MAX PLANCK INSTITUTE FOR PSYCHOLINGUISTICS

CONTROL OF LANGUAGE IN BILINGUAL SPEAKERS WITH AND WITHOUT APHASIA

SASKIA MOOIJMAN

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General introduction

During my time as a volunteer in an aphasia center, I had the opportunity to meet Ivan[1]*, who was originally from Bulgaria. A couple of years prior, Ivan had suffered a stroke that left him with aphasia, an acquired language disorder. As a result of this disorder, he struggled to retrieve words. Despite living in the Netherlands for several decades and having learned Dutch to a high level of proficiency, Ivan repeatedly reported that he experienced more problems speaking Dutch compared to his first language. When he would try to retrieve a lexical item in his second language, words in his native language surfaced. Meeting Ivan encouraged me to explore the existing research literature on the impact of aphasia on bilingual individuals. How could it be that Ivan's first language was easier to access than his second language, if this was not the case before his stroke? Had the lexical representations in Dutch been damaged or were they more difficult to access? Did Ivan's brain damage result in a loss of control over his languages, making it difficult to suppress the irrelevant language?*

The starting point of this research was to investigate the consequences of aphasia for bilinguals. In doing so, I focused on how bilingual speakers with and without aphasia *control* their languages. This was investigated with a systematic review of the literature, an analysis of interviews with bilingual speakers with aphasia, and in two experimental investigations of language switching in bilinguals with and without aphasia. As such, this study is at the intersection of three research fields: bilingualism, cognitive control, and aphasiology. I will first set the stage and introduce the relevant research fields, after which I explain how these are combined in the research of this dissertation.

1.1 Bilingualism

It is estimated that over half of the world's population has knowledge of more than one language (European Commission, 2012; Grosjean & Pavlenko, 2021). Therefore, it is surprising that multi- or bilingualism[2] is often still considered the exceptional case (Aboh, 2020; De Bot, 2019). In the Netherlands too, many people speak more than one language. Approximately 15% of its inhabitants were born in another country and an additional 12% has at least one parent who was born abroad (CBS, 2022). Relatedly, Schmeets and Cornips (2021) reported that 24% speaks a language other than Dutch at home. In addition to the variety of home languages, 94% of the people in the Netherlands indicate to speak at least one additional language besides their native language (European Commission, 2012).

1 Ivan is not his real name. All names in this dissertation that refer to participants are fictitious.

2 Henceforth, the term 'bilingual' will be used to refer to individuals who have the ability to speak more than one language, and it is used to encompass bilinguals as well as multilinguals.

The incidence of bilingualism inevitably differs depending on how it is defined, and considerable variability regarding the definition of bilingualism exists. Here, I adhere to Grosjean's (2013) definition and consider people who use more than one language in their everyday lives to be bilingual. This definition stresses the frequency of use, but a larger set of interconnected factors plays a role in bilingualism. The bilingual experience is determined by age and manner of acquisition, level of proficiency, language use, language identity, and frequency of language switching (e.g., Marian & Hayakawa, 2021). The prevalence of bilingualism carries societal implications, particularly for education and health care professionals, who need to cater to the needs of an increasingly culturally and linguistically diverse population (e.g., Centeno, 2015; Faloppa et al., 2022; Norvik et al., 2022; Papadopoulou et al., 2023).

1.2 Controlling multiple languages

Being able to use multiple languages offers numerous obvious advantages but also presents a bilingual with a challenge: When engaging in a conversation, one language needs to be selected for speaking. In the bilingual case, language choice is not a given but determined by the interlocutor, situation, content of the discourse, or the function of the interaction (Grosjean, 2013). Selecting the target language is not effortless, considering that there is convincing empirical evidence that both languages are activated during processing (e.g., Colomé, 2001; Costa et al., 1999; Dijkstra & Van Heuven, 2002; Kroll et al., 2006; Kroll & Stewart, 1994; Marian & Spivey, 2003; Thierry & Wu, 2007). Parallel activation entails that one of the two languages cannot be completely "switched off", which may result in cross-language competition and interference between the two languages (e.g., Kroll et al., 2015). Coactivation of both languages far into the language production process (i.e., on the conceptual, lexical, and phonological level) has led researchers to argue that the language system itself is "fundamentally nonselective" (Kroll et al., 2006, p. 132).

Given the observed co-activation of languages and a non-selective language system, how do bilinguals manage to produce words in the target language? Proposals to account for this problem diverge, but an influential line of research assumes that this is achieved through a set of functions often referred to as *bilingual language control* (e.g., Abutalebi & Green, 2007; Calabria et al., 2018). Bilinguals have to exert control over their languages to efficiently produce the correct output in the intended language. Here, it is proposed that bilingual language production is achieved through control abilities that are not specific to language but instead recruit domain-general *executive control* (e.g., Abutalebi & Green, 2016; Green, 1998; Green & Abutalebi, 2013).

1.3 Executive control

Executive control (also: cognitive control, attentional control, or executive functioning) is an umbrella term that encompasses a range of higher-order cognitive abilities that regulate other cognitive processes (e.g., Diamond, 2013). Executive control is recruited for the initiation, maintenance, evaluation, and adjustment of conscious, complex, goal-directed, or new behavior. In other words, it is important for non-automatic behavior that demands top-down processing. Conversely, automatic processing does not require controlled attention, which allows highly familiar behaviors to be executed quickly and efficiently, but makes it ill-suited for new or unpredictable situations (Miller & Cohen, 2001).

According to an influential proposal by Miyake et al. (2000), executive control consists of (at least) three overlapping but separable functions: updating, inhibiting, and shifting. In their account, *updating* refers to the active maintenance, monitoring, and manipulation of relevant incoming information in working memory. *Inhibition* can be defined as the deliberate and controlled suppression of prepotent responses. Finally, *shifting* is the ability to switch back and forth between multiple tasks, operations, or mental sets (Monsell, 1996). Miyake and colleagues (2000) found that these executive functions were "clearly distinguishable" (p. 86) but also "seem to share some underlying commonality" (p. 87). The assumption of language coactivation dictates the need to suppress the non-target language and as a result, *inhibition* has received much attention in the bilingualism literature.

The Inhibitory Control Model (ICM), first proposed by Green (1998), formalized the role of inhibition in bilingual language production. According to this model, language production in the target language is achieved by a top-down process in which a language-dependent conceptual representation of the message is formed. The conceptual representation subsequently activates lexical nodes in both languages (i.e., language non-selective access). Language task schemas determine which language is appropriate in a given situation and exert top-down, reactive inhibition on the non-target language lexical nodes. The ICM assumes that the amount of inhibition required is proportional to the level of activation of the lexical nodes in the non-target language. Consequently, more inhibition will be required for a more proficient non-target language. A final assumption of the ICM is that the top-down inhibition engaged for language control is domain general rather than domain specific.

This notion of domain generality has been the subject of ongoing debate, and the existing evidence thus far remains inconclusive (see Declerck & Philipp, 2015; Jiao et al., 2022; Lehtonen et al., 2023, for reviews). Yet, the proposition of a domain-general nature of bilingual language control forms the basis for another contested theory: the hypothesis that bilinguals have superior executive control abilities compared to monolinguals (e.g., Bialystok, 2016, 2017;

Bialystok & Martin, 2004). Since the first studies providing evidence for such an advantage, numerous attempts to replicate these effects have followed. The available research has been synthesized, reviewed, and included in meta-analyses, yielding varying conclusions (Lehtonen et al., 2018; Van den Noort, Struys, et al., 2019; De Bruin et al., 2015; Monnier et al., 2022; Paap et al., 2015; Adesope et al., 2010; Hilchey & Klein, 2011; Donnelly, 2016). The current consensus appears to be that *if* bilingual advantages exist, they are modest at best and likely limited to specific contexts.

The previous sections have established that bilingual language production is an inherently competitive process due to language coactivation and non-selectivity. Executive control has been proposed as a candidate to tackle between-language interference. Having to rely on executive control may present problems for individuals with aphasia, as they often experience deficits in executive functions due to neurological damage.

1.4 Aphasia

Most of the research in the field of aphasia focuses on monolinguals and their native language. This is problematic given the size of the bilingual population, especially because research has pointed out that bilinguals and monolinguals have a comparable risk of developing aphasia after stroke (Alladi et al., 2016). Aphasia is a communication disorder due to an impairment of the abilities necessary for language processing, caused by acquired focal brain damage. It can have devastating consequences for participation in society and quality of life of those affected (Berg et al., 2022). Aphasia can impact all language modalities: spoken language production, auditory comprehension, reading, and writing. The personal consequences of aphasia were described by someone who participated in the present research project, and a translation of their account is presented below:

> *"In October 2015, I had a stroke. […] On this day, I changed. I am no longer the same person. Who I am now, I do not yet know."*

While aphasia is often defined as a specific language disorder, individuals with aphasia frequently experience cognitive problems outside the language domain, such as impairments in attention, (working) memory, processing speed, or executive control (El Hachioui et al., 2014; Fonseca et al., 2016, 2018; Fridriksson et al., 2006; Fucetola et al., 2009; Helm-Estabrooks, 2002; Martin, 2000; Murray, 2012a, 2012b; Olsson et al., 2019; Yao et al., 2020). In fact, the ubiquity of non-linguistic deficits has given rise to questions concerning the nature of the language impairments of persons with aphasia. McNeil and colleagues have argued that aphasia should not be viewed as a domain-specific language disorder, but instead argued that aphasic symptoms arise from an interaction of non-linguistic cognitive impairments that preclude access to linguistic representations (Hula & McNeil, 2008; McNeil, 1988; McNeil & Pratt, 2001). In this account, the domain specificity of the language impairment is questioned.

Regardless of the definition of aphasia, there is considerable evidence for deficits in executive control in individuals with aphasia (e.g., Christensen et al., 2018; Kuzmina & Weekes, 2017; Purdy, 2002). A high prevalence of executive control impairments may exist because these abilities have been found to be particularly vulnerable: Diamond (2013) refers to executive control as the "canary in the coal mine" (p.153) because it often suffers first. For individuals with aphasia, nonverbal executive control impairments can have detrimental effects for (treatment-induced) recovery (Brownsett et al., 2014; Lambon Ralph et al., 2010; Leśniak et al., 2008; Simic et al., 2019, 2020) and compensation for language deficits (Fridriksson et al., 2006; Olsson et al., 2019). Compensation involves learning new behavior or enhancing previously infrequently used behavior, which both require overriding the prepotent – but due to brain damage disturbed – impulse to speak and thus appeal to executive control (Keil & Kaszniak, 2002).

Relatedly, communication can be regarded as problem-solving, complex, and goal-oriented behavior, and therefore places demands on executive control, especially when language is no longer processed automatically (Frankel et al., 2007). In one view, impairments in executive control may (partially) explain communicative behavior observed in persons with aphasia (Frankel et al., 2007; Keil & Kaszniak, 2002; Penn et al., 2010; Spitzer et al., 2020). For example, a breakdown in response inhibition could lead to perseveration on the word or sentence level, while problems with updating could result in difficulties to connect old and new information.

1.5 Controlling multiple languages after acquired brain damage

The incidence of executive control impairments in individuals with aphasia and the involvement of executive control in bilingual language processing raises the question whether bilinguals with aphasia have difficulties controlling their languages. Executive control mechanisms have been hypothesized to account for several symptoms, including selective recovery of one language and involuntary language intrusions.

The languages of a bilingual with aphasia do not always recover in parallel and the severity of the language disorder can differ between languages. Various factors related to bilingual experiences have been shown to play a role in selective recovery of a language (Kuzmina et al., 2019). However, Pitres (1895) also suggested that one language could be overly inhibited rather than lost, thereby explaining temporary inaccessibility of one language over the other. This idea was further developed in more recent literature (Green & Abutalebi, 2008; Paradis, 1984).

Besides selective recovery, language control impairments have been suggested to lead to unintended language intrusions, also referred to as "pathological language switching" (Fabbro, 2000). Language switching is common linguistic behavior for any bilingual, but is deemed pathological when speakers switch in pragmatically inappropriate contexts (Ansaldo et al., 2010). Involuntary switching has been argued to occur when inhibition cannot be selectively applied to lexical competitors in the non-target language (Abutalebi et al., 2000; Ansaldo et al., 2010; Abutalebi & Green, 2007; Green & Abutalebi, 2008; Kohnert, 2004; see Fyndanis & Lehtonen, 2022, for a review). Thus, when bilinguals with aphasia suffer from deficits in control abilities, they may experience selective recovery or involuntary language mixing. If bilingual language control relies on domain-general control, these symptoms should coincide with nonverbal impairments in executive control (Calabria et al., 2018; Fyndanis & Lehtonen, 2022).

In the previous paragraphs, the attention was focused on the additional efforts that managing multiple languages requires of bilinguals with aphasia. However, the potential cognitive advantages for healthy bilinguals have also been discussed, which could extend to bilinguals with aphasia. Furthermore, language switching has been interpreted as a strategy to enhance verbal effectiveness (e.g., Goral et al., 2019). This raises the question whether bilingualism should be perceived as a help or a hindrance for individuals with aphasia.

1.6 Current research

The discussion of the literature has revealed that bilingualism can be considered the global norm, highlighting the need for research on the consequences of aphasia for bilingual individuals. The bilingual language system should be viewed as non-selective and potentially competitive. Executive control, inhibition in particular, has been proposed as a mechanism to resolve bilingual language interference. Moreover, individuals with aphasia often exhibit impairments in executive control, which can result in difficulties managing multiple languages. At the same time, knowledge of multiple languages may serve as an additional resource to improve verbal communication, thus offering potential benefits for individuals with aphasia.

Our current understanding of language control in bilingual individuals with aphasia is limited and the present research was intended to bridge this gap. The first way to achieve this was to engage with the population of interest. **Chapter 2** reports on an analysis of interviews with bilingual individuals with aphasia. The interviews focused on the experiences with bilingual language control after having acquired aphasia. Furthermore, instances of language switching were analyzed to provide new insight into the question why bilinguals with aphasia switch between their languages. Should their switches be interpreted as a compensatory strategy to enhance verbal effectiveness, or as involuntary behavior caused by impaired language control?

Chapter 3 presents a systematic review of the research literature on the relationship between executive control, bilingualism, and aphasia. Here, the evidence for executive control impairments in bilingual individuals with aphasia was examined. Moreover, the domain generality of bilingual language control deficits in this population was investigated, by focusing on associations in performance on tasks that tap linguistic and non-linguistic control, and by reviewing whether selective recovery and involuntary switching coincided with executive control impairments. Finally, the evidence supporting bilingual advantages in executive control for individuals with aphasia was evaluated.

The subsequent chapters concern two experimental studies. In **Chapter 4**, the results of a language switching study that involved neurologically healthy bilingual speakers are described. In this web-based study, voluntary switching behavior of late bilinguals and the factors that contributed to language choice were investigated. Additionally, the costs of voluntary and cued switching between the first and second language were compared and related to more general switching abilities.

This study design was replicated in a group of bilinguals with aphasia. The results of this study are reported in **Chapter 5**. The aim of this study was to evaluate the potential benefits associated with free language choice. More specifically, the performance on bilingual picture naming tasks in the first and second language were compared separately, while switching freely between languages, or while switching based on an external cue. Finally, it was investigated whether performance on tasks involving switching between languages and switching within one language was associated.

Chapter 6 presents the general discussion of this dissertation. Here, the findings from the preceding chapters are summarized and interpreted in light of two questions. I first elucidate which of the results obtained in this study can be attributed to control mechanisms. Thereafter, I elaborate on the question whether bilingualism should be considered an advantage for individuals with aphasia. The discussion concludes by addressing the clinical implications of this thesis.

2

Why do bilingual speakers with aphasia alternate between languages? A study into their experiences and mixing patterns

A slightly adapted version of this chapter is submitted as a research article:
Mooijman, S., Schoonen, R., Goral, M., Roelofs, A., & Ruiter, M. B. (*submitted*). Why do bilingual speakers with aphasia alternate between languages? A study into their experiences and mixing patterns.

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Abstract

The factors that contribute to language alternation, technically referred to as code-switching, by bilingual speakers with aphasia have been debated. Some studies suggest that atypical code-switching results from impairments in language control, while others posit that switching is a way to enhance communicative effectiveness. The goal of this study was to provide new insight into this issue.

Semi-structured web-based interviews with bilingual speakers with aphasia (*N* = 19) with varying language backgrounds were conducted. The interviews were transcribed and coded for: (1) self-reports regarding language control and compensation, (2) instances of code-switching, and (3) in two cases, instances of repair initiation. The results showed that several participants reported language control difficulties but that the knowledge of additional languages could also be recruited to compensate for lexical retrieval problems. Most participants showed no or very few instances of code-switching and the observed code-switches appeared to adhere to the pragmatic context and known functions of switching. Three participants exhibited more marked code-switching behavior and reported corresponding difficulties with language control. Instances of atypical code-switching did not coincide with clear problems initiating conversational repair, taken as an indicator of language control abilities.

Our study highlights the variability in code-switching patterns of bilingual speakers with aphasia. Furthermore, most of them appear to be able to effectively control their languages, and may even use their languages for compensatory purposes. Control deficits resulting in atypical code-switching were observed in some participants.

2.1 Introduction

The ability to speak more than one language allows for switching between these languages when necessary or permitted, requires monitoring of the target language in a given situation, and may call for suppression of the irrelevant language. In other words, processing multiple languages demands *control* over these languages. The extent to which bilinguals with aphasia experience difficulties with language control has been a topic of investigation in the research literature, and an approach to this question is to examine their language alternation, or technically called, their code-switching behavior.

Code-switching[3], the use of two or more languages within the same conversation (e.g., Milroy & Muysken, 1995), is common linguistic behavior of neurologically healthy bilinguals. The switch can occur between utterances or sentences (*inter-sentential*) or within utterances by inserting words into the structure of the other language (*intra-sentential*). Content words are more likely to be code-switched than function words (e.g., Muysken, 2000), and switching is driven by a number of factors (e.g., Appel & Muysken, 1987). *Accessibility* of a lexical item may be an important reason to code-switch (Heredia & Altarriba, 2001), thereby serving a psycholinguistic function. Moreover, code-switching can serve pragmatic purposes (e.g., to include or exclude interlocutors), sociolinguistic uses (e.g., to emphasize one's own identity, Poplack, 1980), or metalinguistic functions (to comment on the languages or to show off linguistic skills, Myers-Scotton, 1979).

The underlying motives for the code-switching behavior of bilingual speakers with aphasia and whether these patterns align with those observed in neurologically healthy bilinguals have been subject of ongoing debate (Grosjean, 1985; Perecman, 1984; see Fyndanis & Lehtonen, 2022, for a review). One perspective suggests that code-switching in aphasia originates from control deficits, while an alternative view proposes that bilinguals with aphasia actively engage in code-switching to circumvent language-selective word-retrieval difficulties.

Several clinical reports, typically of single cases, provided evidence for "atypical" code-switching among individuals with aphasia. This may include involuntary switching (Abutalebi et al., 2000; Fabbro, 2000), switching in monolingual settings (Ansaldo et al., 2010), or switching to a language of low proficiency (Leemann et al., 2007). Conversely, Riccardi et al. (2004) described a trilingual case with Wernicke's aphasia who demonstrated remarkable sensitivity to the pragmatic rules governing code-switching. Studies proposed various explanations for atypical code-switching patterns, including deficits in implicit memory systems, insufficient

3 Many definitions of code-switching have been proposed, but we use the term code-switching to encompass all forms of language switching in a conversation.

activation and inhibition resources, or impairments in control mechanisms (Abutalebi et al., 2000; Ansaldo et al., 2010; Fabbro, 2000; Kong et al., 2014; Leemann et al., 2007).

Moving beyond clinical reports, studies employing more constrained tasks also offered diverging interpretations of code-switching by bilinguals with aphasia. Chengappa et al. (2004), who administered the Bilingual Aphasia Test (Paradis & Libben, 1987) to investigate switching, observed increased code-switching of bilinguals with aphasia compared to neurologically healthy controls. They suggested that the higher frequency of code-switching is the result of a strategy to compensate for lexical access difficulties in one language. Similarly, two studies that conducted language switching experiments observed results largely consistent with the idea that difficulties in lexical access may underlie language switching in bilinguals with aphasia (Hameau et al., 2022; Chapter 5). Conversely, Grunden et al. (2020) obtained several results from a switching experiment that could best be explained by deficits in language control.

Most studies into code-switching by bilinguals with aphasia investigated switching in *narrative production*. Muñoz et al. (1999) observed an increase in normally occurring code-switching patterns, which was taken as evidence that persons with aphasia adapt code-switching patterns to improve their verbal effectiveness. This proposal was further supported by subsequent studies demonstrating that persons with aphasia showed higher switching frequencies than neurologically healthy bilinguals, and that they switched more often in the less-proficient language, when their aphasia was more severe, and in more demanding language contexts. Based on these findings, code-switching has been interpreted as a compensatory mechanism to overcome lexical retrieval difficulties and enhance verbal functional communication (Bihovsky et al., 2023; Chen, 2018; Goral et al., 2019; Lerman et al., 2019; Neumann et al., 2017; Neumann-Werth et al., 2010).

Paplikar (2016) followed up on this proposal by directly evaluating the effectiveness of code-mixing as a strategy. These findings aligned with the other studies, indicating higher frequency of code-switching by bilinguals with aphasia compared to a control group. Importantly, this increased switching did not result in higher communicative success, although participants produced more spoken language output and fewer pauses when they switched. Consequently, Paplikar (2016) proposed that a language control deficit, specifically difficulty inhibiting the non-target language, may underlie increased code-switching in aphasia.

To recapitulate, existing research came to varying conclusions regarding the underlying reasons of switching in individuals with aphasia. Most studies investigated this by evaluating the "appropriateness" of code-switching patterns in terms of frequency, pragmatics, realization, and context. Another way to examine whether code-switching is related to control abilities, is to explore whether it co-occurs with other communicative behavior that may rely on control.

Language control is not limited to *bilingual* language production; it also plays a crucial role in everyday language use, particularly when language production is no longer automatic (Frankel et al., 2007; Penn et al., 2010; Spitzer et al., 2020). If an individual with aphasia has a control deficit, they might exhibit behaviors such as perseveration or difficulties initiating repair when a breakdown in communication occurs, because these conversational strategies require control abilities such as active monitoring, interference suppression, updating of working memory, and cognitive flexibility. In line with this, several studies observed a relationship between control abilities and the use of strategies to compensate for communicative difficulties in persons with aphasia (Beckley et al., 2013; Frankel et al., 2007; Fridriksson et al., 2006; Penn et al., 2010; Spitzer et al., 2020). If deviating code-switching patterns of bilinguals with aphasia are the result of a control deficit, they may also experience difficulties employing the communicative strategies that rely on control abilities.

In conclusion, the question regarding the underlying factors to code-switching in bilinguals with aphasia remains unresolved. In the present study, we follow-up on previous research by investigating whether code-switching in aphasia should be understood as a strategy to enhance verbal effectiveness or as involuntary behavior resulting from an impaired control mechanism. While the question itself is not novel, we aim to provide new insight by approaching it from various perspectives. Firstly, we evaluated the personal experiences related to language control in bilinguals with aphasia, drawing from semi-structured interviews. Secondly, we examined instances of code-switching observed during these interviews and evaluated whether the code-switches corresponded to the self-reports and the patterns as described in the literature on neurologically healthy bilinguals. Thirdly, we focused on the variability among bilinguals with aphasia by selecting two cases that represent opposite ends of the spectrum in terms of their language control experiences.

We formulated differing predictions based on the hypotheses that switches resulted from a control deficit or from lexical compensation. If a control deficit underlies switching, participants should report co-occurring control difficulties. Contrarily, if participants use switching as compensation, they might also report benefits of bilingual language knowledge. Whether switches result from control impairments or lexical compensation should also impact code-switching patterns regarding *pragmatic appropriateness* (switching to shared languages), *realization* (on marked or typical linguistic units), and *function* (serving atypical or typical functions). In case of a control deficit, switches should coincide with other impaired language control behavior, whereas this should not be the case for lexical compensation. Table 1 summarizes these predictions.

Table 1. Predictions for control deficit versus lexical compensation in self-reports, code-switches, and language control behavior.

	Indicating control deficit	**Indicating lexical compensation**
Self-reports	Reported difficulties with bilingual language control (e.g., "I find it difficult to suppress my second language.")	Bilingual language knowledge reported to be beneficial in word-retrieval (e.g., "If I don't know a word in Dutch, I say it in Turkish.")
Code-switches		
Pragmatic appropriateness	Switches to languages not shared with interlocutor	**No** switches to languages not shared with interlocutor
Realization	Switches on **marked** word types (e.g., function words, Muysken, 2000)	Switches on **typical** word types (e.g., content words, interjections)
Function	Switches **do not** have functions that correspond to those seen in neurologically healthy bilinguals	Switches have functions that correspond to those seen in neurologically healthy bilinguals
Language control	Switches coincide with other impaired language control behaviour, specifically difficulties initiating conversational repair (e.g., use of gestures, descriptions, or signals)	Switches **do not** coincide with other impaired language control behaviour, specifically difficulties initiating conversational repair (e.g., use of gestures, descriptions, or signals)

2.2 Methods

2.2.1 Participants

Nineteen participants with a range of bilingual backgrounds were included in the study. They were diagnosed with aphasia and were in the chronic phase (>6 months post onset), as confirmed by their (former) speech-language therapist. Sufficient spoken language comprehension abilities were a prerequisite for participation. The features of the participants' connected speech were rated on the six spontaneous speech rating scales of the Dutch Aachen Aphasia Test (AAT; Graetz et al., 1992). Ten participants exhibited speech disorders (dysprosodic speech, dysarthria, and/or apraxia of speech) alongside aphasia, but their speech was sufficiently intelligible to participate in the interviews (i.e., at least 90% intelligible speech output). The clinical information of the participants is provided in Table 2.

Participants had different first languages (L1) and second languages (L2), and they sometimes knew multiple additional languages. Before the onset of their aphasia, they had an excellent command of Dutch. Factors such as age of acquisition, acquisition context, manner of acquisition, and current frequency and context of language use varied across participants and are summarized in Table 2. Informed consent was obtained from all participants prior to participation and the study was approved by the institutional ethics assessment committee (2019-5035).

Table 2. Demographic and clinical characteristics of the participants.

Code name[a]	**Sex**	**Age**[b]	**TPO**[c]	**Etiology**	**Localization**[d]	**AAT spontaneous speech rating scales**[e]						
						Communication	*Articulation*	*Automatic speech*	*Semantics*	*Phonetics*	*Syntax*	*Total*
Arthur	M	47;10	06;07	Ischemic stroke (*recurrent*)	MCA left hemisphere	3	4	5	5	4	1	22
Anton	M	61;11	08;05	Hemorrhagic stroke	MCA left hemisphere	2	5	5	2	4	3	21
Barend	M	57;00	02;06	Hemorrhagic stroke	Not available	4	4	5	4	4	4	25
Bram	M	37;00	06;11	Hemorrhagic stroke	Left hemisphere	4	5	5	5	5	3	27
Bren	M	66;06	00;07	Ischemic stroke (*recurrent*)	MCA left hemisphere	1	3	2	0	0	0	6
Daan	M	22;04	02;07	Traumatic brain injury	Basal ganglia (left)	2	2	4	4	4	3	19
Ersel	M	39;04	02;10	Hemorrhagic stroke	Intracerebral left hemisphere	3	4	5	5	3	2	22
Gerrit	M	53;00	04;09	Hemorrhagic stroke	Basal ganglia	4	5	5	4	4	4	26
Hugo	M	69;04	09;11	Hemorrhagic stroke	Not available	2	3	4	3	4	2	18
Jasper	M	55;02	05;08	Ischemic stroke	MCA left hemisphere	3	4	4	4	5	2	22
Jens	M	65;07	01;09	Ischemic stroke	Not available	3	4	5	4	4	3	23
Lars	M	61;01	04;08	Ischemic stroke	Left hemisphere	3	5	4	5	2	1	20

Table 2. Demographic and clinical characteristics of the participants. *(Continued)*

Code name[a]	**Sex**	**Age**[b]	**TPO**[c]	**Etiology**	**Localization**[d]	**AAT spontaneous speech rating scales**[e]						
						Communication	*Articulation*	*Automatic speech*	*Semantics*	*Phonetics*	*Syntax*	*Total*
Laura	F	74;06	04;02	Ischemic stroke	MCA left hemisphere	3	5	5	4	5	4	26
Madar	M	30;01	01;00	Hemorrhagic stroke	Intracerebral left hemisphere	3	5	4	4	4	1	21
Niels	M	63;05	11;05	Ischemic stroke	Intracerebral left hemisphere	3	4	5	4	4	2	22
Olaf	M	53;00	02;02	Hemorrhagic stroke	Basal ganglia	4	3	5	5	2	5	24
Tessa	F	66;09	04;00	Ischemic stroke	MCA left hemisphere	3	5	3	3	5	2	21
Tobias	M	35;04	04;06	Traumatic brain injury	Not available	3	4	5	4	5	2	23
Valerie	F	26;07	05;04	Ischemic stroke	MCA (total) left hemisphere	3	5	4	4	4	2	22

Note. [a] *All names are fictitious;* [b] *Age in years; months,* [c] *TPO: time post-onset in years; months;* [d] *Localization MCA = middle cerebral artery;* [e] *AAT rating of spontaneous speech for communicative behavior, articulation and prosody, automatized language, semantic structure, phonemic structure, syntactic structure, each on a 6-point scale, ranging from 0 (severely impaired) to 5 (not/only mildly impaired).*

Table 3. Language background of the participants.

Code name[a]	Languages[b]	Age of acquisition[c]	Manner of acquisition[d]	Language context[e]	Current language mode[f]	Language in therapy
Anton	L1: Dutch, L2: English, L3: German	Late (L2, L3)	Both (L2, L3)	**L1**	Monolingual	L1
Arthur	L1: Dialect, L2: Dutch, L3: German, L4: English	Early (L2, L3) Late (L4)	Both (L2, L3, L4)	L1, **L2**, L3	Multilingual	L2
Barend	L1: Dutch, L2: English, L3: German, L4: Portuguese, L5: French	Late (L2, L3, L4, L5)	Both (L2, L3, L4, L5)	**L1**	Monolingual	L1
Bram	L1: Dutch, L2: English, L3: German	Early (L2) Late (L3)	Both (L2) Instruction (L3)	**L1**	Monolingual	L1
Bren	L1: German, L2: English, L3: Dutch	Late (L2, L3)	Both (L2, L3)	L1, L2, **L3**	Multilingual	L3
Daan	L1: Dutch, L2: English, L3: German	Late (L2, L3)	Both (L2) Instruction (L3)	**L1**	Monolingual	L1
Ersel	L1: Turkish, L2: Dutch, L3: English, L4: German, L5: French	Early (L2) Late (L3, L4, L5)	Immersion (L2) Both (L3) Instruction (L4, L5)	L1, **L2**	Multilingual	L2
Gerrit	L1: Dutch, L2: English, L3: French	Late (L2, L3)	Both (L2, L3)	**L1**	Monolingual	L1
Hugo	L1: Dutch, L2: German, L3: English	Late (L2, L3)	Immersion (L2, L3)	**L1**	Monolingual	L1

Table 3. Language background of the participants. *(Continued)*

Code name[a]	**Languages**[b]	**Age of acquisition**[c]	**Manner of acquisition**[d]	**Language context**[e]	**Current language mode**[f]	**Language in therapy**
Jasper	L1: Dialect, L2: Dutch, L3: English	Early (L2) Late (L3)	Immersion (L2) Both (L3)	L1, **L2**	Multilingual	L2
Jens	L1: Dutch, L2: English, L3: French	Late (L2, L3)	Both (L2, L3)	**L1**	Monolingual	L1
Lars	L1: Dutch, L2: English, L3: Swedish	Late (L2, L3)	Both (L2, L3)	**L1**, L2, L3	Multilingual	L1 and L3
Laura	L1: English, L2: Dutch	Late (L2)	Immersion (L2)	L1, **L2**	Multilingual	L2
Madar	L1: Somali, L2: Dutch, L3: English, L4: German	Early (L2) Late (L3, L4)	Immersion (L2) Both (L3) Instruction (L4)	L1, **L2**, L3	Multilingual	L2
Niels	L1: Dutch, L2: English, L3: French	Late (L2, L3)	Both (L2, L3)	**L1**, L2	Multilingual	L1
Olaf	L1: Dutch, L2: English, L3: German, L4: French, L5: Cantonese	Late (L2, L3, L4, L5)	Both (L2, L5) Instruction (L3, L4)	**L1**	Monolingual	L1
Tessa	L1: Papiamento, L2: Spanish, L3: English, L4: Dutch	Early (L2, L3, L4, L5)	Immersion (L2, L3, L4)	L1, L2, L3, **L4**	Multilingual	L4
Tobias	L1: Dutch, L2: German	Early (L2)	Immersion (L2)	**L1**, L2	Multilingual	L1
Valerie	L1: Dutch, L2: English, L3: French	Late (L2, L3)	Instruction (L2, L3)	**L1**	Monolingual	L1

Note. [a] *All names are fictitious;* [b] *Languages spoken by the participant based on order of acquisition, definition of dialects was based on the participant's self-evaluation;* [c] *Early age of acquisition: <8 years old, late age of acquisition: >7 years old;* [d] *Manner of instruction: immersion, formal instruction, or both;* [e] *Language of the interview in bold;* [f] *Information about the current language mode: "Multilingual" indicates that the participant frequently interacts in contexts where multiple languages can be used interchangeably.*

2.2.2 Materials

Semi-structured interviews were conducted using a standard set of questions as a starting point (Appendix A). The interview consisted of more general questions based on the Dutch version of the AAT (Graetz et al., 1992), and questions concerning the interviewee's language background, language use and experiences. We followed the Social Conversation Collection Protocol (Leaman & Edmonds, 2021) to encourage natural, social conversation rather than clinical interaction.

To highlight and examine the variability within the group, we selected two participants who were at the opposite ends of the "control continuum", reporting diverging experiences with language control. We examined their experiences reported during the interview, their observed code-switching behavior, and evaluated instances of conversational repair initiation by focusing on gestures, descriptions, and signals to communicate a breakdown in communication.

2.2.3 Procedure

Due to the COVID-pandemic, the study was conducted remotely in a web-based setting. Participants were recruited through online communities, aphasia centers, and speech-language therapists. After participants expressed their interest through email or telephone, they were contacted and provided information about the study. Eligible participants completed a written informed consent form on a secure web-based platform (Qualtrics, 2005).

The interviews were conducted in a secure peer-to-peer video call in Zoom (Zoom Video Communications Inc., 2012). Participants could use their smartphone, tablet, or computer. Recordings were made to enable transcription. The interviews were conducted exclusively in Dutch (the interviewer's native language) and the interviewer's knowledge of other languages was not explicitly addressed. In six interviews, partners, family members, or speech and language therapists were present to provide help when needed. Their assistance could concern the technical set-up, or they contributed to the content of the conversation, and this resulted in a contribution ranging from 1% to 14% of the interview (expressed in time). Each interview lasted no longer than 45 minutes.

2.2.4 Analysis

Transcription

The interviews were transcribed orthographically to enable a qualitative analysis of the bilingual experiences. Transcriptions were made in the Computerized Language ANalysis platform (CLAN; MacWhinney, 2000), using the Codes for the Human Analysis of Transcripts (CHAT-format, MacWhinney & Wagner, 2010). Seven interviews were initially automatically transcribed with the Whisper model (Radford et al., 2022). These transcripts were subsequently reviewed, corrected where necessary, and converted into CHAT-format.

In the results section, we provide examples using simplified transcriptions and corresponding translations. Errors are underlined with a dotted line and may concern phonology [p], grammar [g], semantics [s], or neologisms [n]. Gestures are presented in [square brackets]. Code-switched material is provided in **bold** in the original transcript and in SMALL CAPITALS in the translation. Pauses are indicated with (.) and unintelligible words with xxx. To increase readability, filled pauses and retraces of the interviewer are omitted in the excerpts.

Coding

We coded the interviews regarding the reported experiences, instances of code-switching, and repair initiation in two selected cases (the codebook is presented in Appendix B). We used qualitative data analysis software ATLAS.ti for coding the transcriptions (ATLAS.ti Scientific Software Development GmbH, 2023) regarding the reported experiences. We first evaluated the participants' reports about their bilingual experiences before and after acquiring brain damage, regarding compensation, control, and speech therapy. The experiences could be coded as neutral, positive, or negative. After coding of the interviews, we evaluated occurrences of the codes in the dataset, while focusing on the reports of compensatory use of code-mixing for word-retrieval difficulties and issues with language control.

Next, we identified all instances of code-switching during the interview. Code-switches that were part of a name (e.g., "Now in *Sverige* [Sweden] for ten years.") or that were listed in the Dutch dictionary and therefore considered loanwords (e.g., "*gaming*"), were excluded in our analysis. We established where the code-switch occurred (*position:* intra-sententially or inter-sententially) and on which *linguistic unit* in the utterance (content words, function words, or phrases). We also coded whether switches were preceded by *hesitations* or followed by attempts to *correct* to the target language. The *function* of the code-switches was also assessed and divided into psycholinguistic, sociolinguistic, pragmatic, or metalinguistic functions. In order to establish a relative frequency of code-switches, we compared the occurrence of other-language material to the total number of words produced by the participant during the interview (see Appendix C for our definition of a word).

The final part of the codebook includes instances of *repair initiation*, which were coded in the transcripts of the two case studies. Instances of repair initiation were coded regardless of the successfulness of that behavior and were taken as an index of monitoring and shifting abilities, both considered to reflect (adequate) language control. We included three forms of repair initiation: explicit behavior to signal communicative difficulties, descriptions to replace a word (focusing on the initiation of the description, disregarding the effectiveness), and meaningful gestures (iconic or deictic) before a word or replacing a word.

The code-switches and the instances of repair initiation were re-coded by second raters to assess the reliability of the initial coding. We analyzed the inter-rater reliability using κ_n, an adjusted version of Cohen's kappa for free marginals (Brennan & Prediger, 1981). The inter-rater reliability for the *position* and the *linguistic unit* of the code-switches was high ($\kappa_n = 0.87$ and $\kappa_n = 0.88$, respectively). There was substantial agreement between coders for the *functions* of the code-switches ($\kappa_n = 0.80$), but only moderate agreement for the coding of the *hesitations* ($\kappa_n = 0.53$), *corrections* ($\kappa_n = 0.55$), and the *repair initiation* of the first case study ($\kappa_n = 0.56$) and the second case study ($\kappa_n = 0.44$). Because of these relatively low inter-rater reliabilities, each discrepancy in the ratings was discussed among the two raters until consensus was reached, rendering the reported kappa's an underestimation of the actual reliability.

2.3 Results

2.3.1 Self reports

Pre- and post-morbid language abilities

Positive and negative long-term consequences of aphasia for the second or additional languages were frequently mentioned. Positive experiences predominantly concerned receptive language skills; twelve participants indicated intact spoken language comprehension of their L2. Conversely, language production abilities in the L2s were reported as impaired by eight participants, compared to three interviewees who noted relatively unimpaired production in their second languages. Seven participants explicitly highlighted disparities between language production and comprehension skills in their L2 (Excerpt 1).

(1) INV[4] : Spreekt u een van die talen nu nog weleens?
Do you still speak one of those languages sometimes?
Jens: Ik ben hier de talenknol is hier aanwezig [points to head].
I am here the knack for languages [p] is present here.
Pff [points to mouth] die woorden zijn niet aanwezig.
Pff those words are not present.

Moreover, interviewees reported discrepancies in post-stroke abilities between the languages. Four participants noted that one language (L1 or L2) initially recovered more quickly or better compared to the other language(s). In the chronic phase of recovery (> 6 months post-onset), some interviewees continued to experience differences between their languages. For instance, Tobias evaluated his post-morbid proficiency as 9/10 in Dutch and 6/10 in German, a difference

4 INV refers to the interviewer.

that was smaller pre-morbidly. Conversely, some participants reported no differences between their languages (Excerpt 2).

(2) INV: En merk je nu ook verschil bij het spreken van het Nederlands en het Engels bijvoorbeeld?
And do you also notice a difference in speaking Dutch and English for example?
Niels: Nee is uh uh uh **the same** [shakes head]. Echt.
No is uh uh uh THE SAME. *Really.*

Compensation for word-retrieval impairments

The potential advantages of bilingualism to mitigate word-retrieval impairments were addressed in several interviews. Among these, eight participants confirmed that their knowledge of two languages could aid word-retrieval in the target language, for example when code-switches served as substitutes for words in the target language, or when switching could facilitate word-retrieval in the target language. Tobias illustrated this process in Excerpt 3.

(3) INV: Ja precies. Dus af en toe is er een woord dat komt dan in het Duits omhoog en dan via het Duitse woord kun je dan bij de Nederlandse vertaling komen? Werkt dat zo?
Yes exactly. So occasionally there's a word that comes up in German, and then through the German word, you can arrive at the Dutch translation? Does it work like that?
Tobias: Ja ja. **Verwendung** eh **verwendung** ehm gebruiken.
Yes yes. USAGE *eh* USAGE *ehm using.*

The extent to which this was perceived as a conscious strategy differed between participants. Arthur explained that there are instances where a word in Dutch does not come to mind, but its translation equivalent in his early-acquired L3 does. He clarified that it is not a conscious trick but rather an automatic process. For Arthur, code-switching does not help in retrieving the Dutch target word, it merely replaces it. Other participants indicated that their knowledge of other languages cannot be harnessed to increase their verbal effectiveness. Bren, for instance, described having the correct concepts in mind but not being able to retrieve the correct lemma regardless of the language. Similarly, Laura explained that she cannot employ her L1 to compensate for word-finding difficulties in her L2 (Excerpt 4).

(4) INV: Dus als u één woord in het Nederlands niet weet, dat u het dan in het Engels kunt zeggen.
So, if you don't know one word in Dutch, you can then say it in English.

Laura:	Nee **because then I don't have a a a** woord **I can't take.**
	No BECAUSE THEN I DON'T HAVE A A A *word* I CAN'T TAKE *[it].*
	Nee [shakes head] **doesn't matter.**
	No DOESN'T MATTER.

Language control

In thirteen interviews, participants shared their experiences with controlling multiple languages. Four participants explicitly recounted mostly positive experiences. For instance, Arthur reported that he does not experience difficulties separating his languages and that he deliberately switches to his stronger L2 when he is tired. Both Hugo and Bren reported it to be easy to switch between their languages. For Niels, unintended mixing occasionally happens but he asserted that he is able to separate his languages.

More prominent control difficulties were reported in eleven interviews, as some interviewees mentioned both negative and positive consequences of aphasia for language control. For some participants, words in non-target language sometimes automatically surface, resulting in somewhat of a "jumble". Relatedly, participants may encounter difficulties separating languages: Bren reported that it is challenging to separate his three languages, although this improved over time. In line with this, Ersel reported to struggle with language comprehension in high-density Turkish-Dutch code-switching contexts.

Finally, participants mentioned that the non-target language may be more active, requiring conscious suppression of that language and a deliberate language choice. Lars, for instance, pointed out that his languages sometimes start to mingle, and that he prefers to focus on one language in a conversation. Olaf experiences pronounced difficulties controlling his languages because his L2 surfaces automatically and before his L1. Laura explained that she unconsciously switches to her L1, which she only notices by observing the reaction of her interlocutors (Excerpt 5).

(5)	INV:	En heeft u het zelf eigenlijk altijd door dat u in het…
		And do you yourself actually always notice that you're in the…
	Laura:	**No** [shakes head].
		NO.
	INV:	Nee precies. Ja.
		No exactly. Yes.
	Laura:	**No** [shakes head]. Nee **I I don't have uh** het door.
		NO. No I DON'T *uh notice it.*

2.3.2 Code-switching

The results of the code-switching analysis showed that there was variability between participants in their use of other-language material during the interviews (Table 4). For instance, Laura produced 49% of her words in the non-target language English, while three participants only used Dutch words during the interview. Crucially, most participants produced only a limited number of words in the non-target language throughout the interview.

Table 4. Occurrences of code-switched verbal units per participant.

Participant	Words produced in non-target language	Total words produced during interview	% words produced in non-target language
Anton	1	1349	0.1%
Arthur	1	2140	0.0%
Barend	1	1534	0.1%
Bram	15	7790	0.2%
Bren	51	978	5.2%
Daan	4	479	0.8%
Ersel	4	1900	0.2%
Gerrit	12	3788	0.3%
Hugo	48	1605	3.0%
Jasper	3	1344	0.2%
Jens	0	1311	0.0%
Lars	26	1815	1.4%
Laura	450	917	49.1%
Madar	0	1245	0.0%
Niels	29	1799	1.6%
Olaf	21	867	2.4%
Tessa	2	1538	0.1%
Tobias	14	1342	1.0%
Valerie	0	1455	0.0%

Table 5 presents the code-switches observed in the dataset, with information about the position of the code-switch, the linguistic unit that was switched, and the realization of the code-switch. After excluding the names and loanwords, 244 instances of code-switching remained. There were more intra-sentential switches ($N = 183$) than inter-sentential switches ($N = 61$).

Table 5. Counts and percentages of the code-switches, including information about position, linguistic unit, and realization.

Position	**Linguistic unit (% of column total)**		**Realization (% of row total)**	
			Preceded by hesitation	*Followed by correction attempt*
Inter-sentential	Content word	3 (5%)	0 (0%)	0 (0%)
	Function word	4 (7%)	0 (0%)	0 (0%)
	Phrase	54 (89%)	12 (22%)	7 (13%)
	Uncategorized	0 (0%)	0 (0%)	0 (0%)
	Total	61 (100%)	12 (20%)	7 (11%)
Intra-sentential	Content word	79 (43%)	33 (42%)	20 (25%)
	Function word	54 (30%)	10 (19%)	12 (22%)
	Phrase	49 (27%)	19 (39%)	6 (12%)
	Uncategorized	1 (1%)	0 (0%)	0 (0%)
	Total	183 (100%)	62 (34%)	38 (21%)
Total	Content word	82 (34%)	33 (40%)	20 (24%)
	Function word	58 (24%)	10 (17%)	12 (21%)
	Phrase	103 (42%)	31 (30%)	13 (13%)
	Uncategorized	1 (0%)	0 (0%)	0 (0%)
	Total	244 (100%)	74 (30%)	45 (18%)

Inter-sentential code-switches

We found 61 inter-sentential code-switches in the dataset. Naturally, most of these switches were on entire phrases (54 instances). