Bilingual advantages in middle-aged and elderly populations

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Chapter 5

An advantage in task switching for late bilinguals proficient in related languages.

Abstract

This study investigated whether the association that was found in an earlier study between lifelong bilingualism and enhanced executive control, particularly mental flexibility, and with a modulation of an age-related decline in these functions, extends to individuals who acquired their second language after age 20. We thereto compared performance of middle-aged and elderly late bilingual speakers of German and Dutch to that of early bilingual speakers of Dutch and Frisian and of functionally monolingual speakers of German, in a cued task-switching paradigm. Both bilingual groups incurred significantly lower switching costs than the monolinguals, and elderly bilinguals were less affected by an age-related increase in switching costs than monolinguals. There were no differences between early and late bilinguals in the switching costs, and bilinguals did not differ from monolinguals in mixing costs. Analyses within the late bilingual group did not show significant correlations between the switch or the mix effect and any language-related factor. We propose that the experience of speaking more than one language, although the second one was acquired at a later age, may have enhanced the efficiency of executive control, particularly mental flexibility and resistance to proactive interference. The presence of this effect may be attributable to the choice of the task and to the cognateness of the languages involved. However, the fact that the late bilinguals were immigrants may also have played a role in this effect.

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5.1. Introduction.

In spite of an increasing amount of research, the question to what extent bilingualism can affect general, non-verbal cognitive functioning has not conclusively been answered yet. Approximately fifteen years ago, Bialystok and her research group reported evidence that bilingual children were better than monolingual children at handling non-linguistic tasks that contained conflicting or misleading information (cf. Bialystok & Martin, 2004). This marked the beginning of a large number of studies into the question whether bilingualism can lead to an enhancement of general cognitive functions tapping into executive control. Whereas a number of studies reported a bilingual advantage, other studies found no differences in performance on executive control tasks between language groups (for reviews, cf. Costa et al., 2009; Hilchey & Klein, 2011). To confuse matters even more, there seems to be no general agreement on what criteria participants in experimental studies on bilingualism have to fit in order to qualify as bilinguals. This evokes the question how much, and which part of the bilingual experience, is necessary to lead to a potential cognitive advantage. Is it the degree of proficiency in a bilingual's languages or the amount and/or recency of use that matters? And related to that question, is it essential for the additional language to be learnt simultaneously with the first one, or can for instance bilingualism attained at a later age lead to cognitive advantages as well? This study investigates whether late bilinguals, i.e. bilinguals who acquired their second language (L2) after puberty, differ in the efficiency of executive control functions from monolinguals and early bilinguals. With this aim, we compare performance on a task-switching test between groups of adult late bilinguals, early bilinguals and monolingual controls.

5.2. Theoretical background.

The concept of executive control is generally taken to refer to a number of high-level cognitive functions, which 'allow us to shift our mind set quickly and adapt to diverse situations while at the same time inhibiting inappropriate behaviours' (Jurado & Rosselli, 2007, p. 233). The research into bilingualism and executive control is generally based on an authoritative study by Miyake et al. (2000), who defined the concept as three separable, but correlating functions: updating (Working Memory), inhibition, and mental flexibility or shifting between mental sets. The bilingual cognitive advantage that some studies found was initially attributed to an increased efficiency of inhibitory functions (cf. Bialystok, 2009), but overviews by Costa et al. (2009) and Hilchey and Klein (2011) of studies using attentional control tasks showed that a bilingual advantage in conflict resolution was relatively rare. If a bilingual advantage was reported at all, it was most often reflected in faster reaction times on both congruent and incongruent trials. Costa and colleagues (2009) therefore suggested that the advantage reflected an interplay of monitoring processes that bilinguals use to select the language of communication, and conflict resolution processes. Likewise, Hilchey and Klein (2011) defined the mechanism underlying a potential bilingual cognitive advantage as a "more global conflict-monitoring system", and Bialystok, Craik and Luk (2012) agreed that the advantage probably reflects interactions of several executive control processes.

When the hypothesis that a single, language-specific inhibitory control mechanism could explain the bilingual advantage was abandoned, the focus shifted to models based on a dynamic interplay between different cognitive control components, as suggested by Bialystok et al (2012). Cued task-switching tests are often used in experiments based on these models: they require participants to switch in response to a cue, and therefore tap into both set-shifting and monitoring, and into the interaction of these processes (cf. Rubin & Meiran, 2005). It has been proposed that these tests also closely resemble bilingual language use, where speakers have to suppress the non-target language, while at the same time monitoring the linguistic context and other environmental cues (c.f. Bialystok et al, 2012, but see e.g. Paap & Greenberg, 2013 & Morton, 2014, for different views). Prior and MacWhinney (2010) report an advantage in switching costs for bilingual compared to monolingual college students in a cued task-switching paradigm. Similar bilingual advantages in task switching were reported by Prior and Gollan (2011), Gold, Kim, Johnson et al. (2013) and in the previous chapter of this dissertation. However, Hernández, Martin, Barceló & Costa (2013), in experiments involving Spanish/Catalan bilinguals, only report an advantage for bilinguals in overall reaction times, and Paap and Greenberg (2013), comparing groups of bilingual and monolingual college students on 15 indicators of executive control including task switching, only found one group difference, i.e. an advantage for monolinguals. Moreover, the absence of consistent cross-task correlations in Paap and Greenberg's results suggested that these executive control tasks are not proper indicators of domain-general abilities. Paap and Greenberg therefore recommend that studies should be based on at least two experiments tapping into the same components of executive functioning.

5.2.1. Variables affecting task performance.

Another problem that arises in experimental studies comparing bilinguals and monolinguals is that there are many factors, besides being bilingual or not, that may affect the efficiency of executive control. Valian (2015) even suggested that bilingualism might be 'just one' of many challenging experiences having such an effect, and that the visibility of potential bilingual effects may depend on the presence and relative strength of these other factors. Recent studies have therefore emphasized the importance of matching language groups on demographic factors, or else to regress the variance caused by them out statistically, to rule out that group differences are wrongly attributed to bilingualism (cf. Hilchey & Klein, 2011; Paap and Greenberg, 2013; Paap, 2014). Musical expertise, computer skills and amount of physical exercise have all been named as factors potentially affecting executive control. Another confounding factor in experimental research is immigrant status: Fuller-Thomson and Kuh (2014) argue that the 'healthy migrant effect' – i.e., evidence that immigrants have better morbidity and mortality outcomes than non-immigrants, after adjustment for socio-economic status- may explain the outcomes of some studies into the bilingual advantage.

A number of language-related factors, besides demographic ones, may also affect task results. The cognateness of the languages involved was controlled for in the study reported on in chapter 3. Other studies look at the role of language dominance and language balance (cf. Treffers-Daller & Korybski, 2015), the implication being that more balanced bilinguals would have more experience in language switching (see chapter 3). Recently, some studies reported that the amount of language switching was indeed positively related to performance on executive control tasks (e.g. Prior & Gollan, 2011; Soveri, Rodriguez-Fornells & Laine, 2013; Verreyt, Woumans, Vandelanotte, Szmalec & Duyck, 2015).

Other language-related issues are whether a bilingual also needs full, native-like proficiency in the L2 for effects to take place. Morton (2014, p. 929) observed that a large amount of studies claim to be testing bilinguals, but do not even measure participants' language proficiency in their L1 or L2. Another crucial question is, whether the L2 needs to have been acquired before a certain age. So far, only few studies have looked into effects of age of onset of bilingualism on efficiency of executive control. Luk, De Sa and Bialystok (2011) report that a group of early bilinguals of ca. 20 years old outperformed their late bilingual and their monolingual counterparts on a flanker task, with no difference between monolinguals and late bilinguals. Early bilinguals had become actively bilingual before, and late bilinguals after age 10. However, because of the age of the participants, the factors age of onset vs duration of bilingualism could not be disentangled. Still, a correlation analysis conducted over the entire sample showed that earlier and continuing bilingualism correlated positively with task performance. Tao et al. (2011) conducted a study in which monolingual English and early (<6) and late (≥ 12) bilingual Chinese-English young adults conducted an attentional network task. Both bilingual groups outperformed the monolinguals, with the late bilinguals showing the greatest advantage in conflict resolution and the early bilinguals also showing faster overall reaction times. The authors suggest that the age of onset of bilingualism impacts particularly on the efficiency of monitoring abilities. Because the late bilinguals were on average more balanced in their language use than the early bilinguals, the authors suggest that degree of language balance may be a factor affecting the efficiency of conflict resolution abilities. Lastly, Pelham and Abrams (2014) conducted a similar study, involving monolingual English, and early (before 7) and late (after 13) Spanish-English bilingual college students. Here as well, both bilingual groups significantly outperformed the monolingual group, confirming Luk et al.'s conclusion that there is no indication that after a certain age of onset bilingualism would no longer lead to enhancement of executive control. However, the age of the samples in these studies does not allow a distinction between the variables onset age vs. duration of bilingualism. This indicates the need for a study involving groups of middle-aged or older adults, because this provides the opportunity to test the effects of these variables separately.

Two more observations call for a study involving middle-aged and older late bilinguals. First, a few studies report an association between bilingualism and a modulation of an age-related decline of executive control (Bialystok, Craik & Luk, 2008a; Bialystok, Craik & Ryan, 2006; Gold et al., 2013; chapter 4 of this dissertation). A study involving middle-aged and elderly late bilinguals can explore the question whether such an association extends to bilingualism acquired at a later age, too. Finally, groups of middle-aged and elderly late bilinguals tend to be fairly heterogeneous, both in language background and proficiency, which enables an investigation of effects of linguistic factors on executive control by means of a within-group analysis.

The above considerations inspired us to start a research project that compares groups of middle-aged and elderly monolingual and bilinguals in a cued task-switching paradigm. In chapter 4 we reported on the performance of monolinguals and early bilinguals (=L2 acquired before age 6) in this same experiment. The primary focus of the present chapter is a comparison of the late bilinguals with their monolingual and early bilingual counterparts. On the basis of earlier studies (Tao et al., 2011; Pelham & Abrams, 2014), we hypothesize that the late bilinguals will outperform the monolinguals, but since Luk et al. (2011) found positive correlations between earlier and continuing bilingualism and task performance, we also hypothesize that the early bilinguals will outperform the late bilinguals. Because in an earlier study (reported on in chapter 4) we only found a difference between language groups in the size of the switch effect but not in the mix effect, we expect these differences between late bilinguals and the other two language groups only in switching costs. Second, we expect an age-related decline in the efficiency of executive control in all groups, which will be reflected both in the size of the switch and the mix effect. We hypothesize that for the late bilinguals this decline will be smaller than for the monolinguals, but larger than for the early bilinguals. Third, in accordance with the results from the previous chapter. we expect an age-related increase in the overall response times, but no effects of language group, and no interactions between overall response times, language group and aging. The second focus of our study concerns an analysis within the group of late bilinguals. We hypothesize that executive control efficiency in this group will correlate positively with the variables age of onset, years passed since immigration/duration of bilingualism and L2 proficiency.

