rosselli, 2011) were smaller (.59 and .69 respectively) and null effect studies had a medium probability to detect them (average of .52 and .66 respectively). The same procedure was used for flanker and task-switching studies. In the flanker task used by Costa et al. (2009), the effect size of bilingualism was .61. Null effect flanker-task studies (8 studies) on average had a medium probability (.62) of detecting this effect. In a task-switching paradigm, Gold et al. (2013a) found a bilingualism effect size of .68 and null effect task-switching studies (3 studies) on average had a high probability of detecting it (.94).

Finally, I calculated the power of both supporting and challenging abstracts to detect the effect size found in the meta-analysis (.30). Eighty studies (45 supporting and 35 challenging studies, see Appendix C1 for references) provided sufficient information to be included in the analysis. For studies classified as supporting the bilingual advantage, the power to detect an effect size of .30 was .19. For studies classified as challenging the bilingual advantage, this power was .17. Both types of studies thus had a comparable, but low probability to detect the effect size observed in the meta-analysis.

### 3.4. Discussion

I have analysed conference abstracts presented between 1999 and 2012 on the topic of bilingualism and executive control. Conference abstracts were classified on the basis of their outcome and an effect of result type on publication was found.

Studies were published relatively often (68%) if the data demonstrated a bilingual advantage. In contrast, only 29% of the studies that showed no effect of bilingualism or a bilingual disadvantage were published. Publication chances of studies with mixed results were in-between these two groups, with studies partly supporting the bilingual advantage being published more often than partly challenging studies. The asymmetrical funnel plot of published studies also hinted at a publication bias.

This difference in publication percentage based on the outcomes of the study could be the result of a bias during several steps of the publication process: Authors, reviewers, and editors can decide to only submit or accept studies with positive results.

In the first step of the publication process, the file drawer problem could play an important role in the observed publication bias. Authors could decide not to publish studies with null or mixed results or they can choose to submit their results only partially, for example by leaving out tasks that did not show an effect of bilingualism. The paper by Treccani et al. (2009) is an example of file drawing as it excluded the experiments that did not show an effect of bilingualism. Similarly, the published paper by Prior and MacWhinney (2010) describes the positive effects of bilingualism on task switching. In a footnote, however, they mention that the same groups of participants completed two additional executive control tasks that showed no effect of bilingualism. Studies examining publication bias in clinical research (e.g., Easterbrook et al., 1991; Dickersin et al., 1992) have argued that this bias indeed often originates from researchers themselves not publishing null results.

On the next level, reviewers and/or editors might reject a submitted paper reporting null, negative, or mixed results more often than studies finding positive effects. This rejection is often based on the argument that null effects are difficult to interpret, the result of poor stimulus design, or the result of a Type-II error (Ferguson & Heene, 2012). Mahoney (1977) asked journal reviewers to referee studies reporting positive, null, or mixed results with identical methodological procedures. Although the methodology was the same, reviewers scored the positive papers as methodologically better than the negative or mixed results papers. For papers with positive results, reviewers usually recommended accepting with moderate revisions. For papers with negative results, however, their usual recommendation was major revision or rejection. Papers with mixed results were mostly rejected.

Unfortunately, I cannot determine whether studies in my overview were not submitted to a journal or rather rejected after submission. I did ask all authors to take part in a short survey concerning journal submission. Unfortunately, 33 of the 52 authors contacted did not reply or refused to complete the questionnaire. Of the six respondents from abstracts supporting a bilingual advantage, two indicated that they had not submitted their results to a journal. Of the thirteen respondents from abstracts challenging an advantage, eight indicated that they had not submitted their results. This suggests that more than half of the null or negative findings had not been submitted. However, I clearly do not have enough data to draw reliable conclusions. This lack of responsiveness, particularly from very productive research groups, complicates the interpretation of these findings.

Bialystok, Kroll, Green, MacWhinney, and Craik (2015) wrote a commentary in response to this study in which they argued that the analysis of conference abstracts is not a reliable measurement of publication bias. This method, however, is not new (e.g., Scherer, Dickersin, & Langenberg, 1994) nor rare (e.g., Song et al., 2009); it has been widely used, among other disciplines, in epidemiology (e.g., Petticrew et al., 2008), health technology (e.g., Dundar et al., 2006), stroke research (e.g., Brazzelli, Lewis, Deeks, & Sandercock, 2009), medical interventions (e.g., Peinemann, McGauran, Sauerland, & Lange, 2008), paediatrics (e.g., Zamakhshary, Abuznadah, Zacny, & Giacomantonio, 2006), orthopaedics (e.g., Harris, Mourad, Kadir, Solomon, & Young, 2006), vet medicine (e.g., Snedeker, Totton, & Sargeant, 2010), and it is endorsed by The Cochrane Collaboration (Young & Hopewell, 2011; Scherer, Langenberg, & von Elm, 2007). Hence, I am not the first to use this method to examine a potential publication bias.

It is true that conference abstracts may only include preliminary results or interpretations that are corrected in final versions and therefore publications may be argued to be improved versions of abstracts. Moreover, studies described in conference abstracts may not be published because they only present preliminary data with small sample sizes or because they were meant to pilot a new task. Indeed, I found that half of all studies described in the conference abstracts were not published. I do not know the reasons why several studies were not eventually published, but the percentage of published studies is similar to other fields. For example, Easterbrook et al. (1991) report that 52% of their investigated clinical studies were published. Similarly, based on an overview of studies, Dickersin et al. (1992) estimate that 30 to 60% of studies presented in abstracts eventually get published. Crucially, I did carefully analyse potential background differences between abstracts supporting and challenging bilingual-advantage theories to ensure that null or negative results were not less likely to be published because of quality differences. I did not find any differences in terms of year of conference abstract, number of participants, or power to detect an effect. Furthermore, most studies analysed here (showing positive, mixed, or null effects) have used the same tasks (e.g., Simon, task-switching, or flanker task). This strongly suggests it was not the quality of the study that led to publication differences between positive and null or negative results.

Interestingly, there was a difference between the different abstract types in the number of reported tasks. Abstracts supporting the bilingual advantage reported fewer tasks than abstracts challenging the bilingual advantage. It is difficult to interpret this difference, as it might reflect a difference in the number of tasks that were reported rather than a difference in the number of tasks that were actually used. Although this is speculative, the difference in number of tasks between these studies could be the result of some of the ‘supporting’ studies leaving out data that suggested otherwise (cf., John, Loewenstein, & Prelec, 2012).

Alternatively, a significant effect could be most likely to occur if only one test is used, whereas more tests might also yield non-significant or negative results. Researchers could submit a paper after one successful task without trying to replicate this effect, even if the positive outcome could be the result of a Type-I error (cf., Pashler & Harris, 2012).

Only a few of the analysed studies (4 of the 104 abstracts) found a bilingual *disadvantage.* A lack of this kind of abstracts could result from file drawing on the level of conference submission already. Indeed, the finding of a bilingual disadvantage can hardly be interpreted as indicating better executive control abilities in monolinguals. The only reasonable conclusions would be that, in the tested domain, there is no bilingual advantage and a Type-I error occurred. Authors then might not submit their negative results to a conference. The study by Easterbrook et al. (1991) indeed suggests that a submission bias may already exist at the level of presenting at a conference. Combining ‘published and presented’ and ‘presented only’ showed that 72% of studies with significant findings were presented at a meeting compared to only 49% of studies with null results. In this respect, it is worth noticing that file drawing occurring at conference-submission level might have obscured the existence of differences in publication rates even larger than those I found: These results might only be the ‘tip of the iceberg’.

The small percentage of bilingual disadvantage studies, however, could also suggest that the cognitive bilingual advantage is genuine, albeit smaller and less stable than often presented in the literature. In fact, the existence of a publication bias does not imply that bilingualism does not have any effect on executive functions. The presence of a possible publication bias may explain why the magnitudes of many reported positive effects appear to decrease over time (i.e., decline effect), even when the effects have been shown to be reliable and are still widely-accepted (cf., Schooler, 2011; see also Lehrer, 2010).

To gain a complete overview of the field, my study included both non-verbal as well as verbal executive control tasks. Bialystok et al. (2015) argue that bilinguals may have a disadvantage on purely lexical tasks and that this may affect the findings. However, I did not include conference abstracts that discuss lexical tasks without an executive control component. I did include executive control tasks with verbal materials, in which, according to the studies mentioned by Bialystok et al. themselves (e.g., Bialystok, 2009), bilinguals should outperform monolinguals. These tasks have been linked to no bilingual effects (e.g., Paap & Liu, 2014), but also to bilingual advantages (e.g., Filippi, Leech, Thomas, Green, & Dick, 2012). However, when I do exclude all studies using verbal materials from the analysis (leaving 78 abstracts and 125 tasks in the funnel plot), the results remain the same. The funnel plot still shows an asymmetry ($z$ = 6.61, $p$ < .0001) and the publication rates are similar to the ones found in the original analysis: 70% of studies fully supporting an advantage were published, compared to 55% of the mainly supporting, 41% of the mainly challenging, and 23% of the fully challenging studies. The outcome is thus not affected by the nature of the materials.

My overview shows that there is a distorted image of the actual effects of bilingualism, with researchers (and media) believing that the positive effect of bilingualism on non-linguistic cognitive processes is strong and unchallenged. Recently, however, several studies (e.g., Paap, 2014; Paap & Liu, 2014) have criticised the findings in the existing literature. Their criticisms focus especially on the impossibility to assign randomly the independent variable (i.e., language group), and on the differences between bilingual and monolingual groups on background variables such as socio-economic or immigration status. In light of these issues, it is especially important to avoid publishing positive studies only.

A potential publication bias also poses a problem for meta-analyses. On the basis of an estimation of the number of *possible* unpublished null-effect studies, Adesope, Lavin, Thompson, and Ungerleider (2010) concluded that it was unlikely that their meta-analysis on bilingualism and cognitive effects could be threatened by a publication bias. Conversely, my overview shows the number of *actually conducted* unpublished null-effect studies and suggests that the results of a meta-analysis can be in fact affected by such a bias. Hilchey and Klein (2011) reviewed published studies that specifically address the issue of bilingualism and executive control. Although this review rightfully criticised some of the current theories, it is still necessarily based on published work only. Similarly, my meta-analysis did show an effect of bilingualism, but for the aim of the funnel plot, I only included published studies. The bilingual advantage found in this meta-analysis would be smaller if the unpublished abstracts (with more null and negative effects) were included too.

Of course, publication bias is not a phenomenon that only affects research on bilingualism and executive control. It has been suggested to affect the literature on a wide range of topics, including clinical research and psychology. Due to the different methodological approaches used, it is hard to evaluate whether the bias observed in this study is comparable to biases observed in other fields. Yet, Easterbrook et al. (1991) used a relatively similar approach for clinical studies and found percentages comparable to the ones presented here. While I found that 68% of positive studies were published and 29% of null/negative results, Easterbrook observed that 60% of studies with significant findings were published and 34% of studies with null effects. However, it is not my aim to say that certain fields are more or less affected by biases. In all fields, researchers should be aware of biases and their impact. If we want to get a better understanding of any effect, in this case the effect of bilingualism and its boundaries, publication chances should not depend on the direction of the study results. Studies with mixed results, for example, may be especially valuable because they can identify the circumstances under which a bilingualism effect may and may not occur, but, as shown by this analysis, they are published less often than studies that report data in favour of the bilingual advantage. Furthermore, studies showing no effects of bilingualism are often unfairly criticised. Recently, Kroll and Bialystok (2013) claimed that "The considerable literature that reports group differences between monolingual and bilingual participants is greatly more informative than the attempted replications that fail to find significance." (p. 502) and "… unless all conditions have been accounted for and all other explanations have been exhausted, it is misleading to call into question the reliability of the phenomena themselves." (p. 503). In their commentary, Bialystok and colleagues (2015) go even further and claim "imagine the state of journals if these studies [that show no effect] were published with the same frequency [as papers that show some effect]" (p. 944). I disagree. Instead of selecting exclusively those tasks and results that support current theories, investigators should make an attempt to include all conducted tasks and all findings. On the other hand, reviewers and editors should be more open to studies that challenge the existing theories, especially when these are not yet fully established. While bilingualism should be conceived, a priori, as a positive and desirable achievement, educational and political debates addressing the relevance of bilingualism should not be promoted by ignoring null or negative results. We should share all data and let them speak for themselves, also and especially in issues like bilingualism for its enormous societal relevance and implications.

# Chapter 4. Effects of age on inhibitory control are affected by task-specific features

This chapter is based on:

De Bruin, A., & Della Sala, S. (submitted). Effects of age on inhibitory control are affected by task-specific features.

*Author contribution: All authors contributed to the study concept and design. Data collection and analysis were performed by A. de Bruin. A. de Bruin drafted the manuscript and S. Della Sala provided critical revisions.*

*I would like to thank Stephen Rhodes for his help with the implementation of the motion flanker task.*

## 4.1. Introduction

Effects of bilingualism have been argued to be largest for older adults. Indeed in Chapter 1 (see Appendix A1), I observed that studies with older adults more often found positive effects of bilingualism on inhibitory control tasks than studies with children or younger adults. This absence of a behavioural effect in younger adults has been attributed to young adults already being at the peak of cognitive functioning, thus masking potential effects of bilingualism (e.g., Kroll & Bialystok, 2013). In contrast, older adults have generally been found to have decreased cognitive abilities (e.g., Hashler & Zacks, 1988). This age-related decline in performance on executive control tasks may leave more possibilities for effects of bilingualism to emerge. However, the effects of ageing on inhibition in particular have been questioned and may evaporate when correcting for general age-related slowing. In this chapter, I present two experiments investigating the relationship between inhibition, age, and processing speed across three tasks.

Effects of age on inhibition and interference suppression (i.e., the ability to suppress task-irrelevant information) have been investigated across a wide range of tasks, including the Simon and flanker task (see Chapter 1, p. 10). The Simon/flanker cost is taken as a measurement of inhibition. Older adults not only show longer overall RTs, but also have larger Simon costs than younger adults (e.g., Van der Lubbe & Verleger, 2002; Proctor, Pick, Vu, & Anderson, 2005; Castel, Balota, Hutchison, Logan, & Yap, 2007). These effects of age on the Simon effect remain when corrected for general processing speed differences, implying that the effects of age on inhibition go beyond general age-related slowing.

The flanker effect too has been observed to be smaller for young than older adults (e.g., Shaw, 1991; Zeef & Kok, 1993; Zeef, Sonke, Kok, Buiten, & Kenemans, 1996; Colcombe, Kramer, Erickson, & Scalf, 2005; Zhu, Zacks, & Slade, 2010; Zhou, Fan, Lee, Wang, & Wang, 2011). Although not all of these studies presented analyses correcting for overall RT differences (e.g., Zeef & Kok, 1993; Zeef et al., 1996), those which did (e.g., Colcombe et al., 2005; Zhou et al., 2011) observed effects of age on corrected flanker costs too.

The finding that older adults have an inhibition deficit has been challenged in other flanker studies that show overall RT effects of age but no difference on inhibition costs (e.g., Fernandez-Duque & Black, 2006; Jennings, Dagenbach, Engle, & Funke, 2007; Wild-Wall, Falkenstein, & Hohnsbein, 2008; Collette, Schmidt, Scherrer, Adam, & Salmon, 2009; Gamboz, Zamarian, & Cavallero, 2010; Hsieh & Fang, 2012) or even small advantages for older adults (e.g., Mathewson, Dywan, & Segalowitz, 2005; Hsieh, Liang, & Tsai, 2012). In some of these studies, effects of age were found on raw inhibition costs, but not on costs corrected for age-related slowing (e.g., Jennings et al., 2007).

Age effects on flanker tasks may thus be related to general slowing rather than a deficit on specific components such as inhibition (see also Salthouse, 1994; Verhaeghen & De Meersman, 1998). In a meta-analysis of ageing studies using a wide range of executive control tasks (including the flanker task), Verhaeghen

(2011) concludes that most tasks did not show age effects beyond those already observed in baseline conditions without conflict.

An EEG study by Wild-Wall et al. (2008) shed more light on the processes used by younger and older adults during a flanker task. Firstly, the N1 amplitude was increased for older adults compared to younger adults in response to the target arrow. This component has been interpreted as reflecting sustained covert attention, suggesting that older adults paid more attention to the target. Secondly, the N2 component (reflecting response conflict) was larger in the incongruent than congruent condition for younger adults, but this difference was absent in older adults. This suggests that younger, but not older adults, experienced more conflict from the incongruent trials. Lastly, the LRP (lateralised readiness potential; reflecting response selection and motor preparation) was delayed for older adults. This could mean that older adults needed more time for stimulus transmission from visual to motor areas. Combining these results, the authors suggest that older adults showed enhanced attention to the target, less inference from incongruent trials, and slower transmission of flanker items. Baseline processing speed and particularly the speed with which flanker items are processed may thus affect the link between ageing and inhibition. I aimed to investigate this issue across two experiments. In Experiment 1, I examined effects of age and baseline speed on inhibition in a motion flanker task. As these effects may be modified by task-specific features, Experiment 2 compared effects of age and speed across three inhibition tasks.

### 4.2. Experiment 1: Age and inhibition in a motion flanker task

To examine effects of baseline processing speed on age and inhibition, I used moving stimuli as motion perception generally deteriorates with age (e.g., Tran, Silverman, Zimmerman, & Feldon, 1998; Billino, Bremmer, & Gegenfurtner, 2008). This should yield more variability in baseline processing speed than static items. If older adults indeed perceive motion more slowly, flanker items should cause less interference, and thus flanker costs should either be similar to or lower than younger adults. Furthermore, if slower motion perception leads to less interference, I hypothesised that older adults with faster motion perception should show larger flanker costs than slower adults.

I therefore designed a flanker task with moving dots (cf., Lange-Malecki & Treue, 2012, who observed similar flanker costs for motion and static flanker tasks for young adults). The use of moving rather than static stimuli also allowed us to manipulate the percentage of conflict by changing the motion coherency of flanker dots. For example, in a low coherency condition, a small percentage of flanker dots would move in a congruent or incongruent manner with the other dots moving randomly. In a high coherency condition, all flanker dots would move (in)congruently, thus leading to more conflict. In this way, I examined whether age groups were affected differently by the amount of conflict.

Experiment 1 thus had two main aims. Firstly, it examined effects of age, congruency, and coherency (i.e., conflict level) on a motion flanker task. Secondly, I aimed to investigate whether baseline processing speed affected inhibition costs in younger and older adults.

### 4.2.1. Methods

**Participants**

Twenty younger adults (9 male; mean age = 21.45, *SD* = 2.84, range = 18-27) and 20 older adults (9 male; mean age = 66.35, *SD* = 3.92, range = 60-74) participated in Experiment 1[10]. All participants had normal or corrected-to-normal vision and hearing, no known neurological disorders, and gave written informed consent. All participants were monolingual English native speakers living in the United Kingdom. Younger and older adults did not differ in years of education (young: $M$ = 15.60, $SD$ = 1.85; old: $M$ = 16.45, $SD$ = 2.67; $t(38) = 1.17$, $p = .248$). Furthermore, scores on an 18-item lifestyle questionnaire (Scarmeas et al., 2003, maximum score = 54) were similar for young ($M$ = 39.85, $SD$ = 3.13) and older adults ($M$ = 41.55, $SD$ = 4.98; $t(38) = 1.29$, $p = .204$). Older adults also completed the Addenbrooke's Cognitive Examination-III as a dementia screening (ACE-III, Hsieh, Schubert, Hoon, Mioshi, & Hodges, 2013) and all scored above the cut-off of 88 points ($M$ = 97.85, $SD$ = 2.37).

**Materials and procedure**

Participants completed a motion flanker task in which they saw groups of dots moving to the left or right and were asked to indicate motion direction with a

[10] Zhou et al. (2011) showed a significant effect of age on conflict costs in a static flanker task with $d$ = 1.12 (calculated from the young – old comparison, excluding the middle-aged group). Based on this effect size, 14 participants per group would yield > 80% power to detect a significant effect of age.

button press (see Figure 4.1). In the baseline condition, participants saw one group of dots on the centre of the screen with all dots moving left or right. In the conflict condition, this central group of dots was surrounded by two other groups of dots that moved randomly (neutral condition), in the same (congruent), or opposite (incongruent) direction. Participants were asked to respond to the central group of dots. The motion coherency of the flanker dots was manipulated, thus leading to different conflict levels (40%, 60%, 80%, or 100% coherent movement). Thus, in a 60% congruent condition, 60% of the flanker dots would move in the same direction as the target dots. The other 40% of the flanker dots would move in a random direction. The difference between incongruent and congruent trials was defined as the flanker effect.

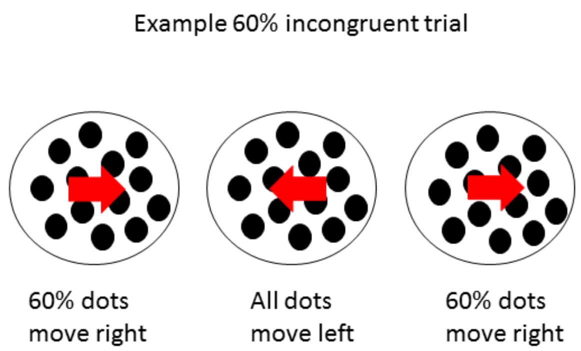


*Figure 4.1.* Example of a 60% incongruent trial in which 60% of the flanker dots move to the right while all target dots move to the left.

Each trial started with a fixation cross on the centre of the screen for 500 ms. Then, the flankers and central dots were presented for 3000 ms or until a response was given. Following Lange-Malecki and Treue (2012), the flanker dots were presented 100 ms prior to the presentation of the central target.

Participants first completed a practice block for the baseline condition, containing a minimum of 8 trials. Practice continued until an accuracy level of 80% was reached. During the practice block, participants received feedback about their performance. This was followed by a baseline block of 30 trials. Participants then completed a practice block for the conflict condition with a minimum of 24 trials. The conflict condition consisted of a total of 300 trials divided over four blocks. Sixty trials were neutral trials in which the flanker dots moved randomly. Of the 240 conflict trials, 120 were incongruent and 120 congruent. Congruency (incongruent or congruent), motion direction (left or right), and coherency (40%, 60%, 80%, 100%) were distributed evenly across trials.

The task was presented in PsychoPy v 1.82 (Peirce, 2007) and moving dots were generated through the DotStim package. Each group of dots consisted of 80 dots presented within a circle. The dot size was two pixels, the life of each dot was 8 frames, and the speed .09 pixels per frame. The size of the group of dots was 100 pixels. The randomly moving dots followed a random but constant direction, while the coherent dots moved right or left. The black dots were presented on a grey background on a 19-inch screen with 1280x1024 resolution.

**Data analysis**

Data were analysed using both null hypothesis statistical testing (NHST) as well as Bayesian analysis. If the null is true, the *p*-value used in NHST only states that there is lack of evidence for an effect, but it cannot support the null hypothesis directly. Bayesian analysis, however, allows us to directly compare evidence favouring the null (‘no effect of age’) to evidence favouring the alternative (‘an effect of age’). In this way, it is possible to quantify evidence for the null hypothesis. The Bayes factor (BF) is the likelihood ratio of the probability of the data given the alternative hypothesis over the probability of the data given the null. For example, when $BF_{10} = 5$, the observed data are five times more likely to have occurred under the alternative hypothesis than the null hypothesis. When $BF_{10} = .20$, the observed data are five times more likely to have occurred under the null hypothesis. Contrary to *p*-values, a null effect can therefore be supported by statistical evidence. I used the Bayes Factor package in R (Morey & Rouder, 2014), with the default prior (Rouder, Morey, Speckman, & Province, 2012), and one million iterations to calculate the Bayes factors.

To further examine effects of baseline processing speed, I ran a regression analysis with age and baseline processing speed as centred predictors and flanker cost as the dependent variable.

Moreover, in order to study inhibition and the possible effects of age in more detail, I conducted a delta-plot analysis (cf., Ridderinkhof, van den Wildenberg, Wijnen, & Burle, 2004). Inhibition is argued to require time to build up and may thus be more effective as time increases. Delta plots present the conflict effect (e.g., flanker cost) as a function of response time. Thus, if time is needed to apply inhibition, smaller inhibition costs are expected for slower RTs (visible as a negative slope in the delta plot). Furthermore, this decrease is expected to be larger for adults with better inhibition compared to poor inhibition and for experimental conditions that require more inhibition compared to conditions with lower demands. Indeed, Ridderinkhof et al. (2004) showed that participants with lower Simon costs showed a reduction in conflict costs as RTs increased, while participants with higher Simon costs showed larger conflict costs for slower RTs. Furthermore, on a Simon task, young adults (19 – 26 years) showed decreasing conflict costs, while older adults (60 – 69 years old) showed similar costs or increasing costs (in the 70 – 82 age group) for increasing RTs (Juncos-Rabadán, Pereiro, & Facal, 2008).

For the delta-plot analysis, RTs were ordered from fast to slow for each participant for the congruent and incongruent condition for low (40% + 60%) and high coherency level (80% + 100%). Then, tertiles (33.33% bins, one with fastest RTs, one with middle RTs, and one with longest RTs) were created for each participant, condition, and coherency level. I regrouped the four coherency levels into two levels to have more trials per tertile. Per bin, the average RT (AvQ) was calculated across incongruent and congruent conditions. Furthermore, the delta (D; difference between incongruent and congruent) was calculated per bin. Then, the slopes between each bin were calculated (e.g., (D2-D1)/(AvQ2-AvQ1). I analysed effects of coherency level and age on the slopes.

### 4.2.2. Results

**RT analysis**

***Effects of age, coherency, and congruency***

Accuracy scores were close to ceiling for both younger and older adults in the baseline (young: *M* = 99.33, *SD* = 7.06; old: *M* = 99.50, *SD* = 8.14) and conflict condition (young: *M* = 98.87, *SD* = 10.59; old: *M* = 97.85, *SD* = 14.51) and were not analysed further. Incorrect trials and RTs more than 2.5 *SD* above the mean (2.14% of the correct trials) were removed for the RT analysis.

In the baseline condition, older adults (*M* = 733.89, *SD* = 293.01) responded more slowly than young adults (*M* = 530.98, *SD* = 275.94; *t*(38) = 2.09, *p* = .043, $\eta^2$ = .10, $BF_{10}$ = 1.67± 0).

For the conflict condition, I first carried out a two-way repeated ANOVA with trial type (congruent, neutral, incongruent) as a within-subject factor and age group (young, old) as a between-subject factor. There was a main effect of trial type (*F*(2, 76) = 15.72, *p* < .001, $\eta_p^2$ = .29). While RTs were similar for congruent trials (*M* = 601.81, *SD* = 186.28) and neutral trials (*M* = 593.40, *SD* = 180.61), they were slower for incongruent trials (*M* = 618.83, *SD* = 180.56). Older adults (*M* = 701.50, *SD* = 170.12) performed more slowly than younger adults overall (*M* = 512.12, *SD* = 142.24; *F*(1, 38) = 14.45 , *p* = .001, $\eta_p^2$ = .28). The interaction between age and trial type was not significant (*F*(2, 76) = 1.00, *p* = .374). This suggests that the flanker effect did not differ between age groups (see Table 4.1). This was confirmed by the Bayesian analysis. Comparing the model with the interaction age x trial type to the model with the main effects age and trial type only, showed that the model without the interaction fits the data better by a factor of 3.55 (± 2.40%).

I then examined the effects of coherency level by only including congruent and incongruent trials in a three-way repeated ANOVA with trial type (congruent, incongruent) and coherency level (40%, 60%, 80%, 100%) as within-subject factors and age group (young, old) as a between-subject factor. Similar to the previous analysis, the main effects of congruency ($F(1, 38) = 10.76$, $p = .002$, $\eta_p^2 = .22$) and age ($F(1, 38) = 14.79$, $p < .001$, $\eta_p^2 = .28$) remained significant. The effect of coherency was significant ($F(3, 114) = 15.56$, $p < .001$, $\eta_p^2 = .29$), with RTs increasing for higher coherency levels. The interaction between coherency and congruency was also significant, ($F(3, 114) = 4.38$, $p = .006$, $\eta_p^2 = .10$), suggesting that flanker costs increased as coherency level increased (see Table 4.1). There was no interaction between age and congruency ($F(1, 38) = .77$, $p = .386$), age and coherency ($F(3, 114) = .46$, $p = .712$), nor a three-way interaction ($F(3, 114) = .87$, $p = .458$). The Bayesian analysis showed that a model with main effects of age and congruency only was preferred compared to a model including an interaction between age and congruency by a factor of 2.45 (± 1.16%).

To correct for baseline RT differences, I calculated proportional flanker costs (incongruent – congruent / congruent trials) for the 100% coherency level. There was no significant effect of age on proportional inhibition costs ($t(38) = 1.18$, $p = .246$; $BF_{10} = 2.10 \pm 0\%$). The BF suggests anecdotal evidence for an effect of age but flanker costs go in the opposite direction (larger costs for younger than older adults).

Table 4.1. *Mean RTs for younger and older adults per coherency level for incongruent and congruent trials. The flanker effect indicates the difference between incongruent and congruent trials. Standard deviations are given between parentheses.*

| **Coherency** | **Younger** | | | **Older** | | |
|---|---|---|---|---|---|---|
| | Congr. | Incongr. | Flanker effect | Congr. | Incongr. | Flanker effect |
| 40% | 498.14 (144.14) | 503.88 (139.75) | 5.74 (23.94) | 691.18 (170.58) | 698.99 (171.45) | 7.80 (37.54) |
| 60% | 500.03 (133.16) | 526.61 (155.95) | 26.58 (36.21) | 694.26 (172.50) | 705.86 (171.77) | 11.60 (37.08) |
| 80% | 509.02 (140.82) | 524.09 (141.37) | 15.08 (28.25) | 706.02 (185.09) | 715.24 (160.38) | 9.22 (57.02) |
| 100% | 509.30 (142.91) | 548.21 (159.13) | 38.91 (37.36) | 707.26 (187.77) | 728.55 (156.63) | 21.29 (63.79) |

***Effects of baseline RTs on flanker costs***

As a second question, I examined effects of baseline RT on the flanker cost. To ensure comparisons with the static tasks in Experiment 2, I calculated flanker costs for the 100% coherency only and ran a regression with age and baseline RTs as well as their interaction as predictors. This model suggested that while baseline ($b$ = .001, $t$ = 1.29, $p$ = .206) was not a significant predictor, the interaction between baseline and age was ($b$ = -.005, $t$ = -3.05, $p$ = .004). This suggests that the baseline

RTs may have different effects for the two different age groups and I therefore analysed the two age groups separately. For the young adults, baseline RTs were a significant and positive predictor of flanker costs (*b* = .06, *t* = 3.13, *p* = .006, $BF_{10}$ = 7.71 ± 0). Thus, younger adults with faster baseline RTs also showed smaller flanker costs. For older adults, the effects of baseline RTs went in the opposite direction, with faster baseline RTs associated with larger flanker costs (*b* = -.12, *t* = -2.27, *p* = .036, $BF_{10}$ = 2.12 ± 0). However, it should be noted that the BF is small and as such only provides anecdotal evidence.

**Delta-plot analysis**

The delta-plot analysis showed a main effect of coherency as the slopes were more negative for high coherency levels than low coherency levels ($F(1, 38) = 4.79$, $p$ = .035, $\eta_p^2$ = .11). This suggests that more inhibition was needed for conditions with higher coherency levels. Furthermore, slopes did not differ between younger and older adults (see Figure 4.2; $F(1, 38) = .63$, $p$ = .432), implying that both age groups used similar levels of inhibition. There was no main effect of bin ($F(1, 38) = 3.06$, $p$ = .088). None of the interactions were significant (all *p*s > .05). The Bayesian analysis showed that the model without age as a main effect fits the data better by a factor of 4.74 (± 0.71) than a model including age.

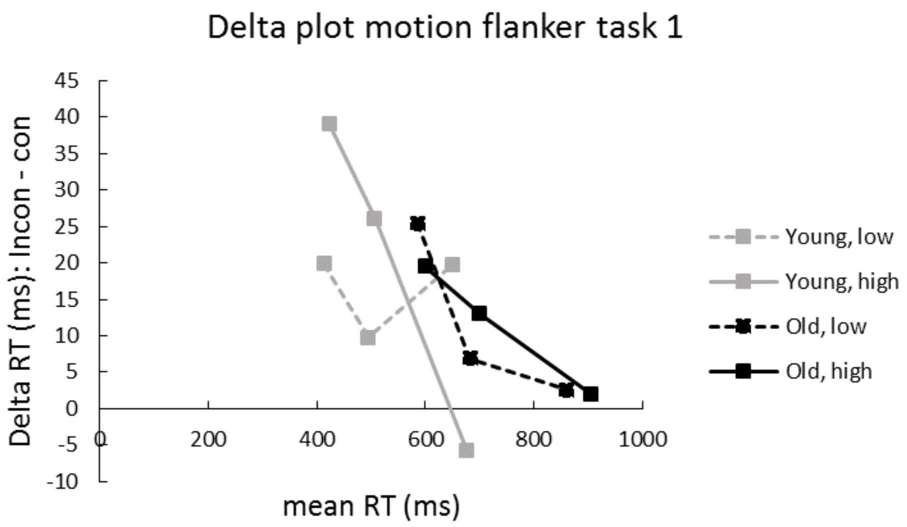


*Figure 4.2.* Delta-plot analysis for the motion flanker task. Dotted lines represent the low coherency conditions, solid lines the high coherency condition.

### 4.2.3. Discussion

The motion flanker task showed that overall RTs as well as the flanker effect increased as coherency level increased. Regarding age, older adults performed more slowly than younger adults but showed similar flanker costs and delta plots. Furthermore, while more inhibition appeared to be needed in the more coherent conditions, this affected younger and older adults in similar manners.

While ageing did not affect inhibition costs, baseline speed predicted flanker costs in different ways in younger and older adults. For younger adults, this relation was positive. Participants with faster motion perception also showed smaller costs. This could be related to overall performance: Those who performed better at a baseline task also performed better at interference suppression. However, for older adults, the relation was negative. Participants with faster motion perception showed larger flanker costs. Thus, those older participants who responded faster to motion (i.e., who performed more similar to younger adults) had worse inhibitory control. Older adults who responded more slowly to motion in the baseline task showed smaller flanker costs. Due to slower motion perception, they may have been less affected by the motion from the flanker items. If so, the flanker items would present less interference and thus lower levels of inhibition would be needed to resolve the conflict. Processing speed, and specifically the speed with which motion is perceived and processed, may therefore affect inhibitory control. However, it is unclear whether these findings are specific to the motion flanker task or extend to other types of inhibition tasks.

## 4.3. Experiment 2: Age and inhibition across three tasks

In Experiment 2, I therefore compared effects of age across three inhibition tasks. Even tasks that are often argued to measure similar mechanisms, such as the Simon and flanker task, depend on task-specific features. For example, while the Simon task only presents one arrow at a time, the flanker task uses multiple arrows. Distracting information is thus presented differently in these two tasks. In the flanker task, distracting information is presented in the periphery. In the Simon task, the distracting information is the presentation side on the screen and part of the target itself. Indeed, when the Simon and flanker effects were compared, Paap and Greenberg (2013) only observed a correlation of $r = -.01$.

Task-specific features could interact with possible effects of ageing. In many studies on ageing and inhibition, younger and older adults are compared on one inhibition task only. Effects of ageing on inhibition appear to be more consistently found in the Simon task than in flanker tasks, but different studies are hard to compare. Kawai, Kubo-Kawai, Kubo, Terazawa, and Masataka (2012) form an exception as they compared younger and older adults completing a Simon arrow and flanker task. While older adults showed larger Simon costs than younger adults, there was no difference in flanker costs between the two groups.

Experiment 2 firstly aimed to replicate the findings on the motion flanker task. As a second aim, I wanted to examine effects of age on inhibition across a Simon arrow (also called spatial Stroop) task, static flanker task, and motion flanker task. All tasks present distracting information and require participants to suppress task-irrelevant information. However, the specific type of stimulus and type of distracting information differs between the three tasks. While the Simon arrow and static flanker task use static stimuli (i.e., arrows), the motion flanker task uses moving stimuli. In terms of the type of interference, the Simon task differs from the two flanker tasks. If this matters, the static and motion flanker task should show similar effects of ageing with a deviating pattern on the Simon arrow task. Thirdly, I aimed to investigate whether the link between baseline processing speed and inhibition control was specific to moving stimuli or extends to other stimuli.

### 4.3.1. Methods

**Participants**

Thirty younger adults (4 male; mean age = 20.50, *SD* = 2.60, range = 18-25) and 28 older adults (5 male; mean age = 68.57, *SD* = 6.97, range = 60-86) completed Experiment 2. Two further older adults took part in the study but could not complete the motion flanker task. All participants had normal or corrected-to-normal vision and hearing, no known neurological disorders, and gave written informed consent. All participants were monolingual English native speakers and were born and raised in Scotland. In terms of years of education, there were no differences between young (*M* = 15.37, *SD* = 1.97) and older adults (*M* = 16.36, *SD* = 3.68; $t(56) = 1.26$, $p = .214$). Furthermore, the two groups did not differ on the lifestyle questionnaire (Scarmeas et al., 2003; young adults: *M* = 38.27, *SD* = 3.51; old adults: *M* = 40.11, *SD* = 3.55; $t(56) = 1.98$, $p = .052$). Older participants also completed the ACE-III as a dementia screening (Hsieh et al., 2013) and all participants scored above the cut-off of 88 points (*M* = 97.79, *SD* = 2.47).

**Materials and procedure**

All participants completed three tasks: a motion flanker, static flanker, and Simon arrow task.

The motion flanker task was similar to the task described in Experiment 1. In the static flanker task, participants were presented with arrows pointing left or right and were asked to indicate the pointing direction with a button press. In the baseline condition, one arrow was presented on the centre of the screen. In the conflict condition, participants were still asked to respond to the arrow presented on the centre of the screen. However, this arrow was now surrounded by other arrows or by black squares (neutral condition). The surrounding arrows could point in the same (congruent) or opposite (incongruent) direction. To ensure comparability with the motion flanker task in Experiments 1 and 2, flanker arrows were presented 100 ms prior to presentation of the target arrow. Arrows were presented in black on a white background and were 50 x 23 pixels. Horizontally, the five arrows were presented respectively in position (-104, -52, 0, 52, 104). In the Simon arrow task, participants saw one arrow pointing left or right and were asked to indicate the pointing direction with a button press. In the baseline condition, all arrows were presented on the centre of the screen. In the conflict condition, arrows were presented on the left or right side of the screen. This led to congruent (match between presentation side and pointing direction) and incongruent trials (mismatch between presentation side and pointing direction). The arrows were 100x46 pixels and were presented in black on a white background. Laterally presented arrows were presented 300 pixels from the centre of the screen.

The order of the three tasks was counterbalanced across participants. Each task took approximately fifteen minutes to complete and was presented in PsychoPy v 1.82 (Peirce, 2007) on a 19-inch screen with 1280x1024 resolution. Each task followed the structure baseline – conflict – baseline condition. The baseline and conflict conditions were preceded by a minimum of 12 practice trials. The two baseline blocks together consisted of 96 trials. For the Simon task, the conflict condition had four blocks with a total of 384 trials (192 congruent, 192 incongruent). The two flanker tasks had five blocks with 480 trials (96 neutral, 192 congruent, 192 incongruent). In each task, a trial started with a fixation cross on the centre of the screen for 500 ms, followed by stimulus presentation for 3000 ms or until a response was given.

**Data analysis**

Again, data were analysed using both NHST and Bayesian analysis as well as through delta-plot analyses. As these tasks included more trials, I divided the RTs in five bins to allow for a better comparison of slopes across bins. To examine comparability between the three tasks, I furthermore tested for correlations between overall RTs as well as inhibition costs across tasks.

### 4.3.2. Results

**RT analysis**

***Effects of age, coherency, and congruency***

*Motion flanker task*

Accuracy scores were close to ceiling for both younger and older adults in the baseline (young: $M$ = 98.92, $SD$ = 2.07; old: $M$ = 99.03, $SD$ = 1.44) and conflict condition (young: $M$ = 97.36, $SD$ = 3.33; old: $M$ = 98.42, $SD$ = 2.84) and were not analysed further. Incorrect trials and RTs more than 2.5 *SD* above the mean (3.47% of the correct trials) were removed for the RT analysis.

In the baseline condition, older adults (*M* = 640.43, *SD* = 138.85) responded more slowly than young adults (*M* = 494.72, *SD* = 138.99; $t(56) = 3.99$, $p < .001$, $\eta^2 = .22$, $BF_{10} = 125.67 \pm 0\%$ ).

For the conflict condition, I carried out a two-way repeated ANOVA with trial type (congruent, neutral, incongruent) as a within-subject factor and age group (young, old) as a between-subject factor. There was a main effect of trial type ($F(2, 112) = 14.86$, $p < .001$, $\eta_p^2 = .21$) While RTs were similar for congruent trials (*M* = 596.33, *SD* = 138.12) and neutral trials (*M* = 581.22, *SD* = 122.62), they were slower for incongruent trials (*M* = 608.00, *SD* = 117.54). Older adults (*M* = 667.25, *SD* = 111.84) performed more slowly than younger adults overall (*M* = 532.68, *SD* = 99.30; $F(1, 56) = 24.13$, $p < .001$, $\eta_p^2 = .30$). The interaction between age and trial type was not significant ($F(2, 112) = .36$, $p = .696$). This suggests that flanker, suppression, and facilitation effects did not differ between age groups (see Table 4.2) as was also confirmed by the Bayesian analysis comparing the model with interaction age x trial type to the model with main effects only. The model without an interaction fits the data better by a factor of 7.76 (± 6.43%).

I then examined the effects of coherency level by only including congruent and incongruent trials in a three-way repeated ANOVA with trial type (congruent, incongruent) and coherency level (40%, 60%, 80%, 100%) as within-subject factors and age group (young, old) as a between-subject factor. Similar to the previous analysis, the main effects of congruency ($F(1, 56) = 4.31$, $p = .042$, $\eta_p^2 = .07$) and age ($F(1, 56) = 22.21$, $p < .001$, $\eta_p^2 = .28$) reached significance. Contrary to the results of Experiment 1, the effect of coherency ($F(3, 168) = 1.10$, $p = .350$) and the interaction between coherency and congruency ($F(3, 168) = .77$, $p = .511$) did not reach significance (see Table 4.2). There was no interaction between age and congruency ($F(1, 56) = .33$, $p = .567$), age and coherency ($F(3, 168) = 1.60$, $p = .192$), nor a three-way interaction ($F(3, 168) = 1.33$, $p = .266$), suggesting that inhibition costs were similar for the two age groups. The Bayesian analysis showed that a model without an interaction between age and congruency was preferred compared to a model with this interaction by a factor of 3.81 (± 1.35%).

Again, I calculated proportional flanker costs for the 100% coherent condition and examined effects of age. There was no significant effect of age ($t(56) = 1.34$, $p = .186$; $BF_{10} = 1.78 \pm 0\%$)[11].

*Static flanker task*

Accuracy scores were close to ceiling for both younger and older adults in the baseline (young: *M* = 96.91, *SD* = 3.32; old: *M* = 99.26, *SD* = 1.06) and conflict condition (young: *M* = 97.12, *SD* = 2.93; old: *M* = 99.30, *SD* = .70) and were not analysed further. For the reaction time analysis, I removed all incorrect trials as well as RTs more than 2.5 *SD* above the mean (2.02% of the correct trials).

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[11] Similar to Experiment 1, the BF provides some evidence for an effect of age but this effect goes in the opposite direction (larger costs for young than older adults).

The baseline condition showed that older adults (*M* = 548.29; *SD* = 84.62) responded more slowly than young adults (*M* = 408.66, *SD* = 62.83; $t(56) = 7.10$, $p < .001$, $\eta^2 = .48$, $BF_{10} = 3480590 \pm 0\%$).

For the conflict condition, I carried out a two-way repeated ANOVA with trial type (congruent, neutral, incongruent) as a within-subject factor and age group (young, old) as a between-subject factor. RTs were fastest for congruent trials (*M* = 488.46, *SD* = 99.61), followed by neutral trials (*M* = 506.18, *SD* = 97.43), and incongruent trials (*M* = 551.47, *SD* = 95.58; $F(2, 112) = 168.41$, $p < .001$, $\eta_p^2 = .75$) and older adults (*M* = 590.40, *SD* = 83.43) performed more slowly than younger adults overall (*M* = 448.38, *SD* = 41.53; $F(1, 56) = 70.56$, $p < .001$, $\eta_p^2 = .56$). The interaction between age and trial type was not significant ($F(2, 112) = .59$, $p = .555$). This suggests that flanker, suppression, and facilitation effects did not differ between age groups (see Table 4.2). This was confirmed by the Bayesian analysis comparing the model with interaction to the model with main effects only. The model without an interaction fits the data better by a factor of 3.62 (± 1.05%).

Proportional flanker costs were calculated next to correct for age-related differences in processing speed. This yielded a significant effect of ageing on proportional flanker costs ($t(56) = 2.29$, $p = .026$, $\eta^2 = .09$; $BF_{10} = 2.27 \pm 0\%$). Although the BF only provided anecdotal evidence (BF < 3), this difference went in the opposite direction: Younger adults had larger proportional inhibition costs than older adults.

*Simon arrow task*

Accuracy scores were close to ceiling for both younger and older adults in the baseline (young: *M* = 98.41, *SD* = 1.91; old: *M* = 99.29, *SD* = 1.04) and conflict condition (young: *M* = 96.51, *SD* = 3.41; old: *M* = 98.20, *SD* = 2.04) and were not analysed further. For the reaction time analysis, I removed all incorrect trials as well as RTs more than 2.5 *SD* above the mean (2.50% of the correct trials).

The baseline condition, showed an effect of age group ($t(56) = 8.09$, $p < .001$, $\eta^2 = .54$; $BF_{10}$ = 118644827 ± 0%), with older adults (*M* = 532.71, *SD* =76.86) being slower than younger adults (*M* = 393.45, *SD* = 52.88).

To examine effects of age on inhibition, I analysed the conflict condition and carried out a two-way repeated ANOVA with trial type (congruent, incongruent) as a within-subject factor and age group (young, old) as a between-subject factor. RTs were faster for congruent (*M* = 568.81, *SD* = 107.08) than for incongruent trials (*M* = 601.47, *SD* = 126.08; $F(1, 56) = 74.73$, $p < .001$, $\eta_p^2 = .57$) and older adults (*M* = 673.79, *SD* = 94.72) performed more slowly than younger adults overall (*M* = 501.58, *SD* = 55.53; $F(1, 56) = 72.43$, $p < .001$, $\eta_p^2 = .56$). The interaction between age and trial type was also significant ($F(1, 56) = 19.38$, $p < .001$, $\eta_p^2 = .26$), suggesting that older adults had larger inhibition costs than younger adults (see Table 4.2). This was confirmed by the Bayesian analysis. Comparing the model with the interaction age x trial type to the model with the main effects age and trial type only, showed that the model with the interaction fits the data better by a factor of 274.85 (± 1.48%).

To correct for age-related slowing, I then calculated proportional Simon costs. The effect of ageing on inhibition costs remained present ($t(56) = 3.60$, $p = .001$, $\eta^2 = .19$; $BF_{10} = 45.84 \pm 0\%$).

Table 4.2

*Means and standard deviations (between parentheses) of the Simon and flanker effects (incongruent – congruent trials) per task and per age group. For the two flanker tasks, suppression effects (incongruent – neutral trials) and facilitation effects (congruent – neutral trials) are included too.*

| | **Young** | **Old** |
|---|---|---|
| **Simon arrow task** | | |
| Simon effect | 16.31 (21.51) | 50.17 (35.77) |
| | | |
| **Static flanker task** | | |
| Flanker effect | 64.28 (22.08) | 61.65 (34.67) |
| Suppression effect | 48.95 (23.04) | 41.37 (24.97) |
| Facilitation effect | -15.32 (27.50) | -20.28 (27.90) |
| | | |
| **Motion flanker task (across all coherency levels)** | | |
| Flanker effect | 14.54 (26.78) | 8.59 (52.56) |
| Suppression effect | 30.67 (26.37) | 22.61 (16.90) |
| Facilitation effect | 16.12 (35.63) | 14.02 (52.21) |
| | | |
| **Motion flanker effect per coherency level** | | |
| 40% | 5.11 (26.01) | 7.53 (46.93) |
| 60% | 11.94 (25.81) | 12.41 (63.56) |
| 80% | 20.14 (38.54) | 8.32 (55.14) |
| 100% | 21.26 (39.27) | 4.81 (79.82) |

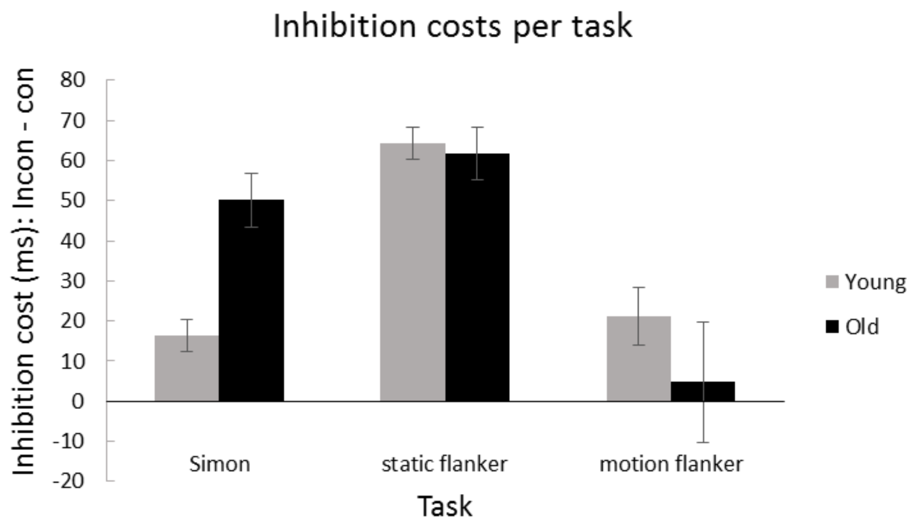


*Figure 4.3.* Flanker/Simon costs per task (100% condition only for the motion flanker task) and per age group. Grey bars represent young adults, black bars older adults.

Thus, ageing affected inhibition costs on the Simon task but not on the two flanker tasks (Figure 4.3). To ensure that this interaction indeed differed per task, I ran an additional ANOVA with task (Simon, static flanker, motion flanker) as a within-subject variable, age (young, old) as a between-subject variable, and flanker/Simon cost as the dependent variable. For the motion flanker task, I only included the 100% flanker cost to ensure comparability between tasks. There was no main effect of age ($F(1, 56) = .57$, $p = .455$) on inhibition costs but there was a main effect of task ($F(2, 112) = 19.76$, $p < .001$, $\eta_p^2 = .26$). Post-hoc analyses showed that the static flanker task had larger flanker costs than the Simon and motion flanker task (respectively $p = .001$, $p < .001$). The Simon and motion flanker task did not differ significantly ($p = .058$). Furthermore, there was a significant interaction between age and task ($F$(2, 112) = 5.29, $p$ = .006, $\eta_p^2$ = .09), confirming that the effects of ageing on inhibition were different for the three tasks. This was also confirmed by the Bayesian analysis. The model including main effects of age and task as well as an interaction between task and age scored best and was preferred by a factor of 12.07 (± 2.23) over a model without an interaction between task and age.

***Effects of baseline RTs on inhibition costs***

For the motion flanker task, an interaction between baseline and age ($b$ = -.29, $t$ = -3.11, $p$ = .003) was found. Again, I ran the analysis separately for the two age groups. For the younger adults, baseline RT was not a significant predictor of flanker costs ($b$ = -.10, $t$ = -1.98, $p$ = .058, $BF_{10}$ = 1.44 ± 0). For older adults, baseline RT was a significant and negative predictor of flanker costs ($b$ = -.39, $t$ = -4.79, $p$ < .001, $BF_{10}$ = 324.66 ± 0). Thus, similar to Experiment 1, older adults with slower baseline speed processing showed smaller flanker costs.

For the static flanker task, there was no main effect of baseline ($b$ = -.01, $t$ = -.12, $p$ = .909, $BF_{10}$ = .50 ± 0) nor an interaction with age ($b$ = -.10, $t$ = -.90, $p$ = .373), suggesting that flanker costs and processing speed were unrelated for both age groups.

For the Simon task, a main effect of baseline ($b$ = .14, $t$ = 6.00, $p$ < .001) was found that did not interact with age ($b$ < .01, $t$ = .24, $p$ = .812). This suggests that for both younger and older adults, faster baseline processing speed was related to smaller Simon costs. The Bayes factor provided strong evidence for an effect of baseline RT ($BF_{10}$ = 72969.17 ± 0)

**Delta-plot analysis**

***Motion flanker task***

The motion flanker task firstly showed a significant effect of bin ($F(3, 168) = 7.49$, $p < .001$, $\eta_p^2 = .12$), with inhibition costs decreasing with slower responses. Slopes were also more negative for the higher coherency level ($F(1, 56) = 8.45$, $p = .005$, $\eta_p^2 = .13$). Furthermore, there was a main effect of age ($F(1, 56) = 13.01$, $p = .001$, $\eta_p^2 = .19$) with more negative slopes for older than younger adults (Figure 4.4). The Bayesian analysis showed that the model with age and bin as main effects fits the data better by a factor of 26.67 (± .44) than a model excluding age. None of the interactions were significant (*p*s > .05).

***Static flanker task***

On the static flanker task too, there was a significant effect of bin ($F(3, 168) = 3.68$, $p = .013$, $\eta_p^2 = .06$). The slopes, however, did not differ between age groups ($F(1, 56) = .57$, $p = .456$; see Figure 4.4) and age did not interact with bin ($F(3, 168) = .28$, $p = .837$). The model with bin as the only main factor explained the data better by a factor of 3.62 (± .3) compared to a model with bin and age as the main factors.

***Simon arrow task***

On the Simon arrow task, there was a significant effect of bin ($F(3, 168) = 3.66$, $p = .014$, $\eta_p^2 = .06$). Furthermore, the slopes were steeper for younger than older adults, although the *p* value did not reach significance ($F(1, 56) = 3.98$, $p = .051$, $\eta_p^2 = .07$). Age did not interact with bin ($F(3, 168) = .70$, $p = .551$). Although the model including age and bin as main factors was the best model in the Bayesian analysis, the model including age was only 1.20 times (± .29) better than a model without age. As Figure 4.4 shows, while inhibition costs decreased with slower responses in young adults, the costs increased with response times for older adults[12].

[12] Figure 4.4 also shows an unexpected increase in slope in the last bin for younger adults. Delta plots differ between young adults with low and high inhibitory control (cf., Ridderinkhof et al., 2004). As an exploratory analysis to explain this increased slope, I excluded young participants that showed Simon costs > 2 *SD* above the mean ($N = 3$). Indeed without these three young participants with large inhibition costs, the slope for the last bin becomes negative too for younger adults.

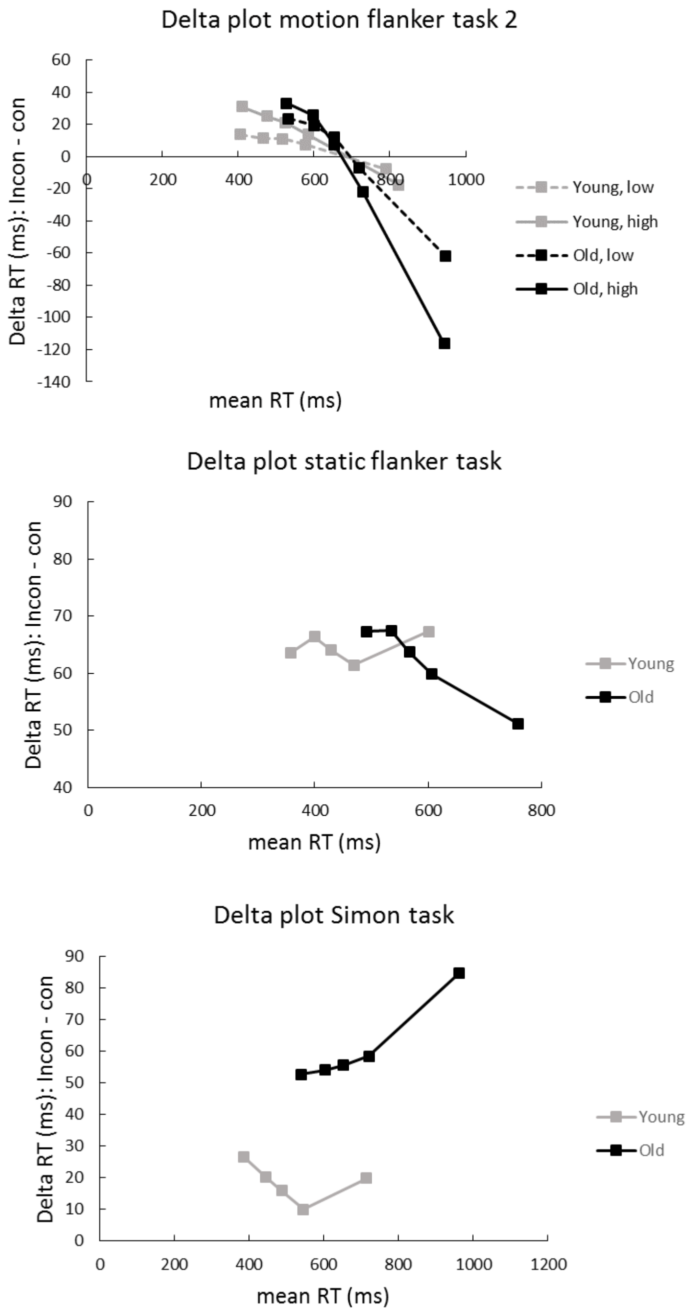


*Figure 4.4.* Delta plots for the motion flanker (top), static flanker (middle), and Simon task (bottom). For the motion flanker graph, dotted lines represent the low coherency condition, solid lines the high coherency condition.

**Correlations between the three tasks**

The overall RTs were all highly correlated between the three tasks (Simon & static flanker: $r = .88$, $p < .001$; Simon & motion flanker: $r = .77$, $p < .001$; static flanker & motion flanker: $r = .74$, $p < .001$). None of the inhibition costs correlated significantly between the three tasks (Simon & static flanker cost: $r = .14$, $p = .313$; Simon & 100% motion flanker cost: $r = -.17$, $p = .192$; static flanker & 100% motion flanker cost: $r = .25$, $p = .062$).

### 4.3.3. Discussion

Similar to Experiment 1, the motion flanker task showed a main effect of age and congruency, but no interaction between the two. However, flanker costs did not significantly increase with coherency in this experiment.

As a second aim, I compared effects of age on inhibition across three tasks. All tasks showed that older adults performed more slowly than younger adults. On the static flanker and motion flanker task, there was no difference in flanker costs between younger and older adults. Yet, on the Simon arrow task, older adults did show larger inhibition costs than younger adults. This suggests that age may affect inhibition differently depending on the task. This was confirmed by the delta-plot analysis. Although this did not reach significance, on the Simon arrow task, younger adults showed negative slopes while older adults showed positive slopes (see e.g., Juncos-Rabadán et al., 2008, for similar results). This is compatible with the interpretation that younger adults were more successful at inhibiting the irrelevant information than older adults. Furthermore, the delta plots suggested that there were further differences between the static flanker and motion flanker task despite both tasks not showing an effect of age on inhibition costs. In the static flanker tasks, slopes were similar for older and younger adults, suggesting that their inhibitory performance was comparable. However, in the motion flanker task, slopes were more negative for older than younger adults. Indeed, the older adults showed smaller (but not significantly smaller) inhibition costs in the motion flanker task, especially in the more coherent conditions. This could mean that for longer RTs, inhibition for older adults was more efficient on the motion flanker task than for younger adults.

The effects of baseline speed on inhibition costs showed different findings for the three tasks. For the Simon task, both younger and older adults with faster baseline processing speed showed smaller inhibition costs. This is compatible with the type of inhibition present in this task. Participants have to respond to one arrow only and are distracted by the presentation side of the screen. Thus, those perceiving the arrow's pointing direction faster may also have less interference from the presentation side. On the static flanker task, there was no effect of baseline processing speed on inhibition costs. However, on the motion flanker task, I again observed a negative relation between motion perception and inhibition costs for older adults but not for younger adults. Older adults who perceived motion faster also showed larger inhibition costs, possibly because they were more affected by interference from the flanker dots. For younger adults, this relation is unclear. In Experiment 1 it was positive while in Experiment 2 it did not reach significance but went in a negative direction.

### 4.4. General discussion

Across two experiments, younger and older adults completed three inhibition tasks: a Simon arrow, static flanker, and motion flanker task. Although these three tasks can all be argued to measure interference suppression, they have different task-specific features. While all tasks showed effects of congruency and slower RTs for older than younger adults, the effects of age on inhibition costs differed. On the Simon arrow task, older adults showed larger inhibition costs, while age did not affect inhibition in the static and motion flanker tasks. Delta-plot analyses confirmed that older adults showed diminished inhibitory control performance on the Simon arrow task, but not on the two flanker tasks. This analysis also showed different patterns for the motion versus static flanker task, implying that the type of stimuli matters too. Furthermore, the motion, but not static flanker task, showed a relation between baseline processing speed and inhibition costs in older adults. Slower stimulus perception may lead to lower interference and consequently to smaller inhibition costs.

#### 4.4.1. What are the effects of age on inhibition?

On the Simon arrow task, older adults showed larger inhibition costs than younger adults, even when proportional Simon costs were analysed to correct for baseline differences (see also Proctor et al., 2005; Castel et al., 2007). On the two flanker tasks, I did not observe effects of age on inhibition costs. When proportional costs were analysed, the static flanker task even showed smaller costs for older adults (see also Jennings et al., 2007; Hsieh et al., 2012). Although the literature suggests that different patterns of age may arise on Simon versus flanker tasks, not many studies have directly compared the two. An exception is Kawai et al. (2012), who also tested older adults on a Simon arrow and static flanker task. Similar to my study, effects of ageing were only found on the Simon but not the flanker task. This different pattern could be related to the type of inhibition in the Simon versus flanker task. In the Simon task, the irrelevant information is part of the stimulus itself and thus highly salient. In the flanker task, however, the irrelevant information is not part of the stimulus, but presented next to the target. Wild-Wall et al. (2008) suggested that older adults focus more on the target stimulus and are less affected by the congruency of the surrounding information. This may explain why older adults show similar or even smaller (proportional) inhibition costs than younger adults on flanker tasks. Furthermore, peripheral vision generally declines with age (e.g., Johnson, Adams, & Lewis, 1989). Although our older participants all had normal or corrected-to-normal vision and did not report any vision problems, they may be less affected by peripheral information than younger adults. In contrast, in the Simon arrow task, older adults will not benefit from enhanced target processing and decreased interference from flanker items as interference is part of the target.

My study thus shows that task-specific characteristics such as the type of interference can modify effects of age.

#### 4.4.2. Baseline processing speed and inhibition

As a second question, I examined effects of baseline processing speed on inhibition costs for both age groups. Again, I observed different patterns for the three tasks. The Simon arrow task showed, for both age groups, that faster baseline processing speed relates to smaller inhibition costs. Those who responded more quickly to the pointing direction of the arrow were also less affected by the interference. For the static flanker task, no effects of baseline speed on inhibition costs were found for either age group. The motion flanker task showed different patterns for younger and older adults. Older adults who responded faster to baseline motion showed larger inhibition costs, possibly because they had more interference from the motion flankers. These findings are compatible with the interpretation by Wild-Wall et al. (2008) regarding the automaticity of information transfer from visual to motor areas. If baseline information is processed faster, this could lead to increased interference from flanker items. On the other hand, if baseline information is processed more slowly, the delayed transmission may also cause less interference and thus older adults with slower motion processing show smaller flanker costs.

While the motion flanker task showed effects of processing speed, the static task did not. I used a motion flanker task as motion perception generally deteriorates with age (e.g., Tran et al., 1998). For both flanker tasks, older participants performed more slowly than younger adults in the baseline condition with the difference between the young and older adults being similar for the two tasks. Yet, the standard deviations are larger on the motion task, suggesting that performance is more heterogeneous. Due to this variability, effects may have been more likely to occur on the motion than static flanker task. The delta-plots also suggested that there may be differences between the static and motion flanker task. An effect of age was only observed on the motion task, with more negative slopes for older adults (i.e., more efficient inhibitory control) than younger adults, while this difference was absent for the static flanker task. Therefore, the type of stimulus materials and the speed with which they are processed may affect the relationship between ageing and inhibition.

A remaining question is whether possible effects of stimulus perception and processing speed are specific to older adults or could occur for younger adults too. In the current sample, all younger adults reported good vision and showed no problems in the motion perception task. However, it could be argued that when younger adults with good and poor motion perception are compared, similar results should arise as for the older adults.

#### 4.4.3. Task comparability

Inhibition costs across tasks sometimes correlate poorly (e.g., Paap & Greenberg, 2013). I observed a similar pattern. While overall RTs correlated highly between the three tasks, the inhibition costs did not correlate significantly. The low correlations between the Simon and flanker tasks highlight the issue of task impurity. Inhibition tasks not only measure the component that we aim to measure (i.e., inhibition), but are also largely affected by other components such as processing speed and task-specific features. Given the differences between tasks, differential effects of ageing on inhibition can be expected and were indeed observed in this study. These low correlations and the influence of task-specific features on age effects show that task impurity affects measurements of executive control. This also poses problems for research on bilingualism and executive control as tasks may not exactly or only measure what we want to them to measure. This issue will be discussed in more detail in respect to bilingualism research in Chapter 8 (General discussion).

### 4.5. Conclusion

In conclusion, this study suggests that the effects of age on inhibitory control depend on task-specific features. An effect of age on inhibition occurred on the Simon but not the flanker tasks. More detailed analyses furthermore suggested that effects of age and interactions with processing speed differed between the two flanker tasks and may depend on stimulus materials. With moving stimuli, slower processing of flanker items may cause less interference for older adults. This pattern was not observed with static stimuli. Effects of age on inhibition can thus depend on the type of task-irrelevant information, the type of stimulus materials, processing speed, as well as the interactions between these components.

# Chapter 5. The effects of language use on lexical processing in bilinguals

This chapter is based on:

De Bruin, A., Della Sala, S., & Bak, T. H. (in press). The effects of language use on lexical processing in bilinguals. *Language, Cognition and Neuroscience.*

*Author contribution: All authors contributed to the study concept and design. Data collection and analysis were performed by A. de Bruin. A. de Bruin drafted the manuscript and T. H. Bak and S. Della Sala provided critical revisions.*

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## 5.1. Introduction

Bilinguals tend to perform worse than monolinguals on lexical tasks. For example, bilinguals show slower and less accurate picture naming in both the dominant language as well as the second language (e.g., Gollan et al., 2005; Ivanova & Costa, 2008), more tip-of-the-tongue experiences (e.g., Gollan & Acenas, 2004), smaller vocabulary sizes in each language (e.g., Bialystok & Feng, 2009), and they name fewer items on verbal fluency tasks (e.g., Rosselli et al., 2000). This could result from parallel activation of both languages, even if only one is needed (e.g., Dijkstra & Van Heuven, 2002). Competition from the active non-target language could delay or weaken lexical access in the target language (Inhibitory Control, IC, model, Green, 1998).

Language proficiency has been suggested to modify the amount of competition from one language on another, but the effects of language use remain understudied. The 'weaker links hypothesis' (Michael & Gollan, 2005)[13] has suggested that a bilingual uses each language less often than a monolingual, which could lead to weaker links between concepts and words. Hence, not only language competence and proficiency, but also the bilingual's active language use could modulate lexical processing.

In this chapter, I present a study examining the effects of language use on lexical performance. If a bilingual raised fluently in two languages continues to speak only one, is their lexical processing still affected by the inactive language? If

[13] In more recent papers, a revised version of this hypothesis is referred to as the 'frequency-lag hypothesis'.

the bilingual difficulty in lexical processing is due to language proficiency independent of use, the effects should persist once a bilingual has reached a high proficiency in both languages, even if they continue to speak only one. In contrast, if not only language competence but also actual use affects lexical processing, inactive bilinguals who only use one of their languages should perform more similar to monolinguals.

The Gaelic-English population of the Hebrides (Scotland) is particularly well-suited to address this question. For much of the 20th century, Gaelic was the dominant language in families and communities while English was the exclusive language of schooling and, to a large extent, working life. Accordingly, many older adults who grew up in the Hebrides acquired both Gaelic and English during childhood and reached full proficiency in both. However, over the past decades, Gaelic use was also reduced in more informal community settings. While some Gaelic-English bilinguals continued to use both languages, others moved to a predominant or even exclusive use of English.

Against this background, I compared three groups: Gaelic-English bilinguals who continued to use both languages throughout their lives *(active bilinguals)*; Gaelic-English bilinguals who used almost exclusively English for much of their adult life *(inactive bilinguals)*; and English-speaking *monolinguals*.

## 5.2. Methods

**Participants**

Seventy-six older adults (25 men) participated in the study (mean age = 70.91, *SD* = 6.82, range = 60 – 89 years). All participants were born and raised on the Hebrides and were living on the Isles of Harris, Islay, Lewis, Mull, or Skye. All participants had normal or corrected-to-normal vision and none reported colour blindness. All took part in the experiment in their home or a community centre and gave informed consent. Participants received a gift card in return for participation.

Twenty-eight participants were Gaelic-English bilinguals and still used both languages on a daily basis (‘active bilinguals’; 32% men). Twenty-four participants were Gaelic-English bilinguals, but mainly used English (‘inactive bilinguals’; 29% men). Twenty-four adults were English monolinguals (33% men). All active and inactive bilinguals had acquired Gaelic and English during childhood. Gaelic was acquired by all participants from birth. The average age of acquisition for English was 4.3 years old for active bilinguals and 3.8 years old for inactive bilinguals. Twenty-four adults were English monolinguals with no or very limited proficiency in Gaelic. The isolated location of these islands leads to a relatively homogeneous population and participants in the three language groups had similar backgrounds (see Chapter 6 for more details).

Participants were asked to rate their proficiency in Gaelic on a scale from 1 (‘no proficiency’) to 10 (‘excellent proficiency’) in terms of speaking, understanding, reading, and writing. Similarly, for language use, they were asked to score their language use in Gaelic and English on a scale from 1 (‘never’) to 10 (‘always’) for five time frames: childhood at home, childhood at school, later life at work, later life at home, and after retirement (i.e., at the moment of testing). Although this was not required, most participants who provided a high score for English provided a low score for Gaelic and vice versa.

***Language use***

Active and inactive bilinguals reported similar usage of Gaelic and English during childhood at home and school, but different patterns during later life (Appendix D1 and Figure 5.1). The *active bilinguals* still used both Gaelic and English on a daily basis, mainly with family members, neighbours, and through Gaelic radio and television programmes. The frequency of use varied from equal use of both languages to Gaelic-dominant speakers, although even the latter used English frequently as well. In terms of language switching, active bilinguals reported to switch often between English and Gaelic. On a scale from 1 (‘never’) to 4 (‘very often)’, the mean rating for switching on a daily basis was 3.82 (*SD* = .48), for switching in a conversation 3.54 (*SD* = 3.54), and for switching in a sentence 3.20 (*SD* = 1.26). The *inactive bilinguals* used predominantly English and reported using Gaelic only monthly or less. The most common reasons to use English instead of Gaelic were marrying an English-speaking spouse, the general decrease of Gaelic speakers in the direct environment, and an increase of English-speaking immigrants.

The third group consisted of *monolinguals*, who reported no or very little use of Gaelic during all five time frames.

A significant effect of language group on language use was found in all five time frames for both languages. Post-hoc comparisons (see Appendix D1) showed that active and inactive bilinguals did not differ in Gaelic and English use during their childhood. Both groups predominantly used Gaelic at home, but had to use English at school. Although active and inactive bilinguals were highly similar during their childhood, only active bilinguals continued to use both languages during their later life. Active bilinguals used more Gaelic than inactive bilinguals in later life at work and at home and this difference continued after retirement. Conversely, active bilinguals used less English than inactive bilinguals and monolinguals across their later life. The inactive bilinguals and monolinguals used similar amounts of English and Gaelic during their later life at home. However, after retirement, inactive bilinguals used Gaelic more often and English less often than the monolinguals.

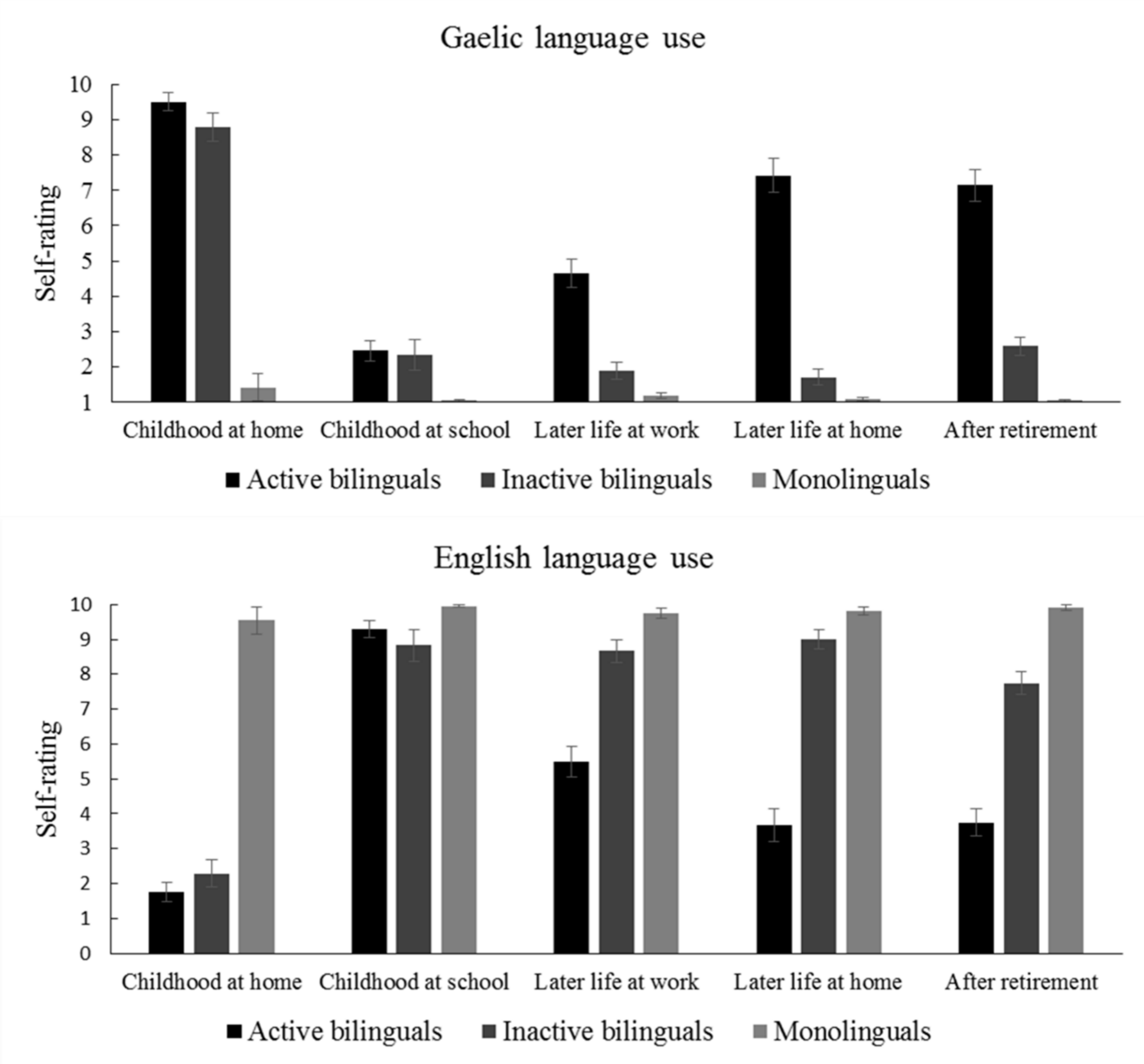


*Figure 5.1.* Gaelic and English language use per time frame for the three language groups (active bilinguals, inactive bilinguals, monolinguals). Error bars indicate +/- 1 s.e.m.

***Proficiency***

Gaelic and English proficiency self-ratings are provided in Table 5.1. For Gaelic proficiency, the three language groups differed significantly in terms of speaking ($\chi^2(2) = 60.18$, $p < .001$), understanding ($\chi^2(2) = 56.82$, $p < .001$), reading ($\chi^2(2) =$

47.98, $p < .001$), and writing ($\chi^2(2) = 44.91$, $p < .001$). Pair-wise comparisons showed higher scores for bilinguals than monolinguals (i.e., English monolinguals reported having no or very little Gaelic proficiency) and higher proficiency for active bilinguals than inactive bilinguals (all *p*s < .05). Regarding English proficiency, the three language groups only differed significantly for speaking ($\chi^2(2) = 7.61$, $p = .022$). Pair-wise comparisons showed that active bilinguals had a significantly lower self-rating than monolinguals, with no difference between inactive bilinguals and monolinguals ($p > .05$). No group differences were found in understanding, reading, and writing.

Table 5.1

*Means and standard deviations (in parentheses) of self-rated language proficiency for Gaelic and English.*

| | **Active bilingual** | **Inactive bilingual** | **Monolingual** |
|---|---|---|---|
| **Gaelic** | | | |
| Speaking | 9.57 (.69) | 6.63 (2.20) | 1.75 (1.54) |
| Understanding | 9.61 (.74) | 7.63 (1.88) | 2.71 (1.99) |
| Reading | 7.54 (2.43) | 4.83 (2.46) | 1.33 (.87) |
| Writing | 6.82 (2.74) | 3.96 (2.53) | 1.13 (.34) |
| **English** | | | |
| Speaking | 9.43 (.75) | 9.79 (.41) | 9.88 (.34) |
| Understanding | 9.50 (.69) | 9.79 (.41) | 9.88 (.34) |
| Reading | 9.43 (.74) | 9.79 (.41) | 9.79 (.51) |
| Writing | 9.39 (.83) | 9.79 (.41) | 9.79 (.51) |

**Tasks**

Lexical processing speed was measured in a picture-word matching task. Participants saw pictures accompanied by a written word that either formed a match or mismatch and were asked to indicate with a button press the match (e.g., picture of a bird accompanied by the word 'bird') or mismatch (e.g., picture of a bird accompanied by the word 'apple'). The picture was always presented on the left side of the screen, the word on the right side; both remained on the screen until a response was given. Both accuracy and response times (RTs) were measured. Sixty picture-word pairs (based on Dawson, 2013) were presented in both Gaelic and English. Half of the words were nouns, half verbs, and all were non-cognates (see Appendix D2 for stimulus materials). Pictures were easily recognisable black-white drawings from An Object and Action Naming Battery (Druks & Masterson, 2000). The pictures were presented in blocks of Gaelic and English with the order of languages counterbalanced across participants. The order of the pictures was randomised within the language block. For half of the participants, a word was part of a matched pair; for the other half, the word was part of a mismatch. Each picture and each word were presented once per language. English monolinguals only completed the English picture-word matching task.

As part of the dementia screening (Addenbrooke's Cognitive Examination-III, ACE-III, Hsieh et al., 2013), participants also completed a letter fluency and category fluency test. In the category task, they were asked to name as many animals as possible in 60 seconds. In the letter fluency task, they were asked to name words starting with a 'P'. The dementia screening and fluency tasks were completed in English. The participants also completed several non-verbal cognitive tests, which are reported in Chapter 6.

**Data analysis**

Self-ratings on language use and proficiency from the questionnaire were analysed using the non-parametric Kruskal-Wallis test. Data from the picture-word matching task were analysed using a linear mixed-effects analysis for RTs and a generalised linear mixed-effects analysis for accuracy. Contrary to the averages used in ANOVAs, mixed-effect models take all individual trials into account. This has several advantages. While averages do not necessarily reflect the participant's true performance, inclusion of individual trials gives a more realistic overview of actual performance. Mixed-effect analyses include both individual participants as well as items. Thus, one analysis incorporates both while otherwise two ANOVAs need to be reported (one across participants, one across items). This is especially valuable for language tasks that include multiple language items with their own properties (e.g., word length). Furthermore, people and items differ from each other. Mixed-effect models account for this variability by allowing for inclusion of intercepts and slopes for individual participants and items.

Analyses were performed in the lme4 package in R (Bates, Maechler, Bolker, & Walker, 2015). To normalise their distribution, RTs were log transformed. To compare language groups in the English task, language group and word class as well as their interaction were included as fixed effects. I furthermore included self-rated Gaelic proficiency. In order to directly examine effects of language use in a continuous rather than categorical manner, I reran the model with self-rated English use after retirement instead of language group. Intercepts for participants and items and the slopes for the effects with word class (participants) and language group (items) were included as random effects. In the second analysis, comparing active and inactive bilinguals in English and Gaelic, I included language group, language, and word class in the model, as well as their interactions as fixed effects. As random effects, I included intercepts for participants, items, and word length[14] as well as the slopes for the effects with language and word class (participants) and language group and language (items). *Z*-scores (for accuracy) and *t*-scores (for RTs) greater than 2 were interpreted as significant effects (see Meier & Kane, 2013; Coderre & Van Heuven, 2014b). For the RT analysis, incorrect answers as well as RTs more than 2.5 *SD*s above the mean were excluded. Two Gaelic words received low accuracy scores (*bee/beach*: 57.14%; *cherry/siris*: 64.29%) from active Gaelic-English bilinguals and were removed from all analyses. Although analyses were performed on transformed RTs, averaged raw values are provided in the text and tables to simplify data interpretation and enable comparisons with other studies.

[14] I entered number of phonemes as a measurement of word length as participants reported covert vocalisation of the written words. Entering number of letters instead of phonemes did not change the results.

## 5.3. Results

### 5.3.1. Picture-word matching task

**Comparison of bilinguals and monolinguals on the English task**

English accuracy (see Figure 5.3) was close to ceiling for all three groups and was therefore not analysed further. RTs (see Table 5.2) showed a main effect of word class, with nouns ($M$ = 1478.72, 95% confidence interval (CI): ± 123) being processed faster than verbs ($M$ = 1657.58, 95% CI: ± 145, $t$ = 3.11). Self-rated Gaelic proficiency was a significant predictor of English RTs ($t$ = 2.69). Higher Gaelic proficiency was associated with longer RTs on the English task. There was furthermore an effect of language group. Monolinguals ($M$ = 1346.99, 95% CI: ± 109) were faster in the English task than active bilinguals ($M$ = 1750.10, 95% CI: ± 187, $t$ = 4.06). RTs of inactive bilinguals ($M$ = 1577.02, 95% CI: ± 166) fell in-between and did not differ significantly from either group ($t$ < 2, see Figure 5.2). There was no interaction between word class and language group ($t$ < 2).

To ensure that differences between language groups were related to language use, I reran the analysis with self-rated English language use during retirement as a continuous variable. This confirmed the effects of language use: the higher the amount of English use, the faster performance on the English task ($t$ = -3.78).

Table 5.2

*Fixed effects of the mixed-effects analysis of RT performance of bilinguals and monolinguals on the English task. The reference levels for this model are nouns for word class and monolinguals for language group. For example, the fixed effect 'language group: inactive bilinguals' compared inactive bilinguals to monolinguals. Significant effects (*t *> 2) are indicated with an asterisk.*

| **Predictor** | **Estimate** | **SE** | **t-ratio** |
|---|---|---|---|
| Intercept | 6.89 | 0.11 | 63.97* |
| Word class: Verbs | 0.12 | 0.04 | 3.11* |
| Gaelic proficiency | 0.16 | 0.01 | 2.69* |
| Language group: Inactive bilinguals | 0.18 | 0.17 | 1.07 |
| Language group: Active bilinguals | 0.88 | 0.22 | 4.06* |
| Word class x Inactive bilinguals | .008 | 0.05 | 1.67 |
| Word class x Active bilinguals | 0.10 | 0.06 | 1.82 |

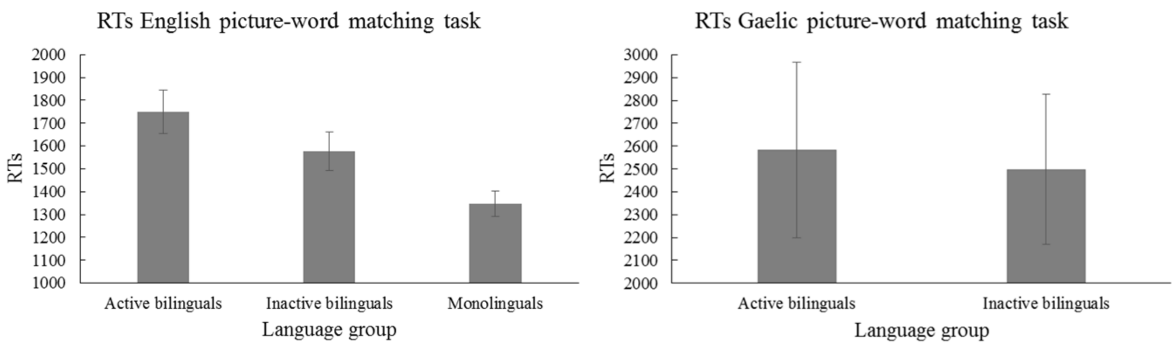


*Figure 5.2.* Reaction times from the picture-word matching task in English (left) and Gaelic (right) per language group. Error bars indicate +/- 1 s.e.m.

**Comparison of active versus inactive bilinguals in Gaelic**

Accuracy scores showed that Gaelic items ($M$ = 89.56, 95% CI: ± 1.79) were less accurate than English items ($M$ = 97.18, 95% CI: ± .68, $z$ = -2.69). There was a main effect of language group ($z$ = -2.53) and an interaction between language group and language ($z$ = -2.62), suggesting that inactive bilinguals were less accurate than active bilinguals in Gaelic (respectively $M$ = 85.07, 95% CI: ± 2.85, and $M$ = 93.40, 95% CI: ± 1.79; see Figure 5.3). However, for both active and inactive bilinguals, accuracy in English was higher than in Gaelic.

RTs (see Table 5.3) showed that Gaelic items ($M$ = 2544.21, 95% CI: ± 283) were answered more slowly than English words ($M$ = 1670.22, 95% CI: ± 126, $t$ = 4.12) and nouns ($M$ = 1949.67, 95% CI: ± 192) were processed faster than verbs ($M$ = 2264.75, 95% CI: ± 267, $t$ = 3.41). There was an interaction between language group and language, with the difference between Gaelic and English being larger for inactive bilinguals than active bilinguals ($t$ = 2.21). However, again, both bilingual groups were faster in English than Gaelic. There were no other main effects or interactions ($t$s < 2).

Table 5.3

*Fixed effects of the mixed-effects analysis of RT performance of bilinguals on the English and Gaelic task. The reference levels for this model are nouns for word class, English for language, and active bilinguals for language group. Significant effects (*t *> 2) are indicated with an asterisk.*

| Predictor | Estimate | SE | t-ratio |
|---|---|---|---|
| Intercept | 7.32 | .07 | 108.38* |
| Word class: Verbs | 0.09 | .04 | 3.41* |
| Language group: Inactive bilinguals | -0.09 | 0.09 | -0.98 |
| Language: Gaelic | 0.23 | 0.06 | 4.12* |
| Word class x Inactive bilinguals | -0.04 | 0.03 | -1.11 |
| Word class x Gaelic | 0.05 | 0.05 | 0.97 |
| Inactive bilinguals x Gaelic | 0.15 | 0.07 | 2.21* |
| Word class x inactive bilinguals x Gaelic | 0.03 | 0.04 | 0.82 |

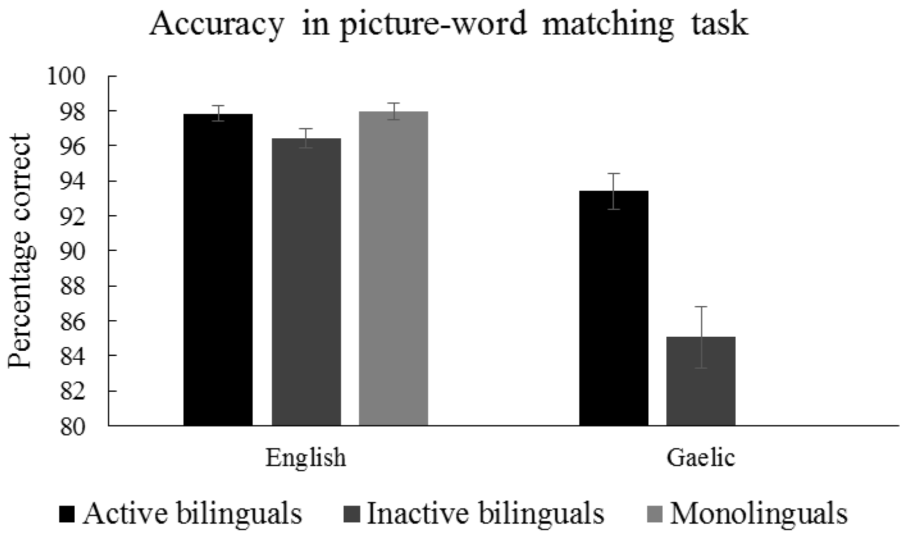


*Figure 5.3.* Accuracy scores from the picture-word matching task in English and Gaelic per language group. Error bars indicate +/- 1 s.e.m.

### 5.3.2. Verbal fluency tasks

A linear regression on the fluency data showed that language group ($b$ = 3.75, $t$ = 3.77, $p$ < .001) was a significant predictor of category fluency, with monolinguals producing most items ($M$ = 19.75, $SD$ = 4.80), followed by inactive bilinguals ($M$ = 17.88, $SD$ = 5.47), and active bilinguals ($M$ = 16.04, $SD$ = 4.86). Post-hoc tests showed that only active bilinguals differed significantly from monolinguals ($p$ = .027), with no significant differences between monolinguals and inactive bilinguals ($p$ = .394) or active and inactive bilinguals ($p$ = .406). On the letter fluency task, monolinguals ($M$ = 14.42, $SD$ = 5.91), inactive bilinguals ($M$ = 14.33, $SD$ = 5.57), and active bilinguals ($M$ = 13.14, $SD$ = 4.97) performed similarly ($b$ = .65, $t$ = .86, $p$ = .392).

## 5.4. Discussion

This study examined the effects of bilingualism and language use on lexical processing by comparing active bilinguals, inactive bilinguals, and monolinguals. All bilinguals grew up speaking Gaelic and English at a very high proficiency level. Yet whereas active bilinguals continued to use both languages during adulthood, inactive bilinguals moved to a predominant or exclusive use of English.

On the picture-word matching task, English accuracy was close to ceiling for all three groups, showing that even active bilinguals had a very high proficiency in English. The response times, however, showed an effect of language use. Active bilinguals were slowest on the English task, followed by inactive bilinguals and monolinguals. Inactive bilinguals did not differ significantly from either active bilinguals or monolinguals. An additional analysis with language use as a continuous predictor showed a significant effect of language use on English RTs. Previous studies (cf., Bialystok, 2009, for an overview) have found similar lexical difficulties in bilinguals compared to monolinguals. Verbs showed slower RTs than nouns (see e.g., Mätzig, Druks, Masterson, & Vigliocco, 2009), but the effects of language use were similar for both word classes.

A similar pattern of results was observed on verbal fluency, a task in which the performance in the native tongue can be modified by learning further languages (Vega-Mendoza, West, Sorace, & Bak, 2015). On the category fluency task, active bilinguals performed significantly worse than monolinguals, while performance of the inactive bilinguals fell in-between the two groups. No effects of bilingualism were found on the letter fluency task (see e.g., Rosselli et al., 2000). Together with the picture-word matching task, this suggests that language use affects both lexical perception as well as production.

The bilingual lexical disadvantage is commonly explained by two main theories. The Inhibitory Control (IC) model poses that the disadvantage results from competition from the non-target language slowing down the bilingual's performance. The 'weaker links hypothesis' suggests that bilinguals use each of their languages less often, thus leading to weaker links between words and concepts. My findings firstly show an effect of Gaelic proficiency on English RT performance, thus confirming the importance of language proficiency and supporting the IC model. However, above these proficiency effects, those who used Gaelic more often also responded more slowly to English words. The performance of inactive bilinguals suggests that the effects of bilingualism on lexical processing may be modulated by the actual use of two languages, thus supporting the 'weaker links hypothesis' (Michael & Gollan, 2005). However, my results can reconcile these two theories if the IC model incorporates language use as a modifying variable. In such case, not only lower proficiency, but also lower use of a language (and thus a weaker link between the words and concepts in that language), could lead to lower levels of competition. Infrequent language use could lower the activation of the non-target language and could thus cause less language competition in lexical tasks. Thus, inactive bilinguals are less hindered by Gaelic when completing an English task than active bilinguals.

The slower lexical processing in active bilinguals is not likely to be due to lack of exposure to English. All participants have received their education in English and live in an environment dominated by English. This dominance is particularly pronounced for the written language, which was the basis of the picture-word matching task. Indeed, self-rated English reading and writing scores were high for all language groups (> 9) and showed little variability. In the picture-word matching task itself, all three language groups scored at ceiling in terms of English accuracy. Yet those who used the language more often were also faster in the picture-word matching task. I suggest therefore that the amount of use of the target language together with the amount of use of the non-target language can influence the speed of lexical processing.

The current study only included participants above the age of 60. Although cognitive ageing could affect language processing, single word comprehension tasks appear relatively stable in older adults (Burke & MacKay, 1997). Furthermore, the average age was similar across all three groups.

The Adaptive Control Hypothesis (Green & Abutalebi, 2013) classifies three language contexts (single language, dual language, dense code-switching) that enable different types of language use and could have different effects on performance in both cognitive and lexical tasks. My findings extend this hypothesis by demonstrating how language use and context can change dramatically within the same individual throughout their lifetime. I propose, therefore, that in future studies language use should be part of the basic characterisation of bilingual populations as much as age of acquisition and proficiency.

# Chapter 6. Examining the effects of active versus inactive bilingualism on executive control in a carefully matched non-immigrant sample

This chapter is based on:

De Bruin, A., Bak, T. H., & Della Sala, S. (2015). Examining the effects of active versus inactive bilingualism on executive control in a carefully matched non-immigrant sample. *Journal of Memory and Language, 85*, 15-26.

*Author contribution: All authors contributed to the study concept and design. Data collection and analysis were performed by A. de Bruin. A. de Bruin drafted the manuscript and T. H. Bak and S. Della Sala provided critical revisions.*

## 6.1. Introduction

It is often maintained that speaking two languages requires a constant control of both. Although various theories of bilingual language control have been proposed, the often used Inhibitory Control model states that activating a word in the target language not only requires the bilingual speaker to activate that word, but also to inhibit the corresponding one from the non-target language (Green, 1998). As discussed in Chapter 1, this ongoing practice of language inhibition has been argued to lead to improved interference suppression in bilinguals performing non-linguistic inhibition tasks. Furthermore, bilinguals have been claimed to also be better at switching between two non-verbal tasks than monolinguals. However, as I discussed in Chapter 2, many studies suffer from poor matching between participant groups. For example, in previous studies, bilingual and monolingual groups differed on socio-economic status (SES), education, or immigrant status. These background differences hinder a reliable interpretation of the results: Are the advantages truly related to bilingualism? In this chapter, I present a study that compared bilinguals and monolinguals on an inhibition and task-switching paradigm. Crucially, all bilingual and monolingual participants were non-immigrants and came from similar backgrounds. Furthermore, I examined the effects of language use. While some previous studies have investigated the role of age of acquisition and language proficiency, the actual use of the languages remains understudied. To this end, I compared two groups of bilinguals who all acquired two languages during childhood. Yet while the active bilinguals continued to use both during later adulthood, the inactive bilinguals only or predominantly continued to use one.

### 6.1.1. Bilingualism, inhibition, and task switching

Evidence for a bilingual advantage on inhibition tasks has been found for different age groups (see Appendix A1). Bilingual children have been found to outperform monolingual children on various inhibitory control tasks (e.g., Martin-Rhee & Bialystok, 2008; Bialystok & Viswanathan, 2009; De Abreu et al., 2012). Although more inconsistently, similar inhibitory advantages have also been observed for younger adults (e.g., Costa et al., 2008; Treccani et al., 2009; Pelham & Abrams, 2014). Several studies comparing younger to older adults have furthermore suggested that bilingual advantages on inhibition tasks may be larger in older adults. Bialystok et al. (2004) compared middle-aged to older bilinguals and monolinguals on a Simon task (see Chapter 1, p. 10). The Simon cost was found to be smaller for bilinguals than monolinguals. This bilingual advantage was furthermore greater for older than middle-aged adults. Similarly, using a Simon arrow paradigm, Bialystok et al. (2008) found that older bilinguals were better at suppressing irrelevant information than monolinguals. This advantage was not found for the younger adults tested in the same study.

However, these findings have been challenged in other studies. Testing participants across a range of inhibitory control tasks, several studies failed to observe a behavioural bilingual advantage in children (e.g., Antón et al., 2014;

Duñabeitia et al., 2014), younger adults (e.g., Kousaie & Phillips, 2012b; Paap & Greenberg, 2013), and older adults (e.g., Kousaie & Phillips, 2012a; Kirk et al., 2014).

