LEIDEN UNIVERSITY

MASTER'S THESIS

The Effect of Code-Switching on Cognitive Control

Author:
V. BOUWER
s2049465

Supervisor:
DR. E. BOSMA

A thesis submitted in fulfillment of the requirements
for the degree of Master in Theoretical and Experimental Linguistics
in the Faculty of the Humanities

Universiteit Leiden

Abstract

Intrasentential code-switching requires cognitive control in production (Verreyt et al., 2016) as well as comprehension (Adler et al., under review). The first language needs to be inhibited as soon as the second languages is encountered. The neurological system that is associated with cognitive control may stay active for a while after being triggered. Cognitive control is used for any (cognitive) task that requires inhibition, selected attention or decision making. An example of such a task is the Flanker task, in which a participant has to determine the direction of an arrow surrounded by four (congruent or incongruent) distractors. In general, when the arrows all point in the same direction (congruent condition) participants have a shorter reaction time than when the surrounding arrows point in the opposite direction of the target arrow (incongruent condition).

The effect of code-switches on Flanker trials has been studied behaviourally. These studies show that processing a code-switch has a positive effect on the reaction time on the incongruent Flanker trials. In this study, we support previous behavioural findings with an electrophysiological investigation of the effect of code-switch detection on cognitive control.

We recorded the EEG of 34 participants while they alternated between reading sentences (with and without code-switches) and Flanker trials. In the analysis of the EEG, we were specifically interested in the P300 component, which is associated with shifts in attention. The P300 amplitude is higher when more cognitive control is required (Neuhaus et al., 2010). Since incongruent Flanker trials require more cognitive control than congruent trials, the classic Flanker effect is that the incongruent trials produce a larger P300. However, after being activated by a code-switch, if the cognitive control mechanism indeed stays active for a while, the P300 amplitude of an incongruent Flanker after a code-switch would be lower than one after a sentence without a code-switch.

The mean ERP amplitudes were analysed with a 4-way repeated measures ANOVA. Significant interactions were found between sentence type and congruency. There was a significantly larger P300 in the congruent condition than in the incongruent condition, but only when the preceding sentence did not have a code-switch. The P300 was significantly larger after sentences with a code-switch than after sentences without a code-switch, but only in the incongruent condition. There was no effect of sentence type in the congruent condition. These results provide electrophysiological support for previous findings by Adler et al., (under review).

Chapter 1 Introduction

In certain situations, bilingual speakers produce or perceive utterances in which there is a switch from one language to another. This phenomenon is called intrasentential code-switching (Gumperz, 1982). Several studies indicate that switching between languages requires cognitive control mechanisms, i.e. the inhibition of the non-target language (Green & Wei, 2014; Hofweber et al., 2016; for reviews, see Bobb & Wodniecka, 2013 and Declerck & Philipp, 2015). Cognitive control entails selecting appropriate perceptual information and everyday decision making. Bilingualism has been associated with performance advantages across various cognitive tasks (Bialystok, Craik & Luk, 2008 and Lee Salvatierra & Rosselli, 2011). Not all researchers found the same effect. Based on a comparison of proficiency levels and the use of code-switches, Verreyt et al. (2016) suggest that the actual process of code-switching is a crucial element in this bilingual advantage.

Research by Adler et al. (2017) shows that there might indeed be a carry-over effect of neurological activity from code-switching to other (non-linguistic) tasks that require similar executive functions. Adler et al. combined the Flanker task (Eriksen & Eriksen, 1974) with a self-paced reading task. In the Flanker task, a participant must indicate the direction of a target arrow (left or right), ignoring four distracting arrows (two on each side of the target) which point either in the same direction as the target (congruent condition) or in the opposite direction (incongruent condition). In this type of tasks, the congruent trials are generally performed with a lower reaction time than the incongruent trials. Also, if two incongruent trials occur following each other, the second incongruent trial is generally performed faster than the first incongruent trials. In the self-paced reading task, a participant reads a sentence word-by-word using a key button to see the next word. Adler et al. presented participants with sentences with and without code-switches (congruent and incongruent, respectively). Results showed that incongruent Flankers preceded by an incongruent sentence had shorter reaction times (RT) than those preceded by a congruent sentence, but no difference was found between congruent Flankers.

The present study follows a dual task paradigm similar to the one applied by Adler et al., but focuses on the neurophysiological instead of the behavioural aspect. The aim of this study is to investigate neurophysiological carry-over effects of cognitive control from a linguistic to a non-linguistic task. Like Adler et al., we combine a reading task (with Dutch - English code-switches) and the Flanker task.

The approach that we use to examine the neurophysiological effects in code-switching and cognitive control functions is electroencephalography (EEG). EEG is a non-invasive method to record electrical activity in the brain over time. Variations in this activity are measured by electrodes placed on the scalp (Luck, 2014). EEG has a relatively poor spatial resolution, but the temporal resolution is very high (Srinivasan, 1999). EEG-recording is highly sensitive to a participant's movement, which creates unwanted artifacts or noise in the raw data. Therefore, eye movement and speech are to be avoided as much as possible. Although EEG is not suited to look into code-switch production, it is an excellent measure during the perception of code-switches in text or ongoing speech. Where behavioural measures such as reaction times are a cumulative sum of all ongoing processes, EEG can reveal different mechanisms as a code-switch is encountered, since it measures the neural response to the stimulus (Van Hell, 2017).

Wu & Thierry (2013) carried out a study very similar to the present one, in which they investigated P300 effects in a dual task setting with a Flanker task and a single-word reading task with monolingual and bilingual trial sets. In the monolingual set, words from a single language were presented, whereas in the bilingual set words from two languages were presented . They found a lower P300 amplitude for incongruent Flankers in the bilingual condition compared to the monolingual condition.

With these factors in mind, the expectation of the present study is to find a classic Flanker effect, i.e. an increase in P300 amplitude for all incongruent conditions compared to the congruent conditions, since more cognitive control is required. However, a smaller increase in P300 amplitude is expected when an incongruent Flanker is preceded by a code-switch, than when it is preceded by a congruent sentence. No difference is expected between congruent Flankers preceded by sentences with and without a code-switch. There might be a smaller P300 during code-switches in longer sentences, because of the heavier workload for the working memory.

1.1 Bilingualism and Cognition

Over half of the world's population is bilingual (Grosjean, 2010), but there are several definitions of bilingualism. The most important point of discussion is whether bilingualism suggests an equally high proficiency in speaking, comprehending, writing and listening for both languages. Beardsmore (1986) argues that this type of equal proficiency is actually relatively rare and calls it ambilingualism. Another issue is the age of acquisition; at what point in life is one too old to become bilingual? If we take into account proficiency only, age should not be very relevant. Marinova-Todd et al. (2000) state that, although older learners are less likely than young children to master a second language, a close examination of studies relating age to language acquisition reveals that age differences reflect differences in the situation of learning rather than in capacity to learn. For this study, we will define bilingualism as the ability to speak, comprehend, write and read in a second language (in this case English) in an academic setting. In practice, this means that our participants will all have followed university courses in English.

1.1.1 The bilingual brain

For a long time it has been assumed that bilingualism was confusing for children and had negative conseqences for the developing brain (Hakuta, 1986). However, already in 1962 a study by Peal and Lambert showed that French-English bilingual children outperformed a monolingual group when carrying out linguistic as well as nonverbal spatial tasks. Later studies found a significant difference between monolingual and bilingual children in their metalinguistic awareness (Ben-Zeev, 1977) and ability to ignore misleading information (Bialystok & Majumder, 1998). But in terms of vocabulary size, it seems that bilingual children and adults are weaker than monolinguals in both of their languages. For example, in picture-naming tasks results have been found where bilingual participants were slower (Bialystok et al. 2008) and less accurate (Gollan et al., 2007) than monolinguals. In other words, finding both advantages and disadvantages for bilinguals, it is clear that there is a cognitive effect from knowing more than one language.

An important question to address when looking at the effect of bilingualism on cognitive control, is how the bilingual brain is organized. One possibility is that it consists of two independent language systems (i.e. lexicon, grammar, etc.) which are accessed depending on the situation or context. However, several studies have suggested that bilinguals show some activation of both languages in every situation (Beauvillain & Grainger, 1987 and Kroll & de Groot, 1997). Interaction between both languages occurs even in contexts that are entirely focused on only one of the languages. They have shown this joint activation by using tasks such as cross-language priming (where a word in one language facilitates retrieval of a semantically related word in the other language) and lexical decision tasks (Bialystok et al., 2012). These tasks show that one language can be interfering with the other.

1.1.2 Code-switching and cognitive control

In general, interference is seen as any situation in which contradictory information enters the brain, and one signal has to be inhibited in order to process the other. Specifically within the field of bilingualism, this is a very interesting phenomenon. Berthold et al. (1997) define interference as the first language influencing the second language in terms of grammar, phonology and lexical decisions. Dealing with interference and successfully inhibiting inappropriate responses or ignoring contradicting information requires cognitive control, i.e. when someone speaks several languages, the correct words and grammar have to be chosen during speech.

Sometimes, someone who is bilingual may alternate between two languages when speaking to someone with knowledge of the same languages. This type of alteration, or code-switching, can occur between sentences in a longer narrative, or within sentences (intrasentential code-switching) and is relatively frequent among bilinguals (Skiba, 1997).

Possible reasons for code-switching are discussed by Crystal (1987) in the Cambridge Encyclopedia of Language. The first possible reason is that a speaker may not be able to express everything as well in the second language as in the first language. In this case, code-switching is used to compensate for the deficiency and the speaker may keep speaking in the other language for a while. Another situation in which code-switching tends to occur is in social contexts or groups, where a speaker may want to express solidarity or exclude others who do not speak the language. In production, it seems that code-switching is not a language interference but rather a supplement that contributes to continuity of speech or (socio)linguistic advantage.

However, to understand and accurately parse code-switches, cognitive control is essential. For example when reading a text, a sudden change of language asks for quick inhibition of the first language to be able to process the words in the second language. In any situation of code-switching, when brain regions associated with cognitive control are activated, we want to investigate if they stay active for a while. The study by Adler et al. (2017) gives more insight in the immediate effects of code-switches on cognitive control performance.

1.2 Electroencephalography

Electroencephalography (EEG) reflects the electrical activity (in voltage) of the human brain over time. This technique produces a mixed up collection of hundreds of distinct neural sources of activity, making it complicated to recognise individual neurological processes. EEG uses voltage (E) which is electrical pressure, also called potential, and current (I), the number of charged particles. Current is analogous to measuring a certain quantity of water passing through a pipe in a fixed time period (e.g. 10 liters per minute). Resistance (R) is the inverse of conductance and when multiplied by current results in voltage (Ohm's Law). Current flowing through a conductor generates a magnetic field, and a magnetic field flowing through a conductor induces an electrical current. These are the basic concepts of the electrical and magnetical principles of EEG. For more details on this matter, I would refer to the book by Luck mentioned above.

Conducting an EEG experiment has several steps. First of all, electrodes need to be attached to a subject's scalp to pick up the EEG. Three types of electrodes are used: 1) the ground; 2) the reference electrodes (placed on e.g. the mastoids) and 3) the active electrodes used for actual measurements. The EEG must be adjusted (e.g. filtering, amplifying, see section EEG-analysis) to be able to create a dataset of discrete voltage measurements on a computer. At this point, various artifacts such as eyeblinks are still present in the EEG. Therefore, one needs to apply artifact reduction which can be done manually or automatically using a computer. The data need to be averaged to extract the Event Related Potentials

(ERPs) from the overall EEG. A grand average would be the average waveform of the averages per subject.

ERPs are the neural responses, embedded within the EEG, that are related to specific events. ERP can be extracted from the overall EEG by averaging. The ERP technique is only usable for a small field of research, since interpretation is very complicated. For example, ERP is a great complement in studies using fMRI or PET scanning techniques to gain a better temporal resolution.

Electrical activity in the brain provides with two different types of potentials. Action potentials are voltage spikes at the release of neurotransmitters, and postsynaptic potentials are the voltages that arise when neurotransmitters bind to receptors. ERP measures mostly postsynaptic potentials. An important distinction to make is that ERP reflects the difference in activity between two sites, and never the activity at a single site.

The aim of ERPs is to find components. A component is scalp-recorded neural activity that is generated in a given neuroanatomical module when a specific computation operation is performed (Luck, 2014). A component can occur at different times and under different conditions, but it always comes from the same module and represents the same cognitive function. Examples of components are the Contingent Negative Variation (CNV, Walter et al., 1964) which represents the motor preparation for the upcoming target. A similar component is Readiness Potential, different in that it can occur without stimulus and is lateralized. Other important components are the P300, a large positive peak around 300ms poststimulus if a stimulus is unexpected, the N400 for violations of semantic expectancies and the P600 for violations of syntactic expectancies. This study focuses on the P300, which is discussed in more detail later.

1.2.1 EEG analysis

Before one can analyse the raw signals of an EEG experiment, the data need to be preprocessed. This cleaning process has many possibilities of which I will describe the most relevant for this study. The raw EEG signal still contains noise recorded during the experiment. Reducing this noise is very important to get a clear signal which is suitable for analysis. The first step in noise reduction is applying filters. Since in most studies we are not interested in any activity over 30 Hz, this step would be to apply a filter that eliminates everything above 30 Hz. The exact threshold is to be chosen based on the study at hand.

Noise in the signal is not only caused by equipment, but also by the participant. These forms of noise are called artifacts and result in spikes in the signal which are not due to neurological activity. Two of the most important artifacts are eye blinks and movements. These can be removed manually, but there are computational methods available as well, such as independent components analysis (ICA). Aside from eye blinks and movements, muscle activity and skin potentials can also cause artifacts, making averaging more problematic. To deal with these artifacts, there are two main methods. With artifact rejection, large artifacts are detected in the single trial EEG epochs, and contaminated trials are excluded from the averaged ERP waveforms. When using artifact correction, the estimated contribution of the artifacts to the ERP is substracted from the average. Correction is less precise and thus less secure than rejection. However, rejection causes more loss of data.

Before averaging, a baseline correction is applied. Often, the average of the first 200ms before stimulus is used as a baseline, or representation of the zero point, to make the difference between the pre- and post-stimulus state visible and interpretable. Averaging itself is another method to reduce noise (since noise is often random, the average should lie around zero) and the ERP remains. Also, the average of all the trials per participant or condition can be used. To make the data easier to handle digitally, downsampling is applied, reducing the resolution of the data.

Another useful step in preprocessing the data is segmentation. Before segmentation, one places markers at specific points in the raw signal, for instance at the start and end of every trial or stimulus. This can also be done automatically in the testing fase, if this is included in the experimental design. Segmentation of the data gives cut pieces of signal which can be analysed apart from each other. If a study has different conditions within the trials, one could segmentate those conditions to be able to create an average per condition.

To analyse and interpret the now obtained ERP waveforms, one needs to compare the waveforms of different groups, conditions or times. When a difference in the signal is visible, this needs to be statistically supported.

1.2.2 Possibilities and Limitations of EEG

Compared to behavioural measures, EEG is better capable of showing the difference between a slow reaction and a slow part of a process. Even when there is no behaviour at all, the processes are still visible. Compared to other physiological measures, EEG has the advantage of being non-invasive to a subject (in contrast with e.g. single neuron measurements). EEG also has an excellent temporal resolution, on the order of milliseconds. Other advantages are low costs, silent measuring and no risk of provoking claustrophobia (all in contrast to e.g. fMRI).

The most important limitation of EEG is the low spatial resolution. fMRI, for instance, can directly present active brain areas, while EEG requires excessive interpretation to only be able to hypothesize about the relevant areas. One of the spatial resolution issues is called the Inverse Problem: it is impossible to know what configurations were responsible for the observed voltage distribution. Interpretation of timing can be difficult as well. Although longer latencies are fairly easy to observe, the reason is not always clear. To be able to avoid interpretation ambiguities, it is useful to focus on a specific component or a well studied experimental manipulation.

1.3 The issue

Previous research has investigated the cognitive effects of bilingualism and debated the advantages and disadvantages it may entail. There is an ongoing debate about whether lexical access is more difficult for bilinguals than for monolinguals. Both languages are active and interact during speech, which either results in a facilitation effect, or creates the need for some type of selection or inhibition (Bialystok et al., 2008). The essential ability underlying this skill is cognitive control, which entails selecting appropriate perceptual information and is active in everyday decision making.

Verreyt et al. (2016) investigated the influence of code-switching on executive control. They compared the performance of unbalanced bilinguals, balanced nonswitching bilinguals and balanced switching bilinguals on two executive control tasks. The distinction between balanced and unbalanced bilinguals was made in order to see whether the cognitive effect occured due to language proficiency. The tasks that the participants had to perform were a Flanker task and a Simon task, both testing inhibition. They found no difference between the unbalanced and the balanced non-switching groups, but the switching bilinguals outperformed both of the other groups. This suggests that the actual process of code-switching is a crucial element in the effect of bilingualism on cognitive control, rather than language proficiency.

Wu & Thierry (2013) carried out a study very similar to the present one, in which they investigated P300 effects in a dual task setting with a Flanker task and a single-word reading task with monolingual and bilingual trial sets. They found a lower P300 amplitude for incongruent Flankers in the bilingual condition compared to the monolingual (congruent) condition. However, Neuhaus et al., (2010) topographically analyzed top-down Flanker effects on visual event-related potential morphology and found that the P300 amplitude was lower in the incongruent condition in the parietal lobe, but higher in the same condition in the frontal lobe. It is uncertain why these findings are opposite.

In the present study we will investigate carry-over effects of the neurological activity associated with cognitive control when a participant comes across a code-switch. We look into reaction times and neurological activity measured with electroencephalography. The component most relevant to this study is the P300, which is a positive peak around 250-500 ms post-stimulus in the parietal lobe (Sutton, 1965). A more recent view by Polich (2007) is that the P300 scalp distribution is defined as the amplitude change over the midline electrodes (Fz, Cz, Pz) instead of just in the parietal lobe. He states that the generation of the P300 might be caused by brain mechanisms engaged to inhibit extraneous brain activation and reflects rapid neural inhibition of ongoing activity to facilitate transmission of stimulus information from frontal (P3a) and temporal-parietal (P3b) locations.

The distinction between the P3a and P3b components derives from findings from the 1970s where on the one hand, active attention towards a target stimulus was needed to elicit a P300, while on the other hand studies had demonstrated that an oddball paradigm (unpredicted stimuli in an ongoing repetitive series of stimuli) elicits a P300. In other words, conditions with active attention and conditions with non-attention or inhibition could both elicit a P300. Squires et al. (1974) then made a distinction between the P3a, which is the positive potential between 220 and 280ms after stimulus associated with inhibition, and the P3b, a positive potential between 310 and 380ms after stimulus associated with attention.

They found that the P3a has a peak amplitude at the frontal midline sites and the P3b at the temporo-parietal midline sites.

The P300 is associated with shifts in attention that update representations in working memory (Polich and Kok, 1995) and its amplitude increases when more attention (cognitive control) is required for the current task (Duncan et al., 2009). The P300 is sensitive to demands placed on working memory. When the P300 is compared in a single and dual task setting, it is concluded that the amplitude decreased when working memory load increased (Isreal et al, 1980; Kramer et al., 1985).

The P300 amplitude is higher when more cognitive control is required. Since incongruent Flanker trials require more cognitive control than congruent trials, the classic Flanker effect is that the incongruent trials produce a higher P300 amplitude. However, after being activated by a code-switch, if the cognitive control mechanism indeed stays active for a while, the P300 amplitude of an incongruent Flanker after a code-switch would be lower than one after a sentence without a code-switch.

Chapter 2 Methods

2.1 Participants and Procedures

2.1.1 Participants

The 34 participants (25 female, 9 male) were university students or graduates between age 17 and 30 (M = 23, SD = 3.5) with Dutch as their only native language. Considering brain lateralisation, all participants were right-handed. Subjects were paid 15 euros for their participation. All participants were proficient in English as a second language, which was tested using a proficiency test by Meara (1987) and by self-rating on a scale from 1 to 7.

In the proficiency test, the participant was presented with a list of words and asked to mark which words they knew. The list consisted of real words as well as nonwords, which resulted in hits (real words that the participant recognized) and false alarms (nonwords that the participants claimed to know) Correct rejections and unrecognized real words are not taken into account for calculating the true hit rate (Meara, 1994). The mean score of the proficiency test was 82.95 out of 100 (SD = 11.58).

In a questionnaire, participants reported the age of English acquisition, their language experience and self-rated proficiency. Participants self-rated their English proficiency between 4.5 and 7 (M = 5.6, SD = 0.6) on a scale from 1 to 7. The mean age of English acquisition was 9 years old (SD = 2.3 years). During activities such as watching TV, reading and writing, they spent on average 56 percent of their time using English (SD = 20.4). When speaking to family, friends, classmates and colleagues, an average of 20 percent of the time was spent speaking English (SD = 13). On average, participants indicated that they felt more comfortable speaking Dutch in 82 percent of the presented situations (watching TV, speaking

Language experience English	*M*	*SD*	Range	Max.
Meara score	82.95	11.58	50 - 97	100
Self rating	5.6	0.6	4.5 - 7	7
Age of English acquisition	9	2.3	3 - 12	n/a
Use of English in reading, writing, tv	56%	20.4%	6 - 96%	100%
Use of English in speaking	20%	13%	1 - 52%	100%

to friends, etc.). Of the participants, 94 percent stated that they used code-switches sometimes, of which most were using an English word in a Dutch setting. This information in combination with the self ratings, Meara's proficiency test and the fact that all participants used English on an academic level on a daily basis, convinced us that the English proficiency of our participants was in order (see table 1).

2.1.2 TASKS

Participants were asked to perform two tasks simultaneously: a rapid serial visual presentation (RSVP, Forster (1970)) reading task and the Flanker task. In the RSVP reading task, participants read sentences which were presented word-by-word. This way, participants did not need to move their eyes or press a key, which would both negatively influence the EEG data. RSVP reading also alters the information processing which is normally required for reading, which allows for contrasting conditions (Young, 1984). In this experiment, each sentence was preceded by a fixation cross (500 ms), after which the words appeared in the center of the screen for 300 ms with a 200 ms blank screen in between every word (see figure 2.1).

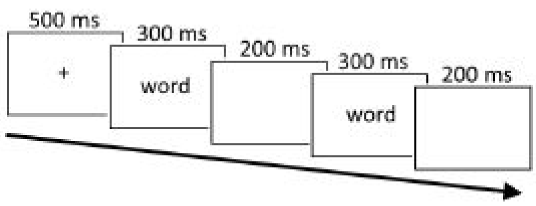

FIGURE 2.1: RSVP: word-by-word presentation

Of the 274 sentences (mean length 12 words), 96 had no code-switch (e.g. *De beroemde chef bereidde het diner voor de familie van Vera*. "The famous chef prepared the dinner for Vera's family.") and 78 sentences included a code-switch in the last 2 - 5 words (e.g. *Het echtpaar besloot een nieuwe tv te kopen for their new house.* "The couple decided to buy a new TV for their new house."). Sentences without a code-switch were all in Dutch. There was never more than one code-switch in a sentence, and this code-switch was marked in the EEG-signal for all target trials. The sentences with a code-switch always started in Dutch and ended in English, since the participants native language was Dutch, and we expected to find a clearer effect after code-switches from L1 to L2. Between sentences, a blank screen of 1000 ms appeared. 76 sentences were followed by a yes/no-question, in order to see whether participants were actually paying attention and understanding what they read. Questions were displayed until a participant answered using the arrow keys (left arrow for yes, right arrow for no). After answering, a blank screen appeared for 1500 ms.

Some of the sentences were followed by a Flanker trial. The Flanker task (Eriksen & Eriksen, 1974) presented participants with images of five arrows. The middle arrow was the target, and the four surrounding arrows were the distractors. Participants had to indicate the direction of the middle arrow by pressing a key on the keyboard (right or left arrow). In the congruent condition, all arrows pointed either to the left or to the right. In the incongruent condition, the target arrow pointed in the opposite direction of the distractors (see figure 2.2).

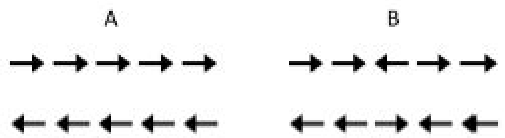

FIGURE 2.2: Flanker images: A = congruent, B = incongruent

The Flanker trials started with a blank screen of 1000 ms, followed by a fixation cross for 500 ms. The Flanker image was then displayed for 1000 ms (see figure 2.3).

The participant had to react as quickly as possible, with a time limit of 2000 ms after stimulus. Correct responses were logged and marked in the EEG-signal.

Combining these two tasks into one experiment resulted in four possible procedures: 1) a filler sentence (N = 26), in which a participant only reads the sentence without taking any

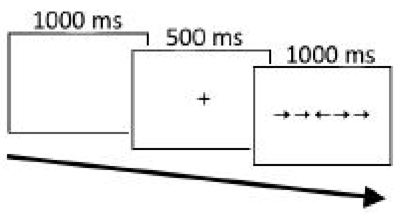

FIGURE 2.3: Overview of flanker procedure

further action, 2) a sentence followed by a question (N = 76), 3) a sentence followed by a Flanker trial (N = 72) and 4) a filler Flanker (N = 93) as summarised in table 2.

TABLE 2: Trials

Procedure	N
Filler sentence	26
Sentence + Question	76
Filler flanker	93
Sentence + Flanker	76

TABLE 3: Conditions

Condition	Sentence	Flanker
1	no CS	Congruent
2	CS	Congruent
3	no CS	Incongruent
4	CS	Incongruent

There was a total number of 274 sentences (= 26 + 72 + 76). The filler sentences and filler Flankers were not used for data analysis. A sentence followed by a target Flanker never included a question. The target trials (sentence + target Flanker) occured in four conditions: 1) a congruent sentence followed by a congruent Flanker, 2) an incongruent sentence followed by a congruent Flanker, 3) a congruent sentence followed by an incongruent Flanker, and 4) an incongruent sentence followed by an incongruent Flanker (see table 3). Each condition comprised 18 sentences. A balanced Latin square design was applied to the target trials based on condition. With a Latin square design, one makes sure that each combination of conditions occurs only once. A balanced Latin square design takes into account order of presentation as well. This design resulted in four different versions. The sentences were presented in a randomised order.

2.1.3 PROCEDURE

Subjects were first asked to sign an informed consent sheet. Then they completed a questionnaire with background information on language experience and the English proficiency test, which took about ten minutes. After this, they were prepared for EEG-recording. The actual task was performed in a quiet EEG-booth and started with instructions, followed by a practice session for the Flanker trials and a practice session for the full experiment (a short version of the actual task, 10 trials). Before starting the actual task, participants got a moment to ask questions. The experiment consisted of three blocks of 90 trials with two breaks of at least one minute each. EEG as well as reaction times were recorded. After the task, participants could use the facilities to wash their hair and received their payment.

2.2 Analysis

2.2.1 ERP acquisition

Electrophysiological data were recorded using the BioSemi ActiveTwo system in reference to the common sense mode (CMS, active electrode for reference) and driven right leg (passive electrode as ground) from 32 Ag/AgC electrodes. Impedances were kept below 15 kW. For analysis, reference was taken from the average signal measured at the mastoids. Flat electrodes were placed around the eyes to record ocular movements in order to filter these out during preprocessing of the data.

Brain Vision Analyzer 2 was used for preprocessing the raw EEG material and analysis. Several participants were eliminated from the data due to different circumstances, such as a second mother tongue, misunderstanding the tasks or unusable raw data due to very poor quality. Of the 40 initial participants, 6 were eliminated. Of the remaining 34 participants, topographic (spherical spline) interpolation was used to correct bad channels. After this, markers were edited, referencing was applied based on the mastoid electrodes and linear derivation was applied to the ocular channels. Butterworth (zero-phase) filtering (Butterworth et al., 2008) was used with a low cutoff of 0.1 Hz (24 dB/oct) and a high cutoff of 25 Hz (24 dB/oct). Ocular artifact correction was performed using the algorithm by Gratton, Coles and Donchin (1983) with a common reference of the vertical and horizontal ocular channels.

In the raw data inspection, gradient conditions were set to a maximal allowed voltage step of 100 μV/ms (100 ms before and 100 ms after event marked as bad). The maximal allowed difference of values in intervals were set to 200 μV with an interval length of 200 ms (200 ms before and 200 ms after event marked as bad). The minimal allowed amplitude was -150 μV and the maximal allowed amplitude 150 μV (100 ms before and 100 ms after event marked as bad). The lowest allowed activity intervals were set to 0.5 μV with an interval length of 100 ms (100 ms before and 100 ms after event marked as bad). All artifacts were rejected and incorrect responses were disregarded.

A segmentation process from 200 ms before to 1000 ms after the stimuli was used to separate the four conditions (allowing overlapped segments, skipping bad intervals). A baseline correction was applied with a 200 ms interval. Grand averages of the four conditions were calculated for each electrode.

2.2.2 STATISTICAL ANALYSIS

The classic time window of the P300 is 250 - 500 ms. Since Wu and Thierry (2013) found a later P300, the peak could occur delayed in our data as well. A visual inspection of the averages of the relevant segments seemed to show a later P300 indeed. With this in mind, area information of the mean activity in μV was exported for the time windows 250 - 500 ms (classic P300) and 450 - 800 ms (based on the visual inspection). To examine the scalp distribution, electrodes were grouped into Frontal Left (AF3, F3, F7), Frontal Central (Fp1, Fp2, Fz), Frontal Right (AF4, F4, F8), Medial Left (FC5, C3, CP5), Medial Central (FC1, FC2, Cz), Medial Right (FC6, C4, CP6), Parietal Left (P3, P7, O1), Medial Central (Pz, CP1, CP2, Oz) and Medial Right (P4, P8, O2).

Both the time windows were then used for a 4-way repeated measures ANOVA with the within-subject factors hemisphere (left, central, right), position (frontal, medial, parietal), code-switch (code-switch, no code-switch) and congruency (congruent, incongruent).

Chapter 3 Results

The aim of this study was to investigate whether code-switches provoke a cognitive control process. In order to test this, participants performed a task in which they read sentences with and without code-switches, followed by congruent and incongruent Flanker trials. Incongruent Flanker trials are associated with a difference in P300 amplitude compared to congruent Flanker trials. Where Wu and Thierry (2013) found a higher amplitude for the incongruent condition, Neuhaus et al. (2010) found a lower amplitude for the incongruent condition.

During the experiment, 76 sentences were followed by a question about the content of the sentence, in order to check whether participants were paying attention to the meaning of the sentence as well. Of the 76 questions, an average of 72 was answered correctly (range = 68 - 75, SD = 1.9). Reaction times revealed the classic Flanker effect, i.e. the reaction on incongruent Flanker trials was significantly slower than the reaction on congruent Flanker trials ($p < .001$) for trials preceded by sentences with as well as without code-switches (see table 4). The last column of table 4 shows the mean accuracy of the Flanker trials per condition.

TABLE 4: Reaction times and accuracy.
NoCS_Con = No code-switch - congruent Flanker
NoCS_Incon = No code-switch - incongruent Flanker
CS_Con = code-switch - congruent Flanker
CS_Incon = code-switch - incongruent Flanker.

	M	*SD*	range	Flanker effect	Acc.
Con_NoCS	462.32 ms	81.24 ms	367.67 - 635.89 ms	90.24 ms	99.71%
Con_CS	464.12 ms	66.69 ms	356.94 - 655.06 ms		99.51%
Incon_NoCS	552.57 ms	83.76 ms	407.35 - 827.22 ms	90.69 ms	97.71%
Incon_CS	554.81 ms	80.17 ms	410.13 - 822.72 ms		96.57%

Although the difference is minimal, we see a higher accuracy on average in the congruent conditions than in the incongruent conditions, which matches the Flanker effect. The reaction times did not show any significant difference between the sentences with and without code-switches, as seen in the column "Flanker effect", which shows the difference in reaction time between the congruent and incongruent condition with and without code-switch.

For the EEG analysis we performed a 4-way repeated measures ANOVA with the variables hemisphere, position, code-switch and congruency on the time window 250 - 500 ms. There was a significant main effect for position ($p < .001$) and hemisphere ($p < .001$). There were no main effects for congruency and code-switch. This means that the brain location has a relevant influence on the dependent variable (the amplitude of the P300) but that congruency and code-switch do not have an effect on their own. To further investigate congruency and code-switch, we have to look at the interactions between variables.

Mauchly's Test for Sphericity was significant for position, and for the interaction between position, code-switch and congruency. Therefore, sphericity was not assumed and the Greenhouse-Geisser test results were used in the within-subjects effects.

A significant interaction was found between code-switch and congruency ($F(1, 33) = 5.616$, $p = .02$, $\eta_p^2 = .15$). No significant interactions were found with regard to position and hemisphere. LSD post hoc tests showed that the amplitude of the P300 was significantly larger after sentences with a code-switch than after sentences without a code-switch, but only in the incongruent condition ($p = 0.05$). The amplitude of the P300 was significantly smaller in the incongruent condition than in the congruent conditions ($p = 0.04$), but only when preceded by a sentence without a code-switch, meaning that the Flanker effect only occurs in sentences without a code-switch.

Figure 3.1 shows how Flanker trials in the incongruent condition (red) elicit a lower P300 than in the congruent condition (blue). The sentences without a code-switch (filled line) elicit a higher P300 than sentences with a code-switch (dotted line). Although incongruent Flanker trials with and without a code-switch show a lower P300 amplitude compared to the congruent Flanker trials, the incongruent trials with a code-switch show a smaller decrease in P300 amplitude than the incongruent trials without a code-switch.

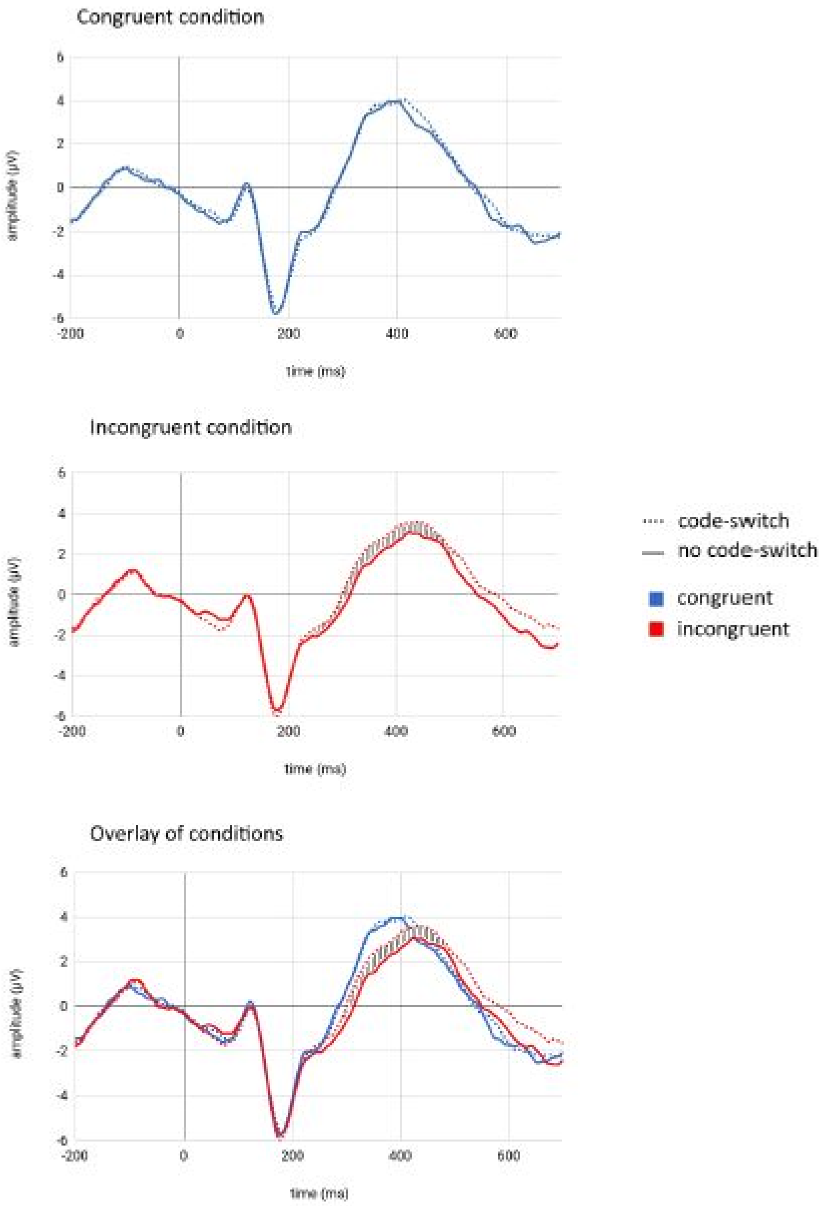

FIGURE 3.1: Event-related brain potentials elicited by the Flanker task. Comparison of code-switch versus no code-switch and congruent versus incongruent conditions.

Chapter 4 Discussion

In this study we investigated cognitive control processes provoked by code-switches. Instead of the behavioural, this study focuses on the neurological aspect of cognitive control. EEG data and reaction times of 34 participants were recorded while they performed a task in which they read sentences with and without code-switches, followed by congruent and incongruent Flanker trials. The classic Flanker effect is that the reaction time for incongruent Flanker trials is longer than for congruent Flanker trials. This is due to the inhibition (cognitive control) that is required for the incongruent trials.

We expected to find not only the classic Flanker effect, but also an influence of whether the preceding sentence did or did not include a code-switch. The relevant ERP component (the P300) is associated with cognitive control and is known to change in amplitude related to the amount of cognitive control needed. We expected the P300 to be higher in incongruent Flanker trials than in congruent Flanker trials, and that the difference in P300 amplitude would be influenced by whether the preceding sentence had a code-switch.

The results show the classic Flanker effect in both reaction times (behavioural) and P300 amplitude (neurological). The reaction times were significantly lower in the incongruent condition compared to the congruent condition. Although very little, there was also a difference in accuracy; the participants had a higher average accuracy in the congruent condition compared to the incongruent condition. However, in both reaction times and accuracy, no difference was found between sentences with or without code-switch.

EEG analysis showed that the P300 was significantly smaller in the incongruent condition compared to the congruent condition, but only when preceded by a sentence without a code-switch. This means that the Flanker effect only occurs after sentences without a code-switch. Having a code-switch in the preceding sentence thus seems to avert the Flanker effect. The P300 was significantly larger after sentences with a code-switch than after sentences without a code-switch, but only in the incogruent condition. In other words, in the congruent condition a code-switch has little to no effect on the P300.

Although incongruent Flanker trials with and without a code-switch show a lower P300 amplitude than the congruent Flanker trials, the incongruent trials preceded by a code-switch show a smaller decrease (compared to the congruent condition) in P300 amplitude than the incongruent trials without a code-switch.

These results give neurophyisological evidence of cognitive control engagement in code-switching, in support of previous (behavioural) findings. They also suggest that there are carry-over effects in cognitive control, i.e. reading a code-switch influences the P300 amplitude of the following Flanker trial. This neurological evidence supports Adler et al. (under review) who found carry-over effects from code-switching to other tasks based on reaction times. It is not clear why we did find differences between sentences with and without code-switch in the P300 amplitude, but not in the reaction times.

Wu & Thierry (2013) investigated P300 effects in a dual task setting and found a higher P300 amplitude for incongruent Flankers than for congruent Flankers. However, the P300 was lower in a bilingual setting compared to a monolingual setting in the incongruent condition. Although our results are exactly the other way around (a lower P300 amplitude for the incongruent condition instead of higher) the findings with regard to the bilingual versus monolingual setting do agree. Similar to Wu & Thierry, we found that the code-switch (bilingual setting) decreased the difference between the P300 amplitudes of the congruent and incongruent condition.

It is not clear why we found a lower P300 amplitude in the incongruent condition where Wu & Thierry found a higher amplitude in the incongruent condition (both compared to the congruent condition). However, Neuhaus et al. (2010) found a lower P300 amplitude for incongruent trials in the parietal lobe, but a higher P300 amplitude for incongruent trials in the frontal lobe. Further research is needed to gain a deeper understanding of this phenomenon. This research should focus both on positivity versus negativity and on localisation of the P300 component. Lateralisation and anteriority were both used as variables in our statistical analysis and although we found a main effect for both, there were no significant interactions with congruency or code-switch. Different statistical methods might give more insight in this issue.

A last note has to be made about the definition of bilingualism. In our study, the average age of English acquisition was 9 years old, meaning that our participants were sequential bilinguals. Knowing two languages is not influencing cognitive control per se. Luk, De Sa and Bialystok (2011) used a Flanker task in a group of monolinguals, late bilinguals and early bilinguals. Only the early bilinguals outperformed the monolinguals, no difference was found between the late bilinguals and monolinguals. Carrying out this research with simultaneous bilinguals might result in different findings, since inhibition of a native language when speaking a second languages might involve a different process than inhibition of one of two more or less equal languages.

REFERENCES

Adler, R. M., Valdés Kroff, J. R., & Novick, J. M. (2017). Does code-switching engage cognitive control? Presentation ISB.

Beardsmore, H. B. (1986). Bilingualism: basic principles (Vol. 1). Multilingual Matters.

Beauvillain, C. & Grainger, J. (1987). Accessing interlexical homographs: Some limitations of a language-selective access. *Journal of memory and language*, 26(6), 658-672.

Ben-Zeev, S. (1977). The influence of bilingualism on cognitive strategy and cognitive development. *Child development*, 1009-1018.

Berthold, M., Mangubhai, F., & Batorowicz, K. (1997). Bilingualism & multiculturalism: Study book. Distance Education Centre, University of Southern Queensland: Toowoomba, QLD.

Bialystok, E., & Majumder, S. (1998). The relationship between bilingualism and the development of cognitive processes in problem solving. *Applied Psycholinguistics,* 19(1), 69-85.

Bialystok, E., Craik, F. I. M., & Luk, G. (2012). Bilingualism: Consequences for Mind and Brain. *Trends in Cognitive Sciences,* 16(4), 240–250.

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.

Blom, E., Boerma, T., Bosma, E., Cornips, L., & Everaert, E. (2017). Cognitive advantages of bilingual children in different sociolinguistic contexts. *Frontiers in psychology*, 8, 552.

Bobb, S. C., & Wodniecka, Z. (2013). Language switching in picture naming: What asymmetric switch costs (do not) tell us about inhibition in bilingual speech planning. *Journal of Cognitive Psychology*, 25(5), 568-585.

Butterworth, J. A., Pao, L. Y., & Abramovitch, D. Y. (2008). The effect of nonminimumphase zero locations on the performance of feedforward model-inverse control techniques in discrete-time systems. In *American Control Conference*, 2008 (pp. 2696-2702). IEEE.

Cook, V. (2013). Second language learning and language teaching. Routledge. Crystal, D. (1987). *The Cambridge encyclopedia of language (Vol. 1, p. 987).* Cambridge: Cambridge University Press.

Declerck, M., & Philipp, A. M. (2015). A review of control processes and their locus in language switching. Psychonomic bulletin & review, 22(6), 1630-1645.

Duncan, C. C., Barry, R. J., Connolly, J. F., Fischer, C., Michie, P. T., Näätänen, R., ... & Van Petten, C. (2009). Event-related potentials in clinical research: guidelines for eliciting, recording, and quantifying mismatch negativity, P300, and N400. *Clinical Neurophysiology*, 120(11), 1883-1908.

Eriksen, B. A., & Eriksen, C.W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Attention, Perception, & Psychophysics*, 16(1), 143-149.

Forster, K. I. (1970). Visual perception of rapidly presented word sequences of varying complexity. *Attention, Perception, & Psychophysics*, 8(4), 215-221.

Gollan, T. H., Fennema-Notestine, C., Montoya, R. I., & Jernigan, T. L. (2007). The bilingual effect on Boston Naming Test performance. *Journal of the International Neuropsychological Society*, 13(2), 197-208.

Gratton, G., Coles, M. G., & Donchin, E. (1983). A new method for off-line removal of ocular artifact. *Electroencephalography and clinical neurophysiology,* 25 55(4), 468-484.

Green, D.W., & Abutalebi, J. (2013). Language control in bilinguals: The adaptive control hypothesis. *Journal of Cognitive Psychology*, 25(5), 515-530.

Green, D. W., & Wei, L. (2014). A control process model of code-switching. *Language, Cognition and Neuroscience*, 29(4), 499-511.

Grosjean F. (2010). Bilingual: life and reality. Harvard University Press.

Gumperz, J. J. (1982). Discourse strategies (Vol. 1). Cambridge University Press. Hakuta, K. (1986). *Mirror of Language. The Debate on Bilingualism.* Basic Books, Inc., 10 East 53rd Street, New York, NY 10022.

Hofweber, J., Marinis, T., & Treffers-Daller, J. (2016). Effects of dense code-switching on executive control. *Linguistic approaches to bilingualism*, 6(5), 648-668.

Isreal, J. B., Chesney, G. L., Wickens, C. D., & Donchin, E. (1980). P300 and tracking difficulty: Evidence for multiple resources in dual-task performance. *Psychophysiology,* 17(3), 259-273.

Kramer, A. F.,Wickens, C. D., & Donchin, E. (1985). Processing of stimulus properties: evidence for dual-task integrality. *Journal of Experimental Psychology: Human Perception and Performance*, 11(4), 393.

Kroll, J. F., & De Groot, A. (1997). Lexical and conceptual memory in the bilingual: Mapping form to meaning in two languages.

Lee Salvatierra, J., & Rosselli, M. (2011). The effect of bilingualism and age on inhibitory control. *International Journal of Bilingualism*, 15(1), 26-37.

Luck, S. J. (2014). An introduction to the event-related potential technique. MIT press.

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(4), 588-595.

Marinova-Todd, S. H., Marshall, D. B., & Snow, C. E. (2000). Three misconceptions about age and L2 learning. *TESOL quarterly,* 34(1), 9-34.

Meara, P. (1994). The complexities of simple vocabulary tests. Meara, P., & Jones, G. (1987). Tests of vocabulary size in English as a foreign language. *Polyglot,* 8(1), 1-40.

Neuhaus, A. H., Urbanek, C., Opgen-Rhein, C., Hahn, E., Ta, T. M. T., Koehler, S., ... & Dettling, M. (2010). Event-related potentials associated with Attention Network Test. *International Journal of Psychophysiology*, 76(2), 72-79.

Peal, E., & Lambert, W. E. (1962). The relation of bilingualism to intelligence. *Psychological Monographs: general and applied*, 76(27), 1.

Petten, C. (2009). Event-related potentials in clinical research: guidelines for eliciting, recording, and quantifying mismatch negativity, P300, and N400. *Clinical Neurophysiology,* 120(11), 1883-1908.

Polich, J., & Kok, A. (1995). Cognitive and biological determinants of P300: an integrative review. *Biological psychology*, 41(2), 103-146.

Poplack, S. (1980). Sometimes i'll start a sentence in spanish y termino en espanol: toward a typology of code-switching1. *Linguistics,* 18(7-8), 581-618.

Pratt, N., Willoughby, A., & Swick, D. (2011). Effects of working memory load on visual selective attention: behavioral and electrophysiological evidence. *Frontiers in human neuroscience*, 5.

Skiba, R. (1997). Code-switching as a countenance of language interference. *The internet TESL journa*l, 3(10), 1-6.

Squires, N. K., Squires, K. C., & Hillyard, S. A. (1975). Two varieties of longlatency positive waves evoked by unpredictable auditory stimuli in man. *Electroencephalography and clinical neurophysiology*, 38(4), 387-401. 27

Srinivasan, R. (1999). Methods to improve the spatial resolution of EEG. *International Journal of Bioelectromagnetism*, 1(1), 102-111.

Sutton, S., Braren, M., Zubin, J., & John, E. R. (1965). Evoked-potential correlates of stimulus uncertainty. *Science,* 150(3700), 1187-1188.

Treffers-Daller, J. (2009). Code-switching and transfer: an exploration of similarities and differences (pp. 58-74). Cambridge University Press.

Van Hell, J. G., Fernandez, C. B., Kootstra, G. J., Litcofsky, K. A., & Ting, C. Y. (2017). Electrophysiological and experimental-behavioral approaches to the study of intra-sentential code-switching.

Verreyt, N., Woumans, E., Vandelanotte, D., Szmalec, A., & Duyck, W. (2016). The influence of language-switching experience on the bilingual executive control advantage. *Bilingualism: Language and Cognition*, 19(1), 181-190.

Walter, W. G., Cooper, R., Aldridge, V. J., McCallum, W. C., & Winter, A. L. (1964). Contingent negative variation: an electric sign of sensori-motor association and expectancy in the human brain. *Nature*, 203(4943), 380.

Wu, Y. J., & Thierry, G. (2013). Fast modulation of executive function by language context in bilinguals. *Journal of Neuroscience,* 33(33), 13533-13537.

Young, S. R. (1984). RSVP: A task, reading aid, and research tool. *Behavior Research Methods,* 16(2), 121-124.