Finally, in the same study two other tests were administered. In the first place, we conducted a verbal fluency test, to investigate differences in performance in linguistic functioning between bilinguals and monolinguals; this part of our study is reported on in chapter 6. Another reason for conducting a verbal fluency test is that it enables us to measure our participants' language proficiency: in the case of the late bilinguals, this concerned their L1. We decided to test their L2 proficiency by means of a Lexical Decision test instead of administering a second verbal fluency test, because we were concerned about possible interference effects with the same test in their L1. Lastly, we conducted a Corsi Blocks spatial Working Memory Test, because we expect an age-related decline in Working Memory span (Chen & Naveh-Benjamin, 2012; Hoyer & Verhaeghen, 2006), which could interact with the switch and the mix effect.

5.3. Methodology.

5.3.1. Participants.

Our experiment involved three different language groups, namely a control group of functional monolinguals, a group of early bilinguals and a group of late bilinguals. In the original design of the experiment, we also defined a middle-aged group (35-56 years old) and an elderly group (65-85), with the participants of each language group equally divided over these age groups. The functionally monolingual group was composed of 48 speakers of German, living in the northwestern part of Germany, and 2 speakers of English, living in the UK. 25 participants belonged to the middle-aged group (mean age 48.1, SD 5.3) and 25 to the elderly group (mean age 73.7, SD 4.0). Participants were assigned to this group on the basis of a questionnaire, containing a self-assessment report with yes/no questions on their knowledge of and proficiency in any language they were familiar with. Of the middle-aged group, 8 participants were male, and 17 female; of the elderly group, 13 participants were male and 12 female. We chose native speakers of German for this study instead of native speakers of Dutch, because it would be virtually impossible to find monolinguals in the Netherlands who would match the other two language groups in their educational level. The language situation in Germany is different from that in the Netherlands: exposure to foreign languages, e.g. through the media, is limited, which makes it is still possible to find "functional monolinguals" in Germany, especially for the elderly age group. For the middle-aged group, finding participants who fitted this criterion already proved more difficult, which explains why we included two monolingual speakers of English in this group. As German, Dutch and Frisian are very closely-related West Germanic languages, sharing many cognates and other linguistic features, German monolinguals seemed to be an appropriate control group for comparing bilinguals and monolinguals. Participants were only defined as functionally monolingual when they had never actively used a dialect either.

The early bilingual group was composed of 50 speakers of Dutch and Frisian; 25 participants belonged to the middle-aged group (mean age 46, SD 5.7), and 25 to the elderly age-group (mean age 73.2, SD 6.2). Of the middle-aged group, 9 participants were male, and 16 female; of the elderly group, 13 participants were male and 12 female. All the early bilinguals participants were fluent in both Frisian and Dutch, had acquired them before the age of seven and used them on a daily basis ever since. Frisian is a minority language spoken in Friesland, a northern province of the Netherlands, and is highly related to Dutch and to German. Thus, within each bilingual group, all participants were bilingual in the same language pairs (either Dutch/German or Dutch/Frisian). For both the early and late bilinguals, knowledge of additional languages, learned after age 12, was logged but not taken into account as an additional variable, because we did not test proficiency in these languages, and did not want to rely on self-reported proficiency.

The late bilingual group originally comprised 50 speakers of German and Dutch; 25 participants belonged to the middle-aged age-group (mean age 48.1, SD 5.6), and 25 to the elderly age-group (mean age 72.4, SD 3.2). Of the aged group, 4 participants were male, and 21 female; of the elderly group, 7 participants were male and 18 female. Because in the analysis we conducted on the data of our monolinguals and early bilingual we found that it was better to use age as a continuous variable, we decided to also include the data of 15 more late bilingual participants between age 56 and 68. The mean age of this group was 63.5 (SD 2.2). This implied that in total there were 65 late bilinguals, with a mean age of 61 (SD 11.5).

Of this late bilingual group, 54 participants had spoken German during the first part of their lives, and had acquired Dutch in a natural setting, between ages 21 and 49. The remaining 11 late bilinguals had a Dutch language background, and had moved to Germany between ages 22 and 66.

Most participants were recruited via the personal network of the first author of this paper, or via the network of the German student assistant. Participants from both language groups were selected also according to educational background: they had at least 4 years of secondary education.

In accordance with recommendations by Hilchey and Klein (2011), Paap and Greenberg (2013) and Paap (2014), the language groups were matched on demographic factors as much as possible. Importantly, our early bilinguals were not bicultural, nor were they immigrants; speaking two languages was not a matter of choice, but a result of being born in a bilingual region. To conform to the recommendation (Paap & Greenberg, 2013) to match language groups on socioeconomic status, we defined the factors occupational level and education. We operationalized occupational level on a three-point scale, to give an indication of participants' occupational prestige and concomitant income. Manual or unqualified jobs were rated as 1, jobs requiring advanced vocational training as 2, and academic professions, e.g. doctor, lawyer, or teacher in higher education as 3. Concerning education, we recruited exclusively participants with at least 4 years of secondary education. Moreover, since education in the Netherlands and Germany is offered at different levels, we defined educational level as a factor with a three- point scale. The German student assistant and a qualified German teacher working in the Netherlands made sure that the divisions for educational levels in Germany and the Netherlands were matched.