Besides inhibitory control, bilingual advantages may also be related to task switching. Bilinguals were found to be faster at switching between non-verbal tasks than monolinguals in groups of children (e.g., Barac & Bialystok, 2012; Bialystok & Viswanathan, 2009), younger adults (e.g., Prior & MacWhinney, 2010), and older adults (e.g., Gold et al., 2013a). Prior and MacWhinney (2010) presented participants with stimuli that had to be responded to according to colour or shape (see Chapter 1, p. 20). Bilingual participants were found to be better at switching than monolinguals. No difference was observed for the mixing costs: the difference between non-switch trials in the mixed condition and the blocked condition. These mixing costs have been argued to reflect more global mechanisms needed to maintain two competing tasks in a mixed condition (Rubin & Meiran, 2005). This suggests that the bilingual advantage is related to switching specifically rather than more global task control. Comparing younger to older adults on a switching task, Gold et al. (2013a) only found a bilingual switching advantage for the older but not the younger group. Yet bilingual switching advantages have been challenged too (e.g., Paap & Greenberg, 2013; Hernández et al., 2013).

Effects of bilingualism have predominantly been tested in inhibitory control and task-switching paradigms. However, if an advantage is found, its exact nature remains debated (see Chapter 2). Bilingual advantages have been found on inhibition costs such as the Simon costs (e.g., Bialystok et al., 2008), suggesting that the bilingual advantage concerns incongruent trials specifically. Yet bilingual advantages have not only been found on incongruent trials, but also on both congruent and incongruent trials (e.g., Bialystok, 2006). In 2011, Hilchey and Klein reviewed 31 experiments examining effects of bilingualism on executive control tasks. They concluded that there was hardly any evidence to support the hypothesis that bilinguals have an advantage on inhibitory control. Rather, they concluded, that bilinguals may have a more global advantage in monitoring conflict and regulating task demands. If bilinguals indeed have a more global monitoring advantage, this should be reflected in faster overall RTs on both congruent and incongruent trials in inhibition tasks and both switch and non-switch trials in switching tasks.

However, the idea of a bilingual advantage on either inhibitory control or switching specifically or on a more global level has been challenged in several recent studies. Paap et al. (2015) estimated that over 80% of studies after 2011 do not show a positive effect of bilingualism. Similarly, in an update to their 2011 review, Hilchey et al. (2015) conclude that the evidence for a bilingual advantage on inhibitory control is still weak. Contrary to the 2011 review, however, they now also argue that evidence for a more global bilingual advantage has evaporated since their initial review. Furthermore, in Chapter 3 I presented a meta-analysis of studies on bilingualism and executive control. While this showed an average effect size of *d* =.30, suggesting a small effect of bilingualism, there was also evidence for publication bias.

Thus, the current literature shows an inconsistent pattern of results (see Baum & Titone, 2014; Valian, 2015; Paap et al., 2015 for recent overviews). Whereas several studies have found a cognitive effect of bilingualism, this is challenged in more recent studies. Two key issues may affect the type of results found in studies on bilingualism and executive control: the extent to which language groups are matched on potentially confounding variables, and the type of bilinguals that is tested. In the present study, I therefore matched the language groups on background variables. I also examined the effects of language use on executive control. The importance of background variables will be discussed first.

#### 6.1.2. The importance of confounding variables

In order to examine effects of *bilingualism* on executive control, one has to ensure that bilingual and monolingual groups only differ in the number of languages that they speak. In most studies, however, this is not the only difference between language groups. As I discussed in Chapter 2, many studies have confounded background variables, including SES, country of origin, and immigration status. For example, Bialystok et al. (2004) compared Canadian monolinguals to Indian bilinguals. The majority of older bilingual participants (20 out of 24) in Bialystok et al. (2008) were immigrants, whereas all monolinguals were non-immigrants. In Gold et al. (2013a), 75% of the older bilinguals were immigrants compared to 15% of the monolinguals. Similarly, two of the first studies on bilingualism and Alzheimer's disease (Bialystok et al., 2007; Craik et al., 2010) confounded bilingualism and immigration. The issue of immigration, however, also plays a role in studies that have not found effects of bilingualism (e.g., Paap & Greenberg, 2013).

Some studies have examined effects of bilingualism in non-immigrant samples, but the effects are mixed. Some have found positive effects for healthy adults (e.g., Costa et al., 2008; Bak et al., 2014; Woumans et al., 2015b) and dementia patients (Alladi et al., 2013, Woumans et al., 2015a). Yet, other studies with non-immigrant samples did not observe a cognitive effect of bilingualism in children (e.g., Antón et al., 2014), younger adults (e.g., Kousaie & Philips, 2012b, although some differences were found in the ERP data), healthy older adults (e.g., Kousaie & Philips, 2012a), and dementia patients (e.g., Chertkow et al., 2010; Lawton et al., 2015).

In a recent study, Kirk et al., (2014) compared Gaelic-English bilinguals to monodialectals, bidialectals, monolinguals, and Asian-English bilinguals. All five language groups showed similar Simon costs. Crucially, the control groups were living in an urban environment, whereas the Gaelic-English bilinguals were living in a rural and more isolated environment. Lifestyle and environment thus might have been confounding factors. It is furthermore not always the bilingual group that consists of immigrants. In a recent study by Clare et al. (2014), which found no evidence for a delaying effect of bilingualism on the onset of Alzheimer's Disease, many monolinguals were people who migrated to Wales from other parts of the country, while the bilingual group consisted mainly of autochthonous population.

### 6.1.3. The importance of language use

In Chapter 5, I showed that language use can modulate effects of bilingualism on lexical tasks. Still, very little is known about the potential effects of language use on executive control. Yet bilinguals differ in language acquisition, proficiency, and use, and these differences could explain the inconsistent effects on executive control. Bilingual-monolingual differences may be due to the knowledge of different languages or to the actual use of two languages. Prior and Gollan (2011) suggested that task-switching performance may be affected by daily language switching. A group of frequently switching Spanish-English bilinguals showed smaller switching costs than monolinguals, whereas this advantage was not found for less frequently switching Mandarin-English bilinguals. Verreyt et al. (2016) tested balanced switching, balanced non-switching, and unbalanced bilinguals on a Simon and flanker task and found a relative advantage for the balanced switching bilinguals. These two studies suggest that language use may affect executive control. On the other hand, Bak et al. (2014) found only small differences when comparing the impact on cognitive ageing of actively using two languages (active bilingualism) to low use of a second language (passive bilingualism). However, the interpretation of their results was limited by the fact that the vast majority of their participants used their second language only rarely. In the field of dementia studies, Freedman et al. (2014) argued that the differences between the results of studies conducted in Toronto, Montreal and Hyderabad could be due to different patterns of language use (in particular of switching) in these places. However, in previous studies, participants not only differed in language use, but also in language acquisition and language proficiency. To examine the effects of language use rather than competence more specifically, I compared participants with the same pattern of language acquisition but diverging patterns of language use.

### 6.1.4. Present study

The present study aimed, therefore, to address two issues. First, I wanted to examine effects of bilingualism on executive control in a sample carefully matched for potentially confounding variables such as lifestyle, education, SES, immigrant status, and IQ. I therefore tested groups of bilinguals and monolinguals on the Hebrides, a group of islands located in the Western part of Scotland. All participants were born and raised and at the time of testing living on these islands. Bilinguals acquired both Gaelic and English during their childhood, whereas monolinguals only spoke English. The isolated location of these islands has resulted in a relatively homogenous population with similar levels of education and SES. Hence, the bilinguals and monolinguals only differed in their languages, but not in their background or country of origin. Furthermore, when effects of bilingualism are observed, they are mainly found in samples of children and older adults. In studies directly comparing older and younger adults, effects of bilingualism are largest or only found in the group of older adults (e.g., Bialystok et al., 2008; Gold et al., 2013a). Consistent with these findings, I tested bilinguals and monolinguals who were aged 60 years or older.

Secondly, I examined not only the *knowledge* of a second language but also its *active use*. The specific environment of the Hebrides offers a unique opportunity to dissociate these two aspects of bilingualism. As discussed in Chapter 5, most people on the Outer Hebrides over 60 years grew up in a Gaelic-speaking family and neighbourhood environment and acquired English with the beginning of their schooling (age 5 years). However, in their adulthood some Gaelic-English bilinguals continued to actively use both languages (active bilinguals), while others mainly used English in their later life (inactive bilinguals). This allowed me to examine the effects of *knowing* versus actually *using* two languages on executive functioning while keeping the age of acquisition (AoA) constant. The monolingual controls came from the Inner Hebrides: an environment very similar in terms of landscape, living conditions, and lifestyle to the Outer Hebrides. However, due to a closer proximity to the English-speaking mainland, Gaelic has been replaced by English in this area already in the early 20$^{th}$ century and the monolinguals had either no or only minimal knowledge of Gaelic or another second language.

To examine effects of bilingualism and language use on executive functioning, I tested bilinguals' and monolinguals' performance on two executive tasks that have been used in previous studies of bilingualism. Firstly, I used a Simon arrow task, which has been linked to advantages for both young bilinguals (Bialystok, 2006) and older bilingual immigrants (Bialystok et al., 2008). Furthermore, Chapter 4 showed that the Simon arrow task showed an effect of ageing, while this was not present in two flanker tasks. Thus, the age-related increase in inhibition costs in a Simon arrow task may allow for effects of bilingualism to emerge in a sample of older adults. If bilinguals are better at interference suppression than monolinguals, they should show smaller Simon costs. If bilinguals have a more global cognitive advantage, they should show faster RTs on both congruent and incongruent trials. Secondly, participants completed a task-switching paradigm. Prior and MacWhinney (2010) and Gold et al. (2013a) found smaller switching costs for bilinguals as opposed to monolinguals and these effects have been associated with daily language-switching frequency (Prior & Gollan, 2011). If bilinguals are better at switching they should have smaller switching costs than monolinguals. If this is furthermore affected by language use, active bilinguals should have smaller switching costs than inactive bilinguals. If bilingualism affects general monitoring rather than switching specifically, bilinguals should have reduced mixing costs.

## 6.2. Methods

**Participants**

The same 76 participants described in Chapter 5 completed several non-verbal cognitive tasks. None of the participants were immigrants. Data from one Simon task and one task-switching paradigm were not recorded due to equipment malfunction.

Participants first completed a questionnaire including questions about their language use and proficiency, education, and lifestyle. Following Hollingshead's

Four Factor Index of Social Status (1975), I calculated their socio-economic status (SES) score based on education and occupation. I also derived a lifestyle score from participation in 18 activities (Scarmeas et al., 2003). As further background measures, participants completed two non-verbal components (block design and matrix reasoning) of the Wechsler Abbreviated Scale of Intelligence (WASI), which were taken as a measure of IQ. As a screening for dementia, I also administrated the Addenbrooke's Cognitive Examination-III (ACE-III, Hsieh et al., 2013). The three language groups were matched on age, SES, years of education, lifestyle (including music practice), ACE-III score, and IQ (all *F*s < 1). These background data are provided in Table 6.1.

Furthermore, participants completed two background measurements that were not expected to show a beneficial effect of bilingualism; the outcome of these measures was not used as an inclusion/exclusion criteria. In the Tower of London task (TOL; Shallice, 1982), participants had to move coloured balls on three pegs of different height to solve 12 problems increasing in difficulty (PEBL software, cf., Mueller & Piper, 2014). They received 3 points for solving the problem in the first attempt, 2 points for the second attempt, and 1 point for the third attempt (maximum score of 36). In a baseline processing speed task, participants saw 96 centrally presented arrows pointing to the left or the right and they had to press the corresponding button. Although participants were not matched on these two tasks, they did not differ significantly on TOL performance ($\chi^2(2) = .15$, $p = .928$) or speed processing ($F(2, 72) = .34$, df = 2, $p = .713$).

Table 6.1

*Means and standard deviations (in parentheses) of the background variables per language group.*

| | **Active bilinguals** | **Inactive bilinguals** | **Monolinguals** |
|---|---|---|---|
| Age | 71.86 (7.06) | 70.50 (7.69) | 70.21 (5.66) |
| SES | 34.89 (13.82) | 38.88 (11.60) | 35.92 (9.58) |
| Years of education | 12.64 (2.79) | 13.17 (3.56) | 11.88 (1.72) |
| Lifestyle | 39.11 (4.44) | 38.50 (5.49) | 38.08 (4.45) |
| ACE-III | 92.68 (3.68) | 92.96 (3.43) | 93.75 (3.29) |
| WASI | 102.61 (17.21) | 101.71 (9.79) | 103.58 (11.27) |
| Tower of London | 29.96 (5.51) | 27.08 (6.21) | 25.67 (7.52) |
| Processing speed (RTs) | 794.21 (191.35) | 772.73 (226.51) | 824.51 (230.19) |

Chapter 5 provides a more comprehensive overview of the participants' language characteristics. In summary, all active and inactive bilinguals acquired Gaelic as their first language. Monolingual participants were all native English speakers and did not speak any other language. Active and inactive bilinguals did not differ in English and Gaelic language use during their childhood at home or at school. During their later life, however, active bilinguals reported a much more frequent use of Gaelic than inactive bilinguals.

Language proficiency in English and Gaelic was measured using both self-ratings as well as a picture-word matching task. Language proficiency was close to ceiling in English for all three language groups. In Gaelic, active bilinguals showed higher proficiency than inactive bilinguals on both the picture-word matching task and the self-ratings (see Chapter 5).

**Materials and procedure**

Participants completed a Simon arrow task, and a task-switching paradigm[15].

***Simon arrow task***

The Simon arrow task was adapted from the paradigm used by Bialystok et al. (2008), Bialystok (2006), and Bialystok and DePape (2009). Participants were presented with arrows pointing to the left or right and had to press the button corresponding with the direction of the arrow. The arrows were presented on the left or right side of the screen. In this way, stimulus presentation and arrow direction could be congruent (e.g., left side, left direction) or incongruent (e.g., left side, right direction). The difference between incongruent and congruent trials was defined as the Simon cost. There were an equal number of congruent and incongruent trials as well as an equal number of arrows pointing to the left and right. The experimental trials were preceded by a minimum of ten practice trials; participants could only start the experiment if 80% of the practice trials were answered correctly. The conflict blocks consisted of two experimental conditions: a low and high switching task. Following Bialystok (2006), I manipulated the frequency of inter-trial response switching (i.e., how often the required response for the present trials differed from the response required on the preceding trial). In the high switch condition, the 96 trials included 67 inter-response switches. In the

[15] Our experiment also included the Test of Everyday Attention (TEA). Twenty-two participants, however, were not able to complete this task because of hearing difficulties (the task requires to distinguish between high- and low-pitched tones). Therefore, we did not include the full results of this task. Performance on the TEA did not differ significantly between the three groups ($F(2, 51) = .23$, $p = .795$).

low switch condition, the 96 trials contained 36 inter-response switches. Each switching condition consisted of two blocks of 96 trials each. The order of high and low switching blocks was counterbalanced.

A trial started with the presentation of a fixation cross for 250 ms, followed by the presentation of the arrow that remained on the screen until a response was given. Arrows were 8 cm long and 4 cm wide at the widest point. The Simon task lasted approximately 10 minutes.

***Task-switching paradigm***

The task-switching procedure was adapted from Prior and MacWhinney (2010). Participants were presented with red or blue triangles or circles. The experiment consisted of a blocked and a mixed part. In the blocked condition, participants were asked to perform one task only (i.e., sort on colour or shape). In the mixed conditions, participants had to switch between colour and shape task according to a visual cue. These conditions consisted of both switch (task differs from previous trial) and non-switch (task is the same in two or more subsequent trials) trials. The difference between mixed non-switch and blocked trials was defined as mixing costs; the difference between switch and non-switch trials as switching costs. Following Gold et al. (2013a), who used a similar paradigm with older adults, I calculated proportional switching ([switch trials RT – non-switch RT]/non-switch RT x 100) and mixing costs ([non-switch trials RT – blocked RT]/blocked RT x 100) for each participant individually to correct for potential baseline differences.

The trials followed an unpredictable pattern of switch and non-switch trials. Each part of the experiment was preceded by a practice block. Participants could only start the experiment if they scored 80% correct on the practice trials. Participants completed two single task blocks (colour and shape were counterbalanced across participants), which consisted of 8 practice trials and 36 experimental trials each, and a mixed condition consisting of 16 practice trials and 144 experimental trials. In the mixed condition, half of the trials were switch trials and the other half non-switch trials, equally distributed across shape and colour. No more than three stimuli of the same trial type appeared in a row. In the mixed condition, the first trial after the breaks was excluded from analysis.

A trial started with the presentation of a fixation cross for 350 ms, followed by a blank interval for 150 ms. Then, the visual cue appeared on the screen above the fixation cross for 250 ms. Next, the stimulus was presented while the visual cue remained present. The stimulus remained on the screen for 4000 ms or until a response was given. After a blank interval of 500 ms, the next trial started. The cue for the colour task was a colour gradient; the cue for the shape task was a row of small black shapes. Although participants did not need the cue to select the task in the blocked context, the cue was present in both the blocked and mixed condition to minimise differences between the two conditions. Participants were instructed to perform one task using their left hand and the other one using their right hand (counterbalanced across participants). The specific responses were assigned to the middle or index finger. Stimuli were presented at the centre of a white background. Visual cues were presented 2.5 cm above the stimulus (4 x 4 cm).

**Data analysis**

I analysed all data using both null hypothesis statistical testing (NHST) as well as Bayesian analysis (see Chapter 4) with the Bayes Factor package in R (Morey & Rouder, 2014), the default prior (Rouder et al., 2012), and one million iterations to calculate the Bayes factors. It should be noted that, contrary to Chapter 4, BFs are presented as $BF_{01}$ (i.e., a value >1 indicates evidence for the null hypothesis).

## 6.3. Results

### 6.3.1. Simon arrow task

Accuracy scores were close to ceiling (see Table 6.2) and were not analysed further. For RT analysis, all incorrect answers as well as RTs more than 2.5 *SD* above the mean (calculated separately for each condition; an additional 2.06% of the correct trials) were removed. I carried out a three-way repeated ANOVA with language group as the between-subject variable, and congruency (incongruent, congruent), and condition (high switch, low switch) as the within-subject variables.

RT analysis showed a main effect of congruency ($F(2, 72) = 118.72$, $p < .001$, $\eta_p^2 = .63$), with incongruent trials being slower ($M = 946.44$, $SD = 241.76$) than congruent trials ($M = 872.49$, $SD = 220.06$). There was also a main effect of condition ($F(2, 72) = 5.78$, $p = .019$, $\eta_p^2 = .08$), with reaction times being faster in the low switch condition (*M* = 892.56, *SD* = 220.37) than high switch condition (*M* = 926.05, *SD* = 251.77). There was no main effect of language group ($F(2, 72) = .09$, $p = .914$), indicating that active bilinguals (*M* = 896.78, *SD* = 170.91), inactive bilinguals (*M* = 912.91, *SD* = 244.46), and monolinguals (*M* = 919.12, *SD* = 274.64) were equally fast. We observed an interaction between congruency and condition ($F(2, 72) = 8.27$, $p = .005$, $\eta_p^2 = .10$), suggesting that the Simon cost was larger in the low switch condition (*M* = 85.55, *SD* = 58.07) than the high switch condition (*M* = 61.61, *SD* = 72.13). There was no significant interaction between language and congruency ($F(2, 72) = .28$, $p = .757$), nor a three-way interaction between language, congruency, and condition ($F(2, 72) = .03$, $p = .969$), suggesting that Simon costs were similar for the three language groups[16]. The absence of an interaction was also supported by the Bayesian analysis. Comparing the model with main effects only to the model with main effects + congruency x language, to examine the interaction of congruency and language specifically, provided strong evidence against the model with the interaction. The model without an interaction fits the data better by a factor of 26.78 (± 1.09%), showing that bilingualism did not affect Simon costs (see Figure 6.1).

[16] Proportional Simon costs (incongruent-congruent/congruent) were calculated to correct for age-related slowing and also did not show an effect of language group: $F(2, 72) = .60$, $p = .554$.

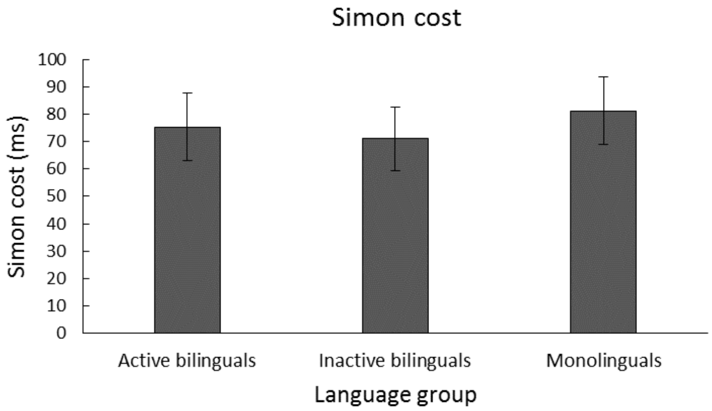


*Figure 6.1.* Simon costs across the high and low switch condition in the Simon arrow task for active bilinguals, inactive bilinguals, and monolinguals. Error bars indicate +/- standard error of the mean.

Table 6.2

*Reaction times (RT) and percentage correct (ACC) for the three language groups per Simon task condition. Standard deviations are indicated between parentheses.*

| | **Conflict high switch** | | **Conflict low switch** | |
|---|---|---|---|---|
| | Incongruent | Congruent | Incongruent | Congruent |
| **Active bilinguals** | | | | |
| RT | 945.68 | 888.73 | 918.27 | 834.77 |
| | (223.49) | (190.9) | (161.06) | (156.06) |
| ACC | 94.1 | 96.1 | 94.2 | 96.4 |
| | (8.5) | (8.6) | (10.0) | (8.5) |
| **Inactive bilinguals** | | | | |
| RT | 979.67 | 916.99 | 940.21 | 859.62 |
| | (272.46) | (269.3) | (233.42) | (224.85) |
| ACC | 96.3 | 98.2 | 95.1 | 96.8 |
| | (3.2) | (1.8) | (10.5) | (8.6) |
| **Monolinguals** | | | | |
| RT | 948.60 | 882.84 | 953.77 | 855.83 |
| | (300.78) | (285.6) | (301.95) | (256.91) |
| ACC | 97.1 | 98.4 | 97.2 | 97.7 |
| | (3.9) | (2.1) | (7.1) | (7.4) |

### 6.3.2. Task switching

Accuracy scores were close to ceiling and were not analysed further (see Table 6.3). For RT analysis, I removed all incorrect answers and trials preceded by an incorrect trial. RTs more than 2.5 *SD* above the mean (calculated separately for each condition) were also excluded from analysis (an additional 1.95% of the correct trials). I carried out a two-way repeated ANOVA with language group as the between-subject variable, and trial type (switch, non-switch, or blocked trial) as the within subject variable. This showed a main effect of trial type, ($F(2, 144) = 208.516$, $p < .001$, $\eta_p^2 = .74$), with switch trials being slower (*M* = 1352.91, *SD* = 306.37) than non-switch trials (*M* = 1266.97, *SD* = 279.52) and blocked trials (*M* = 857.21, *SD* = 185.41). There was no main effect of language group ($F(2, 72) = .290$, $p = .749$), indicating that overall reaction times were equally fast for active bilinguals (*M* = 1119.58, *SD* = 463.60), inactive bilinguals (*M* = 1186.68, *SD* = 487.44), and monolinguals (*M* = 1137.98, *SD* = 432.29). The interaction between trial type and language group was not significant ($F(2, 144) = 1.38$, $p = .244$). Using BFs to compare the model with main effects only to the model with main effects + trial type x language, in order to examine the interaction of trial type and language specifically, provided strong evidence against the model with the interaction. The model without an interaction fits the data better by a factor of 22.49 (± .86%), showing that bilingualism did not affect RT differences between blocked, non-switch, and switch trials (see Figure 6.2).

I also examined effects on switching and mixing costs specifically. Raw switching costs did show a significant effect of language group ($F(2, 72) = 3.51$, $p = .035$, $\eta_p^2 = .09$, $BF_{01} = .60 \pm .03\%$). A post-hoc Tukey test showed that active bilinguals and monolinguals differed significantly ($p = .032$), but the group of inactive bilinguals did not differ significantly from either active bilinguals or monolinguals (*p*s > .05). Raw switching costs, however, were affected by (non-significant) slower RTs on non-switch trials for bilinguals. Using proportional costs to correct for these baseline differences, language group did not have a significant effect on switching costs ($F(2, 72) = 2.99$, $p = .057$, $BF_{01} = .89 \pm .03\%$). Language groups also did not differ on raw ($F(2, 72) = 1.29$, $p = .282$, $BF_{01} = 3.17 \pm .03\%$) or proportional mixing costs ($F(2, 72) = 1.73$, $p = .184$, $BF_{01} = 2.32 \pm .04\%$).

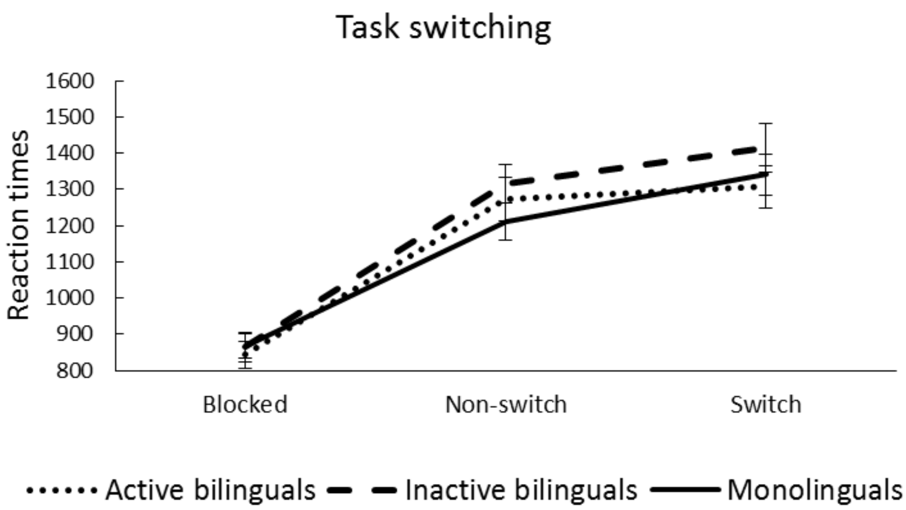


*Figure 6.2.* Reaction times for active bilinguals, inactive bilinguals, and monolinguals on switch and non-switch trials in the blocked and mixed condition of the task-switching paradigm. Error bars indicate +/- standard error of the mean.

Table 6.3

*Reaction times (RT) and percentage correct (ACC) for the three language groups per task-switching condition. Standard deviations are indicated between parentheses.*

| | **Blocked** | **Mixed** | | **Raw mixing costs** | **Raw switching costs** |
|---|---|---|---|---|---|
| | | Non-switch | Switch | | |
| **Active bilinguals** | | | | | |
| RT | 842.59 (192.79) | 1273.41 (318.24) | 1307.70 (304.15) | 430.81 (306.02) | 34.19 (129.24) |
| ACC | 99.07 (1.84) | 96.44 (3.98) | 95.59 (4.60) | -2.63 (4.33) | -.09 (3.45) |
| **Inactive bilinguals** | | | | | |
| RT | 863.71 (199.97) | 1314.83 (263.94) | 1414.58 (336.47) | 451.13 (226.73) | 99.79 (124.33) |
| ACC | 98.58 (2.32) | 97.33 (3.29) | 96.46 (4.46) | -1.25 (3.31) | -.88 (2.52) |
| **Monolinguals** | | | | | |
| RT | 867.17 (167.93) | 1211.88 (248.22) | 1342.08 (278.77) | 344.71 (174.14) | 129.83 (143.96) |
| ACC | 99.75 (.85) | 98.88 (1.73) | 97.58 (2.12) | -.88 (1.62) | -1.29 (2.44) |

### 6.3.3. Examining effects of language use on the Simon and task-switching task

Similar to Chapter 5, I also examined effects of language use on the Simon and task-switching task directly by running a linear mixed-effect analysis with self-rated English language use as a predictor. In this way, I can examine effects of language use in a continuous manner rather than by comparing the three language groups in a categorical manner. The Simon task again showed main effects of congruency (*t* = 4.46) and condition (*t* = - 5.50), but there was no overall effect of language use (*t* = -.28) nor an interaction with trial type (*t* = -.12). For the task-switching task, I only included the mixed condition to directly examine effects of language use on the switching costs. Although the analysis showed a main effect of trial type (*t* = 2.94), importantly there was no overall effect of language use on overall RTs (*t* = -.78), nor an interaction with trial type (*t* = 1.66). This suggests that language use did not have a direct impact on the (raw) switching costs.

## 6.4. Discussion

This study examined the effects of bilingualism on executive control in older bilinguals and monolinguals matched on background variables such as immigrant status, education, IQ, SES, and lifestyle. Performance of active bilinguals, inactive bilinguals, and monolinguals was compared on two executive tasks. No consistent effects of bilingualism were observed on the task-switching paradigm or Simon arrow task. Accordingly, I did not reproduce the bilingualism effects described in previous studies in our population that was carefully matched on background variables.

Bilingual participants did not have an advantage over monolinguals on the Simon task. The Simon arrow task has shown an effect of ‘bilingualism’ in groups with bilingual immigrants (Bialystok, 2006; Bialystok et al., 2008; Bialystok & DePape, 2009). Following Bialystok’s (2006) suggestion that the bilingual advantage may be strongest or only present in the most difficult executive control condition, I manipulated switching in the Simon task to modify task difficulty. No effect of bilingualism on the Simon effect was found in either the low-switching or high-switching Simon task. The Bayes Factor supported that there was no difference between the two bilingual groups on the Simon effect. This is compatible with the view of Hilchey and Klein (2011), who argued that there is only limited evidence for a bilingual advantage on local inhibitory control processes. At the same time, they argued that bilinguals may have a more global conflict monitoring advantage. My study does not support this idea, as it did not show an effect of bilingualism on overall RTs on both congruent and incongruent trials. This study, however, is not the first to find no difference between bilinguals and monolinguals on a Simon task. Several other studies, including those that tested non-immigrants, also observed no bilingual advantage on Simon costs or overall RTs (e.g., Paap & Greenberg, 2013; Kousaie & Phillips, 2012b; Kirk et al., 2014).

A bilingual advantage on inhibition tasks is often said to result from the bilingual's daily practice with language inhibition. As both languages are constantly active, a bilingual continuously needs to suppress the non-target language. This 'training' has been argued to lead to disadvantages on lexical tasks as well as to advantages on non-verbal inhibition tasks. However, by examining verbal and non-verbal tasks in the same groups of bilinguals and monolinguals, I showed that the disadvantages and advantages are not necessarily two sides of the same coin. While

Chapter 5 shows a disadvantage for bilinguals on lexical tasks, the same set of bilinguals did not show an advantage on a non-verbal inhibition task.

On the task-switching paradigm, no effect of bilingualism was observed on either overall RTs or proportional switching costs. This is contrary to two studies with younger and older immigrants (Prior & MacWhinney, 2010; Gold et al., 2013a) who found a bilingual advantage on switching trials. I did observe an effect of bilingualism on raw switching costs, an effect that was only significant for active but not inactive bilinguals compared to monolinguals. This finding, however, is difficult to interpret as raw switching costs were not only based on differences in switch, but also non-switch trials. In the study conducted by Prior and MacWhinney (2010), the effect of bilingualism on switching costs was driven by switch trials only. Their two language groups had virtually identical RTs on non-switch trials. In my study, however, active bilinguals not only showed a small (but not significant) advantage on the switch trials, but also a disadvantage on the non-switch trials. When we corrected for differences on non-switch trials by analysing proportional switching costs, the effect of bilingualism was no longer significant. The pattern of the interaction thus does not support a bilingual advantage for switching specifically (cf., Wagenmakers, 2015). However, it could suggest that active bilinguals use a different approach to switch and non-switch trials in this task than monolinguals. If this is the case, further research will be needed to elucidate possible mechanisms of this phenomenon. In Chapter 7, I therefore study the effects of language switching and language use on task-switching performance in more detail.

Hilchey and Klein (2011) suggested that bilinguals may have an advantage in more global conflict monitoring processes rather than conflict resolution. Bilinguals may not show a switching advantage, but they could still be better at monitoring task switching in a mixed block compared to monolinguals. However, the mixing costs in this study did not differ between the three language groups. This does not support the idea that bilinguals are better at global monitoring processes.

I aimed to replicate task-switching paradigms that have been linked to bilingual advantages (Prior & MacWhinney, 2010; Gold et al., 2013a). To replicate the exact paradigm, I only used one cue for colours and one cue for shapes. Several task-switching studies (cf., Monsell & Mizon, 2006) have suggested that using a single cue confounds task changes with cue repetition, because the cue is repeated on non-switch trials but not on switch trials. The use of single cues could thus affect the task-switching results. In future task-switching studies, two cues per task would therefore be recommendable.

I only included older adults in this study as this is the age group found to be most susceptible to effects of bilingualism (e.g., Bialystok et al., 2008). Although a direct comparison with younger adults would be ideal, this was not possible in the current sample on the Hebrides. While many older adults grew up speaking both Gaelic and English, this is no longer the case on the Outer Hebrides. Even though the current generation of younger adults and children have the opportunity to study Gaelic at school, they rarely use Gaelic as their home language. Furthermore, younger adults often leave the Hebrides to pursue further education elsewhere.

Thus, a direct comparison between younger and older adults was not feasible due to differences in education, language acquisition, and language use.

This study thus failed to replicate previous results that showed an effect of bilingualism on Simon tasks and task-switching paradigms. The data add to an increasing literature of studies that have found no effect of bilingualism or only in restricted circumstances. A commonly used argument when no bilingual advantage is found in groups of younger adults is that this age group has already reached a peak in executive control performance, thus masking potential effects of bilingualism (cf., Kroll & Bialystok, 2013). This is unlikely the case in our sample of older adults, who had not participated in cognitive tests before and had limited experience with computers. Similarly, in some studies, an effect of bilingualism may not be found because of the type of language groups tested (e.g., bilinguals with a low proficiency, or monolinguals that have some knowledge in a second language). The bilinguals in our study, however, had acquired both languages during childhood and up to a high proficiency level. The monolinguals had never spoken a second language. The unsuccessful attempt to replicate previous positive findings of bilingualism may be due to the different populations recruited. In our case, the populations were well-matched and exempt from the immigration effect. In many previous studies, this is not the case and group effects that have been attributed to bilingualism may have been the result of other background differences.

As a second question, I examined the effects of language use on executive control. The inconsistent findings in studies measuring the effects of bilingualism on executive control may partly be explained by the different types of bilinguals that have been tested. The present study shows that bilinguals cannot be treated as one homogenous group. The active and inactive bilinguals did not differ in AoA of Gaelic and English or in language use during their childhood at home or school. During their later life, however, inactive bilinguals reported a lower use of Gaelic than active bilinguals. Language use, and the changes across the life span, are often neglected in bilingualism studies. I did not find significant differences between active and inactive bilinguals on the Simon task or proportional task-switching costs. Yet, I did find a significant difference between active bilinguals and monolinguals on raw switching costs, whereas this difference was absent for inactive bilinguals. Active bilinguals used both languages on a daily basis and also reported switching regularly between the two languages. This may suggest that bilingual-monolingual differences could be related to using and switching between two languages rather than purely knowing two languages. However, this effect was not found when correcting for baseline non-switch differences in the proportional switching costs and thus does not seem to be *switching* specifically. Furthermore, a different analysis with language use as a continuous variable showed no effect of language use on the switching costs. Nevertheless, in combination with Chapter 5, my study shows that bilingualism cannot be treated as a categorical variable and emphasises the need to characterise bilingualism in terms of language use.

## 6.5. Conclusion

This study is not the first to question the reliability of bilingual advantages in executive control tasks. Paap and Greenberg (2013), Paap and Sawi (2014), Gathercole et al. (2014), and Duñabeitia et al., (2014) all reported no effects of bilingualism across multiple tasks and using large sample sizes. This study, however, has been particularly thorough in matching participant groups on all background variables other than bilingualism itself. The Simon task and task-switching paradigm used in this study have been shown to be influenced by bilingualism in other studies comparing bilingual immigrants to monolingual non-immigrants (e.g., Bialystok et al., 2008; Gold et al., 2013a). My study shows the need to match bilingual and monolingual groups on background variables, including immigrant status. If we want to investigate the effects of *bilingualism*, we have to ensure that language groups only differ in terms of the languages that they speak. Moreover, we need to dissociate the effects of the knowledge of a language from the effects of its regular use.

# Chapter 7. Does language-switching practice affect task-switching performance in bilinguals?

*I would like to thank Guillaume Thierry for his feedback on and suggestions for the designs of the paradigms presented in Experiment 1.*

## 7.1. Introduction

Evidence regarding effects of bilingualism on executive control tasks is mixed (e.g., Bialystok et al., 2004 vs. Paap & Greenberg, 2013). The discrepancy in findings may partly be related to the type of bilinguals and monolinguals tested and the degree to which participant groups are matched on background variables. In Chapter 6, I presented a study with well-matched participant groups that showed no consistent bilingual-monolingual differences on non-verbal tasks. Yet, even though these participant groups were matched on background variables as closely as possible, the issues of a between-subject comparison remain. Language groups may have differed on variables that I did not measure. Furthermore, a between-subject design cannot address the issue of causality: Does bilingualism *cause* a cognitive advantage?

In this chapter, I therefore present a study examining effects of language use and language switching on both verbal and non-verbal task switching. The same group of bilinguals completed several types of language tasks prior to a colour/shape switching task. The language tasks required them to name pictures in one language only, in two languages in a blocked manner, or while switching between two languages. In this way, I aim to assess whether there is a causal effect of language use and language switching on task-switching performance within bilinguals.

### 7.1.1. The bilingual language mode

Many studies treat bilinguals as a homogeneous group, but no two bilinguals are the same. They can differ in many features including age of acquisition, proficiency, and language use. Furthermore, the language behaviour within individual bilinguals varies too. The same bilingual speaker can be using one language only when talking to a monolingual speaker while other surroundings may require them to switch between the two languages. The differences in the bilingual's language use depending on the circumstances and conversation partners have been dubbed *speech mode* or *language mode* by Grosjean (1985). Even within the monolingual and bilingual mode, there are many intermediate stages requiring more or less use of the second language.

These different language modes can also have different impacts on executive control tasks as formulated in Green and Abutalebi's Adaptive Control Hypothesis (2013). In this hypothesis, three language contexts are identified that could affect executive functioning in different ways. The first context is a single-language context in which one language is used in one setting (e.g., home), and the second language in another context (e.g., school or work). In these circumstances, bilinguals do not often switch between the two languages. The second context is a dual-language context in which the two languages are used in the same context but with different speakers. In this case, language switching may occur in a conversation but usually not at the sentence-level. Thirdly, in the dense code-switching condition, bilinguals frequently switch between their languages. Here language switching is common and can take place within utterances too. These types of language use place different demands on the speaker. In the dense code-switching context, bilinguals can switch freely between their two languages and thus need lower levels of language control. Green and Abutalebi argue that this context places a relatively low demand on control processes such as conflict monitoring, interference suppression, and response inhibition. However, these processes are crucial in the dual-language context, because language switching is not always appropriate. Speakers have to control how and when they switch between the two languages. This hypothesis shows the importance of actual language use. In any of the three settings, the bilingual may have acquired the two languages at an early age and up to a high proficiency level. Yet, the language use and therefore the potential impact on non-verbal executive control can vary greatly.

### 7.1.2. Language use and task switching

Despite the existence of this framework and descriptions of language mode dating back to 1985, not many studies have investigated effects of language use and language switching on non-verbal executive control. A few between-subject studies have suggested that there may be effects of language switching on task switching. For instance, Prior and Gollan (2011) only observed smaller non-verbal switching costs compared to monolinguals for bilinguals who often switch between their two languages. Soveri, Rodriguez-Fornells, & Laine (2011) also observed an association between language-switching and task-switching performance. Contrary to Prior and

Gollan (2011), this effect was not found on the *switching cost RTs* but on *mixing cost errors.* Yim and Bialystok (2012), however, found no association between code switching and non-verbal switching although an effect was found on a language switching task. Others have argued that bilinguals with high levels of language switching and dense code-switching in daily life have an advantage on inhibition tasks (e.g., Verreyt et al., 2016; Hofweber, Marinis, & Treffers-Daller, in press[17]). My study described in Chapter 6 also examined effects of language use on non-verbal task-switching performance. While active bilinguals showed smaller raw (but not proportional) switching costs than monolinguals, there was no direct effect of language use on either raw or proportional switching costs. Thus, it remains unclear if language use could affect non-verbal switching and whether such an effect would be causal.

Prior and Gollan (2013) asked themselves a similar question and examined cross-task transfer effects between non-linguistic colour/shape switching and language-switching tasks. On the first day (training), participants completed either the language or the colour/shape switching task. One week later, all participants first completed the other task (called the transfer task) and then their training task. Both language switching and task switching showed within-task training effects. However, cross-task transfer effects were limited. There was no effect of language switching on task switching. The only cross-task effect that was found concerned smaller mixing costs in the non-dominant language after task-switching training.

[17] Note that this advantage for dense code-switchers contradicts the Adaptive Control Hypothesis which predicts that dense code-switching places low demands on conflict monitoring and inhibition and thus should have a lower impact on inhibition tasks.

However, the training and testing sessions were separated by one week and this time interval was potentially too long to show any effects of training.

Causal effects of monolingual versus bilingual language use may be observed with shorter time intervals. Wu and Thierry (2013) observed effects of bilingual versus monolingual language presentation during a flanker task. While participants performed a flanker task, they were intermittently presented with words in Welsh, English (single-language blocks), or both languages (mixed-language block). Error rates on incongruent trials were reduced in the mixed-language block compared to single-language blocks. This effect was absent for RTs. Their event-related potentials (ERPs) furthermore showed a smaller P300 effect on incongruent trials in the mixed- compared to single-language condition.

The current study examines effects of language use and switching on task-switching performance. I chose to examine effects on task switching as this paradigm is most comparable to language switching and previous studies have found similarities between non-linguistic and linguistic task-switching within the same group of participants (e.g., correlations between mixing and switching costs across the two tasks, Prior & Gollan, 2013). Still, task and language switching are affected by their own task-specific mechanisms as pointed out by others observing differential effects of ageing, different patterns of asymmetry, and the absence of correlations between task and language switching (e.g., Calabria, Hernández, Branzi, & Costa, 2012; Weissberger, Wierenga, Bondi, & Gollan, 2012).

Participants in my study were asked to complete a monolingual naming, bilingual blocked naming, or language-switching task before engaging in a task-switching experiment. The language-switching condition is controlled (i.e., participants strictly had to follow cues) and as such more compatible with Green and Abutalebi's dual-language context than the dense code-switching context in which bilinguals are free to switch when they want. The language task was followed by a verbal or non-verbal colour/shape switching task. The effectiveness of task-switching training on task-switching performance has been observed in several studies (e.g., Karbach & Kray, 2009). Practising task-switching reduced switching and mixing costs in different age groups. Task-switching training can thus improve task-switching performance, but can a different type of switching 'training' (i.e., language switching) achieve this too?

This chapter discusses three experiments examining this question. The first study is a behavioural experiment assessing effects of language use either taking place before or during a task-switching task. The colour/shape switching paradigm was completed verbally in one language only. The second study examined effects of language use prior to a non-verbal task-switching task. This experiment included collection of EEG data. The third behavioural experiment compared effects of language switching prior to a verbal and non-verbal colour/shape switching task, to examine possibly differential effects on verbal versus non-verbal switching.

## 7.2. Experiment 1: Effects of language switching on verbal task switching

The first study assessed effects of language use and switching on verbal task switching in two different paradigms. In paradigm A, participants performed three language tasks prior to the task-switching paradigm. In paradigm B, participants switched between languages while performing a task-switching paradigm. In paradigm A, language and task switching were thus performed consecutively. Similar to Prior and Gollan (2013), task switching was performed verbally. However, contrary to their study, there was no break between the language- and task-switching experiments. In paradigm B, language and task switching were mixed. This condition is most similar to Wu and Thierry (2013) who found a positive effect of mixed-language presentation during a flanker task. Apart from the task, one of the main differences concerns the use of language production rather than the presentation of written words.

As a separate question I also examined effects of trial sequence on task-switching costs by varying the number of trials of the same trial type preceding a switch or non-switch trial. Longer sequences of the same trial type (e.g., five switch trials in a row) were less frequent than shorter sequences of the same trial type. If participants try to predict upcoming trials, they should anticipate a trial of the other trial type after a longer sequence of the same trial type (e.g., a switch trial after five non-switch trials). If this is true, non-switch RTs should be more similar to switch RTs after a long sequence of non-switch trials and vice versa.

### 7.2.1. Methods

**Participants**

Ten Spanish-English and ten Italian-English bilinguals (2 men) participated in the study (mean age = 25.35, *SD* = 4.20). All participants had normal or corrected-to-normal vision and hearing and none reported colour blindness. Responses from one participant were not recorded in task-switching paradigm B due to equipment malfunctioning.

Participants were born in Italian- or Spanish-speaking countries and currently living in the UK. On average, participants had been living in the UK for 3.07 years (*SD* = 2.33). The average age when participants started learning English was 7.55 years old (*SD* = 3.02) and they reported being fluent in English by the average age of 18.35 (*SD* = 5.28). In a questionnaire, participants rated their proficiency for both languages for speaking, understanding, reading, and writing (see Table 7.1). While self-ratings were higher for the L1 than L2, both languages received high ratings for all components (average > 8/10). Furthermore, Table 7.1 provides self-rated language use for both languages during childhood at home, school, current life at home/with friends, and current life at work/university. While the L1 was the only or predominant language during childhood at home and school, language use was more balanced or L2-dominant during later life at work/university and at home/with friends. On a scale from 1 (‘never’) to 4 (‘always’), participants on average reported frequent daily language switching (*M* = 3.05, *SD* = 1.15), as well as occasional switching within conversations (*M* = 2.40, *SD* = .94) and within sentences (*M* = 2.20, *SD* = .95).

Language proficiency was also assessed in a picture-word matching task, requiring participants to indicate whether a picture and a word formed a match in both their L1 and English (see Chapter 5 for more details about this task). Accuracy did not differ significantly between L1 (*M* = 96.75, *SD* = 2.23) and L2 (*M* = 93.51, *SD* = 10.32; Wilcoxon signed-rank test: $z = -1.54$, $p = .120$). However, RTs were faster for L1 (*M* = 1024.91, *SD* = 262.30) than L2 (*M* = 1172.91, *SD* = 263.72; paired t-test: $t(19) = -6.47$, $p < .001$).

Table 7.1

*Self-rated proficiency and language use per language. For proficiency, participants were asked to provide ratings on a scale from 1 ('no proficiency') to 10 ('very high proficiency') for speaking, understanding, reading, and writing. Similarly, for language use, they were asked to give ratings from 1 ('never') to 10 ('all the time') during their childhood at home, school, later life at home/with friends, and at work/university. Means and standard deviations (between parentheses) are provided. An asterisk notes a significant difference between the two languages as indicated by a Wilcoxon signed-rank test.*

| | **L1 (Italian/Spanish)** | **L2 (English)** |
|---|---|---|
| **Proficiency ratings** | | |
| Speaking | 9.45 (.89) | 8.20 (1.24)* |
| Understanding | 9.95 (.24) | 9.05 (1.15)* |
| Reading | 9.75 (.72) | 9.25 (1.21)* |
| Writing | 9.05 (1.23) | 8.50 (.95) |
| | | |
| **Language use ratings** | | |
| Childhood at home | 10.0 (.00) | 1.70( 1.08)* |
| Childhood at school | 9.80 (.70) | 3.62 (2.50)* |
| Later life at home | 6.75 (3.23) | 7.20 (2.48) |
| Later life at work | 3.95 (3.32) | 9.25 (1.86)* |

**Tasks**

***Task-switching paradigm A: colour/shape switching preceded by a language task***

In this paradigm, a colour/shape switching task was completed three times, each time preceded by a different language task. In the monolingual task, participants named pictures in English. In the bilingual blocked task, they named pictures in their L1 in one block and in English in the other block, with the order of blocks being counterbalanced. In this condition, languages thus only switched once. In the language-switching task, pictures were named in both languages in a switching manner. Each language task contained twenty highly nameable pictures that were repeated eight times, thus leading to a total of 160 pictures. In the bilingual blocked condition, 80 pictures were named in each language. In the language-switching task, half of the pictures were non-switch trials (two consecutive pictures to be named in the same language), the other half required a language switch. Pictures were black-white line drawings that depicted high frequent, concrete objects and were presented on a white background. Although pictures names on average had more syllables in L1 than L2, they did not differ in word length in terms of number of letters or phonemes (see Appendix E1 for stimulus materials). Each picture was preceded by either the British or Italian/Spanish flag to indicate the language needed to name the picture. Two different versions of each flag were used to ensure that the cue always changed between two consecutive trials, even if the language remained the same. Each language trial started with the presentation of a fixation cross for 600 ms, followed by the presentation of the cue for a jittered time of 500 to 700 ms. Then, the cue disappeared and the picture was presented, which remained on the screen for 1500 ms even when a response was given earlier. The language task lasted approximately ten minutes.

The colour/shape switching task was similar in set-up to the language tasks. Participants were presented with a stimulus of a certain colour (blue or pink) and shape (square or triangle). Depending on their task, they either had to name the colour or shape of the object (see Figure 7.1). All colours and shapes had to be named in English. First, participants completed two blocks of 36 colours and 36 shapes, followed by the mixed condition in which they had to switch between colour and shape. Lastly, they completed another two blocks of 36 colour and 36 shape decisions. The mixed condition consisted of 140 trials, half of which were switch and half non-switch trials. The number of consecutive switch/non-switch trials was manipulated too and varied from 1 to 7. For instance, a switch trial with distance 5 was preceded by four other switch trials. Similar to the language task, two cues were used per task to ensure that even non-switch trials contained a cue switch. The timing of trials was identical to the language tasks (600 ms fixation cross, 500-700 ms cue, 1500 ms picture).

***Task-switching paradigm B: mixed language-/task-switching paradigm***

In paradigm B, participants switched between languages and tasks in a mixed manner. On language trials, they had to name a picture in either their L1 or L2. On colour/shape trials, they had to name the shape or colour of objects in English. The same materials were used as in Paradigm A. The same cues were used to indicate whether a colour/shape had to be named or the name of a picture in L1/L2 (see Figure 7.1 for an example of a trial sequence). The task started with practice blocks of colour, shape, L1, and L2 naming only (20 trials per practice block). Then, the mixed condition was presented in five blocks with a total of 560 trials. There were four possible trial types: language switch (LS; n = 128), language non-switch (LNS; n

= 128), colour/shape switch (n = 152), colour/shape non-switch (n = 152). To ensure that a colour/shape decision was never a language switch, the preceding language trial was always named in English. I furthermore manipulated the number of language trials preceding colour/shape trials so that colour/shape trials could be preceded by the following language conditions: [LNS LNS]; [LS LS]; [LNS LNS LNS LNS]; [LS LS LS LS]. Similar to paradigm A, a trial started with a fixation cross for 600 ms, followed by cue presentation for 500 – 700 ms. The picture then remained on the screen for 2000 ms.

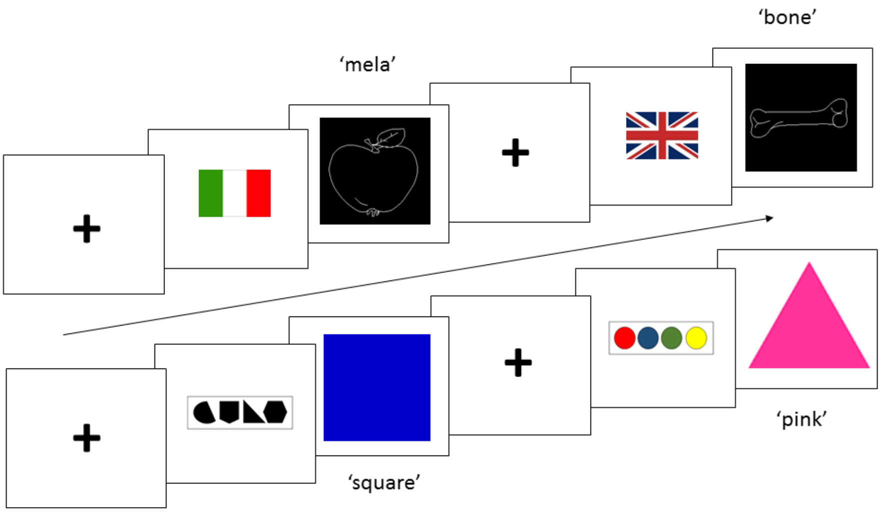


*Figure 7.1.* Example of a trial sequence. In paradigm A, the first row would be part of a separate language-switch task. In paradigm B, the first row would immediately precede the second row. In this example, the order of trials would be: Italian, English (language switch), shape, colour (task switch).

Participants completed these tasks across three sessions of 45 minutes each, with the order of sessions being counterbalanced across participants. The three sessions were separated by approximately a one-week interval to minimise effects of bilingual picture naming tasks on the monolingual condition. In session 1, participants started with a monolingual picture naming task, followed by the colour/shape switching task. They then completed a questionnaire and the picture-word matching task. In session 2, participants completed the bilingual blocked naming task and the language-switching task, both followed by the colour/shape switching task. The order of bilingual language tasks was counterbalanced across participants. In session 3, participants completed the mixed language-/task-switching paradigm B. All tasks were presented in PsychoPy v 1.82 (Peirce, 2007) and vocal responses were recorded and saved. The pictures were presented on a white background on a 19-inch screen with 1680x1050 resolution with a viewing distance of approximately 80 cm. Cues were 200x100 pixels and pictures 200x200. Both cues and pictures were presented on the centre of the screen (the cue disappeared before picture presentation).

**Data analysis**

Voice onset times (VOTs) were automatically derived from the recorded responses in Praat (Boersma, 2001). VOTs shorter than 300 ms were checked and corrected manually through visual inspection of the speech wave forms. For the VOT analysis, the first trial of each block, incorrect answers, and the following trials were removed. Furthermore, outliers were removed through the median absolute deviation method (MAD) through the *mad* package in R. For the analysis of paradigm B, I excluded the first colour/shape trial after a language trial, as the trial type (switch/non-switch) cannot be determined. Both paradigm A and B were analysed using a linear mixed-effects analysis for VOTs and, when analysed, generalised linear mixed-effects analysis for accuracy (logit). Analyses were performed in the lme4 package in R (Bates et al., 2015). *Z*-scores (for accuracy) and *t*-scores (for VOTs) greater than 2 were interpreted as significant effects (see Meier & Kane, 2013; Coderre & Van Heuven, 2014b). To normalise their distribution, VOTs were log transformed. For paradigm A, blocked versus non-switch trials (mixing costs) and switch versus non-switch trials (switching costs) were analysed separately. The first model included language condition (monolingual, bilingual blocked, language switch) and trial type (blocked, non-switch) as well as their interactions as fixed effects. The second model included language condition, trial type (non-switch, switch), and distance (the number of preceding trials from the same trial type) as well as their interactions. Paradigm B only included the colour/shape VOTs as the dependent variable. Trial type (switch, non-switch), preceding language block (language switch, language non-switch), and the number of preceding language trials (2, 4) as well as their interactions were included as fixed factors. As random effects, intercepts for participants and items as well as random slopes for each predictor were included. When this model failed to converge, the random slopes for the predictors were removed. This was the case for the analysis of paradigm B. Although mixed-effect models were performed on transformed VOTs, averaged raw VOT values are given in text and tables to simplify data interpretation and allow for comparisons with previous chapters.

### 7.2.2. Results

**Task-switching paradigm A: colour/shape switching preceded by a language task**

Apart from incorrect answers, an additional 7.99% of trials were removed as outliers or trials preceded by an error for VOT analysis. Full results are given in Appendix E2.

***Blocked versus non-switch***

Accuracy was close to ceiling for all three language conditions in the blocked condition (monolingual: *M* = 99.69, *SD* = .57; bilingual blocked: *M* = 99.76, *SD* = .41; language switch: *M* = 99.64, *SD* = .67) and was not analysed further. Comparing VOTs on blocked versus non-switch trials to examine effects of language condition on mixing costs showed an effect of trial type (*t* = -3.16) with blocked trials (*M* = 622.71, *SD* = 105.92) being faster than non-switch trials (*M* = 702.66, *SD* =125.80). However, there was no main effect of language condition (bilingual blocked: *t* = .07; language switch: *t* = .73) nor an interaction with trial type (bilingual blocked: *t* = -1.87; language switch: *t* =-1.54), suggesting that mixing costs were similar after monolingual naming (*M* = 74.24, *SD* = 106.40), bilingual blocked naming (*M* = 83.93, *SD* = 114.60), and language switching (*M* = 87.13, *SD* = 130.56).

***Switch versus non-switch***

Accuracy was lower for switch (*M* =96.14, *SD* = 3.71) than non-switch trials (*M* = 97.90, *SD* = 2.20, *z* = -3.37). There was no difference between the monolingual condition (*M* = 96.99, *SD* = 1.71) and bilingual blocked (*M* = 97.37, *SD* = 1.60, *z* = .65) or language switching (*M* = 96.47, *SD* = 1.85, *z* = -1.41) condition nor an interaction between bilingual blocked and task-switch trials (*z* = 1.29) or between language-switch and task-switch trials (*z* = 1.75).

VOTs in the mixed condition showed a main effect of trial type (*t* = 2.99). On average, participants responded more slowly to switch (*M* = 726.01, *SD* = 122.52) than non-switch trials (*M* = 702.66, *SD* =125.80). Overall VOTs did not differ between the monolingual condition, the bilingual blocked condition (*t* = -.25) and the language switch condition (*t* = -1.59; see Table 7.2). While there was no interaction between the bilingual blocked condition and switch trials (*t* =.78), language switching did interact with switch trials (*t* = 2.50). Switching costs were larger after language switching than after monolingual naming (see Table 7.2, Figure 7.2). There was no main effect of distance (*t* =. 24), but distance interacted with switch trials (*t* = -2.04). For switch trials, VOTs decreased as the trial was preceded by more switch trials (see Figure 7.3). For non-switch trials, VOTs increased for more preceding trials of the same trial type. After more than four consecutive trials of the same trial type, switching costs reversed.

As an exploratory analysis, I examined whether the effects on switching costs were related to language *switching* or rather to using the non-target language.

Within the bilingual blocked condition, I therefore compared participants who completed the second block in their L1 to participants who completed the second block in English. If using the non-target language (i.e., the L1) prior to task-switching in English causes the interference, switching costs should be larger for participants who completed the last block in their L1. However, this was not the case. Switching costs were similar for L1 block last (*M* = 24.29, *SD* = 38.63) and English block last (*M* = 24.92, *SD* = 14.67, *t* = 0.17).

Table 7.2

*Mean VOTs and standard deviations (in parentheses) for switch trials, non-switch trials, and switching costs per language condition.*

| | **Preceded by monolingual naming** | **Preceded by bilingual blocked** | **Preceded by language switching** |
|---|---|---|---|
| Switch | 715.49 (123.98) | 728.62 (131.50) | 735.87 (119.32) |
| Non-switch | 700.56 (123.61) | 704.02 (135.58) | 705.17 (125.29) |
| *Switching cost* | 14.90 (24.80) | 24.60 (28.44) | 30.70 (37.63) |

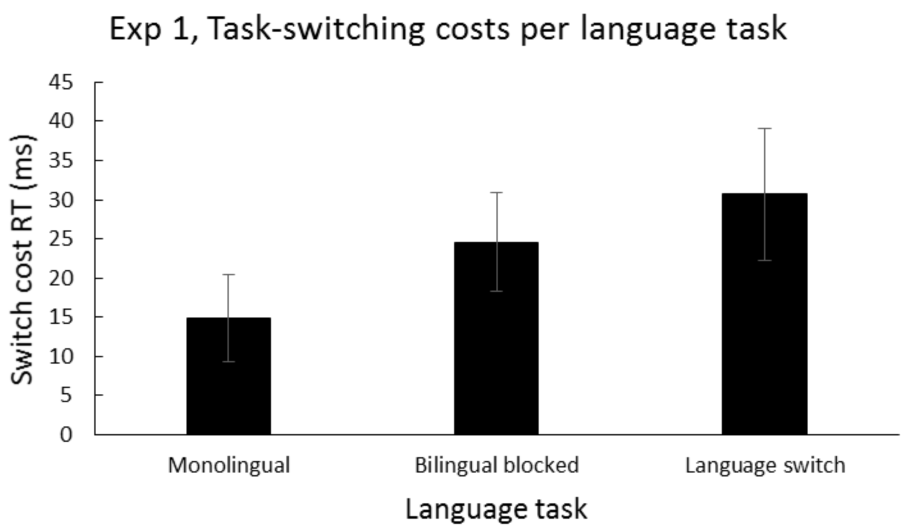


*Figure 7.2.* Switching costs in the task-switching paradigm per language condition.

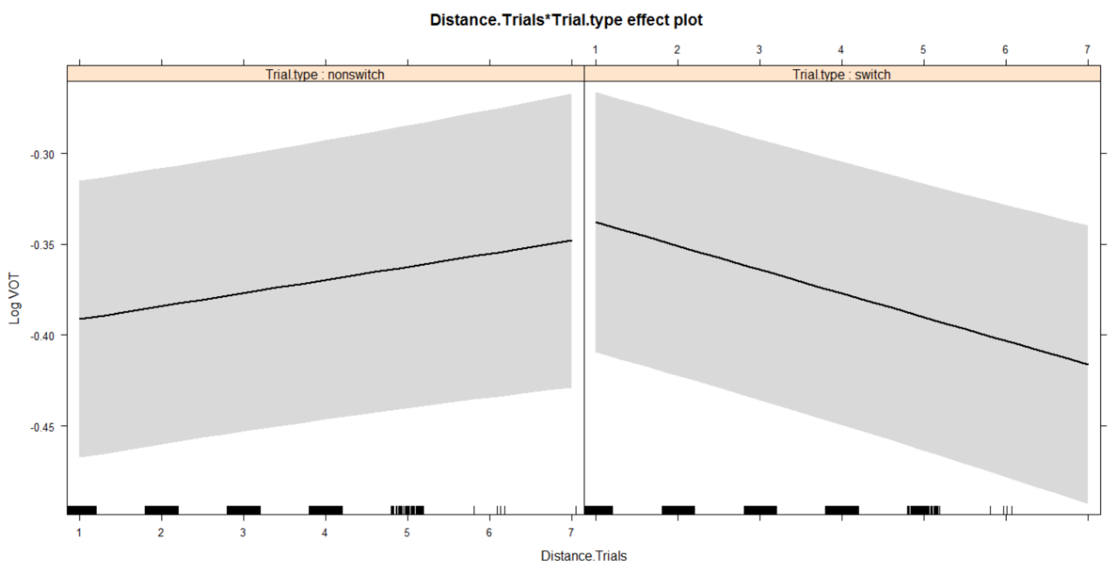


*Figure 7.3.* Model effects of distance on log VOTs per trial type (left: non-switch; right: switch).

I furthermore examined whether language-switching costs correlated with task-switching costs. Language-switching costs did not correlate significantly with either overall task-switching costs ($r(20) = .31$, $p = .190$) or with task-switching costs preceded by language switching ($r(20) = .20$, $p = .404$).

**Task-switching paradigm B: mixed language-/task-switching paradigm**

Accuracy was close to ceiling (task switch trials $M = 98.04$, $SD = 1.42$; task non-switch trials: $M = 99.01$, $SD = 0.99$) and was not analysed further. Apart from incorrect trials, 4.12% of trials were removed as outliers or trials preceded by an error. VOTs showed a main effect of trial type ($t = 2.27$, see Appendix E3 for details) with switch trials ($M = 731.11$, $SD = 158.89$) being slower than non-switch trials ($M = 685.04$, $SD = 135.85$). Overall VOTs on task-switching trials were furthermore largest after four preceding language trials ($t = 2.46$). However, there were no main effects of the preceding language condition (switch or non-switch, $t = -0.94$) nor an interaction between trial type and preceding language condition ($t = .46$) suggesting that colour/shape switching costs were similar after monolingual picture naming ($M = 42.55$, $SD = 52.78$) and after language switching ($M = 48.76$, $SD = 56.14$). No other main effects or interactions were observed. Furthermore, language- and task-switching costs did not correlate ($r(19) = .32$, $p = .186$).

### 7.2.3. Discussion

Experiment 1 presents two paradigms assessing effects of language switching on verbal task-switching performance. In Paradigm A, participants completed a monolingual, bilingual blocked, or language-switching task prior to a verbal task-switching task. Task-switching costs were larger after language switching than after monolingual picture naming. Thus, language switching may have a causal and negative impact on verbal task switching. Switching costs after a blocked bilingual naming task fell in-between the monolingual and language-switching condition and did not differ significantly from either. These findings are contrary to Prior & Gollan (2013), who observed some effects of task-switching training on language-switching performance, but no effects of language switching on verbal task switching. However, their training and testing blocks were separated by a one-week interval, while participants in our study completed language and task switching consecutively without a break. This suggests that effects of language switching on task switching may be short-lasted. Furthermore, the effects of language switching were only observed on switching costs and not in mixing costs. This implies that any effects of language use only affect switching between tasks, not the more global mechanisms of maintaining two competing tasks as expressed in mixing costs (Rubin & Meiran, 2005).

However, when bilinguals were asked to switch between languages *while* performing a task-switching task, no effects of language use on switching costs were observed. This is somewhat contradictory to Wu & Thierry (2013), who observed fewer errors in a flanker task when bilingual words were presented intermittently compared to monolingual words. Similar to my study, though, they did not observe RT effects.

While there was no effect of language condition on switching costs in Paradigm B, overall task-switch VOTs were longer after a longer block of language trials. This could suggest that only a longer language task can affect subsequent task-switching VOTs. Crucially, however, this did not interact with the type of language task (switching or non-switching) suggesting that the VOT increase is related to switching from another task in general rather than the type of language task.

As a separate, exploratory question, the experiment addressed effects of trial sequence on switching costs. Larger numbers of consecutive trials of the same trial type led to increasing VOTs on non-switch trials but decreasing VOTs on switch trials. For the longest distances, switching costs even became reversed. This suggests that participants anticipate the upcoming trial. As shorter distances (e.g., two non-switch trials in a row) were more common than longer distances (e.g., five non-switch trials in a row), participants appeared to expect the opposite trial type after a longer order of consecutive trials of the same trial type. In this way, switching costs reversed as participants started to prepare for a switch trial after a large number of non-switch trials and vice versa.

The first experiment examined effects of language switching on *verbal* task switching. Yet, one of the main questions of this thesis (and a large part of the literature) concerns effects of bilingualism and language switching on *non-verbal* executive control. The next experiment will therefore use paradigm A (language tasks *before* task switching) to examine effects of language switching on non-verbal task switching. Furthermore, EEG data were recorded.

### 7.3. Experiment 2: Effects of language switching on non-verbal task switching: an EEG study

Some studies have investigated bilingual-monolingual differences on executive control tasks using EEG with between-group designs, but this has yielded mixed results. Effects of bilingualism on various executive control tasks (including the Simon and flanker task) have been found on the N2 and P3 components (e.g., Kousaie & Phillips, 2012b). However, the direction of the effect differs. For instance, Morales et al. (2015) found an increased P3 amplitude for bilinguals, while Kousaie and Phillips (2012b) found a reduced ERP for bilinguals compared to monolinguals (see Chapter 1 for a more extensive discussion). These ERP differences are not always accompanied by RT effects, suggesting that differences may be observed in EEG data in the absence of behavioural findings. Wu and Thierry (2013) used a within-subject design and also observed ERP differences in the absence of RT effects (although a difference in accuracy was found). Their ERP data showed a reduced amplitude around the P300 for incongruent flanker items during the mixed-language context compared to monolingual context. The type of language task used may thus affect ERP components elicited by executive control tasks.

The EEG studies reviewed in Chapter 1 have all studied inhibitory control tasks. Although there are many EEG studies on language switching, to my knowledge there are no EEG studies examining effects of bilingualism on non-verbal task switching. Magezi, Khateb, Mouthon, Spierer, and Annoni (2012), however, compared language and task switching within bilinguals and found differences between the two types of tasks in the ERPs elicited in the N2 time range (argued to reflect response inhibition). Thus, language- and task-switching tasks may partly affect different cognitive processes as indicated by the modulation of ERP components, but it is unclear whether one can affect the other.

The ERP components affected by task switching have been studied relatively extensively. ERPs locked to the presentation of the cue typically show an increased positivity for switch compared to non-switch trials (e.g., Nicholson, Karayanidis, Bumak, Poboka, & Michie, 2006; Goffaux, Phillips, Sinai, & Pushkar, 2006; Gajewski & Falkenstein, 2013). This effect has been found across the scalp, but is typically largest in the central-posterior region. The timing of this cue-locked switch/non-switch difference varies from 400 – 600 ms (Nicholson et al., 2006) to later, slower waveforms (Goffaux et al., 2006), but generally occurs before the presentation of a stimulus. The nature of the cue-locked ERP depends on the cue-target interval. When this interval is long enough, behavioural switching costs as well as the ERP effect diminish or disappear (e.g., Karayanidis, Coltheart, Michie, & Murphy, 2003). As such, the cue-locked effect with larger positive ERPs for switch than non-switch trials has been interpreted as reflecting preparation effects in response to the cue and the need to prepare a switch to a new task.

Effects locked to the target presentation typically elicit the opposite pattern, with more positive/less negative ERPS for non-switch than switch trials (e.g., Nicholson, Karayanidis, Poboka, Heathcote, & Michie, 2005; Goffaux et al., 2006). These effects too are mainly centro-parietal and have been found around 200-600 ms after target presentation. This target-locked effect has been argued to reflect processes involved with the retrieval of rules to complete the new task.

I hypothesised that if language switching affects switch preparation, cue-locked switch/non-switch differences should be smaller after language switching than after the monolingual condition. If language switching affects the retrieval and implementation of new task rules, the target-locked difference should be smaller after language switching. The ERP components as well as RTs may be affected by properties of the task itself. In this study, I therefore again manipulated the number of consecutive trials of the same trial type.

### 7.3.1. Methods

**Participants**

A group of eleven Spanish-English and nine Italian-English bilinguals (6 men) participated in the study (mean age = 24.05, *SD* = 5.18). None of them had taken part in Experiment 1. All participants had normal or corrected-to-normal vision and hearing and none reported colour blindness. Two further bilinguals took part but were excluded from analyses due to technical issues in the EEG experiment.

Participants were born in an Italian- or Spanish-speaking country and had been living in the UK for an average of 4.88 years (*SD* = 5.24). On average, participants started learning English at the age of 7.60 (*SD* = 3.58) and became fluent at 16.05 years old (*SD* = 6.00). Self-rated proficiency and language use are reported in Table 7.3. All participants provided high ratings for both L1 and English for all four components. While the L1 was the dominant language during childhood at home or school, language use was more balanced or L2-dominant during the later life. Self-rated language-switching scores were 2.85 (*SD* = 1.18) for daily switching, 2.40 (*SD* = 1.10) for within-conversation switching, and 1.75 (*SD* = .79) for within-sentence switching. The picture-word matching task showed an accuracy difference between L1 (*M* = 97.03, *SD* = 2.24) and L2 (*M* = 94.75, *SD* = 3.99; $z$ = -2.07, $p$ = .039). RTs, however, did not differ between L1 (*M* = 1126.33, *SD* = 223.17) and L2 (*M* = 1134.94, *SD* = 192.81; $t(19)$ = -.161, $p$ = .874).

Table 7.3

*Self-rated proficiency and language use per language. For proficiency, participants were asked to provide ratings on a scale from 1 ('no proficiency') to 10 ('very high proficiency') for speaking, understanding, reading, and writing. Similarly, for language use, they were asked to give ratings from 1 ('never') to 10 ('all the time') during their childhood at home, school, later life at home/with friends, and at work/university. Means and standard deviations (between parentheses) are provided. An asterisk notes a significant difference between the two languages as indicated by a Wilcoxon signed-rank test.*

| | **L1 (Italian/Spanish)** | **L2 (English)** |
|---|---|---|
| **Proficiency ratings** | | |
| Speaking | 9.60 (.50) | 8.25 (.85)* |
| Understanding | 9.85 (.49) | 9.05 (.94)* |
| Reading | 9.85 (.37) | 8.90 (.91)* |
| Writing | 9.30 (1.03) | 8.05 (1.00)* |
| | | |
| **Language use ratings** | | |
| Childhood at home | 9.95 (.22) | 2.30 (2.03)* |
| Childhood at school | 8.65 (2.85) | 4.15 (2.50)* |
| Later life at home | 6.62 (2.70) | 7.20 (2.81) |
| Later life at work | 2.30 (2.73) | 9.70 (.92)* |

**Tasks**

In Experiment 2, participants completed the colour/shape switching task three times, each time preceded by either the monolingual naming, bilingual blocked, or language-switching task (i.e., similar to paradigm A in Experiment 1, see Appendix E1 for pictures used). These three paradigms were completed in two EEG sessions. The monolingual naming part was completed in one session and the two bilingual tasks in the other session, with the order of sessions and the order of bilingual tasks within the session counterbalanced. Several weeks prior to the EEG experiment, participants completed a questionnaire and picture-word matching task, as well as a short version of the colour/shape switching task as practice.

The colour/shape switching task was similar to the one described for Experiment 1 (see Figure 7.1). The main difference was that participants responded with button presses rather than verbally. The colour/shape assignment to left or right hand was counterbalanced across participants. As only switching costs but not mixing costs were affected in Experiment 1, the current experiment only included a mixed condition. Furthermore, the timing of the trials was adapted to minimise eye movements. The cue stayed on the screen for 300 ms, followed by a fixation cross for 300 ms. The picture was then presented for 300 ms and removed from the screen. However, participants were given another 1200 ms to respond (1500 ms in total). Then, the next trial started with the presentation of a fixation cross for 500 ms. The colour/shape task started with a short practice block (16 trials), followed by the mixed condition containing five blocks of 96 trials each. In total, there were 240 switch and 240 non-switch trials per language condition. Distance (i.e., the number of consecutive trials of the same trial type) was manipulated and varied between 1 and 7. Participants were instructed to avoid eye movements and to blink during the time interval between their response and the next cue. The three language tasks were similar to Experiment 1, apart from the timing which followed the structure of the colour/shape switching task (500 ms fixation; 300 ms cue; 300 ms fixation; 300

ms picture; 1200 ms response time with fixation). Thus, following Nicholson et al. (2006) the cue-stimulus interval was 600. The behavioural data were analysed in the same manner as in Experiment 1.

**EEG recordings and analyses**

EEG data were recorded with 64 active electrodes (BioSemi ActiveTwo, sampling rate 512 Hz). Electrode offset was kept between ± 20 µV. Data were pre-processed and analysed in two ways. Firstly, I analysed data with BrainVision and calculated average ERPs across items. This follows the traditional approach analysing mean ERP amplitudes. Secondly, I analysed the data in MATLAB using the LIMO toolbox (Pernet, Chauveau, Gaspar, & Rousselet, 2011). Rather than averaging across trials, LIMO uses a hierarchical general linear model that accounts for single trial variability. In this way, it can test for effects across all EEG channels and all time points. Furthermore, this allowed me to include distance as a variable that differed between trials.

***BrainVision analysis***

Data were re-referenced to the electrodes on the mastoids and were filtered using a low cut-off of .53 Hz, a high cutof-off of 40 Hz, and a notch filter at 50 Hz. Epochs were created [-100, 600] ms cue-locked and [-100, 800] ms target-locked for switch and non-switch trials separately per language condition and baseline corrected from -100 to 0 ms. The electoroculogram (EOG) was recorded from electrodes placed above and below the right eye (vertical EOG) and from electrodes placed at the outer canthi of both eyes (horizontal EOG). To exclude eye blinks and eye movement artefacts, trials with VEOG exceeding 80 ± µV, HEOG exceeding ± 50 µV, and 80 ± µV at any electrode were excluded. Three participants were removed from further analyses as >30% of trials were removed due to artefacts. For the remaining 17 participants, on average 15.53% of trials were removed. Due to a noisy signal, electrode FT7 was interpolated.

Mean waveform amplitudes were then calculated for each participant for correct trials for six conditions: monolingual non-switch, monolingual switch, bilingual blocked non-switch, bilingual blocked switch, language switch non-switch, language switch switch. Clusters of electrodes were created for the statistical analysis (cf., Heed & Roeder, 2010) with separate analyses for midline and lateralised electrodes due to different numbers of electrodes per averaged cluster. For the midline analysis, electrodes were clustered into groups of two (frontal: Fz & FCz; central: Cz & CPz; posterior: Pz & POz). A three-way repeated measures ANOVA with position (frontal, central, posterior), language condition (monolingual, bilingual blocked, language switch), and trial type (switch, non-switch) as within-subject variables was carried out for cue-locked and target-locked averages. Similarly, clusters of six electrodes were created for frontal, central, and posterior electrodes on the right and left hemisphere (left frontal: F1, F3, F5, FC1, FC3, FC5; right frontal: F2, F4, F6, FC2, FC4, FC6; left central: C1, C3, C5, CP1, CP3, CP5; right central: C2, C4, C6, CP2, CP4, CP6; left posterior: P1, P3, P5, P7, PO3, PO7; right posterior: P2, P4, P6, P8, PO4, PO8). A four-way repeated measures ANOVA was carried out with position (frontal, central, posterior), hemisphere (left, right), language condition (monolingual, bilingual blocked, language switch), and trial type (switch, non-switch) as within-subject variables. Effects of interest (trial type, language condition, and the interaction between the two) are always reported. Effects of hemisphere and position are only reported when significant. Greenhouse-Geisser adjusted values are reported where appropriate. Based on Nicholson et al. (2006) and visual inspection of the data, cue-locked averages were analysed for the time windows [400, 500] ms and [500, 600] ms. Target-locked analyses were carried out for the time windows [200, 300] ms, [300, 400] ms, and [400, 500] ms. To correct for multiple time comparisons, the Bonferroni corrected $\alpha$ value was .025 (0.05/2) for cue-locked analyses and .017 (0.05/3) for target-locked analyses. In all figures, positive values are plotted upwards.

***LIMO analysis***

For the LIMO analysis, EEG data were pre-processed using EEGLAB v.13.5.4b (Delorme & Makeig, 2004). Data were filtered using the Basic FIR filter with a low cut-off of 1 HZ and a high cut-off of 40 Hz. Next, data were re-referenced to the electrodes on the mastoids and epochs were created with a time window of [-100, 2200]. After Independent Component Analysis using runica, components reflecting artefacts were rejected manually. For each participant, a design matrix was created that included information about the condition (monolingual non-switch, monolingual switch, bilingual blocked non-switch, bilingual blocked switch, language switch non-switch, language switch switch trials). Furthermore, errors, trials preceded by errors, the type of stimulus (e.g., pink square), and decision (e.g., colour) were included in the design matrix. As continuous variables, z-scored distance per trial type (switch/non-switch) and RTs were included. At the first level, parameters were estimated per subject for each time point and all electrodes. The second level analysis combined the estimated parameters per subject to run group-level analyses. The use of two-level analyses has multiple advantages. Firstly, similar to the behavioural analyses, within-subject trial variability is accounted for. Secondly, unwanted variance (e.g., stimulus types, errors) are regressed out when investigating effects of language condition. Thirdly, it is possible to examine effects of continuous variables such as distance.

Contrasts were created to examine the switching cost (switch vs. non-switch trials) per language condition. The presence of a switching cost was firstly examined through a one sample t-test. Next, effects of language condition on switching cost were examined through a repeated measures ANOVA. To assess effects of distance, I tested for effects of distance across trial types through a one sample t-test as well as for differential effects of distance between switch and non-switch trials with a paired t-test. To correct for multiple comparisons, spatial-temporal clustering was used with bootstrapping set at 1000. In all figures, positive values are plotted upwards.

### 7.3.2. Behavioural results

Accuracy was lower for switch (*M* =93.89 *SD* = 6.04, *z* = -7.49) than non-switch trials (*M* = 98.88, *SD* = 3.98). There was no difference between the monolingual condition (*M* = 96.75, *SD* = 4.34) and bilingual blocked (*M* = 96.45, *SD* = 4.24, *z* = -.06) or language switching (*M* = 95.95, *SD* = 5.79, *z* = .14). There was also no interaction between bilingual blocked and switch trials (*z* = -1.31) or between language switch and switch trials (*z* = -0.84).

Apart from incorrect answers, an additional 10.28% were removed as outliers or trials preceded by an error. RTs showed a main effect of trial type (*t* = 6.53, see Appendix E4 for details) with switch trials (*M* = 681.75, *SD* = 138.85) on average being slower than non-switch trials (*M* = 638.25, *SD* = 124.23). Overall RTs did not differ between the monolingual condition, the bilingual blocked condition (*t* = -.20), and the language switch condition (*t* = -.05; see Table 7.4). Furthermore, compared to monolingual naming, switching costs were similar after bilingual blocked naming (*t* = 1.46) and language switching (*t* = -.11, see Table 7.4 and Figure 7.4). There was a main effect of distance (*t* = 2.92) as well as an interaction with switch trials (*t* = -3.63). For switch trials, RTs decreased with increasing distance while RTs increased for non-switch trials (see Figure 7.5). None of the other interactions were significant. Language-switching costs did not correlate with either overall task-switching costs (*r*(20) = .11, *p* = .633) or with switching costs preceded by the language-switching task (*r*(20) = .18, *p* = .459).

Table 7.4

*Mean RTs and standard deviations (in parentheses) for switch trials, non-switch trials, and switching costs per language condition.*

| | **Preceded by monolingual naming** | **Preceded by bilingual blocked** | **Preceded by language switching** |
|---|---|---|---|
| Switch | 679.94 (139.93) | 689.78 (145.42) | 680.40 (143.44) |
| Non-switch | 640.13 (128.11) | 640.29 (128.90) | 637.09 (128.83) |
| *Switching cost* | 39.81 (11.81) | 49.49 (16.52) | 43.31 (14.62) |

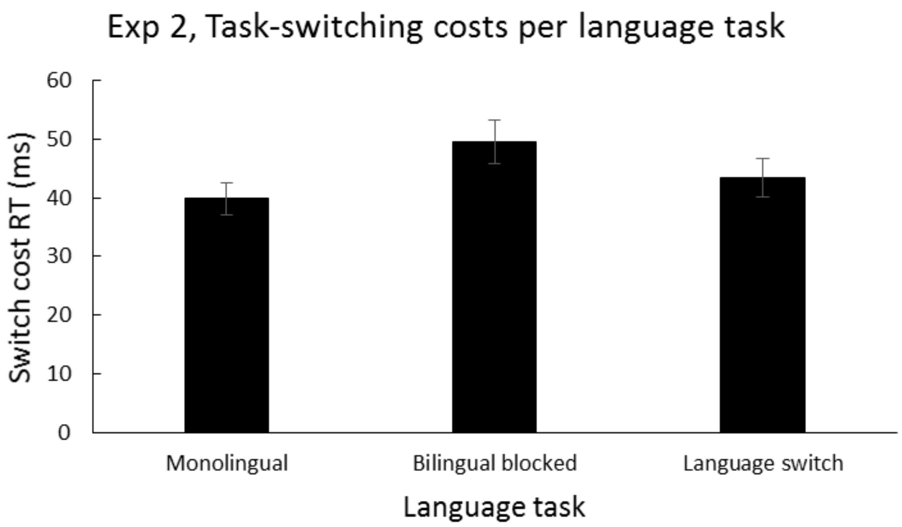


*Figure 7.4.* Switching costs in the task-switching paradigm per language condition.

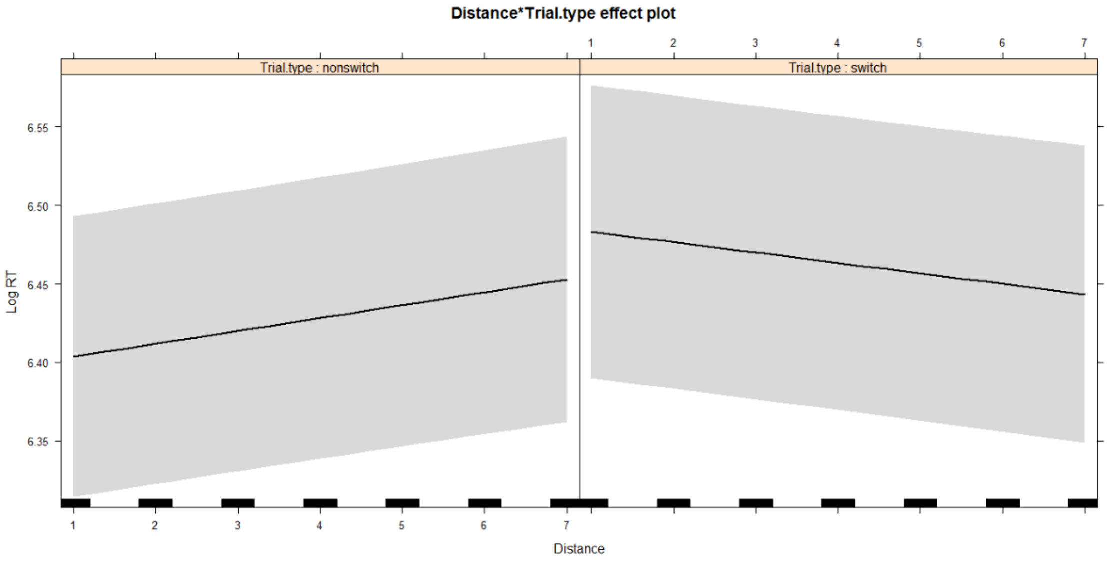


*Figure 7.5.* Effects of distance on Log RTs per trial type (left: non-switch; right: switch).

### 7.3.3. EEG Results

**Cue-locked ERPs (BrainVision)**

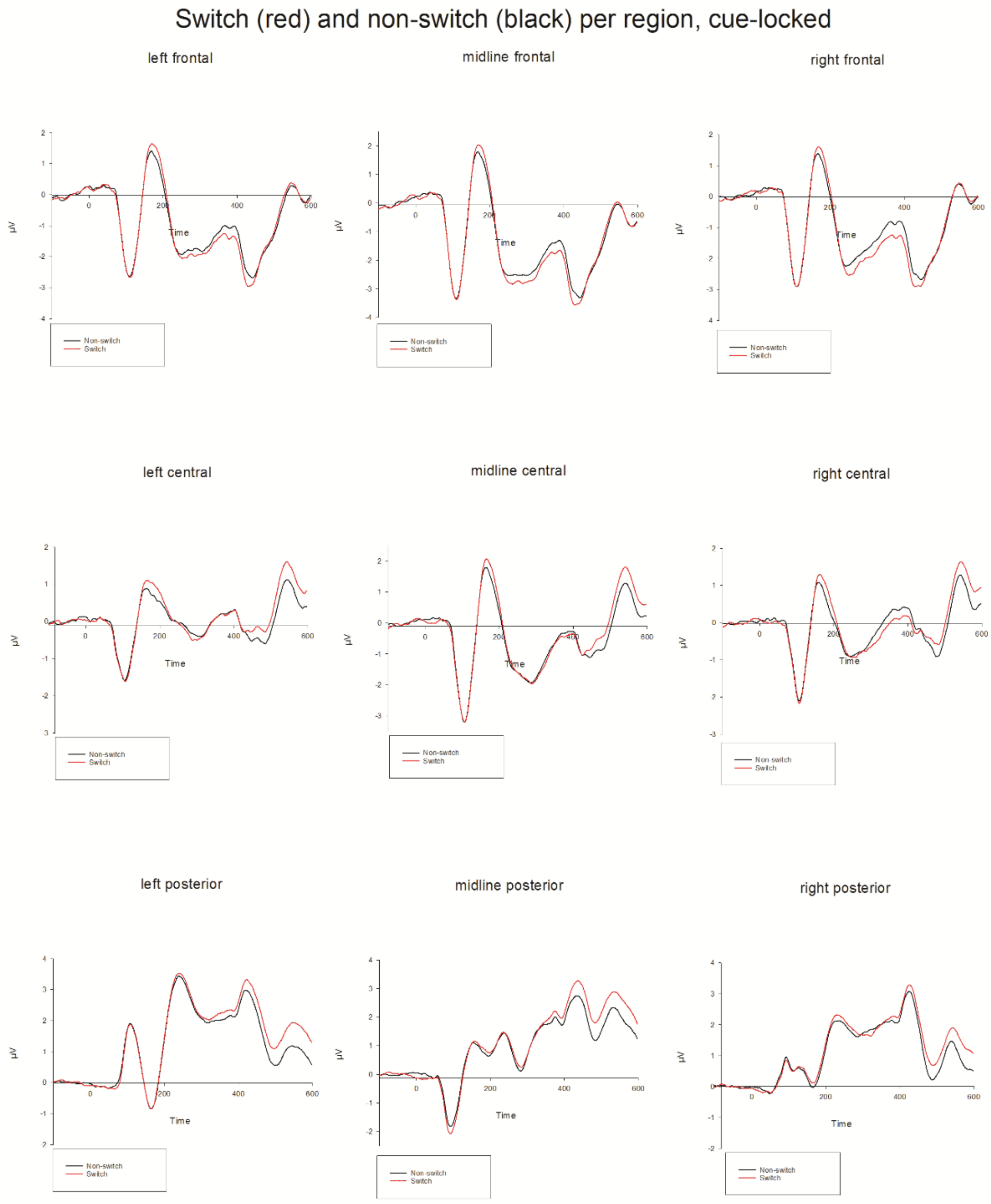


*Figure 7.6.* Overview of switch (red) and non-switch (black) trials in all nine clusters.

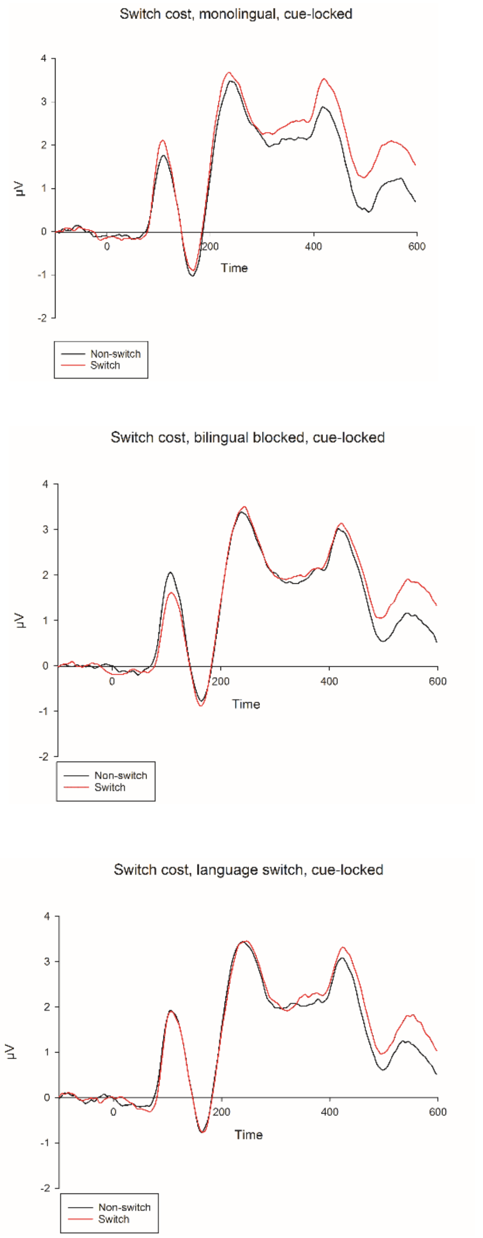


*Figure 7.7.* Overview of switch (red) and non-switch (black) per language condition in the left posterior cluster. The top image shows the monolingual condition, the middle image the bilingual blocked condition, and the bottom image the language switch condition.

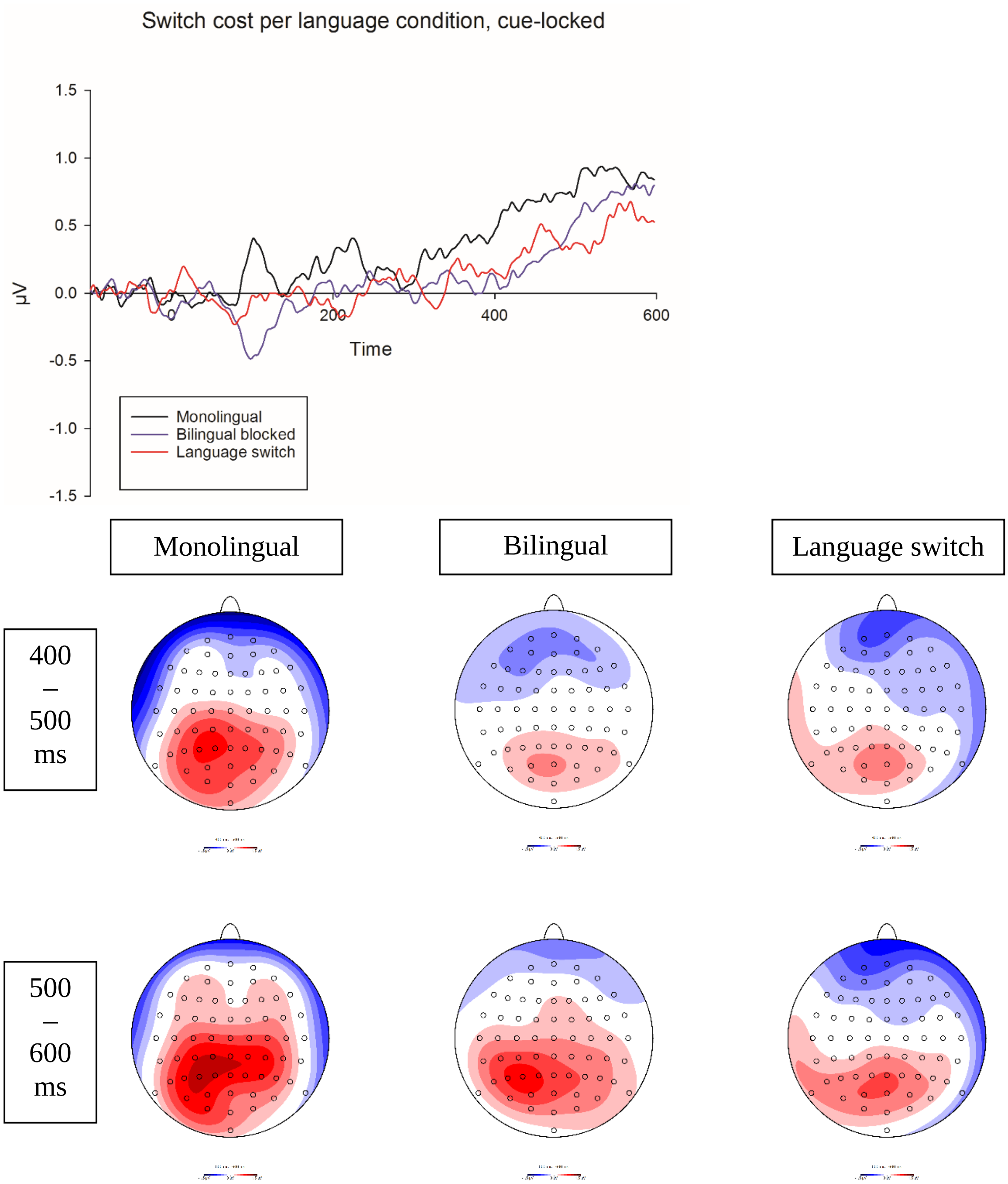


*Figure 7.8.* Difference waves (switch – non switch trials) for monolingual (black), bilingual blocked (blue), and language switch (red) with scalp distributions for the time window 400-500 (top) and 500-600 (bottom)[18].

[18] Visual inspection of the difference waveform suggests that there may be a difference between language conditions around the 100 ms time point. I therefore added an exploratory analysis around this time point, but no significant effect of language condition nor an interaction with trial type was observed.

Figure 7.6, 7.7, and 7.8 suggest an increased positivity for switch compared to non-switch trials appearing 400-600 ms after cue presentation. The scalp distribution in Figure 7.8 shows that this effect is largest in the left posterior region. Regarding effects of language condition, Figure 7.7 suggests that switching costs are similar after monolingual naming, bilingual blocked naming, and language switching.

***400-500 ms***

Both the midline analysis ($F(2, 32) = 125.48$, $p < .001$, $\eta_p^2 = .89$) and lateralised electrodes ($F(2, 32) = 88.76$, $p < .001$, $\eta_p^2 = .85$) showed an effect of position with more positive ERPs at posterior regions (see Figure 7.6 and Figure 7.8). For both midline ($F(1, 16) = 1.17$, $p = .296$) and lateralised electrodes ($F(1, 16) = .68$, $p = .423$), there was no main effect of trial type. However, trial type interacted with position for midline ($F(2, 32) = 7.81$, $p = .009$, $\eta_p^2 = .33$) and lateralised ($F(2, 32) = 8.88$, $p = .007$, $\eta_p^2 = .36$) analyses. Post-hoc comparisons per position showed no significant effects of trial type in the frontal region (midline: $F(1, 16) = .46$, $p = .508$; lateralised: $F(1, 16) = .89$, $p = .360$) or the central region (midline: $F(1, 16) = 1.37$, $p = .260$; lateralised: $F(1, 16) = .93$, $p = .349$). In the posterior region, ERPs were more positive for switch than non-switch trials (midline: $F(1, 16) = 8.74$, $p = .009$, $\eta_p^2 = .35$; lateralised: $F(1, 16) = 12.49$, $p = .003$, $\eta_p^2 = .44$, see Figure 7.7). There was no main effect of language condition (midline: ($F(2, 32) = 1.11$, $p = .350$; lateralised: $F(2, 32) = 1.42$, $p = .257$). Language condition furthermore did not interact with trial type (midline: $F(2, 32) = .78$, $p = .455$; lateralised: $F(2, 32) = 1.35$ , $p = .273$). This suggests that there was no effect of language condition on switching cost ERPs (see Figure 7.7 and 7.8).

***500-600 ms***

A main effect of position was observed (midline: $F(2, 32) = 27.12$, $p < .001$, $\eta_p^2 = .63$; lateralised: $F(2, 32) = 10.53$, $p < .001$, $\eta_p^2 = .40$), with more positive ERPs in the posterior regions. The main effect of trial type did not reach the corrected significance level on the midline analysis ($F(1, 16) = 4.93$, $p = .041$, $\eta_p^2 = .24$) and did not interact significantly with position ($F(2, 32) = 5.20$, $p = .028$). The main effect of trial type was present for lateralised electrodes ($F(1, 16) = 8.42$, $p = .010$, $\eta_p^2 = .35$) with more positive ERPs for switch than non-switch trials as well as an interaction between trial type and position ($F(2, 32) = 9.48$, $p = .005$, $\eta_p^2 = .37$). Post-hoc analyses per position showed more positive switch than non-switch ERPs in the central region ($F(1, 16) = 8.84$, $p = .009$, $\eta_p^2 = .36$) and posterior region (lateralised: $F(1, 16) = 20.76$, $p < .001$, $\eta_p^2 = .57$, see Figure 7.7) but not in the frontal region (lateralised: $F(1, 16) = .163$, $p = .691$). There was no main effect of language condition (midline: $F(2, 32) = 3.07$, $p = .087$; lateralised: $F(2, 32) = 1.27$, $p = .294$) nor an interaction with trial type (midline: $F(2, 32) = 1.09$, $p = .347$; lateralised: $F(2, 32) = 2.21$, $p = .128$; see Figure 7.8).

**Target-locked ERPs (BrainVision)**

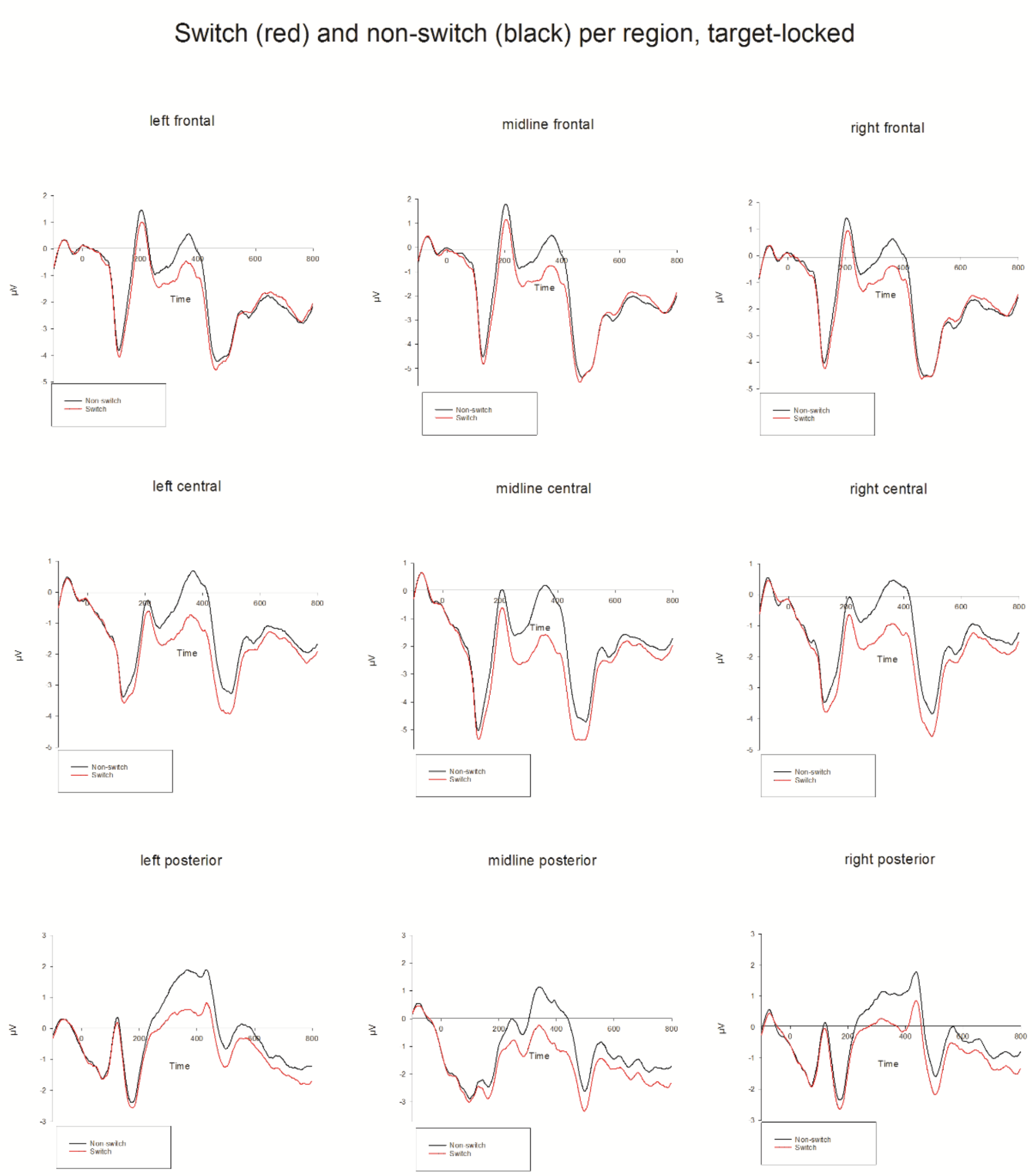


*Figure 7.9.* Overview of switch (red) and non-switch (black) in all nine clusters.

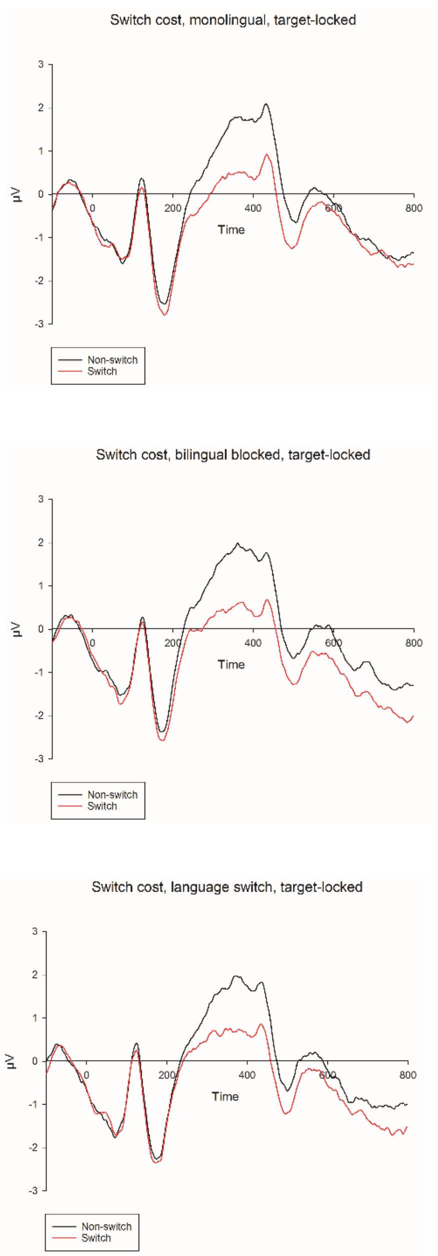


*Figure 7.10.* Overview of switch (red) and non-switch (black) per language condition in the left posterior cluster. The top image shows the monolingual condition, the middle image the bilingual blocked condition, and the bottom image the language switch condition.

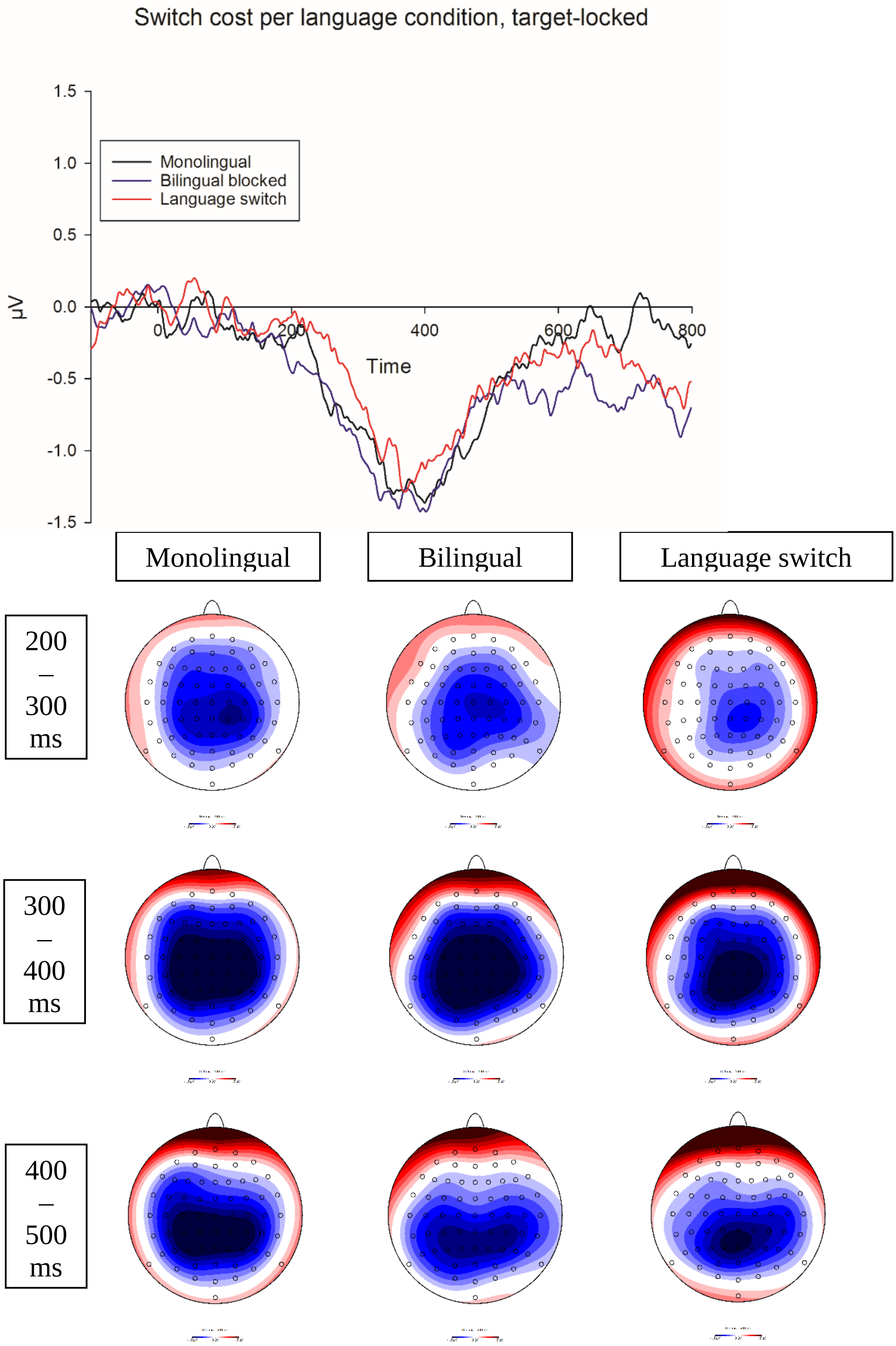


*Figure 7.11.* Difference waves (switch-non-switch) for monolingual (black), bilingual blocked (blue), and language switch (red) with scalp distributions for the time window 200-300 (top), 300-400 (middle), and 400-500 (bottom).

Figure 7.9, 7.10, and 7.11 suggest that non-switch trials elicited a larger positivity compared to switch trials in the time window of 200-500 ms after target presentation. The scalp distribution in Figure 7.11 shows that this effect has a wide distribution across central and posterior regions. Figure 7.10 suggests that there is no effect of language condition on switching costs.

***200-300 ms***

There was a main effect of trial type (midline: $F(1, 16) = 14.05$, $p = .002$, $\eta_p^2 = .47$; lateralised: $F(1, 16) = 11.41$, $p = .004$, $\eta_p^2 = .42$, see Figure 7.9 and 7.10) with more positive/less negative ERPs for non-switch than switch trials. There was no main effect of language condition (midline: $F(2, 32) = 1.43$, $p = .254$; lateralised: $F(2, 32) = .40$, $p = .608$) nor an interaction with trial type suggesting that language condition did not affect switching costs (midline: $F(2, 32) = 1.93$, $p = .163$; lateralised: $F(2, 32) = 2.05$, $p = .147$; see Figure 7.10 and 7.11).

***300-400 ms***

A main effect of trial type (midline: $F(1, 16) = 39.05$, $p < .001$, $\eta_p^2 = .71$; lateralised: $F(1, 16) = 43.47$, $p < .001$, $\eta_p^2 = .73$) was found with more positive/less negative ERPs for non-switch than switch trials. There was no main effect of language condition (midline: $F(2, 32) = .20$, $p = .787$; lateralised: $F(2, 32) = .16$, $p = .850$) nor an interaction with trial type (midline: $F(2, 32) = .20$, $p = .779$; lateralised: $F(2, 32) = .89$, $p = .408$; see Figure 7.10 and 7.11).

***400 -500 ms***

There was a main effect of position (midline: $F(2, 32) = 32.33$, $p < .001$, $\eta_p^2 = .60$; lateralised: $F(2, 32) = 66.87$, $p < .001$, $\eta_p^2 = .81$) with more positive ERPs for posterior regions. There was a main effect of trial type (midline: ($F(1, 16) = 19.51$, $p < .001$, $\eta_p^2 = .55$; lateralised: $F(1, 16) = 23.19$, $p < .001$, $\eta_p^2 = .59$) that interacted with position (midline: $F(2, 32) = 6.04$, $p = .014$, $\eta_p^2 = .20$; lateralised: $F(2, 32) = 8.12$, $p = .006$, $\eta_p^2 = .34$). Post-hoc analyses per position showed more positive ERPs for non-switch than switch trials in the central region (midline: $F(1, 16) = 21.27$, $p < .001$, $\eta_p^2 = .57$; lateralised: $F(1, 16) = 29.63$, $p < .001$, $\eta_p^2 = .65$) and posterior region (midline: $F(1, 16) = 27.61$, $p < .001$, $\eta_p^2 = .63$; lateralised: $F(1, 16) = 36.66$, $p < .001$, $\eta_p^2 = .70$) but no difference in the frontal region (midline: $F(1, 16) = 3.23$, $p = .091$; lateralised: $F(1, 16) = 4.24$, $p = .056$). There was no main effect of language (midline: $F(2, 32) = .22$, $p = .782$; lateralised: $F(2, 32) = .35$, $p = .680$) nor an interaction with trial type (midline: $F(2, 32) = 1.22$, $p = .309$; lateralised: $F(2, 32) = 1.23$ , $p = .305$; see Figure 7.10 and 7.11).

**LIMO analysis**

The LIMO analysis firstly showed that there was a significant switching cost around two main time windows (Figure 7.12). Between 440 and 780 ms after cue presentation (with a peak around 590 ms), a larger positivity was observed for switch compared to non-switch trials. Between 770 and 1130 ms (110-530 ms after target presentation, with two peaks around 330 and 425 ms), this pattern was reversed with non-switch trials being more positive than switch trials. The scalp distribution showed that the effect in the first time window was largely posterior, while the effect in the second time window was more centrally distributed (see Figure 7.13).

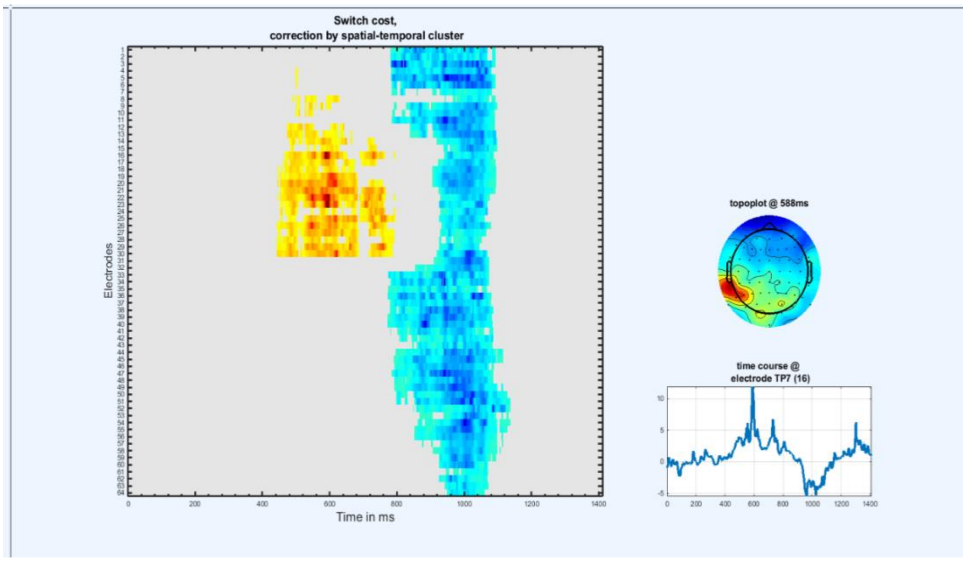


*Figure 7.12.* Difference between switch and non-switch trials across all electrodes (y-axis) and time points (x-axis).

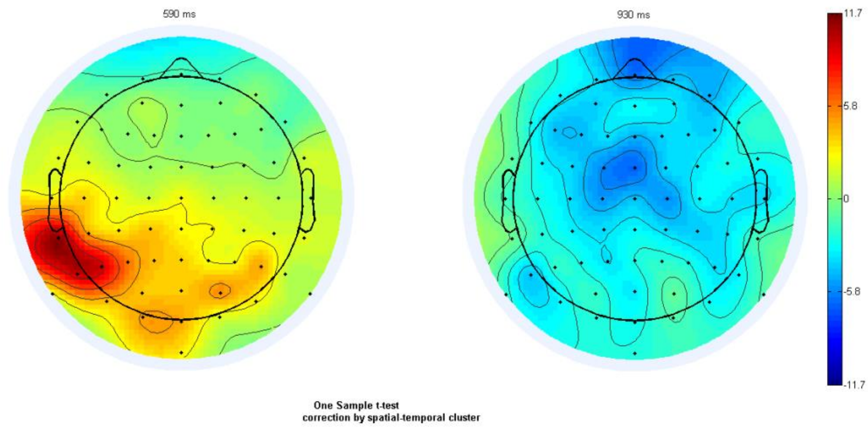


*Figure 7.13.* Scalp distribution for switch compared to non-switch trials at time point 590 (left) and 930 (right).

When language conditions were compared on switching costs, no significant effects were observed. This was confirmed in post-hoc contrasts comparing the switching costs between language conditions (Figure 7.14). Switching costs were similar after the three language conditions (Figure 7.15).

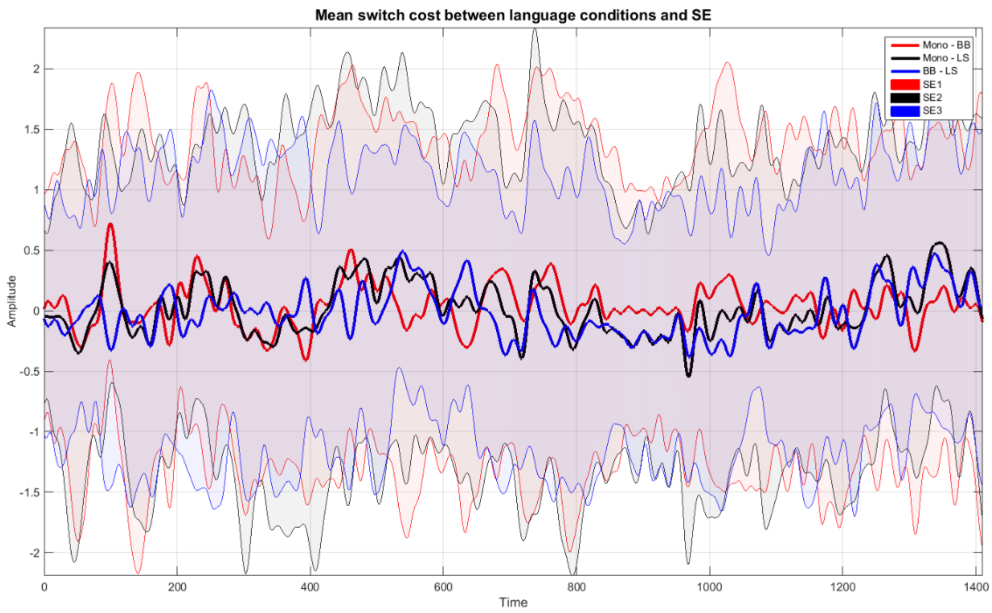


*Figure 7.14.* Post-hoc contrasts of switching costs (task switch – non-switch trials) between the three language conditions on electrode P7. The difference between monolingual and bilingual blocked task-switching costs is indicated in red; the difference between monolingual and language switching task-switching costs in black; and the difference between bilingual blocked and language switching in blue. Shaded colours show the standard error per comparison.

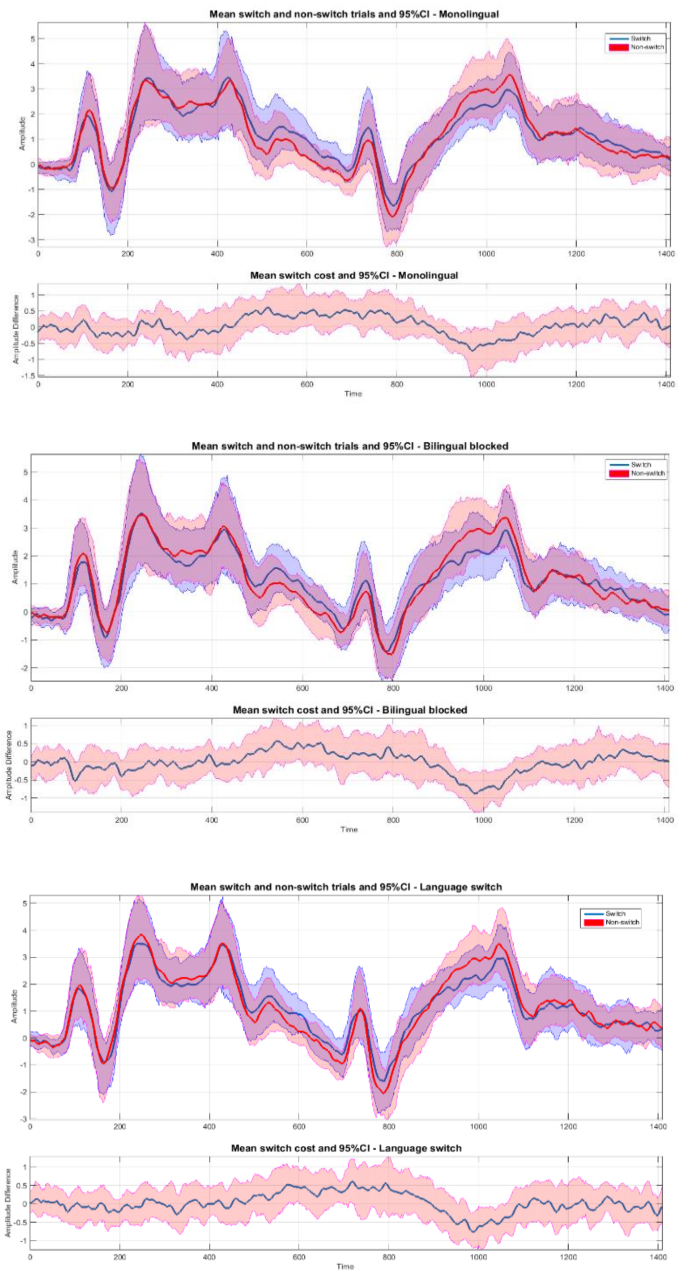


*Figure 7.15.* Switching costs per language condition (top: monolingual, middle: bilingual blocked, bottom: language switching) on electrode P7. For each language condition, the top part shows switch trials in blue and non-switch trials in red; the second part of each image shows the difference line between switch and non-switch trials. Shaded colours show the standard error.

Furthermore, there was no main effect of distance nor a difference between effects of distance on switch or non-switch trials that survived corrections (see Figure 7.16 for the uncorrected comparison).

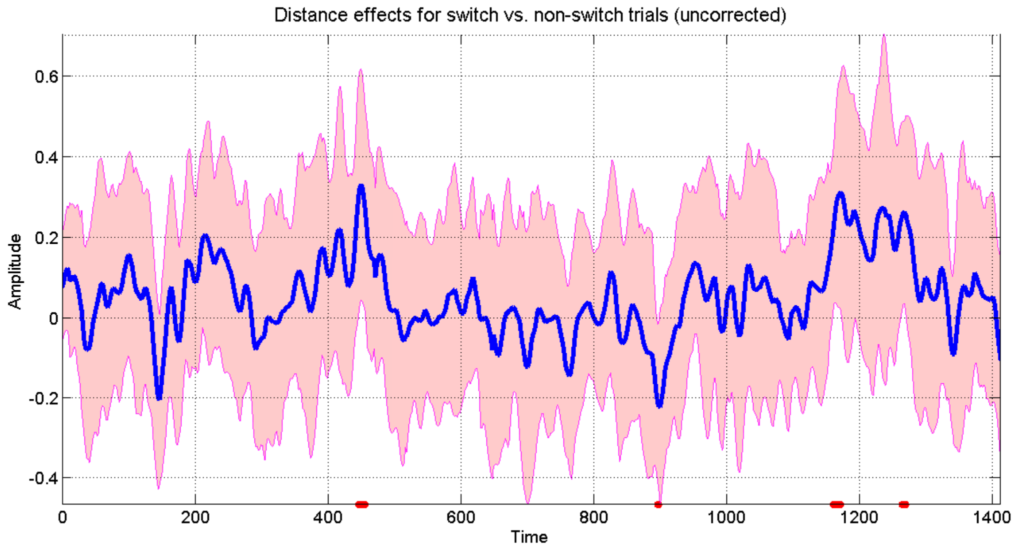


*Figure 7.16.* Effects of distance for switch versus non-switch trials on electrode P7.

#### 7.3.4. Discussion

Experiment 2 examined effects of language switching on non-verbal task switching. Overall RTs and switching costs were comparable after the three language tasks. Contrary to the negative effects on verbal switching, language switching did not affect non-verbal switching costs. The EEG data too showed no effect of language condition. The effects of trial type were consistent with previous task-switching studies. The cue-locked analysis showed more positive ERPs for switch than non-switch trials (cf., Nicholson et al., 2005; Nicholson et al., 2006; Goffaux et al., 2006). This difference was observed 400-600 ms after cue presentation (i.e., just before target presentation) and was largest around the posterior regions. The increased positivity for switch over non-switch trials has been interpreted as reflecting differences related to task preparation in response to the cue. A non-switch cue may be less effortful than a switch trial requiring a change in task set. (e.g., Goffaux et al., 2006). Other researchers have argued that this cue-locked difference may stem from cue repetition in non-switch trials (e.g., Logan & Bundesen, 2003). This alternative interpretation was ruled out in the current experiment as cues changed on both switch and non-switch trials and as such cues were never repeated. In response to target presentation, larger positive ERPs for non-switch than switch trials were found. These effects were observed between 200-500 ms after target presentation and strongest around the central-posterior regions. This has been interpreted as reflecting task-set reconfiguration and response interference (cf., Nicholson et al., 2005). Yet while the effects of task switching were similar to previous studies, no effects of language condition were observed. Therefore, language switching does not appear to affect non-verbal task switching on either behavioural or EEG measurements.

Behaviourally, effects of distance (i.e., the number of consecutive trials of the same trial type) were similar to the previous experiment. RTs to switch trials decreased while RTs to non-switch trials increased for a longer sequence of identical trial types. The EEG data, however, showed no overall effects of distance nor a differential effect of distance between trial types.

### 7.4. Experiment 3: Verbal versus non-verbal task switching

Experiment 1 and 2 showed different findings of language switching on task switching. While task-switching costs were larger after language switching than monolingual naming in Experiment 1, this effect was not found in Experiment 2. One of the main differences between the two experiments was the use of verbal colour/shape switching in Experiment 1, while this was done non-verbally in Experiment 2. However, another main difference concerned the process of EEG recordings during Experiment 2. To assess whether it was indeed the use of verbal versus non-verbal materials that caused the difference between the two experiments, I conducted a third experiment in which the same group of bilinguals was tested behaviourally on both verbal and non-verbal colour/shape switching. These two conditions were preceded by either monolingual naming or a language-switching task.

#### 7.4.1. Methods

Another eleven Spanish-English and five Italian-English bilinguals (5 men; mean age = 24.00, *SD* = 3.18) completed Experiment 3. All participants reported normal or corrected-to-normal vision and hearing and had been living in the UK for a minimum of one year. Although language proficiency was not assessed formally, all participants reported being fluent in English. The task details (materials and presentation times) were the same as in Experiment 2. Half of the participants first completed the monolingual naming task, followed by a verbal and non-verbal colour/shape switching task. Then, they completed the language-switching task, followed by the verbal and non-verbal colour/shape switching tasks. The order of language conditions as well as the order of verbal versus non-verbal switching was counterbalanced across participants. The task-switching tasks consisted of 140 trials (70 switch, 70 non-switch) across two blocks. For the verbal tasks, responses were recorded and VOTs were automatically generated in Praat. VOTs < 300ms were checked and manually corrected if needed. There were two main design differences between the current experiment and the previous two. Firstly, the current experiment only consisted of one session. Thus, while the previous two experiments used approximately a one-week interval between monolingual and bilingual tasks to minimise transfer effects of bilingual tasks on the monolingual task, in the current experiment the two parts were done consecutively. Secondly, the current study did not include a bilingual blocked condition as the main aim concerned the monolingual-language switch difference between verbal and non-verbal tasks.

### 7.4.2. Results

A generalised linear mixed-effect analysis showed an effect of condition (verbal, nonverbal) on accuracy in the task-switching task ($z$ = 3.13). Accuracy was higher in the verbal ($M$ = 95.64, $SD$ = 5.54) than non-verbal condition ($M$ = 90.86, $SD$ = 6.73). Accuracy scores did not differ between tasks completed after the monolingual or language-switching task ($z$ = 0.15) and there was no interaction between condition and language task ($z$ = -1.75), nor a three-way interaction ($z$ = .91).

Before RT/VOT analysis, an additional 13.22% of trials were removed as outliers or trials preceded by an error. The RT/VOT analysis firstly showed a main effect of condition ($t$ = 6.34, see Appendix E5), with verbal responses ($M$ = 637.87, $SD$ = 77.14) being slower than non-verbal responses ($M$ = 528.19, $SD$ = 79.04). There was furthermore a main effect of trial type ($t$ = 7.89), with switch trials ($M$ = 607.41, $SD$ = 71.06) being slower than non-switch trials ($M$ = 562.54, $SD$ = 66.32). There was no main effect of language condition ($t$ = 0.42): RTs were equally fast after language switching ($M$ = 589.89, $SD$ = 85.86) and monolingual naming ($M$ = 578.77, $SD$ = 59.79). Condition interacted with trial type ($t$ = -6.00): Switching costs were larger in the non-verbal ($M$ = 62.30, $SD$ = 34.81) than verbal task-switching paradigm ($M$ = 28.30, $SD$ = 23.22). Other two-way interactions were not significant ($t$ < 2). However, there was a three-way interaction ($t$ = 2.05), suggesting that the effects of language switching on task-switching costs differed between verbal and non-verbal conditions (see Table 7.5 and Figure 7.17). Separate analyses for the non-verbal and verbal task-switching paradigm showed no difference between costs after language switching vs. monolingual naming in the non-verbal task-switching paradigm (interaction Switch x Language switching: $t$ = -0.29). However, in the verbal task-switching paradigm, costs were larger after language switching than after monolingual naming (interaction Switch x Language switching: $t$ = 2.75). Language-switching costs did not correlate significantly with either subsequent verbal task-switching costs ($r$(15) = -.46, $p$ = .088) or non-verbal task-switching costs ($r$(15) = .09, $p$ = .75).

Table 7.5

*Means and standard deviations (in parentheses) for the verbal and non-verbal switch and non-switch trials as well as switching costs.*

| | **Preceded by monolingual naming** | **Preceded by language switching** |
|---|---|---|
| **Verbal task switching** | | |
| Switch | 637.78 (61.40) | 663.53 (91.59) |
| Non-switch | 620.17 (58.43) | 624.34 (98.56) |
| *Switching cost* | 17.61 (15.21) | 39.19 (37.65) |
| | | |
| **Non-verbal task switching** | | |
| Switch | 559.42 (94.40) | 562.03 (92.41) |
| Non-switch | 494.64 (66.08) | 502.20 (95.82) |
| *Switching cost* | 64.78 (39.89) | 59.83 (39.79) |

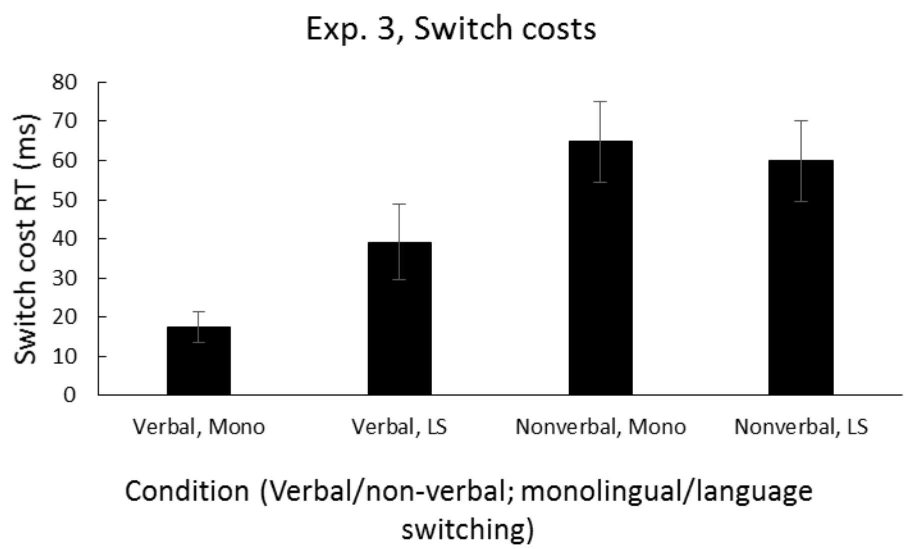


*Figure 7.17.* Switching cost per condition (verbal or non-verbal task switching preceded by monolingual naming or language switching).

### 7.4.3. Discussion

Experiment 3 replicated the findings observed in Experiment 1 and 2. Verbal task switching was affected by the language task and showed larger switching costs after language switching than after monolingual naming. No such effect was found for non-verbal switching costs. This confirms the previous findings that language switching may hinder verbal switching performance without affecting non-verbal switching.

## 7.5. General discussion

Across three experiments, I examined effects of language switching on verbal and non-verbal task switching. Verbal switching costs increased after language switching compared to monolingual picture naming. Non-verbal switching costs were not affected by the type of preceding language task. Similarly, EEG data recorded during the non-verbal switching task showed no effects of language condition.

### 7.5.1. Behavioural effects

Language switching affected verbal but not non-verbal switching performance. This was observed in two separate experiments, but importantly also in a direct comparison of verbal versus non-verbal switching. This is consistent with data reported in Chapter 5 and 6 showing an effect of language use on lexical processing but not on non-verbal executive control tasks. In bilingual-monolingual group comparisons, negative effects of bilingualism have been observed across a wide range of lexical tasks. Bilingual participants typically have a smaller vocabulary than monolinguals (e.g., Bialystok & Feng, 2009), take longer to name pictures (e.g., Gollan et al., 2005), and name fewer items on verbal fluency tasks (e.g., Rosselli et al., 2001). This negative impact of bilingualism is often argued to result from interference from the non-target language. In Chapter 5, I furthermore argued that the amount of interference, and consequently the negative impact, can be modulated by active language use. Bilingual participants who reported higher language use in two languages needed more time in a lexical task. The current study is compatible with these findings. Switching between two languages may cause more interference than picture naming in one language only and this language interference on language switch trials may hinder subsequent verbal task switching in one language. The third language condition, bilingual blocked naming, scored in-between the monolingual and language-switching condition but did not differ significantly from either. However, a comparison of the last language block immediately preceding task switching showed similar switching costs for L1 versus English last. If use of another language alone is sufficient to hinder subsequent task-switching performance, costs should be larger after L1 than English naming as the task-switching paradigm was completed in English. This is not the case, implying that just using a non-target language is not enough to increase switching costs. Rather, active switching between two languages hinders subsequent task switching in one language only. Indeed, one would expect that these effects of language switching should also be observed in the mixed paradigm requiring participants to switch between languages as well as tasks (paradigm B in Experiment 1). In this paradigm, however, task-switching trials were only preceded by two or four language switch trials. It is likely that this low number of language-switching trials was not sufficient to affect task switching.

Furthermore, it should be noted that the language-switching task in the current study immediately preceded the task-switching paradigm. It is unclear whether these causal effects of language switching would survive a longer time interval. Prior and Gollan (2013) did not observe effects of language switching on verbal task switching when the two were separated by a one-week interval, suggesting that the effects may not be long-lasting.

No effects of language condition were found on non-verbal switching costs. While some bilingual-monolingual comparisons have found group differences on non-verbal switching tasks (e.g., Prior & MacWhinney, 2010), others have not observed these differences (e.g., Paap & Greenberg, 2013). Furthermore, in Chapter 6, I examined effects of language use on non-verbal switching costs. While a group difference was found on raw (but not corrected) switching costs, no effects were found of self-rated language use as a continuous variable. Together with these data, the current experiments suggest that bilingual language use (either in a blocked manner or through language switching) does not affect non-verbal switching costs.

An alternative explanation of increased switching costs after language switching could be that the language-switching task is more difficult than the bilingual blocked or monolingual naming task. Tasks requiring higher levels of control may hinder performance on a subsequent task (e.g., Muraven & Baumeister, 2000). Indeed, in Experiment 1 and 2, VOTs were longer for the language-switching condition (Exp 1: *M* = 879.43, *SD* = 78.09; Exp 2: *M* = 967.08, *SD* = 69.41) than in the bilingual blocked condition (Exp 1: *M* = 725.87, *SD* = 69.15; Exp 2: *M* = 811.46, *SD* = 61.32), suggesting that this task is more demanding. However, if task complexity in general (irrespective of the type of language task) hinders task-switching performance, the same negative impact would be expected on both verbal and non-verbal task switching and would furthermore be expected on overall RTs too. The specific finding on verbal switching costs only suggests that it is the type of language task rather than general task complexity that causes the effect.

It could furthermore be argued that the verbal switching task was more similar to the language-switching task than the non-verbal task that required button presses. However, in Experiment 3, verbal responses versus button presses was the only difference between the verbal and non-verbal switching task. Therefore, language switching and use only appear to affect task switching when an overt vocalisation is needed.

### 7.5.2. EEG data

Similar to the behavioural data, I did not observe effects of language condition on either overall performance or on switching costs in the EEG data. Wu and Thierry (2013) too conducted an EEG experiment examining causal effects of bilingual vs. monolingual language mode on non-verbal executive control. In this study, the P300 difference related to inhibition costs was smaller after bilingual word presentation compared to monolingual words. This ERP difference was found in the absence of RT differences. However, there are many differences between the current study and Wu and Thierry (2013) that hinder a reliable comparison of the two. Firstly, I focussed on task switching while Wu and Thierry examined inhibition performance on a flanker task. Secondly, my study used active language production while participants in the flanker study only had to read bilingual or monolingual words. Thirdly, in my EEG study, the language task preceded the executive control tasks, while words were presented during the flanker task in Wu and Thierry's study. Thus, there could be many reasons for the different findings between these two studies. Nevertheless, if anything, my design appears more likely to elicit effects of the language task than Wu and Thierry's design. The tasks used in my study (language switching and task switching) were more similar than the tasks used in Wu and Thierry (word reading and a flanker task). I hypothesised that effects would be more likely to occur for similar task paradigms such as those used in the present study. Regarding active versus passive language use, active language use as used in my study was expected to have a stronger impact than passive language use. Furthermore, while our language task indeed preceded the executive control task in the EEG paradigm, I also did not observe effects of language use when language switching took place *during* the verbal task-switching paradigm in Experiment 1.

There are several EEG studies examining bilingual-monolingual differences on tasks argued to measure inhibition (e.g., Simon, Stroop, flanker tasks). These tasks have yielded several ERP differences between bilinguals and monolinguals on various components, including the N2 and P3. However, these differences are inconsistent both within as well as across studies (see Chapter 1 for an overview). The EEG literature on bilingualism and task switching is scarce. Magezi et al. (2012) compared language and task switching within bilinguals and observed differences around the N2 component, suggesting that different mechanisms may be involved in the two switching tasks. Our findings are consistent with their conclusion as language switching did not affect ERP components associated with task switching.

#### 7.5.3. Studying causal effects of bilingualism

The current study addresses a different question than previous studies assessing a link between bilingualism and task switching. While studies comparing bilinguals and monolinguals (including Chapter 6) typically examine a link between executive control and *lifelong bilingualism,* the present study only investigated effects of a short time of monolingual versus bilingual language behaviour. Ten minutes of performing a language task may not be enough to affect executive control and is not comparable with a lifelong practice of language switching. Furthermore, all participants were already bilingual. Their daily, ongoing language behaviour may mask effects of short-term language switching. Moreover, even the monolingual condition requires inhibition of the non-target language. As the monolingual condition was performed in English, the non-target language that needed to be suppressed was the stronger L1. This may have diminished differences in language control between the three conditions.

However, I did observe effects of language switching on verbal task switching, even within the same group of participants that did not show an impact on non-verbal switching. This suggests that the language manipulation can be effective and the differences between the three language conditions are strong enough to have an impact on verbal switching. The question remains whether effects on non-verbal switching would be found after a longer time of language switching.

## 7.6. Conclusion

In conclusion, the current study examined effects of language switching on verbal and non-verbal task switching. Language switching did not affect non-verbal task switching as observed in both behavioural and ERP switching costs. Verbal switching costs increased after language switching. A short time of language switching can thus have a negative impact on subsequent verbal task switching but does not affect non-verbal switching.

# Chapter 8. General discussion

Parts of this chapter (as indicated in footnotes) are based on:

De Bruin, A., Bak, T. H., & Della Sala, S. (2015). Examining the effects of active versus inactive bilingualism on executive control in a carefully matched non-immigrant sample. *Journal of Memory and Language, 85*, 15-26.

*Author contribution: All authors contributed to the study concept and design. Data collection and analysis were performed by A. de Bruin. A. de Bruin drafted the manuscript and T. H. Bak and S. Della Sala provided critical revisions.*

In this last chapter, I will firstly summarise the main findings of this thesis. Next, I will discuss effects of bilingualism and language use on respectively lexical processing and non-verbal executive control in more detail. After a brief consideration of bilingualism as a type of training, I will discuss several issues in the bilingualism literature including the construct of executive control and problems with task impurity. Lastly, I will give my interpretation of where the field is standing now and present a final conclusion.

## 8.1. Summary of the findings

This thesis aimed to examine effects of bilingualism and language use on lexical processing and non-verbal executive control. In **Chapter 3**, I firstly presented evidence for the existence of a publication bias in the literature on this topic. Studies with positive results were more likely to be published than studies not showing an effect of bilingualism. This suggests that the current literature gives an exaggerated impression of the actual impact of bilingualism on executive control.

**Chapter 4** discussed inhibitory control in more detail and focused on effects of ageing. Effects of bilingualism have been argued to be most likely to occur in older adults as this age group often shows impoverished inhibitory control. However, my study showed that age effects on inhibition depend on task-specific features. Older adults performed more slowly overall than younger adults on three inhibition tasks. However, a deficit on inhibition costs was only found on one of the three tasks. Furthermore, the type of stimuli that is used as well as baseline processing speed may affect the link between age and inhibition.

**Chapter 5 and 6** examined effects of bilingualism and language use on language processing and non-verbal executive control in older adults. Active bilinguals, inactive bilinguals, and monolinguals completed a picture-word matching task as well as a non-verbal task-switching and inhibition task. Importantly, all participants were non-immigrants matched on background variables such as lifestyle and education. Lexical processing was found to be affected by bilingualism as well as by active language use. Active bilinguals, but not inactive bilinguals, performed more slowly on the English lexical task than monolinguals. I therefore suggest that models explaining a bilingual lexical disadvantage should not only include language proficiency, but also actual language use as a modifying factor. The same group of participants, however, showed no overall effects of bilingualism or language use on the inhibition and switching task. Thus, this study did not replicate previous positive effects of bilingualism on inhibition and switching in well-matched groups of non-immigrants.

In **Chapter 7**, I presented three experiments examining causal effects of language switching on verbal and non-verbal task switching. Language switching had a negative impact on verbal task switching: Young bilinguals showed larger switching costs after a block of language switching than after monolingual picture naming. However, no effects of language switching were found on non-verbal task switching, both in behavioural as well as electrophysiological data. Similar to

Chapters 5 and 6, this study thus suggests that bilingualism and language use can affect verbal but not non-verbal tasks.

### 8.2. Effects of bilingualism and language use on lexical processing

In two separate studies, I found effects of bilingualism and language use on verbal tasks. Firstly, effects of language use were found on a lexical processing and verbal fluency task (Chapter 5). This suggests that language use can modify both passive lexical processing as well as active word production. Secondly, effects of language switching were found on a verbal task-switching task (Chapter 7). In both studies, effects of language use and language switching were negative. Active bilinguals recognised words more slowly and produced fewer items. Bilinguals who switched between their two languages showed larger switching costs on a subsequent verbal task. These findings are consistent with the general finding that bilinguals have a disadvantage on lexical tasks and are commonly explained through the Inhibitory Control framework (Green, 1998). This theory takes language proficiency into account. Over and beyond effects of proficiency, I also observed effects of actual language use and language switching. Daily patterns of language use and language switching have recently received increased interest in the Adaptive Control Hypothesis (Green & Abutalebi, 2013). Despite this framework and while proficiency and age of acquisition are usually discussed when describing a bilingual sample, this is often not the case for actual language use. My studies not only show that bilinguals are not homogeneous in their daily language use, but also show that this can have an impact on a wide range of verbal tasks. Thus, models of bilingual language processing as well as participant descriptions in bilingualism studies should not only incorporate language proficiency and age of acquisition but also language use.

## 8.3. Effects of bilingualism and language use on non-verbal executive control

While effects of bilingualism and language use were found on verbal tasks, there was no evidence for consistent effects on non-verbal executive control tasks. In Chapter 6, groups of older bilinguals did not show advantages on inhibition or switching tasks compared to monolinguals. On the inhibition task, effects were neither found for inhibition costs nor for overall RTs. On the switching task, effects were not found on overall RTs. While a small effect of active bilinguals versus monolinguals was found on raw switching costs, this was no longer supported after correcting for baseline differences. Furthermore, I did not observe direct effects of self-rated language use on inhibition or switching costs. Similarly, another set of experiments showed that non-verbal task switching was not affected by language switching in a group of young bilinguals. Thus, neither lifelong active language use nor a short time of language switching appeared to affect non-verbal executive control. Crucially, although these two studies show similar findings, the approaches are very different. While Chapter 6 applies the often used between-subject comparison of monolinguals versus bilinguals, Chapter 7 uses a within-subject design that avoids between-group differences on background variables. Furthermore, two different age groups were tested.

Despite the different methodologies and age groups, the data do not show evidence for a difference between bilinguals and monolinguals or a causal effect of monolingual vs. bilingual language use on non-verbal executive control tasks. This appears inconsistent with previous studies (e.g., Bialystok et al., 2004; Bialystok et al., 2008; Prior & Gollan, 2011) showing effects of bilingualism on inhibitory control or task switching. However, it is in line with the suggestion that 80% of studies conducted after 2011 do not observe a bilingual cognitive advantage (Paap et al., 2015).

It should furthermore be noted that both studies observed diverging patterns on verbal versus non-verbal tasks within the same group of bilingual participants. Both the lexical bilingual disadvantage as well as the non-verbal cognitive advantage have been argued to stem from the same daily practice of language inhibition. This language inhibition should delay access to each of the languages, but could also enhance non-verbal inhibitory control. Two groups of participants, however, showed lexical disadvantages but no non-verbal cognitive advantages. While bilingualism indeed seems to have an impact on verbal tasks, these effects do not necessarily extend to non-verbal control tasks.

## 8.4. Bilingualism as a form of training?

Bilingualism can be and has been argued to be a type of cognitive training (cf., Valian, 2015, for a similar argument) that is comparable to other types of training studies. Especially in older adults, this bilingual expertise has been trained for many years and often on a daily basis. Yet, my own data and many other studies suggest that this ongoing language inhibition training does not necessarily lead to advantages on non-verbal inhibition tasks.

Mixed effects have not only been found in studies testing effects of bilingualism on executive control. Playing video games has been suggested to lead to enhanced attentional control or working memory (e.g., Glass, Maddox, & Love, 2013) but has also been challenged in other studies (e.g., Unsworth et al., 2015). In a recent study, including tasks similar to those used in bilingualism research such as the flanker and Stroop task, Unsworth et al. (2015) concluded that the relation between video-game playing and cognitive abilities is weak or non-existent. The debate in the bilingualism field regarding issues with matching participant groups and causality is furthermore very similar to the discussion in the field of video-game training.

Similarly, training studies have shown improved performance on the trained task (near transfer), but this does not automatically transfer to untrained tasks (far transfer; e.g., Dahlin, Neely, Larsson, Bäckman, & Nyberg, 2008; Redick et al., 2013). In a study with pre-schoolers, effects of inhibition training were found on the trained tasks, but not on the untrained tasks (Thorell, Lindqvist, Bergman, Bohlin, &

Klingberg, 2009). They included inhibition tasks that are also commonly used in bilingualism research: The trained flanker and go/no-go task showed effects of training, whereas this did not extend to the untrained Stroop task. This has not only been found with healthy and young participants, but also for patients with frontal lobe damage. Intervention studies generally reduce the patients' executive problems, but this does not always transfer to untrained tasks (for a review, see Boelen, Spikman, & Fasotti, 2011).

Working memory training is perhaps the most popular type of training. Several companies (e.g., Cogmed, Lumosity) have now developed games allegedly improving the users' working memory capacity. Some studies have indeed suggested that working memory training can improve performance on non-trained tasks. For instance, Jaeggi, Buschkuehl, Jonides, and Perrig (2008) trained participants on a working memory task (*n*-back task) and observed improved performance on untrained fluid intelligence tests (Raven's Advanced Progressive Matrices). Recent reviews and meta-analyses, however, conclude that working memory training may improve performance on trained tasks but this does not generalise to other, untrained aspects such as intelligence or attentional control (e.g., Melby-Lervåg & Hulme, 2013; Melby-Lervåg, Redick, & Hulme, 2016). Shipstead, Hicks, and Engle (2012) reached similar conclusions and specifically argued against claims made by training software *Cogmed* regarding improvements on concentration, attention, and ADHD-related symptoms. A large group of researchers furthermore signed a letter warning against commercial brain games.

They address the importance of more systematic research, evidence-based conclusions, and publication biases being likely to create an overly optimistic interpretation of effects of working memory training (Max Planck Institute for Human Development and Stanford Center on Longevity, 2014). The debate regarding effects of working memory training is similar to the one on bilingualism and shows how easily findings can be over-interpreted by commercial companies and the public.

Considering the inconsistent findings in other training studies, the mixed effects of bilingualism should not be surprising. Even when inhibition tasks (such as the flanker task) are trained, this practice does not necessarily improve other inhibition tasks (such as the Stroop task). Language control and non-verbal cognitive control are not identical. Bilinguals may use language inhibition on a daily basis and studies have suggested that domain-general mechanisms are involved in both language and task switching (e.g., Abutalebi & Green, 2007; De Bruin et al., 2014). Yet, the two types of switching are not identical and are governed by their own task-specific mechanisms. Evidence for this claim is predominantly based on comparisons of language- and task-switching costs. Bilinguals have been found to show different patterns of symmetry in language- and task-switching costs (e.g., Calabria et al., 2012) and diverging effects of ageing on language- versus task-switching performance (e.g., Weissberger et al., 2012). Furthermore, the studies reported in Chapter 7 showed no training effects of language switching on non-verbal task-switching performance and no correlations between language- and task-switching costs.

Language and non-verbal cognitive control may share similar mechanisms, but are also driven by their own specific mechanisms. In this sense, language and non-verbal control may be more dissimilar than the different types of inhibition tasks used in training tasks. If training does not usually affect similar but untrained tasks, we should not expected miracles from bilingualism on untrained, non-verbal tasks[19].

## 8.5. Issues affecting the literature on bilingualism and executive control

In Chapter 2, I discussed several issues affecting research on bilingualism and executive control, including the need for theoretical frameworks, failed replications, biases, data interpretation, matching language groups on background variables, causality, and task impurity. Several of these issues have been the key focus of the chapters in this thesis and will be discussed in more detail here.

### 8.5.1. Biases and failed replications

(Publication) biases and questionable research practices affect many research fields, including psychology (e.g., Bakker et al., 2012; Francis, 2012). Although some researchers (e.g., Paap, 2014) already raised the concern that these biases may

[19] This paragraph is partly based on de Bruin, A., Bak, T. H., & Della Sala, S. (2015). Examining the effects of active versus inactive bilingualism on executive control in a carefully matched non-immigrant sample. *Journal of Memory and Language*, *85*, 15-26.

affect the literature on bilingualism and executive control too, this is more systematically investigated in the studies reported in Chapter 3. Indeed, I found evidence for a publication bias with studies with positive findings being more likely to be published than studies with null or negative findings. This suggests that the literature overestimates the actual effects of bilingualism.

At the same time, failures to replicate are becoming an increasingly important topic in psychology, boosted amongst others by Nosek et al.'s large-scale replication project (2015). Similarly, in the field of bilingualism and executive control, many studies have failed to replicate previous positive effects of bilingualism (e.g., Duñabeitia et al., 2014; Paap & Greenberg, 2013). My own study in Chapter 6 adds to this increasing list of failures to replicate. As shown in Chapter 2, the number of studies not showing an effect of bilingualism has increased over the years and reached a peak in 2014. This is compatible with Paap et al.'s (2015) estimation that over 80% of studies after 2011 do not show an effect of bilingualism.

The increase in failed replications (especially the 80% estimated by Paap et al., 2015) appears to contradict the finding of a publication bias (cf., Bialystok, in press). However, several aspects need to be taken into account here. Paap et al. presented an overview of all individual tests within a study. In contrast, Chapter 3 was based on overall conclusions. A study can include null effects but still conclude that there is a positive effect of bilingualism. This is indeed the case for several papers in Paap et al.'s overview. For instance, Calvo and Bialystok (2014) is included in their overview with two tests (effects of bilingualism on flanker overall RTs and inhibition cost RTs) both showing no effect of bilingualism. However, the paper concludes that there is a positive effect of bilingualism as shown in their title 'Independent effects of bilingualism and socioeconomic status on language ability and executive functioning' (Calvo & Bialystok, 2014). This conclusion is based on higher *accuracy* for bilinguals on the flanker task, while Paap et al. (2015) only include *RT* measurements. This discrepancy between actual data and conclusions is problematic and emphasises the need to refrain from data over-interpretation.

Apart from these methodological differences, there is a crucial difference between analyses in terms of the timespan included. My study on publication bias only included conference abstracts until 2012 and publications until early 2014 while Paap et al. examined studies after 2011. As Figure 2.2 shows, 2014 showed a rise of published studies with null or negative effects. This may give the hopeful suggestion that recent years of the literature have been less biased. Yet an overview of published studies alone does not provide any information about actual publication rates. An updated analysis of conference abstracts will hopefully clarify in a few years whether publication biases are diminishing.

#### 8.5.2. Between-subject designs: issues with background differences and causality

Usually, effects of bilingualism on executive control are studied through between-group comparisons. As discussed in Chapter 2, this approach has two main disadvantages. Firstly, in many studies bilinguals and monolinguals differ on background variables including socioeconomic status, education, and immigrant status. These background differences could go in two directions. Bilingual immigrants with different genetic, cultural, and educational backgrounds may show an advantage because of these background differences. Immigration may furthermore require increased flexibility and lifestyle changes. Some studies have suggested that immigrants have a cognitive advantage (e.g., Hill et al., 2012; Carlson & Choi, 2009). However, assessments of effects of immigration on executive control tasks are rare. I am therefore currently collaborating with researchers at Murdoch University (Perth, Australia). We are collecting data on three inhibition tasks from older Scottish adults who migrated to Australia. These data will be compared to the Scottish older adults who took part in Experiment 2 described in Chapter 4. In this way, we can examine effects of migration on inhibitory control performance between two groups of participants that are otherwise similar in their country of origin, genetic background, and education.

While mismatched backgrounds may lead to positive effects associated with bilingualism, these confounds can go in the other direction too. Monolinguals too may have taken part in enhancing experiences (e.g., music training, physical exercise, language learning) that could potentially mask effects of bilingualism. Thus, when studying effects of bilingualism, it is important to match language groups as closely as possible. When I matched my participant groups and only tested non-immigrant participants born and raised in the same area of Scotland, I did not replicate positive effects of bilingualism on executive control. Yet even though I attempted to control for background differences as closely as possible, this can never be done perfectly and background differences between language groups may be unmeasured but present.

A second main disadvantage of a between-subject approach concerns the issue of causality: Are people with high cognitive skills more likely to be bilingual or does bilingualism lead to higher cognitive skills? When I tested causal effects of language use/switching on non-verbal task switching, the data did not show any such causal effects. Similarly aiming to examine a causal effect, some recent studies have examined effects of second language learning. The results are mixed. While one study already observed positive effects on the Test of Everyday Attention after one week of language learning (Bak et al., 2016), another study did not observe these effects on switching or inhibition tasks after one year of learning (Duñabeitia, 2016).

One should keep in mind that these causal studies address a different question than between-group comparisons. The latter studies have posed the question whether there are cognitive differences between bilinguals and monolinguals, often by testing bilinguals with a lifelong experience of speaking two languages. In contrast, the study presented in Chapter 7 examined effects of a short time of language switching in a group of bilinguals only. Language learning studies address yet another question: Does *language learning* affect executive control? Early bilinguals have not consciously learned a second language. Processes involved with language learning at a later age may not at all be similar to effects of bilingualism. Furthermore, the time of language learning in experiments does not approach the lifelong experience early bilinguals have. Although within-subject studies addressing causal aspects are very important and interesting on their own, these approaches alone will not answer the hotly debated question whether lifelong bilinguals have a cognitive advantage.

### 8.5.3. Task impurity in executive control measurements

Another issue concerns our understanding of the construct ‘executive control’. Although we often refer to ‘executive control’ as if it is one uniform system, it refers to many different subsystems (cf., MacPherson & Della Sala, 2015; Stuss & Knight, 2013). The unity and diversity of executive functions have been discussed widely. Is there one underlying ability that governs all subsystems (unity), or are these subsystems related but distinct processes (diversity)? Evidence has been found for both (cf., Jurado & Rosselli, 2007, for an overview). Miyake et al. (2000) reconciled the unity and diversity account and suggested there are three subcomponents: updating, inhibition, and shifting (also called ‘task switching’). The three components showed moderate correlations but are clearly separable. Within each component, different subtypes are possible too. For instance, ‘inhibition’ is used as a generic term referring to different types including interference suppression and response inhibition.

Yet even these subtypes are not a unity. Chapter 4 examined the component of interference suppression across three tasks. I did not observe significant correlations between interference costs in the three tasks. Correlations were particularly low between the Simon and flanker tasks, paradigms that are often used to examine effects of bilingualism and that are typically assumed to measure similar inhibition processes (see Paap & Greenberg, 2013, for similar findings). Furthermore, I observed different effects of age on inhibition costs across the three tasks as well as different effects of baseline processing speed. Thus, even tasks that are assumed to measure similar aspects of executive control are greatly affected by task-specific features such as the type of interference and type of stimulus materials (also referred to as task impurity).

Apart from being affected by task-specific features, executive control tasks do not measure *one* subcomponent only (cf., Friedman, in press). For instance, the colour/shape switching paradigm is generally presented as a task measuring the ability to switch (or ‘shift’) between tasks. However, inhibition plays a role here too as participants need to suppress the irrelevant feature to reach the correct response (e.g., the colour of the stimulus needs to be inhibited when the decision has to be based on shape). Reversely, inhibition tasks such as the Simon task require switching between responses as well as between trial types (incongruent vs. congruent trials). In an updated framework, Miyake and Friedman (2012) removed the subcomponent of inhibition as it correlated almost perfectly with the ‘common factor’, suggesting that inhibition may be exerted in all executive control tasks.

Executive control may have an underlying domain-general mechanism but it also consists of different subcomponents. Executive control tasks are often assumed to measure one of these components and those tasks measuring the same component are typically assumed to be similar. Yet, executive control tasks are not a pure reflection of individual subcomponents. Besides measuring more than one subcomponent, even seemingly similar tasks are affected by task-specific features. We are thus facing two opposing problems with executive control tasks. Tasks are both broader and more specific than we want them to be. This also has implications for research on bilingualism, both concerning the formulation of hypotheses and the interpretation of findings. If bilinguals have an inhibition advantage and inhibition is a common factor in all executive control tasks, does this mean an effect of bilingualism should be found on all executive control tasks? When an effect of bilingualism is found on switching costs, does this mean that the bilingual advantage is a switching advantage or could it also be explained in terms of increased inhibition needed to suppress the irrelevant feature you are switching away from? Furthermore, low correlations between flanker and Simon costs as well as the different patterns of age effects suggest that the two costs may reflect different types of interference. If we argue that bilinguals should have an advantage on interference suppression as indicated by inhibition costs, should these effects be found on a flanker task, the Simon task, or both?

This task impurity could partly explain why effects of bilingualism on executive control are inconsistent and may not always be found. At the same time, the inconsistency of effects of bilingualism and other training studies have implications for the construct of executive control. If executive functions are exercised by domain-general mechanisms, one would expect general improved executive control performance after cognitive training. However, if executive control tasks are governed by task-specific mechanisms, cognitive training should only enhance performance on trained tasks without automatic transfer to other tasks. Indeed, the research on bilingualism and ageing suggests that executive control measurements are greatly affected by task-specific features[20].

### 8.6. Where do we stand and where do we go?

At this moment, it is not possible to reach a final conclusion regarding the question whether bilingualism affects non-verbal executive control. Despite a large number of papers reporting positive associations between bilingualism and cognition, there is also a large amount of studies challenging this conclusion. Several chapters in this thesis add to the increasing number of studies not finding a bilingual-monolingual difference on non-verbal tasks. It has been argued that we cannot simply ignore the existing positive studies (e.g., Kroll & Bialystok, 2013) and indeed we should not. When results are mixed, the logical approach would be to determine circumstances that may or may not show bilingual effects. In this thesis, I have discussed several factors that could lead to mixed results, including biases, the degree to which

[20] This paragraph is based on de Bruin, A., Bak, T. H., & Della Sala, S. (2015). Examining the effects of active versus inactive bilingualism on executive control in a carefully matched non-immigrant sample. *Journal of Memory and Language*, *85*, 15-26.

participant groups are matched on background variables, and the type of bilinguals that are tested. At the same time, when studying these factors, no clear results emerge either. While it is of great importance to exclude differences as well as possible, effects of bilingualism have and have not been found both when groups were and were not matched on background variables (e.g., Kirk et al., 2014 found no differences in bilingual immigrants vs. monolingual non-immigrants; Woumans et al., 2015a found differences when both bilinguals and monolinguals were non-immigrants). Similarly, features of bilingualism (language proficiency, age of acquisition, language use) have been studied. Again, differences for various features of bilingualism have emerged but are not consistent. For instance, Luk et al., (2011) found effects only for early but not late bilinguals while Pelham and Abrams (2014) observed similar effects for early and late bilinguals. Concerning language switching and use, Verreyt et al. (2016) found effects of switching on non-verbal tasks, while I did not observe effects of language use or switching. Thus, despite many attempts, there is currently no clear interpretation of circumstances that may or may not elicit cognitive effects of bilingualism.

There is another major factor playing a role: our understanding of tasks used to measure executive control. As discussed in this thesis, executive control tasks are greatly affected by task-specific features. Yet, researchers often assume that various tasks tapping into ‘inhibitory control’ or ‘task switching’ are similar and should thus yield similar effects of bilingualism. It is only very rarely the case that two studies on bilingualism use the exact same task paradigm. Small differences such as the type of stimuli may seem meaningless. Yet, Chapter 4 clearly shows that even minor paradigm changes (e.g., moving versus static stimuli) can change the measurement of inhibition as well as how it is affected by another variable. When using different types of executive control tasks, we should not be surprised that inconsistent effects of bilingualism are found.

This is where a theory-driven approach is needed. Considering the multi-faceted nature of both bilingualism as well as executive control, this theory should not aim for a yes/no answer but should consider that multiple relations are possible between bilingualism and executive control (cf., Valian, 2015 for a similar argument). Which types of executive control should be affected by which features of bilingualism? Very broad answers have been formulated, changing over the years from 'bilingualism should enhance inhibitory control' to 'bilingualism improves mental flexibility'. The constant change in hypotheses as well as the vague wording make it difficult to formulate workable hypotheses about the type of tasks, measurements, and types of bilingualism that should be included (cf., Jared, 2015 and Treccani & Mulatti, 2015 for similar arguments). Different types of bilinguals may affect different subcomponents of executive control. For instance, it has been suggested that late bilinguals have a greater need of language inhibition and may thus show non-verbal inhibition advantages while early bilinguals show advantages related to switching (e.g., Bak et al., 2015). Different types of language use could also lead to different effects. A concrete start in this respect has been made by the Adaptive Control Hypothesis (Green & Abutalebi, 2013). Bilinguals who have to follow stricter patterns of language use and switching may need greater amounts of language control in daily life and thus may show advantages on conflict monitoring and interference suppression. In contrast, bilinguals who can freely switch between languages even within utterances may require less language control and thus not show such an advantage. This type of hypotheses could guide a more focused line of research.

Apart from specifying the links between types of bilingualism and subcomponents of executive control, we should also form predictions about the type of measurements that are affected by bilingualism. Even after task selection, many analyses are possible. For instance, in a Simon task, effects of bilingualism could be assessed on incongruent and congruent trials together or on the Simon cost specifically in terms of accuracy and/or RTs. If bilinguals have enhanced inhibitory control (or more specifically interference suppression), the effect should appear on incongruent trials only. However, this is often not the case, which has led to adapted frameworks arguing that bilingual advantages are more global. While inhibition and global advantages are not mutually exclusive, an *a priori* framework is needed to form concrete hypotheses. Currently, both a global accuracy effect and an RT cost effect are interpreted as consistent with the hypothesis of a bilingual advantage. We should refrain from this constant creation of new post-hoc explanations based on inconsistent findings.

Yet, the plea for a theory-driven approach is a difficult one. Formulating a theory on effects of *bilingualism* on *executive control* implies that we have a good understanding of what both bilingualism and executive control entail. We do not have this knowledge. We do not know exactly how bilinguals control two languages. Even the underlying assumption that bilinguals continuously need to inhibit one language is not unchallenged. For instance, Costa and Santesteban (2004) suggested that highly proficient bilinguals (a group commonly tested in the literature on bilingualism and executive control) do not use language inhibition while switching between the proficient L1 and L2 or even a weaker L3. We also do not know exactly how our brain executes inhibition or task switching. Even more importantly, as described in the previous paragraph, we do not know exactly (or maybe not even roughly) what executive control tasks measure. Without a good understanding of the two individual subdomains, how can we study how one is affected by the other? A similar consideration has led some researchers to conclude that effects of bilingualism cannot be studied until we have a better understanding of both bilingualism and executive control (possibly most explicitly stated in Hartsuiker's title (2015) 'Why it's pointless to ask under which specific circumstances the bilingual advantage occurs').

We currently stand in a chaotic field, but where do we go from here? Firstly, a more open debate is needed in which researchers are willing to collaborate and share data regardless of the outcome. This is crucial for psychology in general to progress but also seems very much needed for the research on the 'bilingual advantage'. Secondly, a better understanding of bilingual language control, executive control, and the components that are involved in various tasks is needed to establish a more theory-driven approach (cf., Jared, 2015).

To investigate the circumstances that may or may not elicit differences between bilinguals and monolinguals, large sample-size studies are needed that assess different types of bilinguals on different types of executive control components. Each component should be assessed in multiple tasks to minimise effects of task impurity. Recently, Von Bastian et al. (2016) made a good attempt at this, albeit without a monolingual group, by comparing different dimensions of bilingualism (AoA, proficiency, and use) on nine cognitive abilities each measured in multiple tasks. These large-scale studies should furthermore be replicated independently across multiple labs. Using large numbers of participants and multiple tasks per executive control component also enables the use of latent variable analyses. This analysis minimises effects of task impurity by estimating the proportion of task variance that actually reflects the executive control component (see Friedman, 2016). However, this approach requires great amounts of participants, time, researchers, and funding and it is likely that even this approach would not reach a consensus. Furthermore, we should ask ourselves how valuable it is to know whether bilinguals may or may not be slightly faster than monolinguals on some tasks.

Moving away from these between-group comparisons might be the more interesting approach. The mechanisms behind language control and cognitive control as well as the differences and similarities between the two need to be studied in more detail within bilinguals. Furthermore, bilinguals differ in many features. Moving away from treating bilinguals as a homogeneous group would allow for a more detailed examination of these features and how they may or may not interact with cognitive control. Indeed, some recent studies have advocated an approach focussing on individual bilingual experiences rather than comparing groups (e.g., Keijzer & Schmid, 2016). As suggested in Chapter 7, manipulating the type of bilingual experience within a bilingual may be another way of investigating links between language and cognition. The question regarding a bilingual advantage may not easily be answered. Still, language and cognitive control within bilinguals deserve to be studied in more detail with greater focus on individual bilingual experiences.

### 8.7. Conclusion

In conclusion, this thesis examined effects of bilingualism and language use on lexical processing and non-verbal executive control. Bilingualism and language use were found to affect lexical processing. More active language use and language switching were associated with poorer verbal performance. The same groups of participants, however, did not show effects of bilingualism, language use, or language switching on non-verbal executive control tasks. These studies suggest that bilingualism and language use may affect lexical processing but not non-verbal control. Together with other failed replications, this questions the reliability of cognitive benefits associated with bilingualism. The inconsistency with which these effects have been observed are likely to be related to (publication) biases, the degree to which participant groups are matched, and task impurity. A better understanding of both language and executive control as well as a more theory-driven approach are needed to understand the link between bilingualism and executive control.

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## Appendix A. Supplementary materials for Chapter 1

Table A1

*Overview of studies published until 2015 examining effects of bilingualism on inhibitory control performance. This overview includes the four main tasks that have been used to examine inhibitory control: Simon, flanker (also as part of the ANT), non-verbal Stroop, and anti-saccade tasks. The table only includes published studies with a monolingual control group and only includes RT analyses. 'Inhibition advantage' refers to the difference in reaction times (RTs) between congruent and incongruent trials. In most studies, overall RTs are analysed too; if this is not the case, 'n/a' is used. 'Yes' indicates an advantage for bilinguals. 'No' indicates no difference between bilinguals and monolinguals or, in some instances, a monolingual advantage (indicated with an asterisk). When tasks, age groups, or bilingual groups were analysed together in the paper, they are reported as one comparison. When they were analysed separately, they are included as separate comparisons. M means monolinguals. Full references are provided in the general reference section. Papers were found through SCOPUS and PubMed searches with key terms 'bilingual' and 'Simon' or 'flanker' or 'ANT' or*

*'Stroop' or 'anti-saccade'; additional relevant papers were included through reference searches. When mentioned in the paper, the bilinguals' age of acquisition (AoA) and proficiency levels are described ('early' refers to AoA under 12 years old unless defined otherwise in the paper).*

| **Study** | **Task** | **Language groups** | | **# Participants** | | **Age group** | **Inhibition advantage for bilinguals?** | **Overall RT advantage for bilinguals?** |
|---|---|---|---|---|---|---|---|---|
| | | Bilingual | Monolingual | Bilingual | Monolingual | | | |
| Bialystok et al. (2004) | Simon | Exp 1: Tamil-English (India)<br>Exp 2: Tamil-English and English-Cantonese (Hong Kong)<br>Exp 3: French-English; early and proficient | English (Canada) | Exp 1: 10 per age group<br>Exp 2: 32 per age group<br>Exp 3: 10 | Exp 1: 10 per age group<br>Exp 2: 32 per age group<br>Exp 3: 10 | Middle-aged (MA)<br>Old (O) | Study 1 MA: Yes<br>Study 1 O: Yes<br>Study 2 MA: Yes<br>Study 2 O: Yes<br>Study 3: Yes (not in all blocks) | Study 1 MA: Yes<br>Study 1 O: Yes<br>Study 2 MA: Yes<br>Study 2 O: Yes<br>Study 3: Yes (not in all blocks) |
| Bialystok et al. (2005b) | Simon[21] | French-English | English | Exp 1: 17<br>Exp 2: 18 | Exp 1: 17<br>Exp 2: 22 | Children<br>Young | Exp 1 (children): | Exp 1 (children): |

[21] This paper also includes data from other age groups that have been reported elsewhere (e.g., Bialystok et al., 2004).

| Study | Task | Language groups | | # Participants | | Age group | Inhibition advantage for bilinguals? | Overall RT advantage for bilinguals? |
|---|---|---|---|---|---|---|---|---|
| | | Bilingual | Monolingual | Bilingual | Monolingual | | | |
| | | | | Exp 3: 56 | Exp 3: 40 | | No<br>Exp 2 (children): No<br>Exp 3 (young adults): No | Yes<br>Exp 2 (children): Yes<br>Exp 3 (young adults): No |
| Bialystok et al. (2005a) | Simon | Chinese-English and French-English; early and proficient | English | 10 Chinese-English, 10 French-English | 10 | Young | No | No[22] |
| Bialystok (2006) | Simon arrow | English and a variety of other languages; early and proficient | English | 57 | 40 | Young | Arrow low switch: No<br>Arrow high switch: No<br>Square low switch: No<br>Square high switch: No | Arrow low switch: No<br>Arrow high switch: Yes<br>Square low switch: No<br>Square high switch: No |
| Bialystok et | Anti- | English and a variety | English | Exp 1: 24 per | Exp 1: 24 per | Young | Study 1 | Study 1 |

[22] One group of bilinguals was faster than the other bilingual group and monolinguals, but this difference was also found in the baseline condition.

| **Study** | **Task** | **Language groups** | | **# Participants** | | **Age group** | **Inhibition advantage for bilinguals?** | **Overall RT advantage for bilinguals?** |
|---|---|---|---|---|---|---|---|---|
| | | Bilingual | Monolingual | Bilingual | Monolingual | | | |
| al. (2006) | saccade with button presses [23] | of other languages; early and proficient | | age group<br>Exp 2: 24 per age group | age group<br>Exp 2: 24 per age group | Old | young: No<br>Study 1 old: No<br>Study 2 young: Yes<br>Study 2 old: Yes | young: No<br>Study 1 old: No<br>Study 2 young: No<br>Study 2 old: Yes |
| Morton & Harper (2007) | Simon | English-French | English | 17 | 17 | Children | No | No |
| Bialystok et al. (2008) | Simon<br>arrow | English and a variety of other languages; various ages of acquisitions, proficient | English | 24 per age group | 24 per age group | Young<br>Old | Simon young: No<br>Simon old: Yes | Simon young: No<br>Simon old: No |
| Carlson & Meltzoff | Simon<br>ANT | Spanish-English bilinguals; early and | English | 12 bilingual, 21 immersion | 17 | Children | Simon: No<br>ANT: No | Simon: N/A<br>ANT: N/A |

[23] This study also included an anti-saccade task with eye movements instead of button presses that did not show an effect of bilingualism. As button presses are the common way to measure inhibition costs, only that study is included.

| Study | Task | Language groups | | # Participants | | Age group | Inhibition advantage for bilinguals? | Overall RT advantage for bilinguals? |
|---|---|---|---|---|---|---|---|---|
| | | Bilingual | Monolingual | Bilingual | Monolingual | | | |
| (2008) | | proficient; English with Spanish or Japanese immersion | | | | | | |
| Costa et al. (2008) | ANT | Spanish-Catalan; early and proficient | Spanish | 100 | 100 | Young | Yes (but only in first 2 blocks) | Yes |
| Emmorey et al. (2008) | Flanker | English-ASL bimodal (early childhood); English and a variety of other languages unimodal (late childhood); proficient | English | 30 | 15 | Middle-aged | No | Yes (unimodal bilinguals only) |
| Linck et al. (2008) | Simon | English learners of Spanish (pre-immersion, immersion, post-immersion, and classroom) | English | 128 | 28 | Young | Yes | N/A |

| **Study** | **Task** | **Language groups** | | **# Participants** | | **Age group** | **Inhibition advantage for bilinguals?** | **Overall RT advantage for bilinguals?** |
|---|---|---|---|---|---|---|---|---|
| | | Bilingual | Monolingual | Bilingual | Monolingual | | | |
| Martin-Rhee & Bialystok (2008) | Simon | Exp 1: French-English; Exp 2: French-English, Chinese-English, Spanish-English; early and proficient | English | Exp 1: 17<br>Exp 2: 21 | Exp 1: 17<br>Exp 2: 20 | Children | Exp 1 Immediate: No<br>Exp 1 Short delay: No<br>Exp 1 Long delay: No<br>Exp 2 Simon Arrow: No | Exp 1 Immediate: Yes<br>Exp 1 Short delay: No<br>Exp 1 Long delay: No<br>Exp 2 Simon Arrow: Yes |
| Bialystok & DePape (2009) | Simon<br>Stroop | English and a variety of other languages; early and proficient | English | 24 | 24 | Young | Simon: No<br>Stroop: No | Simon: Yes<br>Stroop: No |
| Bialystok & Viswanathan (2009) | Anti-saccade | Bilinguals living in Canada and India. English and a variety of other languages; early and proficient | English | 30 in Canada; 30 in India | 30 | Children | Yes | No |
| Costa et al. (2009) | Flanker | Spanish-Catalan; early and proficient | Spanish | Exp 1: 30 per task version<br>Exp 2: 31 per | Exp 1: 30 per task version<br>Exp 2: 31 per | Young | Low demand (8%): No<br>Low demand | Low demand (8%): No<br>Low demand |

| **Study** | **Task** | **Language groups** | | **# Participants** | | **Age group** | **Inhibition advantage for bilinguals?** | **Overall RT advantage for bilinguals?** |
|---|---|---|---|---|---|---|---|---|
| | | Bilingual | Monolingual | Bilingual | Monolingual | | | |
| | | | | task version | task version | | (92%): No High demand (50%): No High demand (75%): Yes (but only in the first block) | (92%): No High demand (50%): Yes High demand (75%): Yes (but only in the first block) |
| Bialystok et al. (2010) | ANT | English and a variety of other languages; early and proficient | English and French | 56 | 69 | Children | No | No |
| Hernández et al. (2010) | Non-verbal Stroop | Catalan-Spanish; early and proficient | Spanish | 41 | 41 | Young | Yes | No |
| Luk et al. (2010) | Flanker | English and a variety of other languages; early and proficient | English | 10 | 10 | Young | No | No |
| Namazi & Thordardottir (2010) | Simon | French-English; early and proficient | French and English | 15 | 30 | Children | No | No |

| Study | Task | Language groups | | # Participants | | Age group | Inhibition advantage for bilinguals? | Overall RT advantage for bilinguals? |
|---|---|---|---|---|---|---|---|---|
| | | Bilingual | Monolingual | Bilingual | Monolingual | | | |
| Billig & Scholl (2011) | Simon arrow | Hunsrückisch-Brazilian Portuguese; early and proficient | Brazilian Portuguese | 20 young, 21 old | 21 young, 21 old | Young Old | Young: No Old: No | Young: No Old: No |
| Luk et al. (2011) | Flanker | English and a variety of other languages; early and late bilinguals | English | 43 early, 42 late | 38 | Young | Early vs. M: Yes Late vs. M: No | No |
| Salvatierra & Rosselli (2011) | Simon | Spanish-English; late childhood and proficient | English | 67 young, 58 old | 66 young, 42 old | Young Old | Simple young: No Simple old: Yes Complex young: No Complex old: No | N/A |
| Tao et al. (2011) | ANT | Chinese-English early and late bilinguals | English | 36 early, 30 late | 34 | Young | Early vs M: Yes Late vs M: Yes | Early vs M: Yes Late vs M: No |

| Study | Task | Language groups | | # Participants | | Age group | Inhibition advantage for bilinguals? | Overall RT advantage for bilinguals? |
|---|---|---|---|---|---|---|---|---|
| | | Bilingual | Monolingual | Bilingual | Monolingual | | | |
| Yang et al. (2011) | ANT | Korean-English; early and proficient | English, Korean living in Korea, Korean living in USA | 15 | 41 | Children | Yes | Yes |
| Yudes et al. (2011) | Simon | Spanish-English; early and proficient[24] | Spanish | 16 | 16 | Young | No | No |
| Abutalebi et al. (2012) | Flanker | German-Italian; early and proficient | Italian | 17 | 14 | Young | Block 1: No<br>Block 2: Yes[25] | Block 1: No<br>Block 2: No |
| De Abreu et al. (2012) | Flanker | Portuguese – Luxembourgish; early and proficient | Portuguese | 40 | 40 | Children | N/A | Yes |
| Kousaie & Phillips (2012b) | Simon<br>Flanker<br>Stroop | English-French; early and proficient | English | 26 | 25 | Young | Simon: No<br>Flanker: No<br>Stroop: No | Simon: No<br>Flanker: No<br>Stroop: No |
| Poarch & | Simon[26] | German language | German | 19 language | 20 | Children | Trilingual vs. | Trilingual vs. |

[24] This study also included a group of interpreters.
[25] This is analysed as a reduced flanker cost in Block 2 for bilinguals but not for monolinguals.

| Study | Task | Language groups | | # Participants | | Age group | Inhibition advantage for bilinguals? | Overall RT advantage for bilinguals? |
|---|---|---|---|---|---|---|---|---|
| | | Bilingual | Monolingual | Bilingual | Monolingual | | | |
| Van Hell (2012) | | learners of English, German-English bilinguals, German-English-X trilinguals. | | learners, 18 bilinguals, 18 trilinguals | | | M: Yes Bilingual vs. M: No Language learners vs. M: No | M: No Bilingual vs. M: No Language learner vs. M: No |
| Schroeder & Marian (2012) | Simon | English and a variety of other languages; late childhood and proficient | English | 18 | 18 | Old | Yes[27] | No |
| Kapa & Colombo (2013) | ANT | Early and late Spanish-English bilinguals | English | 21 early, 36 late | 22 | Children | Early vs. M: No Late vs. M: No | Early vs. M: Yes Late vs. M: No |
| Marzecová et al. (2013a) | ANT | Various language combinations; early | Polish | 18 | 17 | Young | Yes | No |

[26] The paper also includes an ANT experiment, but this experiment did not have a monolingual control group.
[27] The significant interaction between trial type and language group is interpreted as a bilingual advantage, but shows a bilingual slowing on congruent trials. See Chapter 2 for further discussion.

| **Study** | **Task** | **Language groups** | | **# Participants** | | **Age group** | **Inhibition advantage for bilinguals?** | **Overall RT advantage for bilinguals?** |
|---|---|---|---|---|---|---|---|---|
| | | Bilingual | Monolingual | Bilingual | Monolingual | | | |
| | | and proficient | | | | | | |
| Morales et al. (2013) | Simon task | English and a variety of other languages; early and proficient | English | 27 | 29 | Children | No | Yes |
| Paap & Greenberg (2013) | Simon Flanker Anti-saccade | English and a variety of other languages; various levels of AoA and proficiency | English | Simon: 121 Flanker: 49 Anti-saccade: 35 | Simon: 150 Flanker: 55 Anti-saccade: 45 | Young | Simon: No Flanker: No Anti-saccade: No | Simon: No Flanker: No Anti-saccade: No |
| Antón et al. (2014) | ANT | Basque-Spanish; early and proficient | Spanish | 180 | 180 | Children | No | No |
| Calvo & Bialystok (2014) | Flanker | English and a variety of other languages; early and proficient | English | 109 | 66 | Children | No | No[28] |
| Duñabeitia et al. (2014) | Non-verbal Stroop | Basque-Spanish; early and proficient | Spanish | 252 | 252 | Children | No | No |

[28] An effect of language group was found for accuracy, but not RTs.

| Study | Task | Language groups | | # Participants | | Age group | Inhibition advantage for bilinguals? | Overall RT advantage for bilinguals? |
|---|---|---|---|---|---|---|---|---|
| | | Bilingual | Monolingual | Bilingual | Monolingual | | | |
| Gathercole et al. (2014) | Simon | Welsh-English bilinguals with various types of language use | English | 423 | 134 | Young children School-aged children and above | Young children: No Older: No | Young children: No* Older: No |
| Kirk et al. (2014) | Simon | 16 Gaelic-English bilinguals; 16 English speakers with a variety of other languages | English | 32 | 48 | Old | No | No |
| Mohades et al. (2014) | Simon Numeric Stroop | French/Dutch (L1) and Romanic/Germanic (L2); early bilinguals and L2 learners | French/Dutch | 19 early bilinguals; 18 L2 learners | 14 | Children | Simon: No* Stroop: No* | No No |
| Mor et al. (2014) | Simon arrow | Russian-Hebrew; early and proficient[29] | Hebrew | 40 | 40 | Young | No | No |

[29] Half of the bilingual and monolingual groups had ADHD.

| **Study** | **Task** | **Language groups** | | **# Participants** | | **Age group** | **Inhibition advantage for bilinguals?** | **Overall RT advantage for bilinguals?** |
|---|---|---|---|---|---|---|---|---|
| | | Bilingual | Monolingual | Bilingual | Monolingual | | | |
| Paap & Sawi (2014) | Simon<br>Flanker<br>Anti-saccade | English and a variety of other languages; early and proficient | English | 58 | 62 | Young | Simon: No*<br>Flanker: No<br>Anti-saccade: No* | Simon: No*<br>Flanker: No<br>Anti-saccade: No |
| Pelham & Abrams (2014) | ANT | Spanish-English early and English-Spanish late bilinguals | English | 30 early bilinguals, 30 late bilinguals | 30 | Young | Early vs. M: Yes<br>Late vs. M: Yes | Early vs. M: No<br>Late vs. M: No |
| Blumenfeld & Marian (2014) | Stroop<br>Simon | Spanish-English; early and proficient | English | Exp 1: 30<br>Exp 2: 60 | Exp 1: 30<br>Exp 2: 60 | Young | Exp 1 Stroop: No<br>Exp 1 Simon: No<br>Exp 2 Stroop: No<br>Exp 2 Simon: No | Exp 1 Stroop: No<br>Exp 1 Simon: No<br>Exp 2 Stroop: No<br>Exp 2 Simon: No |
| Ansaldo et al. (2015) | Simon | French-English; late and proficient | French | 10 | 10 | Old | No | No |
| Ladas et al. | ANT | Greek-Albanian; early | Greek | Exp 1: 26 | Exp 1: 24 | Children | Exp 1: No | Exp 1: No |

| **Study** | **Task** | **Language groups** | | **# Participants** | | **Age group** | **Inhibition advantage for bilinguals?** | **Overall RT advantage for bilinguals?** |
|---|---|---|---|---|---|---|---|---|
| | | Bilingual | Monolingual | Bilingual | Monolingual | | | |
| (2015) | | and proficient | | Exp 2: 28 | Exp 2: 32 | | Exp 2: No | Exp 2: No |
| Woumans et al. (2015b) | Simon<br>ANT | Dutch-French, unbalanced and balanced bilinguals[30] | French | 65 | 30 | Young | Simon: Yes<br>ANT: No | Simon: No<br>ANT: Yes |

[30] This study also included a group of interpreters.

*APPENDICES*

Table A2

*Overview of studies published until 2015 examining effects of bilingualism on task-switching performance. This overview includes various non-verbal task-switching paradigms such as the colour/shape switching task, Wisconsin Card Sorting Task (WCST), the elevator switching task in the Test of Everyday Attention (TEA), as well as switching measurements taken from other executive control tasks (e.g., anti-saccade task). The table only includes published studies with a monolingual control group. 'Switching advantage' refers to the difference in reaction times (RT) between switch and non-switch trials. In the WCST, it refers to the number of errors. In the TEA, it refers to the number of correct trials. In some studies, mixing costs (the RT difference between non-switch and blocked trials) and/or overall RTs are analysed too. For studies not measuring or including mixing and overall RTs, 'n/a' is used. 'Yes' indicates an advantage for bilinguals. 'No' indicates no difference between bilinguals and monolinguals. References are provided in the general references. Papers were found through SCOPUS and PubMed searches with key terms 'bilingual' and 'switching' or 'shifting'; additional relevant papers were included through reference searches.*

| Study | Task | Language groups | | # Participants | | Age group | Switching advantage for bilinguals? | Mixing advantage for bilinguals? | Overall RT advantage for bilinguals? |
|---|---|---|---|---|---|---|---|---|---|
| | | Bilingual | Monolingual | Bilingual | Monolingual | | | | |
| Bialystok et al. (2006) | Switching in anti-saccade (with button presses) | Various L1s-English; early and proficient | English | 48 | 48 | Young Old[31] | Yes | N/A | N/A |
| Costa et al. (2008) | Switching costs in ANT | Spanish-Catalan; early and proficient | Spanish | 100 | 100 | Young | Yes | N/A | N/A |
| Bialystok & Viswanathan (2009) | Switching costs in anti-saccade task | Bilinguals living in Canada and India. English and a variety of L2s; early and proficient | English | 30 in Canada; 30 in India | 30 | Children | Yes | N/A | N/A |

[31] Young and old participant groups are analysed together. Although it is stated that the switching difference is especially pronounced for older adults, it is unclear if this effect was significant in the younger group too, so the two groups are combined in this overview.

| **Study** | **Task** | **Language groups** | | **# Participants** | | **Age group** | **Switching advantage for bilinguals?** | **Mixing advantage for bilinguals?** | **Overall RT advantage for bilinguals?** |
|---|---|---|---|---|---|---|---|---|---|
| | | Bilingual | Monolingual | Bilingual | Monolingual | | | | |
| Garbin et al. (2010) | Colour/shape switching task | Spanish-Catalan; early and proficient | Spanish | 19 | 21 | Young | Yes | N/A | N/A |
| Prior & MacWhinney (2010) | Colour/shape switching | English and a variety of other languages; early and proficient | English | 47 | 45 | Young | Yes | No | No |
| Prior & Gollan (2011) | Colour/shape switching | Spanish-English (high switching) and Chinese-English (low switching); early and proficient | English | 41 Spanish-English, 43 Chinese-English | 47 | Young | Spanish bilinguals: Yes[32]<br><br>Chinese bilinguals: No | No<br><br>No | No<br><br>No |
| Yudes et al. (2011) | WCST | Spanish-English; early and proficient[33] | Spanish | 16 | 16 | Young | No | N/A | N/A |

[32] An effect on switching costs was only found when groups were 'matched' on Socio-Economic status or when proportional switching costs were analysed.

| Study | Task | Language groups | | # Participants | | Age group | Switching advantage for bilinguals? | Mixing advantage for bilinguals? | Overall RT advantage for bilinguals? |
|---|---|---|---|---|---|---|---|---|---|
| | | Bilingual | Monolingual | Bilingual | Monolingual | | | | |
| Barac & Bialystok (2012) | Colour/shape switching | Chinese-English, French-English, and Spanish-English; early and proficient | English | 30 Chinese-English, 28 French-English, 20 Spanish-English | 26 | Children | No | Yes | Yes |
| Hernández et al. (2013) | Exp 1: implicit and explicit cue switching<br>Exp 2: bivalent switching<br>Exp 3: Colour/shape switching | Spanish-Catalan; early and proficient | Spanish | Exp 1 implicit cue: 50<br>Exp 1 explicit cue: 37<br>Exp 2: 20<br>Exp 3: 38 | Exp 1 implicit cue: 50<br>Exp 1 explicit cue: 37<br>Exp 3: 21<br>Exp 3: 39 | Young | Exp 1 Local cost: No | Exp 1 Restart cost explicit condition: No<br>Exp 1 Restart cost implicit condition: Yes | Exp 1: No |

[33] This study also included a group of interpreters.

| **Study** | **Task** | **Language groups** | | **# Participants** | | **Age group** | **Switching advantage for bilinguals?** | **Mixing advantage for bilinguals?** | **Overall RT advantage for bilinguals?** |
|---|---|---|---|---|---|---|---|---|---|
| | | Bilingual | Monolingual | Bilingual | Monolingual | | | | |
| | | | | | | | Exp 2: No<br>Exp 3: No | Exp 2: N/A<br>Exp 3: No | Exp 2: Yes<br>Exp 3: No |
| Gold et al. (2013b) | Colour/shape switching | English and a variety of other languages; early and proficient | English | Exp 1: 15<br>Exp 2: 20 per age group | Exp 1: 15<br>Exp 2: 20 per age group | Exp 1: Old<br>Exp 2: Young & Old | Exp 1: Yes<br>Exp 2 young: No<br>Exp 2 old: No[34] | N/A<br>N/A | Exp 1: No<br>Exp 2 young: No<br>Exp 2 old: No |
| Marzecová et al. (2013b) | Social category switching task | Hungarian-Polish; early and proficient | Hungarian | 22 | 22 | Young | Yes (only on gender task) | N/A | No |
| Paap & Greenberg (2013) | Colour/shape switching | English and a variety of other languages; various levels of AoA and proficiency | English | 109 | 144 | Young | No | No | N/A |

[34] Even though this effect is interpreted as (marginally) significant, the *p* value is > .05.

| **Study** | **Task** | **Language groups** | | **# Participants** | | **Age group** | **Switching advantage for bilinguals?** | **Mixing advantage for bilinguals?** | **Overall RT advantage for bilinguals?** |
|---|---|---|---|---|---|---|---|---|---|
| | | Bilingual | Monolingual | Bilingual | Monolingual | | | | |
| Prior & Gollan (2013) | Colour/shape switching | Hebrew-English, Spanish-English, and Mandarin-English; early and proficient | English | 104 | 54 | Young | No | No | No |
| Rodríguez-Pujadas et al. (2013) | Colour/shape switching | Catalan-Spanish; early and proficient | Spanish | 18 | 18 | Young | No | N/A | No |
| Bak et al. (2015) | | Early (ECB) and late (LCB) childhood, and early adulthood (EAB) speaking various languages | English | Exp 1: 23 ECB, 18 LCB<br>Exp 2: 19 EAB | Exp 1: 19<br>Exp 2: 19 | Young | ECB vs. ML: Yes<br>LCB vs. ML: No<br>EAB vs ML: No | N/A | N/A |
| Kalia et al. (2014) | Auditorily cued number numeral | Early and late bilinguals speaking English and a variety of | English | 40 early, 23 late | 42 | Young | No | N/A | N/A |

| Study | Task | Language groups | | # Participants | | Age group | Switching advantage for bilinguals? | Mixing advantage for bilinguals? | Overall RT advantage for bilinguals? |
|---|---|---|---|---|---|---|---|---|---|
| | | Bilingual | Monolingual | Bilingual | Monolingual | | | | |
| | task | other languages | | | | | | | |
| Kousaie et al. (2014) | WCST | French-English; early and proficient | French and English | 51 young, 36 old | 70 young, 61 old | Young<br>Old | Young: No<br>Old: No | N/A | N/A |
| Mor et al. (2014) | Colour/shape switching | Russian-Hebrew; early and proficient[35] | Hebrew | 40 | 40 | Young | No | No | No |
| | Trail-making task | | | | | | No | N/A | N/A |
| Paap & Sawi (2014) | Colour/shape switching | English and a variety of other languages; early and proficient | English | 58 | 62 | Young | No | No | N/A |
| Houtzager et al. (2015) | Colour/shape switching | Frysian-Dutch; early and proficient | German | 50 | 50 | Middle-aged<br>Old | Middle-aged: No<br>Old: Yes | Middle-aged: No<br>Old: No | N/A |

[35] Half of the bilingual and monolingual groups had ADHD.

| Study | Task | Language groups | | # Participants | | Age group | Switching advantage for bilinguals? | Mixing advantage for bilinguals? | Overall RT advantage for bilinguals? |
|---|---|---|---|---|---|---|---|---|---|
| | | Bilingual | Monolingual | Bilingual | Monolingual | | | | |
| Moradzadeh et al. (2015) | Quantity/identity task | English and a variety of other languages; various proficiency levels | English | 72 | 81 | Young | No | No | N/A |
| Vega-Mendoza et al. (2015) | TEA | Exp 1: English-Spanish bilinguals; English-Spanish-X multilinguals<br>Exp 2: First and fourth year Spanish/Italian students | Exp 1: English<br>Exp 2: First and fourth year literature students | Exp 1: 16 bilingual, 17 multilingual<br><br>Exp 2: 127 in total (bilingual and monolingual) | Exp 1: 18 | Young | Exp 1: No<br><br>Exp 2: Yes | N/A | N/A |

# Appendix B. Supplementary materials for Chapter 2

*B1. References for Bialystok's papers included in Figure 2.1. Papers were found through Scopus searches for 'Bialystok' combined with 'bilingual'. Only studies or review papers discussing behavioural studies using executive control tasks are included. Studies focusing on effects of bilingualism on dementia, (working) memory, task switching, and lexical tasks have been excluded. References are given in chronical order per framework ('inhibition' or 'general executive control').*

**Inhibition**

Bialystok, E. (1999). Cognitive complexity and attentional control in the bilingual mind. *Child Development*, *70*(3), 636-644.

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

Bialystok, E., & Senman, L. (2004). Executive processes in appearance–reality tasks: The role of inhibition of attention and symbolic representation. *Child Development*, *75*(2), 562-579.

Bialystok, E., & Martin, M. M. (2004). Attention and inhibition in bilingual children: Evidence from the dimensional change card sort task. *Developmental Science*, *7*(3), 325-339.

Bialystok, E., Craik, F. I., Klein, R., & Viswanathan, M. (2004). Bilingualism, aging, and cognitive control: evidence from the Simon task. *Psychology and Aging*, *19*(2), 290-303.

Craik, F., & Bialystok, E. (2005). Intelligence and executive control: Evidence from aging and bilingualism. *Cortex*, *41*(2), 222-224.

Bialystok, E., Martin, M. M., & Viswanathan, M. (2005). Bilingualism across the lifespan: The rise and fall of inhibitory control. *International Journal of Bilingualism*, *9*(1), 103-119.

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

Craik, F. I., & Bialystok, E. (2006). Cognition through the lifespan: mechanisms of change. *Trends in Cognitive Sciences*, *10*(3), 131-138.

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

Martin-Rhee, M. M., & Bialystok, E. (2008). The development of two types of inhibitory control in monolingual and bilingual children. *Bilingualism: Language and Cognition*, *11*(01), 81-93.

Bialystok, E., & Viswanathan, M. (2009). Components of executive control with advantages for bilingual children in two cultures. *Cognition*, *112*(3), 494-500.

Luk, G., Anderson, J. A., Craik, F. I., Grady, C., & Bialystok, E. (2010). Distinct neural correlates for two types of inhibition in bilinguals: Response inhibition versus interference suppression. *Brain and Cognition*, *74*(3), 347-357.

Luk, G., De Sa, E. R. I. C., & Bialystok, E. (2011). Is there a relation between onset age of bilingualism and enhancement of cognitive control?. *Bilingualism: Language and Cognition*, *14*(04), 588-595.

**General executive control**

Bialystok, E., & Shapero, D. (2005). Ambiguous benefits: The effect of bilingualism on reversing ambiguous figures. *Developmental Science*, *8*(6), 595-604.

Bialystok, E., Craik, F. I., & Ruocco, A. C. (2006). Dual-modality monitoring in a classification task: The effects of bilingualism and ageing. *The Quarterly Journal of Experimental Psychology*, *59*(11), 1968-1983.

Craik, F. I., & Bialystok, E. (2006). Planning and task management in older adults: Cooking breakfast. *Memory & Cognition*, *34*(6), 1236-1249.

Bialystok, E. (2007). Cognitive effects of bilingualism: How linguistic experience leads to cognitive change. *International Journal of Bilingual Education and Bilingualism*, *10*(3), 210-223.

Bialystok, E., Craik, F., & Luk, G. (2008). Cognitive control and lexical access in younger and older bilinguals. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *34*(4), 859-873.

Emmorey, K., Luk, G., Pyers, J. E., & Bialystok, E. (2008). The source of enhanced cognitive control in bilinguals evidence from bimodal bilinguals. *Psychological Science*, *19*(12), 1201-1206.

Bialystok, E. (2009). Bilingualism: The good, the bad, and the indifferent. *Bilingualism: Language and Cognition*, *12*(01), 3-11.

Bialystok, E., & DePape, A. M. (2009). Musical expertise, bilingualism, and executive functioning. *Journal of Experimental Psychology: Human Perception and Performance*, *35*(2), 565-574.

Bialystok, E., Craik, F. I., Green, D. W., & Gollan, T. H. (2009). Bilingual minds. *Psychological Science in the Public Interest*, *10*(3), 89-129.

Bialystok, E. (2010). Global–local and trail-making tasks by monolingual and bilingual children: Beyond inhibition. *Developmental Psychology*, *46*(1), 93-105.

Bialystok, E., & Craik, F. I. (2010). Cognitive and linguistic processing in the bilingual mind. *Current Directions in Psychological Science*, *19*(1), 19-23.

Bialystok, E., Barac, R., Blaye, A., & Poulin-Dubois, D. (2010). Word mapping and executive functioning in young monolingual and bilingual children. *Journal of Cognition and Development*, *11*(4), 485-508.

Poulin-Dubois, D., Blaye, A., Coutya, J., & Bialystok, E. (2011). The effects of bilingualism on toddlers' executive functioning. *Journal of Experimental Child Psychology*, *108*(3), 567-579.

Bialystok, E. (2011). Coordination of executive functions in monolingual and bilingual children. *Journal of Experimental Child Psychology*, *110*(3), 461-468.

Bialystok, E. (2011). Reshaping the mind: the benefits of bilingualism. *Canadian Journal of Experimental Psychology/Revue Canadienne de Psychologie Expérimentale*, *65*(4), 229-235.

Bialystok, E., & Barac, R. (2012). Emerging bilingualism: Dissociating advantages for metalinguistic awareness and executive control. *Cognition*, *122*(1), 67-73.

Barac, R., & Bialystok, E. (2012). Bilingual effects on cognitive and linguistic development: Role of language, cultural background, and education. *Child Development*, *83*(2), 413-422.

Bialystok, E., Craik, F. I., & Luk, G. (2012). Bilingualism: consequences for mind and brain. *Trends in Cognitive Sciences*, *16*(4), 240-250.

De Abreu, P. M. E., Cruz-Santos, A., Tourinho, C. J., Martin, R., & Bialystok, E. (2012). Bilingualism enriches the poor enhanced cognitive control in low-income minority children. *Psychological Science*, *23*(11), 1364-1371.

*B2. Overview of papers included in Figure 2.2. Papers were found through Scopus and PubMed searches for 'bilingual' combined with 'executive', 'cognitive', or 'advantage'. Only studies testing effects on executive control tasks have been included. Studies purely assessing clinical populations or neuronal mechanisms (without executive control measurements) as well as review papers have been excluded. Papers have been classified as 'supporting' or 'challenging' a bilingual advantage or as 'mixed' if no clear conclusion was reached. Papers are classified based on conclusions rather than actual results.*

<u>2004</u>

**Supporting**

Bialystok, E., Craik, F. I., Klein, R., & Viswanathan, M. (2004). Bilingualism, aging, and cognitive control: evidence from the Simon task. *Psychology and Aging*, *19*(2), 290-303.

Bialystok, E., & Martin, M. M. (2004). Attention and inhibition in bilingual children: Evidence from the dimensional change card sort task. *Developmental Science*, *7*(3), 325-339.

Bialystok, E., & Senman, L. (2004). Executive processes in appearance–reality tasks: the role of inhibition of attention and symbolic representation. *Child Development*, *75*(2), 562-579.

*APPENDICES*

<u>2005</u>

**Supporting**

Bialystok, E., Craik, F. I., Grady, C., Chau, W., Ishii, R., Gunji, A., & Pantev, C. (2005). Effect of bilingualism on cognitive control in the Simon task: evidence from MEG. *NeuroImage*, *24*(1), 40-49.

Bialystok, E., Martin, M. M., & Viswanathan, M. (2005). Bilingualism across the lifespan: The rise and fall of inhibitory control. *International Journal of Bilingualism*, *9*(1), 103-119.

Bialystok, E., & Shapero, D. (2005). Ambiguous benefits: The effect of bilingualism on reversing ambiguous figures. *Developmental Science*, *8*(6), 595-604.

<u>2006</u>

**Supporting**

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

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

Bialystok, E., Craik, F. I., & Ruocco, A. C. (2006). Dual-modality monitoring in a classification task: The effects of bilingualism and ageing. *The Quarterly Journal of Experimental Psychology*, *59*(11), 1968-1983.

Craik, F. I., & Bialystok, E. (2006). Planning and task management in older adults: Cooking breakfast. *Memory & Cognition*, *34*(6), 1236-1249.

2007

**Challenging**

Fernandes, M. A., Craik, F., Bialystok, E., & Kreuger, S. (2007). Effects of bilingualism, aging, and semantic relatedness on memory under divided attention. *Canadian Journal of Experimental Psychology/Revue Canadienne de Psychologie Expérimentale*, *61*(2), 128.

Morton, J. B., & Harper, S. N. (2007). What did Simon say? Revisiting the bilingual advantage. *Developmental Science*, *10*(6), 719-726.

2008

**Supporting**

Bialystok, E., Craik, F. I., & Luk, G. (2008a). Lexical access in bilinguals: Effects of vocabulary size and executive control. *Journal of Neurolinguistics*, *21*(6), 522-538.

Bialystok, E., Craik, F., & Luk, G. (2008b). Cognitive control and lexical access in younger and older bilinguals. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *34*(4), 859-873.

Carlson, S. M., & Meltzoff, A. N. (2008). Bilingual experience and executive functioning in young children. *Developmental Science*, *11*(2), 282-298.

Costa, A., Hernández, M., & Sebastián-Gallés, N. (2008). Bilingualism aids conflict resolution: Evidence from the ANT task. *Cognition*, *106*(1), 59-86.

Emmorey, K., Luk, G., Pyers, J. E., & Bialystok, E. (2008). The Source of Enhanced Cognitive Control in Bilinguals Evidence From Bimodal Bilinguals. *Psychological Science*, *19*(12), 1201-1206.

Kharkhurin, A. V. (2008). The effect of linguistic proficiency, age of second language acquisition, and length of exposure to a new cultural environment on bilinguals' divergent thinking. *Bilingualism: Language and Cognition*, *11*(02), 225-243.

Linck, J. A., Hoshino, N., & Kroll, J. F. (2008). Cross-language lexical processes and inhibitory control. *The Mental Lexicon*, *3*(3), 349-374.

Martin-Rhee, M. M., & Bialystok, E. (2008). The development of two types of inhibitory control in monolingual and bilingual children. *Bilingualism: Language and Cognition*, *11*(01), 81-93.

**Mixed**

Colzato, L. S., Bajo, M. T., van den Wildenberg, W., Paolieri, D., Nieuwehuis, S., La

Heij, W., & Hommel, B. (2008). How does bilingualism improve executive control? A comparison of active and reactive inhibition mechanisms. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 34*(2), 302-312.

2009

**Supporting**

Bialystok, E., & Feng, X. (2009). Language proficiency and executive control in proactive interference: Evidence from monolingual and bilingual children and adults. *Brain and Language*, *109*(2), 93-100.

Bialystok, E., & DePape, A. M. (2009). Musical expertise, bilingualism, and executive functioning. *Journal of Experimental Psychology: Human Perception and Performance*, *35*(2), 565-574.

Bialystok, E., & Viswanathan, M. (2009). Components of executive control with advantages for bilingual children in two cultures. *Cognition*, *112*(3), 494-500.

Costa, A., Hernández, M., Costa-Faidella, J., & Sebastián-Gallés, N. (2009). On the bilingual advantage in conflict processing: Now you see it, now you don't. *Cognition*, *113*(2), 135-149.

Kovács, Á. M., & Mehler, J. (2009). Cognitive gains in 7-month-old bilingual infants. *Proceedings of the National Academy of Sciences*, *106*(16), 6556-6560.

Treccani, B., Argyri, E., Sorace, A., & Della Sala, S. (2009). Spatial negative priming in bilingualism. *Psychonomic Bulletin & Review*, *16*(2), 320-327.

2010

**Supporting**

Bialystok, E. (2010). Global–local and trail-making tasks by monolingual and bilingual children: Beyond inhibition. *Developmental Psychology*, *46*(1), 93-105.

Bialystok, E., Barac, R., Blaye, A., & Poulin-Dubois, D. (2010). Word mapping and executive functioning in young monolingual and bilingual children. *Journal of Cognition and Development*, *11*(4), 485-508.

Garbin, G., Sanjuan, A., Forn, C., Bustamante, J. C., Rodriguez-Pujadas, A., Belloch, V., Hernandez, M., Costa, A., & Ávila, C. (2010). Bridging language and attention: brain basis of the impact of bilingualism on cognitive control. *NeuroImage*, *53*(4), 1272-1278.

Hernández, M., Costa, A., Fuentes, L. J., Vivas, A. B., & Sebastián-Gallés, N. (2010). The impact of bilingualism on the executive control and orienting networks of attention. *Bilingualism: Language and Cognition*, *13*(03), 315-325.

Luk, G., Anderson, J. A., Craik, F. I., Grady, C., & Bialystok, E. (2010). Distinct neural correlates for two types of inhibition in bilinguals: Response inhibition versus interference suppression. *Brain and Cognition*, *74*(3), 347-357.

Moreno, S. Bialystok, E., Wodniecka, Z., & Alain, C. (2010). Conflict resolution in sentence processing by bilinguals. *Journal of Neurolinguistics, 23*(6), 564-579.

Prior, A., & MacWhinney, B. (2010). A bilingual advantage in task switching. *Bilingualism: Language and Cognition*, *13*(02), 253-262.

Wodniecka, Z., Craik, F. I., Luo, L., & Bialystok, E. (2010). Does bilingualism help memory? Competing effects of verbal ability and executive control. *International Journal of Bilingual Education and Bilingualism*, *13*(5), 575-595.

**Challenging**

Gathercole, V. C., Thomas, E. M., Jones, L., Guasch, N. V., Young, N., & Hughes, E. K. (2010). Cognitive effects of bilingualism: Digging deeper for the contributions of language dominance, linguistic knowledge, socio-economic status and cognitive abilities. *International Journal of Bilingual Education and Bilingualism*, *13*(5), 617-664.

Namazi, M., & Thordardottir, E. (2010). A working memory, not bilingual advantage, in controlled attention. *International Journal of Bilingual Education and Bilingualism*, *13*(5), 597-616.

**Supporting**

Bartolotti, J., Marian, V., Schroeder, S. R., & Shook, A. (2011). Bilingualism and inhibitory control influence statistical learning of novel word forms. *Frontiers in Cognition, 2,* 1-9.

Bialystok, E. (2011). Coordination of executive functions in monolingual and bilingual children. *Journal of Experimental Child Psychology*, *110*(3), 461-468.

Calabria, M., Hernández, M., Martin, C. D., & Costa, A. (2011). When the tail counts: the advantage of bilingualism through the ex-Gaussian distribution analysis. *Frontiers in Psychology*, *2*, 1-8.

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**Challenging**

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2012

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**Challenging**

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Kousaie, S., & Phillips, N. A. (2012b). Ageing and bilingualism: Absence of a "bilingual advantage" in Stroop interference in a nonimmigrant sample. *The Quarterly Journal of Experimental Psychology*, *65*(2), 356-369.

<u>2013</u>

**Supporting**

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**Challenging**

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*APPENDICES*

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Coderre, E. L., & Van Heuven, W. J. (2014). The effect of script similarity on executive control in bilinguals. *Frontiers in Psychology*, *5*. 1-16.

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**Challenging**

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<u>2015</u>

**Supporting**

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Bogulski, C. A., Rakoczy, M., Goodman, M., & Bialystok, E. (2015). Executive control in fluent and lapsed bilinguals. *Bilingualism: Language and Cognition*, *18*(03), 561-567.

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Friesen, D. C., Luo, L., Luk, G., & Bialystok, E. (2015). Proficiency and control in verbal fluency performance across the lifespan for monolinguals and bilinguals. *Language, Cognition and Neuroscience*, *30*(3), 238-250.

Houtzager, N., Lowie, W., Sprenger, S., & De Bot, K. (2015). A bilingual advantage in task switching? Age-related differences between German monolinguals and Dutch-Frisian bilinguals. *Bilingualism: Language and Cognition*, 1-11.

Kazemeini, T., & Fadardi, J. S. (2015). Executive Function: Comparing Bilingual and

Monolingual Iranian University Students. *Journal of Psycholinguistic Research*, 1-12.

Krizman, J., Skoe, E., & Kraus, N. (2015, in press). Bilingual enhancements have no socioeconomic boundaries. *Developmental Science*.

Morales, J., Yudes, C., Gómez-Ariza, C. J., & Bajo, M. T. (2015). Bilingualism modulates dual mechanisms of cognitive control: Evidence from ERPs. *Neuropsychologia*, *66*, 157-169.

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Schroeder, S. R., Marian, V., Shook, A., & Bartolotti, J. (2015, in press). Bilingualism and Musicianship Enhance Cognitive Control. *Neural Plasticity*.

Vega-Mendoza, M., West, H., Sorace, A., & Bak, T. H. (2015) The impact of late, non-balanced bilingualism on cognitive functions. *Cognition*, *137*, 40-46.

Woumans, E., Ceuleers, E., Van der Linden, L., Szmalec, A., & Duyck, W. (2015). Verbal and nonverbal cognitive control in bilinguals and interpreters. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *41*(5), 1579-1586.

**Mixed**

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Heidlmayr, K., Hemforth, B., Moutier, S., & Isel, F. (2015). Neurodynamics of executive control processes in bilinguals: evidence from ERP and source reconstruction analyses. *Frontiers in Psychology*, *6*, 1-17.

Tao, L., Taft, M., & Gollan, T. H. (2015). The bilingual switching advantage: Sometimes related to bilingual proficiency, sometimes not. *Journal of the International Neuropsychological Society*, *21*(07), 531-544.

Weber, R. C., Johnson, A., Riccio, C. A., & Liew, J. (2015). Balanced bilingualism and executive functioning in children. *Bilingualism: Language and Cognition*, *19*(02), 425-431.

Qu, L., Low, J. J. W., Zhang, T., Li, H., & Zelazo, P. D. (2015). Bilingual advantage in executive control when task demands are considered. *Bilingualism: Language and Cognition*, *19*(02), 277-293

Sabourin, L., Vinerte, S., & Mayo, M. D. P. G. (2015). The bilingual advantage in the Stroop task: simultaneous vs. early bilinguals. *Bilingualism*, *18*(2), 350-355.

Struys, E., Mohades, G., Bosch, P., & van den Noort, M. (2015). Cognitive control in bilingual children. *Swiss Journal of Psychology*, *74*(2), 65-73.

Xie, Z., & Dong, Y. (2015). Contributions of bilingualism and public speaking training to cognitive control differences among young adults. *Bilingualism: Language and Cognition*, 1-14.

**Challenging**

De Bruin, A., Bak, T. H., & Della Sala, S. (2015). Examining the effects of active versus inactive bilingualism on executive control in a carefully matched non-immigrant sample. *Journal of Memory and Language*, *85*, 15-26.

Garraffa, M., Beveridge, M., & Sorace, A. (2015). Linguistic and Cognitive Skills in Sardinian–Italian Bilingual Children. *Frontiers in Psychology*, *6*, 1-15.

Ladas, A. I., Carroll, D. J., & Vivas, A. B. (2015). Attentional Processes in Low-Socioeconomic Status Bilingual Children: Are They Modulated by the Amount of Bilingual Experience?. *Child Development*, *86*(2), 557-578.

Moradzadeh, L., Blumenthal, G., & Wiseheart, M. (2015). Musical Training, Bilingualism, and Executive Function: A Closer Look at Task Switching and Dual-Task Performance. *Cognitive Science*, *39*(5), 992-1020.

Ratiu, I., & Azuma, T. (2015). Working memory capacity: is there a bilingual advantage?. *Journal of Cognitive Psychology*, *27*(1), 1-11.

Rodrigues, L. R., & Zimmer, M. C. (2015). Bilingualism and inhibitory control: Possible confounds with the variables "profession" and "level of education". *Calidoscópio*, *13*(1), 104-112.

Scaltritti, M., Peressotti, F., & Miozzo, M. (2015). Bilingual advantage and language switch: What's the linkage?. *Bilingualism: Language and Cognition*, 1-18.

# Appendix C. Supplementary materials for Chapter 3

*C1. Overview of the abstracts included in the analysis of published abstracts presented in Chapter 3. The exclamation mark indicates that the study found a bilingual disadvantage in a task in which a disadvantage is assumed to reflect increased inhibitory control (thus supporting the current bilingual advantage theories). An asterisk after the authors indicates that this study was included in the power analysis to detect the bilingualism effect reported in the meta-analysis. An asterisk after the administered task indicates that this task was included in the task-specific power analysis.*

**Published studies showing a cognitive bilingual advantage**

Barac, R., & Bialystok, E. (2009, April)*. *Does the Relation Between the Two Languages Affect the Linguistic and Cognitive Outcomes of Bilingualism?* Poster presented at the Biennial Meeting of the Society for Research in Child Development, Denver.

***Administered task:*** Task-switching paradigm.

Barac, R., Bialystok, E., Blaye, A., & Poulin-Dubois, D. (2008, July)*. *Word learning and executive functioning in young monolinguals and bilingual children.* Poster presented at the 11th Congress of the International Association for the Study of Child Language, Edinburgh, UK.

**Administered task:** Various executive control tasks.

Filippi, R., Leech, R., Dick, F., Green, D. W., & Thomas, M. S. C. (2011, June)*. *A bilingual advantage in controlling language interference during sentence comprehension.* Poster presented at the eighth International Symposium on Bilingualism, Oslo, Norway.

**Administered task:** Speech-in-speech task.

Garbin, G., Sanjuán, A., Forn, C., Rodriguez, A., Bustamante, J. C., Hernández, M., Costa, A., & Avila, C. (2009, September)*. *Brain correlates of the cognitive advantage in bilinguals: Evidence from task switching.* Poster presented at the 15th Annual Conference on Architectures and Mechanisms for Language Processing, Barcelona, Spain.

**Administered task:** Task-switching paradigm.

Heidlmayr, K., Moutier, S., Hemforth, B., Isel, F. (2012, April)*. *Bilingual advantage and effect of linguistic context on executive functions: Behavioural evidence of inhibitory control in a Stroop test.* Poster presented at the Bilingual & Multilingual Interaction meeting, Bangor, UK.

**Administered task:** Stroop task.

Hernández, M. (2006, September)*. *The effect of bilingualism on the attentional system.* Poster presented at the second Rovereto Workshop on Bilingualism, Rovereto, Italy.

**Administered task:** Attention Network Test.

Hernández, M., Costa, A., & Humphreys, G. W. (2009, September)*. *Bilingualism modulates attentional capture from irrelevant information held in WM.* Poster presented at the 15th annual Conference on Architectures and Mechanisms for Language Processing, Barcelona, Spain.

***Administered task:*** Attention and working memory tasks.

Kharkhurin, A. (2007, June)*. *Are bilinguals truly creative? New findings on bilinguals' creative cognition in the Middle Eastern culture.* Poster presented at the sixth International Symposium on Bilingualism, Hamburg, Germany.

***Administered task:*** Abbreviated Torrance Test for Adults and IQ test.

Kovacs, A. M., & Mehler, J. (2008, September)*. *Attention Switching in Monolingual and Bilingual Infants.* Poster presented at the Workshop on Bilingualism, Ghent, Belgium.

***Administered task:*** Attention switching task.

Krizman, J., Marian, V., Shook, A., & Kraus, N. (2012, April)*. *Bilingual Enhancements in Sound Processing Relate to Executive Function Advantages.* Poster presented at the 19th Annual Meeting of the Cognitive Neuroscience Society, Chicago.

***Administered task:*** Sound processing and attention task.

Luk, G., Anderson, J., Bialystok, E., Craik, F. I. M., & Grady, C. (2009, October)*.

*Distinct neural correlates for cognitive control and motor inhibition in bilinguals.* Poster presented at the 39th Annual Meeting of the Society for Neuroscience, Chicago.

***Administered task:*** Flanker task.

Luk, G., Bialystok, E., Craik, F., & Grady, C. (2011, April)*. *Experience-Induced Changes in Brain Structures and Functions: Influence of Lifelong Bilingualism.* Poster presented at the 18th Annual Meeting of the Cognitive Neuroscience Society, San Francisco.

***Administered task:*** Structural connectivity.

Marian, V., & Shook, A. (2008, July). *Bilingual two-way immersion benefits academic achievement.* Poster presented at the 11th Congress of the International Association for the Study of Child Language, Edinburgh, UK.

***Administered task:*** Math and reading tasks.

Marzecová, A., Asanowicz, D., Krivá, L., & Wodniecka, Z. (2009, September)*. *Tell me what languages you speak, and I will tell you what attention you have: Examining the efficiency of Attentional Networks in bilinguals across different language set.* Poster presented at Neurobilingualism, Bangor, UK.

***Administered task:*** Attention Network Test.

Montoya, R. I., Gollan, T. H., Da Pena, E., Galasko, D., & Salmon, D. P. (2008, February)*. *Does Bilingualism Delay Alzheimer's Disease Onset? Evidence from a Hispanic Cohort.* Poster presented at the 36th Annual Meeting of the International Neuropsychological Society, Waikoloa.

***Administered task:*** Cognitive tests.

Peets, K. F., & Bialystok, E. (2009, April)*. *Dissociations Between Academic Discourse and Language Proficiency Among Bilingual Kindergarteners.* Poster presented at the Biennial Meeting of the Society for Research in Child Development, Denver.

***Administered task:*** Various executive control and metalinguistic awareness tasks.

Pelham, S. D., & Abrams, L. (2011, November)*. *Evaluating Lexical Access and Executive Function in Late Bilinguals, Lifelong Bilinguals, and Monolinguals.* Poster presented at the 52nd Annual Meeting of the Psychonomic Society, Seattle.

***Administered task:*** Flanker task.

Prior, A., & MacWhinney, B. (2008, October)*. *Consequences of bilingualism in young adults: Two task-switching studies.* Poster presented at the International Conference on Models of Interaction in Bilinguals, Bangor, UK.

***Administered task:*** Task-switching paradigm.

Schroeder, S. R., & Marian, V. (2010, November)*. *Age-Related Decline in Episodic*

*Long-Term Memory Is Attenuated by Bilingualism.* Poster presented at the 51st Annual Meeting of the Psychonomic Society, St. Louis.

***Administered task:*** Working memory task.

Schroeder, S. R., Marian, V., Shook, A., Bartolotti, J., & Chabal, S. A. (2011, November)*. *Bilingual Experience and Inhibitory Control Influence Novel Word-Form Learning.* Poster presented at the 52nd Annual Meeting of the Psychonomic Society, Seattle.

***Administered task:*** Interference suppression task.

Shook, A., Marian, V., Krizman, J., & Kraus, N. (2011, November)*. *Bilingual Experience Enhanced Subcortical Encoding of Sound.* Poster presented at the 52nd Annual Meeting of the Psychonomic Society, Seattle.

***Administered task:*** Subcortical encoding of sounds and attention tasks.

! Sorace, A., Treccani, B., Argyri, E., & Della Sala, S. (2007, June)*. Spatial Negative Priming in Bilingualism. Poster presented at the sixth International Symposium on Bilingualism, Hamburg, Germany.

***Administered task:*** Spatial negative priming task.

Tse, C., & Altarriba, J. (2011, November)*. *Searching for a Bilingual Advantage in the Tail of Reaction Time Distribution in the Stroop Switching Task.* Poster presented at the 52nd Annual Meeting of the Psychonomic Society, Seattle.

***Administered task:*** Stroop task.

Vega, C., Fernandez, M., & Naidoo, R. (2008, February)*. *Cognitive Flexibility in*

*Spanish/English Bilingual Children.* Poster presented at the 36th Annual Meeting of the International Neuropsychological Society, Waikoloa.

***Administered task:*** Wisconsin Card Sorting Task.

Viswanathan, M., & Bialystok, E. (2007, April)*. *Switching between two types of responses: The effects of bilingualism in children performing a behavioural anti-saccade task.* Poster presented at the Biennial Meeting of the Society for Research in Child Development, Boston.

***Administered task:*** Anti-saccade task.

Wodniecka, Z., Bialystok, E., & Craik, F. (2007, June)*. *Does bilingualism help memory?* Poster presented at the sixth International Symposium on Bilingualism, Hamburg, Germany.

***Administered task:*** Working memory task.

Yang, S., Leal, N., Yang, H., & Lust, B. (2007, May)*. *Dissociating Culture from Bilingualism: The Role of Culture in Beneficial Effects of Bilingualism on Executive Attention.* Poster presented at the 19th Annual Convention of the Association for Psychological Science, Washington.

***Administered task:*** Attention Network Test.

**Unpublished studies showing a cognitive bilingual advantage**

Bak, T. H., Everington, S., Garvin, S. J., & Sorace, A. (2008, September)*. *Differences in Performance on Auditory Attention Tasks between Bilinguals and*

*Monolinguals.* Poster presented at the Workshop on Bilingualism, Ghent, Belgium.

***Administered task:*** Test of Everyday Attention.

Barac, R., Moreno, S., & Bialystok, E. (2010, April)*. *Inhibition of Responses in Young Monolingual and Bilingual Children: Evidence from ERP.* Poster presented at the 17th Annual Meeting of the Cognitive Neuroscience Society, Montréal, Canada.

***Administered task:*** Go/No-go task.

Boros, M. Marzecova, A., & Wodniecka, Z. (2011, June). *Investigating the bilingual advantage on executive control with the verbal and numerical Stroop task: Interference or facilitation account?* Poster presented at the eighth International Symposium on Bilingualism, Oslo.

***Administered task:*** Two different Stroop tasks.

Chin, S., & Sims, V. K. (2006, May). *Working Memory Span in Bilinguals and Second Language Learners.* Poster presented at the 18th Annual Convention of the Association for Psychological Science, New York.

***Administered task:*** Working memory task.

Díaz, U., Facal, D., González, M., Buiza, C., Morales, B., Sobrino, C., Urdaneta, E., & Yanguas, J. (2011, February)*. *The Use of Bilingualism and Occupational Complexity Measures as Proxies for Cognitive Reserve: results from a Community-Dwelling Elderly Population in the North of Spain.* Poster presented at the 39th Annual Meeting of the International Neuropsychological Society, Boston.

***Administered task:*** Working memory task.

Duncan, H., McHenry, C., Segalowitz, N., & Phillips, N. A. (2011, June)*. *Bilingualism, aging, and language-specific attention control.* Poster presented at the eighth International Symposium on Bilingualism, Oslo, Norway.

***Administered task:*** Task-switching paradigm.

Friesen, D. C., Hawrylewicz, K., & Bialystok, E. (2012, November). *Investigating the Bilingual Advantage in a Verbal Conflict Task.* Poster presented at the 53rd Annual Meeting of the Psychonomic Society, Minneapolis.

***Administered task:*** Verbal Simon task.

Grote, K. S., & Chouinard, M. M. (2010, May)*. *The Potential Benefits of Speaking More Than One Language on Non-Linguistic Cognitive Development.* Poster presented at the 22nd Annual Convention of the Association for Psychological Science, Boston.

***Administered task:*** Visual spatial memory task.

Luo, L., Seton, B., Bialystok, E., & Craik, F. I. M. (2008, November)*. *The Role of Bilingualism in Retrieval Control: Specificity and Selectivity.* Poster presented at the 49th Annual Meeting of the Psychonomic Society, Chicago.

***Administered task:*** Working memory task.

Luo, L., Sullivan, M., Latman, V., & Bialystok, E. (2011, November). *Verbal*

*Recognition Memory in Bilinguals: The Word Frequency Effect.* Poster presented at the 52nd Annual Meeting of the Psychonomic Society, Seattle.

***Administered task:*** Working memory task.

Sullivan, M., Moreno, S., & Bialystok, E. (2010, November)*. *Effects of Early-Stage L2 Learning on Nonverbal Executive Control.* Poster presented at the 51st Annual Meeting of the Psychonomic Society, St. Louis.

***Administered task:*** Go/No-go task.

Viswanathan, M., & Bialystok, E. (2007, November). *Effects of Bilingualism and Aging in Multitasking.* Poster presented at the 48th Annual Meeting of the Psychonomic Society, Long Beach.

***Administered task:*** Multitasking conditions.

Viswanathan, M. & Bialystok, E. (2007, June)*. *Exploring the Bilingual Advantage in Executive Control: The Role of Expectancies.* Poster presented at the sixth International Symposium on Bilingualism, Hamburg, Germany.

***Administered task:*** Task-switching paradigm.

**<u>Published studies with results that partially support the cognitive bilingual advantage</u>**

Blumenfeld, H., & Marian, V. (2011, July)*. *Bilingualism influences perceptual inhibition more than stimulus response inhibition.* Poster presented at the 33rd Annual Meeting of the Cognitive Science Society, Boston, MA, USA.

***Administered task:*** Stroop and Simon* tasks.

Carlson, S. M., & Meltzoff, A. N. (2007, April)*. *Executive Function and Bilingual Experience in Young Children.* Poster presented at the Biennial Meeting of the Society for Research in Child Development, Boston.

***Administered task:*** Various conflict and impulse-delay tasks.

DePape, A., Bialystok, E., Fujioka, T., & Craik, F. I. M. (2007, November)*. *Does Musical Expertise Enhance Executive Functioning?* Poster presented at the 48th Annual Meeting of the Psychonomic Society, Long Beach.

***Administered task:*** Simon* and Stroop tasks.

Hernández, M., Costa, A., & Sebastián-Gallés, N. (2008, October)*. *The bilingual advantage in attentional control: Monitor and Conflict resolution processes.* Poster presented at the International Conference on Models of Interaction in Bilinguals, Bangor, UK.

***Administered task:*** Flanker task.

Luk, G., & Bialystok, E. (2007, June)*. *Examining the Bilingual (dis)advantage on the Verbal Fluency Task.* Poster presented at the sixth International Symposium on Bilingualism, Hamburg, Germany.

***Administered task:*** Verbal fluency tasks.

Luk, G., Pyers, J., Emmorey, K., & Bialystok, E. (2007, November)*. *The Source of*

*Enhanced Cognitive Control in Bilinguals: Evidence from Bimodal-Bilinguals.* Poster presented at the 48th Annual Meeting of the Psychonomic Society, Long Beach.

***Administered task:*** Flanker task.

! Prior, A. (2011, November)*. *Too Much of a Good Thing: When Stronger Bilingual Inhibition Leads to Poorer Performance.* Poster presented at the 52nd Annual Meeting of the Psychonomic Society, Seattle.

***Administered task:*** N-2 back task.

**Unpublished studies with results that partially support the cognitive bilingual advantage.**

Astheimer, L. B., Berkes, M., Rakoczy, M., & Bialystok, E. (2012, November). *Allocation of Attentional Resources to Speech in Monolingual and Bilingual Listeners.* Poster presented at the 53rd Annual Meeting of the Psychonomic Society, Minneapolis.

***Administered task:*** Attention during speech processing.

García, M. C., Fernandez, M., & Lim, N. (2009, February)*. *The Effects of Bilingualism on Working Memory in an Attention-Deficit/Hyperactivity Disorder Population.* Poster presented at the 37th Annual Meeting of the International Neuropsychological Society, Atlanta.

***Administered task:*** Working memory tasks.

Moreno, S., Bialystok, E., Wodniecka, Z., & Alain, C. (2009, March)*. *Resolution of Conflict by Bilinguals and Musicians: Evidence from ERP.* Poster presented at the 16th Annual Meeting of the Cognitive Neuroscience Society, San Francisco.

***Administered task:*** Go/No-go task.

Romano, J. C., Garlipp, R. J., Mays, L. E., Howard, D. V., & Howard, J. H. (2007, May). *Spanish-English Bilingualism Influences Control of Attention but not Implicit Sequence Learning.* Poster presented at the 19th Annual Convention of the Association for Psychological Science, Washington.

***Administered task:*** Attention and implicit sequence learning tasks.

Teubner-Rhodes, S. E., Mishler, A., Corbett, R, Sanz-Torrent, M., Trueswell, J. C., & *Cognitive Control, and Syntactic Ambiguity Resolution.* Poster presented at the 52nd Annual Meeting of the Psychonomic Society, Seattle.

***Administered task:*** N-back tasks.

Verreyt, N., Vandelanotte, D., & Duyck, W. (2011, September)*. *Bilingualism and executive control: The role of switching.* Poster presented at the Workshop on Bilingualism, Aix-en-Provence, France.

***Administered task:*** Flanker and Simon arrow tasks.

Yang, H., Yang, S., Ceci, S. J., & Wang, Q. (2003, May)*. *Effects of Bilinguals' Controlled-Attention on Working Memory and Recognition.* Poster presented at the fourth International Symposium on Bilingualism, Arizona.

***Administered task:*** Operation span task and Stroop tasks.

**<u>Published studies with results that partially challenge the cognitive bilingual advantage</u>**

Coderre, E., Van Heuven, W., & Conklin, K. (2010, September)*. *Lexical Access and Executive Control in Monolinguals and Bilinguals.* Poster presented at the 16th Annual Conference on Architectures and Mechanisms for Language Processing, York, UK.

***Administered task:*** Stroop task.

Colzato, L. S. (2006, September)*. *Are bilinguals better inhibitors or do they have a shorter temporal window? Evidence from the Inhibition of Return (IOR) and the stop-signal paradigm.* Poster presented at the second Rovereto Workshop on Bilingualism, Rovereto, Italy.

***Administered task:*** Spatial cueing and stop-signal tasks.

Costa, A., Hernández, M., Martin, C., & Barceló, F. (2009, November)*. *Bilingual Advantage in Nonlinguistic Task Switching.* Poster presented at the 50th Annual Meeting of the Psychonomic Society, Boston.

***Administered task:*** Task-switching paradigm*.

Gathercole, V., Thomas, E., Young, N., Jones, L., Cunnington, L., & Viñas Gausch, N.

(2008, October)*. *Language balance in bilinguals and executive function tasks.* Poster presented at the International Conference on Models of Interaction in Bilinguals, Bangor, UK.

***Administered task:*** Tapping and Stroop tasks.

Giombini, L. (2007, September)*. *Anticipation, inhibition and working memory in bilinguals.* Poster presented at the third Rovereto Workshop on Bilingualism, Rovereto, Italy.

***Administered task:*** Anticipation, working memory, and Go/No-go tasks.

Gollan, T. H., & Prior, A. (2009, November)*. *The Implications of Bilingual Advantages and Disadvantages: Separate Mechanisms.* Poster presented at the 50th Annual Meeting of the Psychonomic Society, Boston.

***Administered task:*** Task switching and flanker tasks.

Kousaie, S., & Phillips, N. (2011, September)*. *ERP measures of conflict monitoring and resolution in bilinguals and monolinguals.* Poster presented at the 51st Annual Meeting of the Society for Psychophysiological Research, Boston, MA, USA.

***Administered task:*** Stroop, Simon*, and flanker* tasks.

Linck, J. A., Bobb, S. C., Hoshino, N., Cheng, K., & Kroll, J. F. (2006, November)*. *Bilingualism and Inhibitory Control: A Cross-Linguistic Comparison.* Poster presented at the 47th Annual Meeting of the Psychonomic Society, Houston.

***Administered task:*** Simon task.

Marzecová, A., Bukowski, M., Lupiáñez, J., Boros, M., & Wodniecka, Z. (2011, October)*. *Tracing bilingual advantage in cognitive control: Conflict processing and categorization switching.* Poster presented at the 17th Meeting of the European Society for Cognitive Psychology, Donostia-San Sebastián, Spain.

***Administered task:*** Simon*, two Stroop, and task-switching tasks.

Morales, J., Bajo, M. T., & Gómez-Ariza, C. J. (2011, October)*. *Effects of bilingualism in inhibitory control and context processing.* Poster presented at the 17th Meeting of the European Society for Cognitive Psychology, Donostia-San Sebastián, Spain.

***Administered task:*** Inhibitory control and goal maintaining tasks.

Moreno, S., Bialystok, E., Wodniecka, Z., & Alain, C. (2008, November)*. *Resolution of Conflict in Sentence Processing by Bilinguals: Evidence from ERP.* Poster presented at the 49th Annual Meeting of the Psychonomic Society, Chicago.

***Administered task:*** Sentence judgment task.

Viswanathan, M., Martin, M. M., & Bialstyok, E. (2002, November)*. *Two Languages Are Better Than One: Bilingualism and Aging Effects on Inhibitory Control.* Poster presented at the 43rd Annual Meeting of the Psychonomic Society, Kansas City.

***Administered task:*** Simon task.

Yudes Gomez, C., Bajo Molina, T., & Macizo Socia, P. (2011, October)*. *Influence of*

*long-term language training in simultaneous interpreters on non-verbal executive processes.* Paper presented at the tenth International Symposium of Psycholinguistics, Donostia-San Sebastián, Spain.

***Administered task:*** Wisconsin Card Sorting Task, Simon* task.

**Unpublished studies with results that partially challenge the cognitive bilingual advantage**

Adrover-Roig, D., Massicote, P. L., Caza, N., & Ansaldo, A. I. (2011, September)*. *Behavioural and neural correlates of interference control in elderly monolinguals and bilinguals.* Poster presented at the 11th International Conference on Cognitive Neuroscience, Palma, Mallorca, Spain.

***Administered task:*** Simon* task.

Badzakova-Trajkov, G., Waldie, K. E., Kirk, I. J., & Milivojevic, B. (2008, April)*. *The Effect of Bilingualism on Cognitive Control in the Stroop Colour-word task in Late Proficient Bilinguals: ERP Study.* Poster presented at the 15th Annual Meeting of the Cognitive Neuroscience Society, San Francisco.

***Administered task:*** Stroop task.

Baus, C., Costa, A., & Carreiras, M. (2011, September). *On the effects of a brief L2 immersion on executive control.* Poster presented at the Workshop on Bilingualism, Aix-en-Provence, France.

***Administered task:*** Attention Network Test and numerical Stroop task.

Bialystok, E., & Feng, X. (2007, June)*. *Bilingualism and Executive Functions: What a Stroop Task Paradigm Can Tell.* Poster presented at the sixth International Symposium on Bilingualism, Hamburg, Germany.

***Administered task:*** Stroop task.

Bialystok, E., & Viswanathan, M. (2004, November). *Effects of Bilingualism and Aging on Task Switching.* Poster presented at the 45th Annual Meeting of the Psychonomic Society, Minneapolis.

***Administered task:*** Task-switching paradigm.

Bovee, J. C., Morgan-Short, K., Brill, K. A., & Raney, G. E. (2011, November). *Age of Second Language Acquisition Predicts Enhanced Executive Control in Bilingual Adolescents.* Poster presented at the 52nd Annual Meeting of the Psychonomic Society, Seattle.

***Administered task:*** Simon task and operation span task.

Brennan-Wilson, A., Wylie, J., & Mulhern, G. (2012, April)*. *Cognitive profiles of low and typically achieving monolingual and bilingual children.* Paper presented at the Bilingual & Multilingual Interaction meeting, Bangor, UK.

***Administered task:*** Trail making test, opposite worlds test, and Stroop tasks.

Carlson, S. M., & Park Choi, H. (2009, April). *Bilingual and Bicultural: Executive Function in Korean and American Children.* Poster presented at the Biennial Meeting of the Society for Research in Child Development, Denver.

***Administered task:*** Various executive control tasks.

Froitzheim, S., Braun, B., & Kabak, B. (2011, October)*. *Which bilinguals are faster in conflict processing? The role of linguistic (dis)similarity.* Poster presented at the tenth International Symposium of Psycholinguistics, Donostia-San Sebastián, Spain.

***Administered task:*** Flanker* task.

Inurritegui, S. & D'Ydewalle, G. (2007, September). *Is There a Bilingual Advantage in Cognitive Control? Evidence from Metalinguistic Awareness and Executive Functioning Tasks.* Poster presented at the 15th Meeting of the European Society for Cognitive Psychology, Marseille, France.

***Administered task:*** Inhibition, switching, and updating tasks.

Kousaie, S., Laliberté, C., Kumar, J., López Zunini, R., & Taler, V. (2012, April)*. *The effect of Bilingualism on Lexical Ambiguity Resolution in Young Adults: Evidence from Behavior and Event-Related Potentials.* Poster presented at the 19th Annual Meeting of the Cognitive Neuroscience Society, Chicago.

***Administered task:*** Lexical ambiguity processing task.

KousaIe, S., & Phillips, N. A. (2012, February)*. *Bilingualism and Cognitive Control in Healthy Older Adults.* Poster presented at the 40th Annual Meeting of the International Neuropsychological Society, Montréal, Canada.

***Administered task:*** Stroop, Simon*, and flanker* tasks.

Lalwani, L. N., & Rosselli, M. (2012, May). *Bilingual Proficiency and Task Type on*

*Executive Function and Working Memory Performance.* Poster presented at the 24th Annual Convention of the Association for Psychological Science, Chicago.

***Administered task:*** Working memory, updating, shifting, and inhibition tasks.

Luo, L., Moreno, S., & Bialystok, E. (2010, November)*. *Bilingualism and Interference Control in Working Memory: The Role of English Proficiency.* Poster presented at the 51st Annual Meeting of the Psychonomic Society, St. Louis.

***Administered task:*** Interference in working memory tasks.

Meuter, R. F. I., & Simmond, M. (2007, June). *The aging bilingual and executive function: Beyond the Simon effect.* Poster presented at the sixth International Symposium on Bilingualism, Hamburg, Germany.

***Administered task:*** Sustained Attention to Response Task, task-switching, and Simon tasks.

Ratiu, I., & Azuma, T. (2012, November)*. *Working Memory Capacity: Is There a Bilingual Advantage?* Poster presented at the 53rd Annual Meeting of the Psychonomic Society, Minneapolis.

***Administered task:*** Working memory tasks.

Rhys, M., Thomas, E. M., Ware, J., & Lye, C. B. (2012, June)*. *Exploring bilingual and*

*L2 speakers' performance on Executive Functioning tasks: issues from Wales.* Poster presented at the 11th Nordic Conference on Bilingualism, Copenhagen, Denmark.

***Administered task:*** Attention Network Test, Simon, and Stroop tasks.

Stephens, C., Wylie, J., & Mulhern, G. (2011, June). *The Effect of Bilingualism on Children's Executive Functioning: A Longitudinal Study.* Poster presented at the eighth International Symposium on Bilingualism, Oslo, Norway.

***Administered task:*** Various executive control tasks.

Wingo, J. M., Luboyeski, E. J., Tuminello, E. R., & Han, D. (2009, February)*. *Effects of Bilingualism on Executive Functions.* Poster presented at the 37th Annual Meeting of the International Neuropsychological Society, Atlanta.

***Administered task:*** Delis-Kaplan Executive Functions System test.

Yang, S., & Lust, B. (2004, November)*. *Effects of Bilingualism on the Attentional Network Test: Its Significance and Implications.* Poster presented at the 29th Boston University Conference on Language Development, Boston, MA, USA.

***Administered task:*** Dimensional change card sort test and Attention Network Test*.

**Published studies that do not show a cognitive bilingual advantage**

Fernandes, M. A., Bialystok, E., & Craik, F. I. M. (2004, November)*. *Memory Under*

*Divided Attention: Effects of Semantic Relatedness, Bilingualism, and Aging.* Poster presented at the 45th Annual Meeting of the Psychonomic Society, Minneapolis.

***Administered task:*** Word recall under divided attention.

Namazi, M., & Thordardottir, E. (2008, October)*. *Controlled attention, working memory & language in bilingual pre-schoolers.* Poster presented at the International Conference on Models of Interaction in Bilinguals, Bangor, UK.

***Administered task:*** Simon* and working memory tasks.

Paap, K. R., Greenberg, Z., Guerrero, D., & Mejia, B. (2010, November)*. *I Left My Bilingual Advantage in San Francisco.* Poster presented at the 51st Annual Meeting of the Psychonomic Society, St. Louis.

***Administered task:*** Anti-saccade, task-switching*, and Simon* tasks.

Paap, K. R., Greenberg, Z. I., & Liu, Y. (2012, November)*. *Bilinguals Show No Enhanced Executive Control for Linguistic Processing Involving Conflict.* Poster presented at the 53rd Annual Meeting of the Psychonomic Society, Minneapolis.

***Administered task:*** Homograph interference task.

Paap, K., Imai, J., Urtecho, C., Alcaine, E., & Keenan, J. (2011, November)*. *There Is No Bilingual Advantage in Executive Processing for Young Adults.* Poster presented at the 52nd Annual Meeting of the Psychonomic Society, Seattle.

***Administered task:*** Anti-saccade, task-switching*, Simon*, and flanker* tasks.

**Unpublished studies that do not show a cognitive bilingual advantage**

Guagnano, D., Rusconi, E., Job, R., & Cubelli, R. (2009, September). *Bilingualism and the acquisition of number skills.* Poster presented at Neurobilingualism, Bangor, UK.

***Administered task:*** Numerical Stroop task.

Humphrey, A. D., & Valian, V. V. (2012, November)*. *Multilingualism and Cognitive Control: Simon and Flanker Task Performance in Monolingual and Multilingual Young Adults.* Poster presented at the 53rd Annual Meeting of the Psychonomic Society, Minneapolis.

***Administered task:*** Simon* and flanker* tasks.

Inurritegui, S., & D'Ydewalle, G. (2008, September). *Bilingual Advantage Inhibited? Factors Affecting the Relation between Bilingualism and Executive Control.* Poster presented at the Workshop on Bilingualism, Ghent, Belgium.

***Administered task:*** Go/No-go, flanker, and task-switching tasks.

Kennedy, I. (2012, April). *Immersion education in Ireland: Linguistic and cognitive skills.* Paper presented at the Bilingual & Multilingual Interaction meeting, Bangor, UK.

***Administered task:*** Inhibition, attention, and task-switching tasks.

Mallery, S. T. (2005, May). *Bilingualism and the Simon Task: Congruency Switching*

*Influences Response Latency Differentially.* Poster presented at the 17th Annual Convention of the Association for Psychological Science, Los Angeles.

***Administered task:*** Simon task.

Mallery, S. T., Llamas, V. C., & Alvarez, A. R. (2006, February)*. *Performance Advantage on the Tower of London-DX for Monolingual vs. Bilingual Young Adults.* Poster presented at the 34th Annual Meeting of the International Neuropsychological Society, Boston.

***Administered task:*** Tower of London test.

Perriard, B., & Camos, V. (2011, October)*. *Working memory capacity in French-German bilinguals.* Poster presented at the 17th Meeting of the European Society for Cognitive Psychology, Donostia-San Sebastián, Spain.

***Administered task:*** Simon and working memory tasks.

Ryskin, R. A., & Brown-Schmidt, S. (2012, November)*. *A Bilingual Disadvantage in Linguistic Perspective Adjustment.* Poster presented at the 53rd Annual Meeting of the Psychonomic Society, Minneapolis.

***Administered task:*** Working memory, Stroop, perceptual speed, Attention Network Test*, anti-saccade, perspective taking, and false belief tasks.

Sampath, K. K. (2003, May)*. *Effects of Bilingualism on Intelligence.* Poster presented at the fourth International Symposium on Bilingualism, Arizona.

***Administered task:*** Verbal and non-verbal intelligence tests.

Tare, M., & Linck, J. A. (2011, November). *Bilingual Cognitive Advantages Reduced*

*when Controlling for Background Variables.* Poster presented at the 52nd Annual Meeting of the Psychonomic Society, Seattle.

***Administered task:*** Working memory, task-switching, and inhibition tasks.

Vongsackda, M., & Ivie, J. L. (2010, May). *Working Memory Differences Between Monolinguals and Bilinguals.* Poster presented at the 22nd Annual Convention of the Association for Psychological Science, Boston.

***Administered task:*** Working memory task.

Weber, R. C., Johnson, A., & Wiley, C. (2012, February). *Hot and Cool Executive Functioning Advantages in Bilingual Children.* Poster presented at the 40th Annual Meeting of the International Neuropsychological Society, Montréal, Canada.

***Administered task:*** Various executive control tasks.

*C2. Reference list of the published papers of Chapter 3. The asterisk indicates that the papers was included in the meta-analysis.*

*Barac, R., & Bialystok, E. (2012). Bilingual effects on cognitive and linguistic development: Role of language, cultural background, and education. *Child Development*, *83*(2), 413-422.

*Bartolotti, J., Marian, V., Schroeder, S. R., & Shook, A. (2011). Bilingualism and inhibitory control influence statistical learning of novel word forms. *Frontiers in Cognition, 2,* 1-9.

*Bialystok, E., Barac, R., Blaye, A., & Poulin-Dubois, D. (2010). Word mapping and executive functioning in young monolingual and bilingual children. *Journal of Cognition and Development*, *11*(4), 485-508.

*Bialystok, E., Craik, F. I., Klein, R., & Viswanathan, M. (2004). Bilingualism, aging, and cognitive control: evidence from the Simon task. *Psychology and Aging*, *19*(2), 290.

*Bialystok, E., Craik, F. I., & Luk, G. (2008). Lexical access in bilinguals: Effects of vocabulary size and executive control. *Journal of Neurolinguistics*, *21*(6), 522-538.

Bialystok, E., & DePape, A. M. (2009). Musical expertise, bilingualism, and executive functioning. *Journal of Experimental Psychology: Human Perception and Performance*, *35*(2), 565.

*APPENDICES*

*Bialystok, E., Peets, K., & Moreno, S. (2012). Producing bilinguals through immersion education: Development of metalinguistic awareness. *Applied Psycholinguistics*, *1*(1), 1-15.

*Bialystok, E., & Viswanathan, M. (2009). Components of executive control with advantages for bilingual children in two cultures. *Cognition*, *112*(3), 494-500.

* Blumenfeld, H. K., & Marian, V. (2014). Cognitive control in bilinguals: Advantages In Stimulus–Stimulus inhibition. *Bilingualism: Language and Cognition*, *17*(03), 610-629.

*Bonifacci, P., Giombini, L., Bellocchi, S., & Contento, S. (2011). Speed of processing, anticipation, inhibition and working memory in bilinguals. *Developmental Science*, *14*(2), 256-269.

*Carlson, S. M., & Meltzoff, A. N. (2008). Bilingual experience and executive functioning in young children. *Developmental Science*, *11*(2), 282-298.

*Coderre, E. L., Van Heuven, W. J., & Conklin, K. (2013). The timing and magnitude of Stroop interference and facilitation in monolinguals and bilinguals. *Bilingualism: Language and Cognition*, *16*(02), 420-441.

*Colzato, L. S., Bajo, M. T., van den Wildenberg, W., Paolieri, D., Nieuwehuis, S., La Heij, W., & Hommel, B. (2008). How does bilingualism improve executive control? A comparison of active and reactive inhibition mechanisms. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 34*(2), 302-312.

*Costa, A., Hernández, M., Costa-Faidella, J., & Sebastián-Gallés, N. (2009). On the bilingual advantage in conflict processing: Now you see it, now you don't. *Cognition*, *113*(2), 135-149.

*Costa, A., Hernández, M., & Sebastián-Gallés, N. (2008). Bilingualism aids conflict resolution: Evidence from the ANT task. *Cognition*, *106*(1), 59-86.

Emmorey, K., Luk, G., Pyers, J. E., & Bialystok, E. (2008). The Source of Enhanced Cognitive Control in Bilinguals Evidence From Bimodal Bilinguals. *Psychological Science*, *19*(12), 1201-1206.

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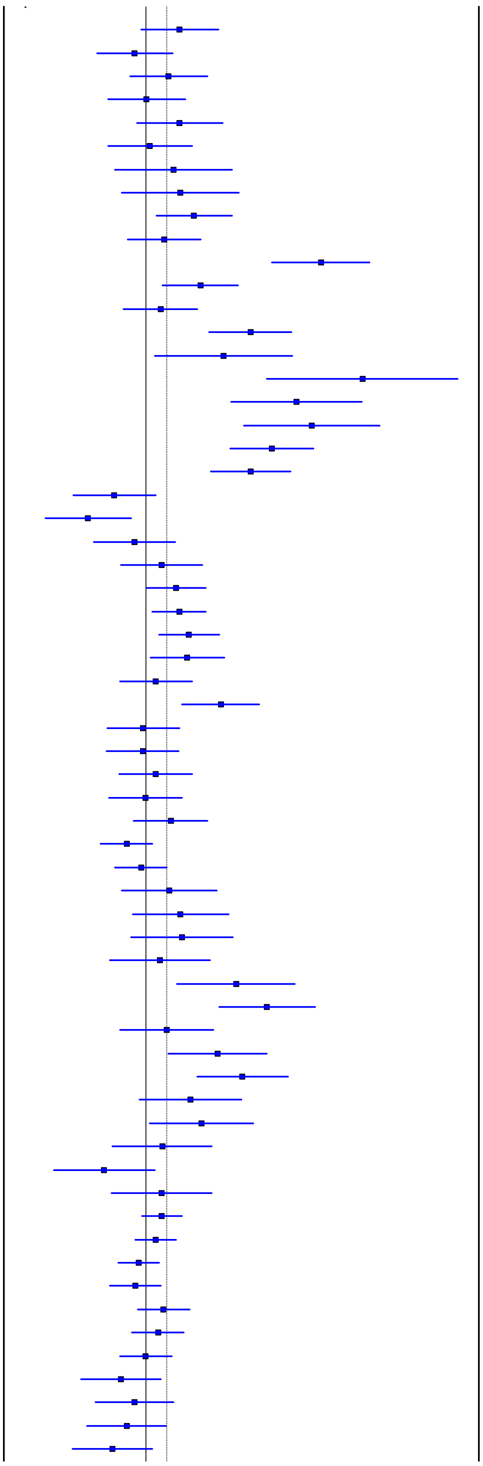
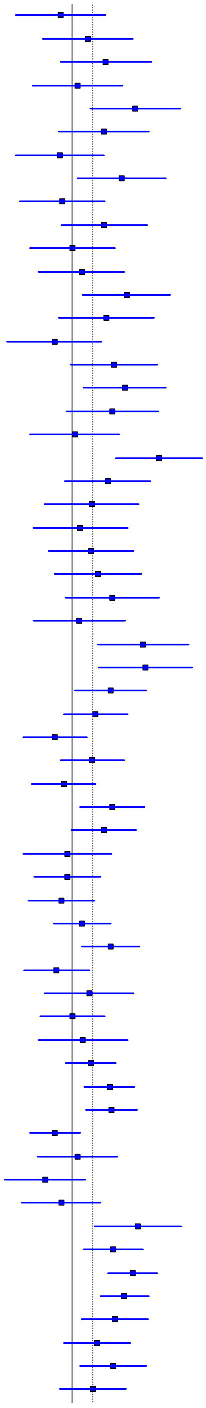
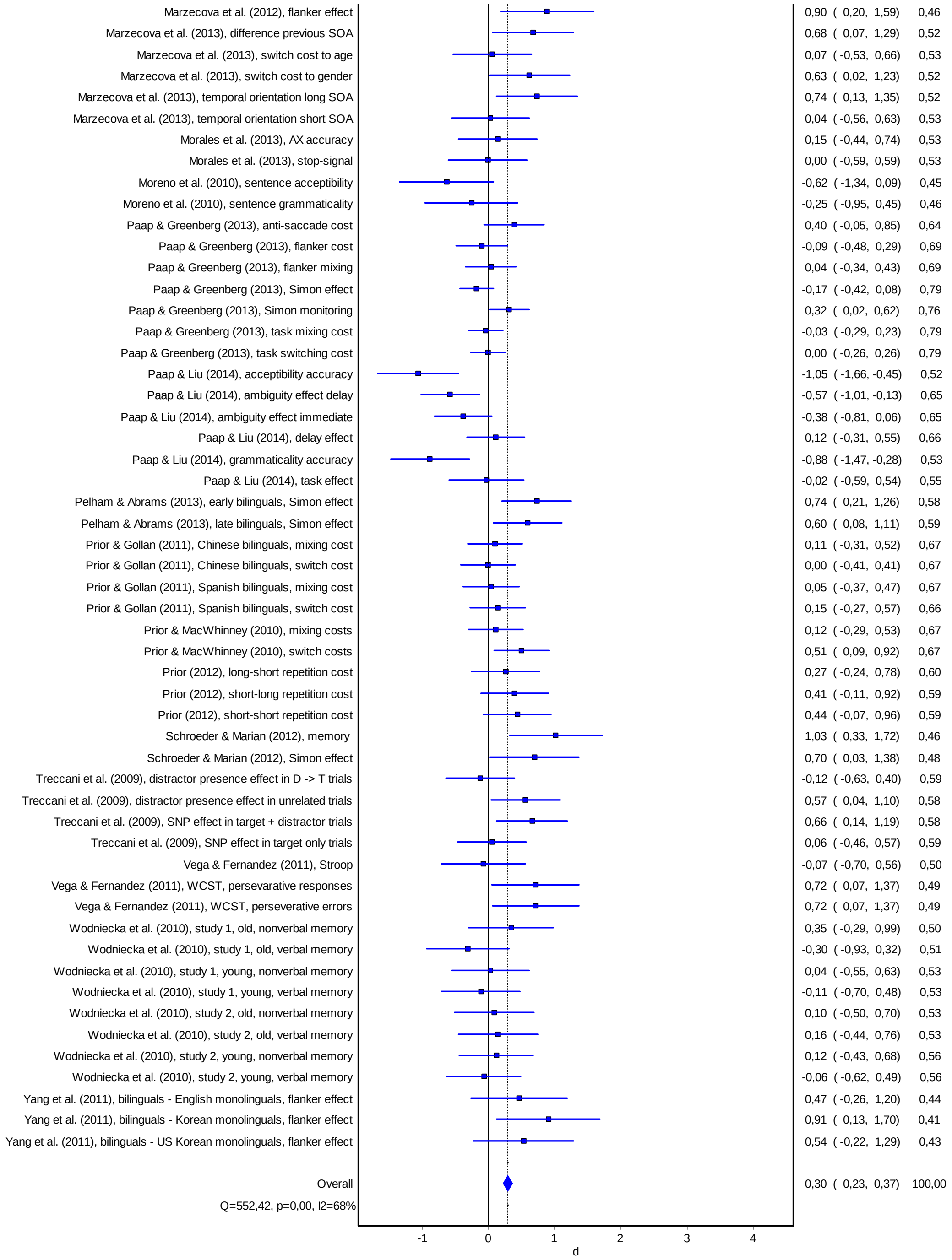
## *C3. Forest plot of the meta-analysis of published papers.*



| Study | d (95% CI) | % Weight |
|---|---|---|
| Barac & Bialystok (2012), Chinese bilinguals, global switch costs | 0,47 ( -0,06, 1,00) | 0,58 |
| Barac & Bialystok (2012), Chinese bilinguals, local switch costs | -0,15 ( -0,67, 0,38) | 0,58 |
| Barac & Bialystok (2012), French bilinguals, global switch costs | 0,32 ( -0,21, 0,86) | 0,57 |
| Barac & Bialystok (2012), French bilinguals, local switch costs | 0,02 ( -0,52, 0,55) | 0,58 |
| Barac & Bialystok (2012), Spanish bilinguals, global switch costs | 0,48 ( -0,12, 1,07) | 0,53 |
| Barac & Bialystok (2012), Spanish bilinguals, local switch costs | 0,06 ( -0,52, 0,65) | 0,54 |
| Bartolotti et al. (2011), high-interference task | 0,39 ( -0,42, 1,20) | 0,40 |
| Bartolotti et al. (2011), low-interference task | 0,48 ( -0,33, 1,29) | 0,39 |
| Bialystok & Viswanathan (2009), Canadian bilinguals, inhibition | 0,67 ( 0,15, 1,19) | 0,59 |
| Bialystok & Viswanathan (2009), Canadian bilinguals, response suppression | 0,26 ( -0,25, 0,77) | 0,60 |
| Bialystok & Viswanathan (2009), Canadian bilinguals, switch | 2,43 ( 1,75, 3,10) | 0,48 |
| Bialystok & Viswanathan (2009), Indian bilinguals, inhibition | 0,76 ( 0,24, 1,29) | 0,58 |
| Bialystok & Viswanathan (2009), Indian bilinguals, response suppression | 0,21 ( -0,30, 0,71) | 0,60 |
| Bialystok & Viswanathan (2009), Indian bilinguals, switch | 1,45 ( 0,88, 2,02) | 0,55 |
| Bialystok et al. (2004), study 1, old adults, Simon effect | 1,08 ( 0,14, 2,03) | 0,33 |
| Bialystok et al. (2004), study 1, young adults, Simon effect | 3,00 ( 1,68, 4,31) | 0,21 |
| Bialystok et al. (2004), study 2, old, 2 colours, Simon effect | 2,09 ( 1,19, 2,99) | 0,35 |
| Bialystok et al. (2004), study 2, old, 4 colours, Simon effect | 2,30 ( 1,36, 3,23) | 0,33 |
| Bialystok et al. (2004), study 2, young, 2 colours, Simon effect | 1,75 ( 1,17, 2,33) | 0,54 |
| Bialystok et al. (2004), study 2, young, 4 colours, Simon effect | 1,46 ( 0,90, 2,01) | 0,56 |
| Bialystok et al. (2008), study 1, category fluency | -0,43 ( -1,00, 0,14) | 0,55 |
| Bialystok et al. (2008), study 1, letter fluency | -0,79 ( -1,38, -0,20) | 0,54 |
| Bialystok et al. (2008), study 2, category fluency | -0,15 ( -0,71, 0,41) | 0,55 |
| Bialystok et al. (2008), study 2, letter fluency | 0,22 ( -0,34, 0,79) | 0,55 |
| Bialystok et al. (2010), opposite world cost | 0,42 ( 0,01, 0,83) | 0,67 |
| Bialystok et al. (2010), reverse categorisation cost | 0,47 ( 0,09, 0,84) | 0,70 |
| Bialystok et al. (2010), tapping | 0,60 ( 0,19, 1,02) | 0,67 |
| Bialystok et al. (2012), old children, sentence task | 0,58 ( 0,07, 1,09) | 0,59 |
| Bialystok et al. (2012), old children, verbal fluency | 0,14 ( -0,36, 0,65) | 0,60 |
| Bialystok et al. (2012), older children, Wug | 1,04 ( 0,51, 1,57) | 0,58 |
| Bialystok et al. (2012), young children, sentence task | -0,03 ( -0,53, 0,47) | 0,60 |
| Bialystok et al. (2012), young children, verbal fluency | -0,04 ( -0,54, 0,46) | 0,60 |
| Bialystok et al. (2012), young children, Wug | 0,14 ( -0,36, 0,64) | 0,60 |
| Blumenfeld & Marian (in press), experiment 1, Simon costs | 0,00 ( -0,51, 0,51) | 0,60 |
| Blumenfeld & Marian (in press), experiment 1, Stroop costs | 0,35 ( -0,16, 0,86) | 0,59 |
| Blumenfeld & Marian (in press), experiment 2, Simon costs | -0,26 ( -0,62, 0,10) | 0,71 |
| Blumenfeld & Marian (in press), experiment 2, Stroop costs | -0,06 ( -0,42, 0,30) | 0,71 |
| Bonifacci et al. (2011), children, anticipation | 0,33 ( -0,33, 0,98) | 0,49 |
| Bonifacci et al. (2011), children, go/no-go | 0,48 ( -0,18, 1,15) | 0,48 |
| Bonifacci et al. (2011), youth, anticipation | 0,50 ( -0,20, 1,21) | 0,46 |
| Bonifacci et al. (2011), youth, go/no-go | 0,20 ( -0,49, 0,90) | 0,46 |
| Carlson & Meltzoff (2008), EF composite score | 1,25 ( 0,44, 2,06) | 0,40 |
| Coderre et al. (2013), L1 Chinese Stroop cost | 1,68 ( 1,02, 2,35) | 0,48 |
| Coderre et al. (2013), L1 English Stroop cost | 0,29 ( -0,35, 0,94) | 0,49 |
| Coderre et al. (2013), L2 Chinese Stroop cost | 1,00 ( 0,31, 1,68) | 0,47 |
| Coderre et al. (2013), L2 English Stroop cost | 1,34 ( 0,71, 1,97) | 0,51 |
| Colzato et al. (2008), attentional blink, Lag 1 | 0,62 ( -0,08, 1,32) | 0,46 |
| Colzato et al. (2008), attentional blink, Lag 3 | 0,78 ( 0,07, 1,49) | 0,45 |
| Colzato et al. (2008), attentional blink, Lag 5 | 0,23 ( -0,46, 0,92) | 0,47 |
| Colzato et al. (2008), attentional blink, Lag 8 | -0,57 ( -1,27, 0,13) | 0,46 |
| Colzato et al. (2008), stop-signal | 0,23 ( -0,47, 0,92) | 0,46 |
| Costa et al. (2008), alerting effect | 0,23 ( -0,05, 0,51) | 0,77 |
| Costa et al. (2008), conflict effect | 0,14 ( -0,14, 0,42) | 0,77 |
| Costa et al. (2008), orienting effect | -0,09 ( -0,37, 0,18) | 0,77 |
| Costa et al. (2009), flanker effect 50% | -0,14 ( -0,49, 0,21) | 0,72 |
| Costa et al. (2009), flanker effect 75% | 0,25 ( -0,10, 0,61) | 0,72 |
| Costa et al. (2009), flanker effect 8% | 0,18 ( -0,18, 0,53) | 0,71 |
| Costa et al. (2009), flanker effect 92% | 0,00 ( -0,35, 0,36) | 0,71 |
| Fernandes et al. (2007), old adults, DA encoding | -0,34 ( -0,89, 0,21) | 0,57 |
| Fernandes et al. (2007), old adults, DA retrieval | -0,15 ( -0,70, 0,39) | 0,57 |
| Fernandes et al. (2007), young adults, DA encoding | -0,26 ( -0,81, 0,29) | 0,57 |
| Fernandes et al. (2007), young adults, DA retrieval | -0,46 ( -1,01, 0,09) | 0,56 |



| | | |
|---|---|---|
| Filippi et al. (2012), canonical Italian sentences | -0,15 ( -0,77, 0,47) | 0,51 |
| Filippi et al. (2012), non-canonical English sentences | 0,22 ( -0,40, 0,84) | 0,51 |
| Filippi et al. (2012), non-canonical Italian sentences | 0,48 ( -0,15, 1,10) | 0,51 |
| Fillipi et al. (2012), canonical English sentences | 0,08 ( -0,54, 0,70) | 0,51 |
| Gathercole et al. (2010), OEH children, matching tap | 0,88 ( 0,26, 1,50) | 0,51 |
| Gathercole et al. (2010), OEH children, Stroop 1 English | 0,45 ( -0,18, 1,07) | 0,51 |
| Gathercole et al. (2010), OEH children, Stroop 2 English | -0,16 ( -0,78, 0,45) | 0,52 |
| Gathercole et al. (2010), OEH children, switching tap | 0,69 ( 0,08, 1,30) | 0,52 |
| Gathercole et al. (2010), OEH teenagers, matching tap | -0,13 ( -0,71, 0,46) | 0,54 |
| Gathercole et al. (2010), OEH teenagers, Stroop 1 English | 0,45 ( -0,14, 1,05) | 0,53 |
| Gathercole et al. (2010), OEH teenagers, Stroop 2 English | 0,01 ( -0,58, 0,60) | 0,54 |
| Gathercole et al. (2010), OEH teenagers, switching tap | 0,14 ( -0,45, 0,73) | 0,54 |
| Gathercole et al. (2010), OWH children, matching tap | 0,76 ( 0,16, 1,37) | 0,52 |
| Gathercole et al. (2010), OWH children, Stroop 1 English | 0,48 ( -0,18, 1,14) | 0,49 |
| Gathercole et al. (2010), OWH children, Stroop 2 English | -0,24 ( -0,89, 0,42) | 0,49 |
| Gathercole et al. (2010), OWH children, switching tap | 0,59 ( -0,01, 1,18) | 0,53 |
| Gathercole et al. (2010), OWH teenagers, matching tap | 0,74 ( 0,17, 1,31) | 0,55 |
| Gathercole et al. (2010), OWH teenagers, Stroop 1 English | 0,56 ( -0,07, 1,20) | 0,50 |
| Gathercole et al. (2010), OWH teenagers, Stroop 2 English | 0,04 ( -0,58, 0,66) | 0,51 |
| Gathercole et al. (2010), OWH teenagers, switching tap | 1,21 ( 0,61, 1,81) | 0,53 |
| Gathercole et al. (2010), WEH children, matching tap | 0,50 ( -0,09, 1,10) | 0,53 |
| Gathercole et al. (2010), WEH children, Stroop 1 English | 0,28 ( -0,37, 0,93) | 0,49 |
| Gathercole et al. (2010), WEH children, Stroop 2 English | 0,12 ( -0,53, 0,77) | 0,49 |
| Gathercole et al. (2010), WEH children, switching tap | 0,28 ( -0,31, 0,86) | 0,54 |
| Gathercole et al. (2010), WEH teenagers, matching tap | 0,37 ( -0,23, 0,97) | 0,53 |
| Gathercole et al. (2010), WEH teenagers, Stroop 1 English | 0,56 ( -0,09, 1,21) | 0,49 |
| Gathercole et al. (2010), WEH teenagers, Stroop 2 English | 0,10 ( -0,53, 0,74) | 0,50 |
| Gathercole et al. (2010), WEH teenagers, switching tap | 0,99 ( 0,36, 1,62) | 0,51 |
| Gollan et al. (2011), onset | 1,03 ( 0,38, 1,67) | 0,50 |
| Heidlmayer et al. (in press), Stroop costs | 0,54 ( 0,04, 1,04) | 0,60 |
| Hernandez et al. (2012), identifying benefit | 0,34 ( -0,11, 0,78) | 0,65 |
| Hernandez et al. (2012), identifying cost | -0,23 ( -0,67, 0,21) | 0,65 |
| Hernandez et al. (2012), singleton benefit | 0,28 ( -0,16, 0,72) | 0,65 |
| Hernandez et al. (2012), singleton cost | -0,11 ( -0,55, 0,33) | 0,65 |
| Hernandez et al. (2012), working memory benefit | 0,57 ( 0,12, 1,02) | 0,64 |
| Hernandez et al. (2012), working memory cost | 0,45 ( 0,00, 0,89) | 0,65 |
| Hernandez et al. (2013), bivalent switch cost | -0,05 ( -0,67, 0,56) | 0,52 |
| Hernandez et al. (2013), explicit local switch cost | -0,06 ( -0,51, 0,40) | 0,64 |
| Hernandez et al. (2013), explicit restart cost | -0,14 ( -0,59, 0,32) | 0,64 |
| Hernandez et al. (2013), implicit local switch cost | 0,14 ( -0,25, 0,54) | 0,69 |
| Hernandez et al. (2013), implicit restart cost | 0,54 ( 0,14, 0,94) | 0,68 |
| Hernandez et al. (2013), mixing cost | -0,21 ( -0,65, 0,24) | 0,64 |
| Hernandez et al. (2013), semi-bivalent switch cost | 0,24 ( -0,37, 0,86) | 0,52 |
| Hernandez et al. (2013), switch cost | 0,01 ( -0,43, 0,46) | 0,64 |
| Hernandez et al. (2013), univalent switch cost | 0,16 ( -0,46, 0,77) | 0,52 |
| Kharkhurin (2008), elaboration | 0,27 ( -0,08, 0,62) | 0,72 |
| Kharkhurin (2008), flexibility | 0,52 ( 0,17, 0,87) | 0,72 |
| Kharkhurin (2008), fluency | 0,55 ( 0,20, 0,90) | 0,72 |
| Kharkhurin (2008), originality | -0,23 ( -0,58, 0,12) | 0,72 |
| Kousaie & Phillips (2012), flanker effect | 0,09 ( -0,47, 0,64) | 0,56 |
| Kousaie & Phillips (2012), Simon effect | -0,37 ( -0,92, 0,19) | 0,56 |
| Kousaie & Phillips (2012), Stroop effect | -0,14 ( -0,69, 0,41) | 0,56 |
| Krizman et al. (2012), attention | 0,91 ( 0,32, 1,51) | 0,53 |
| Linck et al. (2008), Simon effect | 0,58 ( 0,16, 0,99) | 0,67 |
| Marian et al. (2013), 3rd grade math | 0,85 ( 0,51, 1,18) | 0,73 |
| Marian et al. (2013), 3rd grade reading | 0,73 ( 0,40, 1,07) | 0,73 |
| Marian et al. (2013), 4th grade math | 0,60 ( 0,15, 1,06) | 0,63 |
| Marian et al. (2013), 4th grade reading | 0,36 ( -0,10, 0,82) | 0,63 |
| Marian et al. (2013), 5th grade math | 0,57 ( 0,11, 1,03) | 0,63 |
| Marian et al. (2013), 5th grade reading | 0,29 ( -0,17, 0,75) | 0,64 |



Marzecova et al. (2012), flanker effect 0,90 ( 0,20, 1,59) 0,46
Marzecova et al. (2013), difference previous SOA 0,68 ( 0,07, 1,29) 0,52
Marzecova et al. (2013), switch cost to age 0,07 ( -0,53, 0,66) 0,53
Marzecova et al. (2013), switch cost to gender 0,63 ( 0,02, 1,23) 0,52
Marzecova et al. (2013), temporal orientation long SOA 0,74 ( 0,13, 1,35) 0,52
Marzecova et al. (2013), temporal orientation short SOA 0,04 ( -0,56, 0,63) 0,53
Morales et al. (2013), AX accuracy 0,15 ( -0,44, 0,74) 0,53
Morales et al. (2013), stop-signal 0,00 ( -0,59, 0,59) 0,53
Moreno et al. (2010), sentence acceptibility -0,62 ( -1,34, 0,09) 0,45
Moreno et al. (2010), sentence grammaticality -0,25 ( -0,95, 0,45) 0,46
Paap & Greenberg (2013), anti-saccade cost 0,40 ( -0,05, 0,85) 0,64
Paap & Greenberg (2013), flanker cost -0,09 ( -0,48, 0,29) 0,69
Paap & Greenberg (2013), flanker mixing 0,04 ( -0,34, 0,43) 0,69
Paap & Greenberg (2013), Simon effect -0,17 ( -0,42, 0,08) 0,79
Paap & Greenberg (2013), Simon monitoring 0,32 ( 0,02, 0,62) 0,76
Paap & Greenberg (2013), task mixing cost -0,03 ( -0,29, 0,23) 0,79
Paap & Greenberg (2013), task switching cost 0,00 ( -0,26, 0,26) 0,79
Paap & Liu (2014), acceptibility accuracy -1,05 ( -1,66, -0,45) 0,52
Paap & Liu (2014), ambiguity effect delay -0,57 ( -1,01, -0,13) 0,65
Paap & Liu (2014), ambiguity effect immediate -0,38 ( -0,81, 0,06) 0,65
Paap & Liu (2014), delay effect 0,12 ( -0,31, 0,55) 0,66
Paap & Liu (2014), grammaticality accuracy -0,88 ( -1,47, -0,28) 0,53
Paap & Liu (2014), task effect -0,02 ( -0,59, 0,54) 0,55
Pelham & Abrams (2013), early bilinguals, Simon effect 0,74 ( 0,21, 1,26) 0,58
Pelham & Abrams (2013), late bilinguals, Simon effect 0,60 ( 0,08, 1,11) 0,59
Prior & Gollan (2011), Chinese bilinguals, mixing cost 0,11 ( -0,31, 0,52) 0,67
Prior & Gollan (2011), Chinese bilinguals, switch cost 0,00 ( -0,41, 0,41) 0,67
Prior & Gollan (2011), Spanish bilinguals, mixing cost 0,05 ( -0,37, 0,47) 0,67
Prior & Gollan (2011), Spanish bilinguals, switch cost 0,15 ( -0,27, 0,57) 0,66
Prior & MacWhinney (2010), mixing costs 0,12 ( -0,29, 0,53) 0,67
Prior & MacWhinney (2010), switch costs 0,51 ( 0,09, 0,92) 0,67
Prior (2012), long-short repetition cost 0,27 ( -0,24, 0,78) 0,60
Prior (2012), short-long repetition cost 0,41 ( -0,11, 0,92) 0,59
Prior (2012), short-short repetition cost 0,44 ( -0,07, 0,96) 0,59
Schroeder & Marian (2012), memory 1,03 ( 0,33, 1,72) 0,46
Schroeder & Marian (2012), Simon effect 0,70 ( 0,03, 1,38) 0,48
Treccani et al. (2009), distractor presence effect in D -> T trials -0,12 ( -0,63, 0,40) 0,59
Treccani et al. (2009), distractor presence effect in unrelated trials 0,57 ( 0,04, 1,10) 0,58
Treccani et al. (2009), SNP effect in target + distractor trials 0,66 ( 0,14, 1,19) 0,58
Treccani et al. (2009), SNP effect in target only trials 0,06 ( -0,46, 0,57) 0,59
Vega & Fernandez (2011), Stroop -0,07 ( -0,70, 0,56) 0,50
Vega & Fernandez (2011), WCST, persevarative responses 0,72 ( 0,07, 1,37) 0,49
Vega & Fernandez (2011), WCST, perseverative errors 0,72 ( 0,07, 1,37) 0,49
Wodniecka et al. (2010), study 1, old, nonverbal memory 0,35 ( -0,29, 0,99) 0,50
Wodniecka et al. (2010), study 1, old, verbal memory -0,30 ( -0,93, 0,32) 0,51
Wodniecka et al. (2010), study 1, young, nonverbal memory 0,04 ( -0,55, 0,63) 0,53
Wodniecka et al. (2010), study 1, young, verbal memory -0,11 ( -0,70, 0,48) 0,53
Wodniecka et al. (2010), study 2, old, nonverbal memory 0,10 ( -0,50, 0,70) 0,53
Wodniecka et al. (2010), study 2, old, verbal memory 0,16 ( -0,44, 0,76) 0,53
Wodniecka et al. (2010), study 2, young, nonverbal memory 0,12 ( -0,43, 0,68) 0,56
Wodniecka et al. (2010), study 2, young, verbal memory -0,06 ( -0,62, 0,49) 0,56
Yang et al. (2011), bilinguals - English monolinguals, flanker effect 0,47 ( -0,26, 1,20) 0,44
Yang et al. (2011), bilinguals - Korean monolinguals, flanker effect 0,91 ( 0,13, 1,70) 0,41
Yang et al. (2011), bilinguals - US Korean monolinguals, flanker effect 0,54 ( -0,22, 1,29) 0,43
Overall 0,30 ( 0,23, 0,37) 100,00
Q=552,42, p=0,00, I2=68%
-1
0
1
2
3
4
d

## Appendix D. Supplementary materials for Chapter 5

*D1. Means and standard deviations (in parentheses) of self-rated language use during five time frames for Gaelic and English.*

| | **Active bilingual** | **Inactive bilingual** | **Monolingual** | **Statistics**<br>Active vs. inactive<br>Active vs. monolingual<br>Inactive vs. monolingual |
|---|---|---|---|---|
| **Gaelic** | | | | |
| Childhood home | 9.50 (1.35) | 8.79 (2.00) | 1.42 (1.84) | $\chi^2(2)$ = 4.643, $p$ = .407<br>$\chi^2(2)$ = 38.164, $p$ < .001<br>$\chi^2(2)$ = 33.521, $p$ < .001 |
| Childhood school | 2.46 (1.53) | 2.33 (2.10) | 1.04 (.20) | $\chi^2(2)$ = 3.932, $p$ = .470<br>$\chi^2(2)$ = 22.702, $p$ < .001<br>$\chi^2(2)$ = 18.771, $p$ = .001 |
| Work | 4.64 (2.15) | 1.88 (1.15) | 1.17 (.38) | $\chi^2(2)$ = 24.685, $p$ < .001<br>$\chi^2(2)$ = 36.726, $p$ < .001<br>$\chi^2(2)$ = 12.042, $p$ = .046 |
| Later life home | 7.42 (2.59) | 1.71 (1.08) | 1.08 (.28) | $\chi^2(2)$ = 31.051, $p$ < .001<br>$\chi^2(2)$ = 40.030, $p$ < .001<br>$\chi^2(2)$ = 8.979, $p$ = .133 |
| After retirement | 7.14 (2.43) | 2.58 (1.28) | 1.04 (.20) | $\chi^2(2)$ = 25.098, $p$ < .001<br>$\chi^2(2)$ = 45.473, $p$ < .001<br>$\chi^2(2)$ = 20.375, $p$ = .001 |
| **English** | | | | |
| Childhood home | 1.75 (1.48) | 2.29 (1.90) | 9.54 (1.86) | $\chi^2(2)$ = 4.580, $p$ = .433<br>$\chi^2(2)$ = 37.830, $p$ = .001<br>$\chi^2(2)$ = 33.25, $p$ = .001 |

| | **Active bilingual** | **Inactive bilingual** | **Monolingual** | **Statistics**<br>Active vs. inactive<br>Active vs. monolingual<br>Inactive vs. monolingual |
|---|---|---|---|---|
| Childhood school | 9.29 (1.27) | 8.83 (2.24) | 9.96 (.20) | $\chi^2(2)$ = .068, $p$ = .988<br>$\chi^2(2)$ = 10.506, $p$ = .019<br>$\chi^2(2)$ = 10.438, $p$ = .025 |
| Work | 5.50 (2.27) | 8.67 (1.55) | 9.75 (.68) | $\chi^2(2)$ = 24.408, $p < .001$<br>$\chi^2(2)$ = 37.116, $p < .001$<br>$\chi^2(2)$ = 12.708, $p$ = .035 |
| Later life home | 3.68 (2.54) | 9.00 (1.32) | 9.83 (.56) | $\chi^2(2)$ = 29.988, $p < .001$<br>$\chi^2(2)$ = 39.905, $p < .001$<br>$\chi^2(2)$ = 9.917, $p$ = .099 |
| After retirement | 3.75 (2.07) | 7.75 (1.62) | 9.92 (.41) | $\chi^2(2)$ = 24.601, $p < .001$<br>$\chi^2(2)$ = 45.122, $p < .001$<br>$\chi^2(2)$ = 20.521, $p$ = .001 |

*D2. Stimulus list of the thirty nouns and thirty verbs used in the picture-word matching task. An asterisk indicates that the item was excluded from further analysis. English nouns had an average word length of 5.39 (SD = 1.47) letters and 3.96 (SD = 1.24) phonemes. English verbs had an average word length of 7.10 (SD = .75) letters and 5.33 (SD = .60) phonemes. Gaelic nouns had an average word length of 6.11 (SD = 2.30) letters and 4.64 (SD = 1.42) phonemes. Gaelic verbs had an average word length of 8.83 (SD = 1.92) letters and 6.57 (SD = 1.45) phonemes. Although verbs were significantly longer than nouns, there was no significant difference between Gaelic and English items in word length.*

| **Nouns** | | **Verbs** | |
|---|---|---|---|
| English | Gaelic | English | Gaelic |
| butterfly | dealan-dè | barking | a' comhartaich |
| anchor | acair | biting | a' bideadh |
| arrow | saighead | blowing | a' sèideadh |
| axe | làmhag | combing | a' cìreadh |
| bath | amar | digging | a' cladhach |
| beard | feusag | dreaming | a' bruadar |
| bee* | beach* | fishing | ag iasgach |
| bell | clag | floating | a' fleodradh |
| candle | coinneal | jumping | a' leumadh |
| cheese | càise | kicking | a' breabadh |
| cherry* | siris* | kissing | a’ pògadh |
| comb | cìr | knitting | a' fighe |
| crack | sgàin | knocking | a' gnogadh |
| duck | tunnag | licking | ag imlich |
| elephant | ailbhean | melting | a' leaghadh |
| feather | ite | peeling | a' rùsgadh |
| flag | bratach | pouring | a' dòirteadh |
| kettle | coire | raking | a' ràcadh |
| knot | snaidhm | roaring | a' beucaich |
| ladder | àradh | sailing | a' seòladh |
| mouse | luch | shaving | a' bearradh |
| pig | muc | sinking | a' dol fodha |

| **Nouns** | | **Verbs** | |
|---|---|---|---|
| English | Gaelic | English | Gaelic |
| sandwich | ceapaire | sneezing | a' sreothartach |
| sausage | isbean | snowing | a' cuir an t-sneachd |
| sheep | caora | stroking | a' slìobadh |
| shirt | lèine | swimming | a' snàmh |
| shower | frasair | tickling | a' diogladh |
| sword | claidheamh | tying | a' ceangal |
| whistle | feadag | weaving | a' fighe |
| witch | bana-bhuidseach | yawning | a' meananaich |

## Appendix E. Supplementary materials for Chapter 7

*E1. Overview of pictures used in the language tasks in Chapter 7.*

| | **English** | **Italian** | **Spanish** |
|---|---|---|---|
| | apple | mela | manzana |
| | bed | letto | cama |
| | bee | ape | abeja |
| | bone | osso | hueso |
| | book | libro | libro |
| | branch | ramo | rama |
| | chair | sedia | silla |
| | dog | cane | perro |
| | door | porta | puerta |
| | dress | vestito | vestido |
| | finger | dito | dedo |
| | frog | rana | rana |
| | grapes | uva | uva |
| | hand | mano | mano |
| | helmet | casco | casco |
| | leaf | foglia | hoja |
| | monkey | scimmia | mono |
| | pencil | matita | lapiz |
| | spider | ragno | aragna |
| | strawberry | fragola | fresa |
| | | | |
| Average syllables | 1.45 (.60) | 2.15 (.37) | 2.20 (.41) |
| Average letters | 5.05 (1.64) | 4.85 (1.26) | 4.85 (1.04) |
| Average phonemes | 4.25 (1.65) | 4.75 (1.12) | 4.60 (1.10) |

*E2. Experiment 1. Task-switching paradigm A: colour/shape switching preceded by a language task*

*Fixed effects of the mixed-effects analysis of LOG VOTs comparing blocked to non-switch trials. The reference levels for this model are non-switch trials for trial type and monolingual for language condition. Significant effects (*t *> 2) are indicated with an asterisk.*

| **Predictor** | **Estimate** | **SE** | **t-ratio** |
|---|---|---|---|
| Intercept | -0.39 | 0.03 | -13.54* |
| Trial type: Blocked | -0.03 | 0.01 | -3.16* |
| Language: Bilingual blocked | 0.001 | 0.02 | 0.07 |
| Language: Language switch | -0.008 | 0.011 | 0.73 |
| Bilingual blocked X Blocked trials | -0.01 | 0.007 | -1.87 |
| Language switch X Blocked trials | -0.02 | 0.01 | -1.53 |

*Fixed effects of the mixed-effects analysis of LOG VOTs comparing switch to non-switch trials. The reference levels for this model are non-switch trials for trial type and monolingual for language condition. Significant effects (*t *> 2) are indicated with an asterisk.*

| **Predictor** | **Estimate** | **SE** | **t-ratio** |
|---|---|---|---|
| Intercept | -.39 | .04 | -9.68* |
| Trial type: Switch | .05 | .02 | 2.99* |
| Language: Bilingual blocked | -.004 | .02 | -.25 |
| Language: Language switch | -.02 | .02 | -1.59 |
| Distance | .001 | .005 | .24 |
| Bilingual blocked X Switch trials | .02 | .02 | .78 |
| Language switch X Switch trials | .06 | .02 | 2.50* |
| Distance x Switch trials | -.01 | .007 | -2.04* |
| Bilingual blocked X Distance | .003 | .007 | .39 |
| Language switch x Distance | .02 | .07 | 1.26 |
| Bilingual blocked x Distance x Switch trials | -.002 | .01 | -.25 |
| Language switch x Distance x Switch trials | -.02 | .01 | -1.66 |

*E3. Experiment 1. Task-switching paradigm B: mixed language-/task-switching paradigm*

*Fixed effects of the mixed-effects analysis of LOG VOTs for paradigm B. The reference levels for this model are non-switch trials for trial type, language non-switch for language condition, and 2 for the number of preceding language trials. Significant effects (t > 2) are indicated with an asterisk.*

| **Predictor** | **Estimate** | **SE** | **t-ratio** |
|---|---|---|---|
| Intercept | -.41 | .05 | -8.56* |
| Trial type: Switch | .06 | .03 | 2.27* |
| Language condition: Language switch | -.03 | .03 | -.94 |
| Four preceding language trials | .08 | .03 | 2.46* |
| Language switch x Switch trial | .02 | .04 | .46 |
| Language switch x 4 language trials | -.04 | .02 | -1.83 |
| Switch trial x 4 language trials | -.02 | .03 | -.48 |
| Language switch x Switch trial x 4 language trials | -.05 | .05 | -1.04 |

*E4. Experiment 2. Fixed effects of the mixed-effects analysis of LOG RTs for Experiment 2. The reference levels for this model are non-switch trials for trial type and monolingual for language condition. Significant effects (*t *> 2) are indicated with an asterisk.*

| **Predictor** | **Estimate** | **SE** | **t-ratio** |
|---|---|---|---|
| Intercept | 6.40 | 0.05 | 136.61* |
| Trial type: Switch | .09 | .01 | 6.53* |
| Language: Bilingual blocked | -.005 | .03 | -.20 |
| Language: Language switch | -.001 | .02 | -.05 |
| Distance | .01 | .003 | 2.92* |
| Switch x Distance | -.02 | .004 | -3.63* |
| Bilingual blocked x Distance | .003 | .004 | .64 |
| Language switch x Distance | -.007 | .004 | -.74 |
| Bilingual blocked x Switch | .02 | .01 | 1.46 |
| Language switch x Switch | -.001 | .01 | -.11 |
| Bilingual blocked x Distance x Switch | -.004 | .006 | -.68 |
| Language switch x Distance x Switch | .004 | .006 | .66 |

*E5. Experiment 3. Fixed effects of the mixed-effects analysis of LOG VOTs and RTs for Experiment 3. The reference levels for this model are non-switch trials for trial type, non-verbal for condition, and monolingual for language condition. Significant effects (*t *> 2) are indicated with an asterisk.*

| **Predictor** | **Estimate** | **SE** | **t-ratio** |
|---|---|---|---|
| Intercept | 6.17 | 0.04 | 171.44* |
| Trial type: Switch | .12 | .01 | 7.89* |
| Language: Language switch | .01 | .03 | 0.42 |
| Condition: Verbal | 0.23 | 0.04 | 6.34* |
| Language switch x Switch | -0.004 | .02 | -0.29 |
| Language switch x Verbal | -0.009 | 0.01 | -0.62 |
| Switch x Verbal | -0.09 | 0.01 | -6.00* |
| Language switch x Switch x Verbal | 0.04 | .02 | 2.05* |

## Publications

The following articles were published and/or submitted during this PhD:

De Bruin, A., & Della Sala, S. (submitted). Effects of age on inhibitory control are affected by task-specific features.

De Bruin, A., Della Sala, S., & Bak, T. H. (2016). The effects of language use on lexical processing in bilinguals. *Language, Cognition and Neuroscience, 31*(8), 967-974.

Beschin, N., De Bruin, A., & Della Sala, S. (2016). Compulsive foreign language syndrome: A clinical observation not a mystery. *Cortex, 81,* 276-277.

De Bruin, A. & Della Sala, S. (2016). The importance of language use when examining the neuroanatomical basis of bilingualism. *Language, Cognition and Neuroscience, 31*(3), 335-339.

De Bruin, A., Bak, T. H., & Della Sala, S. (2015). Examining the effects of active versus inactive bilingualism on executive control in a carefully matched non-immigrant sample. *Journal of Memory and Language, 85*, 15-26.

De Bruin, A., & Della Sala, S. (2015). The decline effect: How initially strong results tend to decrease over time. *Cortex, 73*, 357 – 377.

De Bruin, A., Treccani, B., & Della Sala, S. (2015). The connection is in the data: We should consider them all. *Psychological Science, 26*(6), 947-949.

De Bruin, A., Treccani, B., & Della Sala, S. (2015). Cognitive advantage in bilingualism: An example of publication bias? *Psychological Science, 26*(1), 99-107.

De Bruin, A., Roelofs, A., Dijkstra, T., & FitzPatrick, I. (2014). Domain-general inhibition areas of the brain are involved in language switching: fMRI evidence from trilingual speakers. *NeuroImage, 90*, 348-359.

**Scientific dissemination**

De Bruin, A., & Della Sala, S. (2016). How biases inflate scientific evidence. *The Psychologist*, *29*(1), 36-39.

De Bruin, A., & Della Sala, S. (2015). Gli sbandierati effetti positivi del bilinguismo potrebbero essere dovuti ad un bias. *Query, 24,* 49-53.