Regarding the elderly groups, all participants still lived independently, prepared their own meals and led active social lives. Regarding living environment, most participants lived in the more rural parts of the north of the Netherlands or Germany, but we also controlled for this factor by means of a distinction between living in a small village, a large village, a provincial town or a large town. Lastly, two other factors which have been claimed to affect executive functions - musical experience and video gaming- were also controlled for. All details on demographic factors are presented in Table 1.

Table 1. Demographic details about the participants.

Factor	Middle-aged			Elderly		
Bilingualism	mono	early	late	mono	early	late
Age	48.1 (5.3)	46.3 (5.6)	48.1 (5.6)	73.7 (4.0)	73.6 (6.1)	69 (5.2)
Gender: male/female	8/17	9/16	4/21	13/12	13/12	11/29
Educational level	2.1 (0.9)	1.9 (0.8)	2.4 (0.8)	2.1 (0.7)	2.2 (0.7)	2.1 (0.7)
Occupational level	1.9 (0.7)	2.0 (0.5)	2.2 (0.9)	1.9 (0.4)	2 (0.5)	2 (0.7)
Living environment: small village/provincial town/large town*	2/15/8	6/17/2	6/10/9	4/15/6	4/21/0	21/16/3
Musical skills: beginner/advanced/(semi)-professional	3/2/0	5/2/0	6/1/4	2/1/2	5/2/1	15/1/1
Playing computer games: Never/seldom/often**	20/5/0	22/3/0	22/2/1	24/1/0	25/0/0	33/6/1

5.3.2. Procedure, general

Both the early and the late bilingual participants were tested by the same experimenter, the first author of this paper, in their own homes, during a single experimental session lasting ca. 120 minutes. The functionally monolingual participants were also tested in their own homes, either by this same experimenter or by a German student assistant. To make sure that the testing conditions for all participants were similar, the entire procedure was carried out according to a written-out script. First, in a test-demo participants were given instructions for the computerized version of the task-switching test. Next, they performed the first part of this task-switching test, to be followed by a verbal fluency test, and then the second part of the task-switching test. Subsequently, participants carried out the forward and backward versions of the Corsi Blocks test (a spatial working-memory test) and were given a questionnaire that was adapted from the language background questionnaire by Gullberg and Indefrey (2003). In the case of the control group, the questionnaire also contained a self-assessment report with yes/no questions about their knowledge of and proficiency in any language they were familiar with. Additionally, between the Corsi Blocks test and the questionnaire, the late bilinguals performed a computerized version of a word recognition test in their L2.

5.3.3. Task-switching test

This test was based on the experiment reported by Prior and MacWhinney (2010), who adapted their procedure from Rubin and Meiran (2005). Participants were seated ca. 60-80 cm from a 15.4 inch laptop monitor screen and had to respond to objects presented on this screen, by pressing buttons on a Serial Response Box (produced by Psychological Software

Tools Inc., Pittsburgh, PA). Experimental script and data collection were managed by the E-prime computer program for response time measurement. Before the actual test, participants were presented with a set of instructions, also programmed in E-prime, to familiarize them with the test procedure. The test itself consisted of three blocks, all comprising a set of instructions, to be followed by a number of practice trials and experimental trials. Trials started with the presentation of a fixation cross for 350 ms., followed by a 150 ms. blank screen. Then a task cue appeared on the screen for 650 ms, slightly above the fixation cross. For the color task the cue was a color wheel and for the shape task a black undefinable shape. While the task cue remained on the screen, the target appeared in the center of the screen. Targets were either red or green squares or triangles and did not contain any linguistic information. Cue and target remained on the screen until the participant responded or for a maximum duration of 7 seconds. Practice trials differed from experimental trials in that written feedback on the screen informed participants whether their response was correct or not. After the participant's response a blank screen was presented during 850 ms., which was followed by the start of the next trial.

During single-task blocks, the color task had to be performed with the right hand, and the shape task with the left hand. During the color task, participants were instructed to respond to the appearance of a red object with the index finger, and to that of a green object with the middle finger, while ignoring the shape of the object. During the shape task, they had to respond to the appearance of a triangle with the index finger, and to that of a square with the middle finger, while ignoring the color of the object. During mixed-task blocks, the conditions from the single-task blocks were combined and the assignment of task to hand and finger was preserved. This implied that during each individual trial, the appearance of either the color circle or the black shape, slightly before the presentation of the target, required participants either to focus on the color of the object and ignore its shape, or to focus on the shape of the object and ignore its color. The buttons of the Serial Response Box to be used for the color task were labeled with red or green stickers, and the buttons to be used for the shape tasks with stickers showing a triangle or a square in black and white, with similar stickers attached slightly above the buttons. Additionally, the same stickers were pasted slightly below the screen, so that participants would not have to move their gaze from the screen to the Serial Response Box to remember the instructions, thus reducing potential time-delay because of working-memory load.

The task-switching experiment consisted of two parts. The first part comprised two single-task blocks (first color, then shape), each including 8 practice trials followed by 24 experimental trials, and one mixed-task block including 8 mixed-task practice trials, followed by 48 experimental trials. In both the single and mixed-task blocks, participants could only start with the experimental trials when at least 80% of their responses on the practice trials were correct. Furthermore, 2 dummy trials were added before each group of experimental trials, to reduce effects of time-delay because of starting problems. These dummy trials were not included in the analysis. In the mixed block, half of the experimental trials were switch trials (i.e., participants had to switch from indicating the color, to indicating the shape of the target, or vice versa) and half of them repetition trials (i.e. they had to focus on the same criterion as in the previous trial), ordered in a semi-random design with a maximum of 3 consecutive trials of the same type. After a break, during which participants did the verbal fluency test, the second part of the task-switching test was administered. This part started with a mixed-task block, which comprised 8 practice trials and 48 experimental trials, again preceded by 2 dummy trials. The mixed-task block was followed by two single-task blocks, again comprising 8 practice trials, 2 dummy trials and

24 experimental trials, and presented in the opposite order from the first part. Altogether, the experimental blocks in this sandwich design contained 48 switch, 48 repetition trials, and 96 single-task trials (48 color and 48 shape).

5.3.4. Lexical Decision Test

This test measured visual word recognition and was presented on 15.4 inch laptop monitor screen. Participants were instructed to indicate by pressing a button whether they thought the words that were subsequently presented on the screen were existing words or not. There was no time restriction for responding. Experimental script and data collection were managed by the E-prime computer program. The German late bilinguals completed the Dutch version of the test. This test contained a total of 200 Dutch words, 100 of which were pseudo words and 100 existing words. The words were taken randomly from 10 frequency bands of the Dutch corpus of the CELEX lexical database. The Dutch late bilinguals completed the German version of the test. This test contained 150 German words, 75 of which were pseudo words and 75 existing words. The words were randomly selected from the German corpus as used by the CELEX lexical database. Although reaction times were recorded, only the accuracy scores were used for analysis. See Appendix 1 for the lists of words used in both tests.

5.4. Results

The average working memory scores (Corsi blocks, forward span) are shown in Table 2.

Table 2. Average working memory scores for the three groups of speakers.

Group	Mean (min-max)	Standard deviation
Monolingual		
Middle-aged	6.4 (3-8)	1.2
Elderly	5.6 (4-6)	0.7
Early bilingual		
Middle-aged	6.3 (4-9)	1.1
Elderly	5.8 (4-8)	1.0
Late bilingual		
Middle-aged	6.4 (4-9)	1.1
Elderly	6.0 (4-8)	0.7

In order to test our hypotheses with respect to the influence of bilingualism and age on switch-task performance, we analyzed the response times in the single and mixed blocks by means of a linear mixed effects (LME) model (R version 3.0.2). The factors that we included into the model directly derive from the study design and were chosen such that the analyses are maximally similar to the ones presented in chapter 4..

Our first set of hypotheses concerned the effect of bilingualism on task switching costs. We hypothesized that the bilinguals would outperform the monolinguals in the switching task, showing lower switching costs. More specifically, we hypothesized that just like the early bilinguals (as was shown in chapter 4) the late bilinguals would outperform the monolingual controls. In addition, we hypothesized that the early bilinguals would outperform the late bilinguals, assuming that task performance is a function of the onset of bilingualism.

To test these hypotheses, we created an LME model of the response times in the mixed blocks.

This model included a factor that represents the trial type (repetition or switch trial), a factor that represents whether a subject is bilingual or not (treatment-coded as either 0 or 1), the subjects' age (centered) and their working memory score (Corsi Block forward span, centered), as well as a random effect of Subject, with random slopes per trial type. The working memory scores were included in order to control for possible group differences in this domain. Also, our analyses in chapter 4 of this dissertation had shown that the inclusion of this factor significantly improved the model fit. To encode for the difference between early and late bilinguals, the model included an additional factor Late (treatment coding, -.5 and .5). This factor was introduced as an interaction with bilingualism, bilingualism and trial type, bilingualism, trial type and age, and bilingualism, trial type and working memory score.. All analyses were performed on the log-response times, in order to compensate for the positive skew that is characteristic for response time distributions. For an overview of the complete model, please refer to Table A.3 in the Appendix. Here, we present a summary of the results, both in terms of the original parameters and in in terms of the derived non-log response time effects, as those are easier to interpret. The intercept of 741 ms represents the average response time in the repetition trials, for the average subject ($\beta = 6.608$, $SE = 0.037$, $t = 179.76$, $p < .000$). In the switch trials, the responses are significantly slowed down by on average 169 ms ($\beta = 0.205$, $SE = 0.015$, $t = 13.44$, $p < .000$). While bilingualism as such does not have a significant overall effect ($\beta = -0.004$, $SE = 0.043$, $t = -0.10$, $p = .923$), it significantly reduces the response times in the switch trials by 47 ms ($\beta = -0.053$, $SE = 0.018$, $t = -2.99$, $p = .003$). In addition, there is a significant effect of age, with average response times increasing by 9 ms for every additional year ($\beta = .012$, $SE = .003$, $t = 4.61$, $p < .001$). More importantly, we see an additional significant increase with age in the switch trials (9 ms, $\beta = 0.012$, $SE = 0.003$, $t = 4.61$, $p < .000$), which is compensated by a significant decrease if the speakers are bilingual (-4 ms, $\beta = -0.004$, $SE = 0.001$, $t = -3.19$, $p = .002$). There is no significant effect of working memory score. More importantly, late bilingualism, which has been introduced as an interaction with the other factors, does not result in significant effects. In other words, both early and late bilinguals show the same reduced switching costs. Our hypothesis that early bilinguals would outperform late bilinguals is not supported by the model.

The results of this model further support our hypothesis that response task performance in general and task switching in particular becomes more difficult with old age, as we see the same pattern as in chapter 4, even though the analysis now includes an additional group of late bilingual speakers. Age-related decline is partly compensated by bilingualism. However, we do not find evidence for the assumption that the size of this effect is a function of the age of onset of bilingualism. That is, the additional group of late bilinguals that we introduced in this chapter does not behave differently from the early bilinguals who were the focus of chapter 4.

In a next step, we turned to possible effects of bilingualism on mixing costs. That is, we compared the response times in the single-block trials to the repetition trials (or non-switch trials) in the mix-blocks. We built one linear mixed effect model, according to the same principles as described for the switching costs. The difference lies in the types of trials that we compare to each other.

In this model, we analyzed the subset of monolingual speakers and the late bilinguals with respect to possible effects of bilingualism on mixing costs. We do not find a significant effect of bilingualism, nor a significant interaction. Taken together, the results suggest that neither early nor late bilingualism affect the mixing costs in our switch task. The complete set of model parameters can be found in Appendix A4.

To further test our assumptions about the relationship between bilingualism and executive control, we explored the relationship between the size of the switching costs and individual measures of bilingualism within the group of late bilinguals. Figure 1 shows the relationship between the size of the switching costs and an individual subject's lexical decision score.

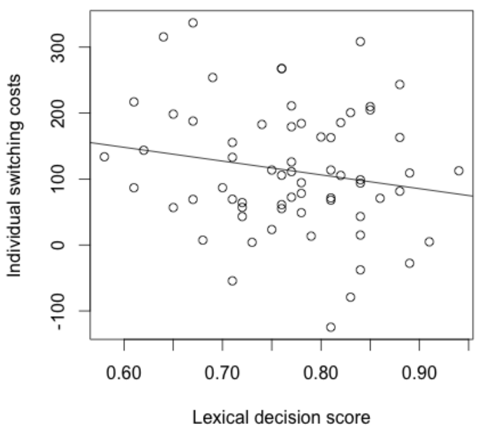

Figure 1. Relationship between the individual switching costs and the lexical decision score in the group of late bilinguals. Each dot represents a subject.

There is a small negative correlation between the two coefficients, which is however not significant ($r = -0.18$, $t = -1.439$, $df = 63$, $p = 0.155$).

Figure 2 shows the relationship between the individual switching costs and the number of years since immigration.

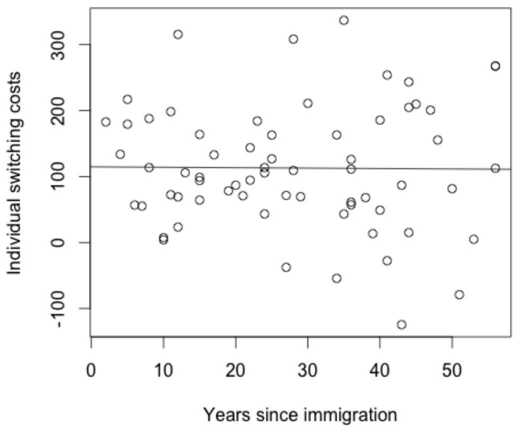

Figure 2. Relationship between the individual switching costs and the years since immigration in the group of late bilinguals. Each dot represents a subject.

As can readily be deduced from the figure, there is no significant correlation between the two coefficients (r = -0.01, t = -0.0845, df = 64, p-value = 0.933).

Next, we looked at the relationship between the size of the individual switching costs and age at immigration, which is depicted in Figure 3. Again, we find no significant correlation (r = 0.044, t = 0.3517, df = 64, p-value = 0.726).

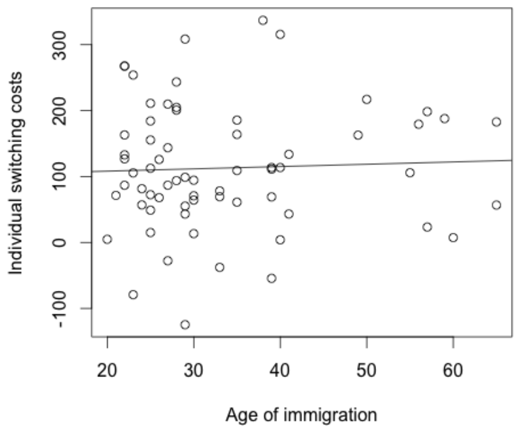

Figure 3. Relationship between the individual switching costs and the age at immigration in the group of late bilinguals. Each dot represents a subject.

5.5. Discussion and conclusion

This paper reports on a study investigating possible associations between bilingualism and efficiency of executive control, by comparing performance of groups of monolingual and bilingual participants on a cued task switching test and a Working memory test. In an earlier paper, reporting on two of the three groups included here, we showed that early bilinguals incurred significantly lower switching costs than monolingual controls, and that this difference increased with age. The present paper has a special focus on bilinguals who acquired L2 proficiency after puberty, and compares their performance on the same set of tests with the performance of both the monolingual controls and the early bilinguals. Because, just like in the previous paper, we also want to investigate whether late bilingualism can be associated with a modulation of an age-related decline in executive control, we looked again at the performance of both middle-aged and elderly participants. Following a seminal study by Prior and MacWhinney (2010), in our data analyses we focused on the switch effect (i.e., the difference between repetition and switch trials) and the mix effect (i.e., the difference between single block trials and repetition trials in the mixed blocks). Additionally, we looked at age-related and bilingualism-related effects on overall response times. Finally, unlike Prior and MacWhinney, our study explicitly looked at age-related effects, and as expected, we found an age-related decline in WM span. We therefore included WM span scores in the analyses of our results, so as to make sure to disentangle age-related effects as much as possible from effects of WM.

Regarding the switch effect, we expected an age-related increase in the size of the switching costs (c.f. Kray, Li and Lindenberger, 2002), and this expectation was confirmed. We also hypothesized that, in line with earlier research (c.f. Tao et al., 2011; Pelham & Abrams, 2014; but see Luk et al., for contradicting evidence), the late bilinguals would outperform the monolinguals. Our results show that not only the entire group of bilinguals, but also the late bilinguals as a separate group incurred a significantly smaller switch effect than the monolingual controls. Additionally, similar to our findings for early bilinguals, the positive effect of bilingualism is most pronounced in the elderly speakers. This is reflected by the significant interaction between the factors bilingualism and aging in the switch trials. Our hypotheses regarding the late bilinguals and the monolinguals are therefore confirmed. Second, since Luk et al. (2011) reported that earlier, continuing bilingualism correlated positively with executive control efficiency, we also hypothesized that the early bilinguals would outperform the late bilinguals. However, a comparison of the late bilinguals with the early bilinguals showed no difference between these two groups: there was no difference in the size of the switch effect, and no interaction with the specific type of bilingualism and the other factors, which contradicts our expectations.

Regarding the mix effect, we expected an age-related rise for all groups (c.f. Kray & Lindenberger, 2000; Reimers & Maylor 2005), and this expectation was confirmed. Because neither Prior and MacWhinney (2010) nor Prior and Gollan (2011) found a difference between language groups for mixing costs, and we found no difference in mixing costs between early bilinguals and monolinguals either (see chapter 4), we hypothesized no difference here between the late bilinguals and the other language groups, nor any interactions here between the factors language group and aging, and these hypotheses were confirmed. We also found an age-related increase in overall response times, which implies slower processing speed in the elderly (c.f. Cerella & Hale, 1994; Salthouse, 2000; Eckert, 2011). However, in accordance with our expectations, we did not find any association between overall response times and the factor language group, nor did this factor modulate the age-related increase in response times.

Finally, we performed a number of analyses within the late bilingual group. Luk et al. (2011) report correlations between earlier, continuing bilingualism and task performance, but we did not find significant correlations between any of the scores reflecting performance on the task-switching test on the one hand, and either the factor age of onset or years since immigration, on the other. Task-switching performance did not correlate with proficiency in the L2, reflected by the results on the lexical decision test, either.

In summary, most of our hypotheses regarding this experiment were confirmed. First, we found an age-related rise in the overall response times and in the switch and the mix effect, implying both a decline in general processing speed and in the efficiency of executive control in elderly individuals. Further, especially for older individuals we found that late bilinguals outperformed monolingual controls in the size of the switch effect, suggesting higher efficiency in executive control for this group, and a modulation of the age-related decrease of executive control efficiency. This latter finding can be interpreted in more than one way. The crucial issue is whether it is likely that this advantage that we found for the late bilinguals in our experiment is a result of their experience of speaking more than one language. Since on average, the members of the late bilingual group had actively used at least two languages for 27 years, it is not unlikely that this language experience has enhanced a number of interacting executive control processes which are tapped into during our task-switching test, in particular the ability to switch between mental sets and of the resistance to proactive interference (c.f. Prior & MacWhinney, 2010). This interpretation would be in line with results from a body of previous research pointing to a bilingual advantage in executive control (c.f. Costa et al., 2009 and Hilchey & Klein, 2011, for overviews), in particular those based on task-switching paradigms (e.g. Prior & MacWhinney, 2010; Prior & Gollan, 2011; Gold et al., 2013) and on experiments involving late bilingual participants (Tao et al. 2011; Pelham & Abrams, 2014). In this account, the inconsistency in findings between the relatively small difference in switching costs between middle-aged monolinguals and bilinguals in the present experiment, and the significant bilingual advantage in switching costs for college students, reported by Prior and MacWhinney (2010), could be attributed to a possible ceiling effect for the middle-aged group. This was created by the manipulation of the time-intervals, i.e. the time between the presentation of the cue and the target, and between the response on a trial and the start of the subsequent trial, which had to be relatively long on account of the participation of the elderly participants (see chapter 4).

However, two observations in the present study emphasize the need for caution in this interpretation of our results. First, we hypothesized that the early bilinguals in our experiment would outperform the late bilinguals. Unlike their late bilingual counterparts, the early bilinguals all had full, native proficiency in both languages, which they had all acquired before age 6 at the latest, and had used both languages on a daily basis ever since. It would therefore be logical to assume that, if the presence or the strength of a bilingual advantage is dependent on the attainment of full, native-like proficiency, the age of onset or the duration of bilingualism, or the relative amount of language switching, the early bilinguals would have outperformed the late bilinguals. However, our data show no evidence for such a conclusion; on the contrary, there was no visible sign that early bilinguals were doing better in any respect than bilinguals who had acquired their L2 later in the life span. Moreover, the analyses within our late bilingual group provided no evidence for any correlation between efficiency of executive control and language-related variables, such as level of L2 proficiency, age of L2 onset or the number of years since immigration. When we assume a linear relation between executive control and language use, this makes it even more unlikely that the advantage for the late bilinguals should be – entirely – attributed to their experience of speaking two languages. Still, it is possible that the combination of having to acquire and use an L2 at a later age is such an intense and challenging experience, that it could also lead to an enhancement of certain aspects of the cognitive system (c.f. Valian, 2015). On such a view, it would rather be the amount of challenge or effort involved in having to switch between languages and/or in having to suppress the non-target language, than the amount of experience in doing so, that would lead to more generalized cognitive enhancement. When we take a step further in this line of argumentation, it is even possible that once both languages have been acquired sufficiently well and switching has become effortless, the challenge will be over, so that from then on speaking more than one language will no longer boost the executive control system.

However, we are very cautious in making such a hypothetical suggestion, because the analyses within the group of late bilinguals provide no evidence for any negative correlation between the number of years passed since immigration and executive control, either.

The last interpretation that we can propose for the advantage that we found for our late bilingual group is what we call the confounding variables account: its essence is that group studies always bring the inherent risk that differences between groups are wrongly attributed to bilingualism (see Hilchey & Klein, 2011; Paap & Greenberg, 2013; Paap, 2014). In our study we controlled for a multitude of factors, such as gender, educational and occupational levels, living environment, etc. Additionally, we included the factor WM span in our data-analyses. However, we are aware that – at least - one factor remains that we could not control for, and that is immigration. Immigration effects have recently become a topic of debate in the literature on the bilingual advantage. Bialystok and Poarch (2014) propose that of all possible experiences with the potential of enhancing cognitive functioning (such as for instance musical skills), bilingualism is less prone to ambiguities in interpretation, because people usually become bilinguals not by choice or selection, but because of "life necessity, such as immigration" (p. 435). This may be true in some cases, but apart from groups of political refugees, it cannot be denied that there is a considerable group of immigrants who, for completely valid reasons, did make a deliberate choice to move to a country with better prospects – and this tends to set them out as a group from those who, either by choice or because of a lack of initiative, a failing health or whatever other reason, did not make that choice. Health in particular has been argued to be a strong 'selection' criterion for immigration, not only because immigrants are more likely to make the choice to emigrate when they are healthy, but also because once they have made that decision they have better chances to pass the health screening tests of the country of immigration (see Kennedy, McDonald & Biddle, 2006). Evidence shows that the relatively better health of immigrants extends to a slower rate of cognitive decline in later life (Hill, Angel & Balistreri, 1982). Fuller-Thomson and Kuh (2014) argue that this 'healthy migrant effect' – i.e., evidence that immigrants have better morbidity and mortality outcomes than non-immigrants, after adjustment for socio-economic status, c.f. Kennedy et al., 2006 - may explain the outcomes of some of the studies into the bilingual advantage. Another reason why immigrants may – or may not, for that matter – show improved cognitive performance compared to non-immigrants is that they will have to show more initiative, relative to non-migrants, in order to be successful in the country to which they migrated, and develop a relatively more active life style. This could possibly also lead to better performance on cognitive tests.

In summary, we conducted an experiment involving a cued task-switching test and a working memory test to investigate whether bilinguals who had acquired their L2 after puberty differed from monolinguals and from bilinguals who had acquired their L2 before the age of 6. An earlier study had already reported significantly lower switching costs for the early bilinguals compared to the monolinguals. The late bilinguals differed from the monolinguals in that they incurred lower switching costs and in that they showed a smaller increase in switching costs with age, but they did not differ in any respect from the early bilinguals. Moreover, analyses within the late bilingual group did not show significant correlations between the switch or the mix effect and any language-related factor. On the basis of these analyses, we propose that it is possible that for the late bilinguals, too, the experience of speaking more than one language, although the second one was acquired at a later age, has enhanced the efficiency of their executive control system, particularly the ability to switch between mental sets and their resistance to proactive interference (see Prior

& MacWhinney, 2010). However, it cannot be ruled out that one or more confounding variables have affected our task results, although we have matched our participant groups as meticulously as possible on a vast amount of demographic variables. In particular, the fact that, unlike the two other groups, the late bilinguals were immigrants, might have played a role.

This paper therefore emphasizes once more that studies investigating effects of bilingualism by comparing participants recruited from different populations run the risk that differences in task results are wrongly attributed to differences in patterns of language use or acquisition (c.f. Paap & Greenberg, 2013). This does not mean that we exclude the possibility that bilingualism may have some kind of enhancing effect on cognitive functioning. In particular some experimental studies that looked at effects of a particular aspect of language use by means of analyses within the same population have come up with compelling evidence, because they decrease the risk of being confounded by effects of other variables (c.f. chapter 4 of this dissertation; Verreyt et al., 2015). However, we would like to stress that for this type of experimental research there is a need for valid, sensitive instruments, such as questionnaires that can give a full and detailed picture of a participant's behavior over the life span. It is evident that such a picture should not only reflect - multiple - aspects of language use, but that as many other life-style factors should be taken into account as possible.

Chapters 4 and 5 reported on comparisons of general cognitive performance between groups of bilinguals and of monolingual controls. Chapter 6 reports on a comparison of performance on a verbal fluency task between a group of early bilinguals and a group of monolingual controls.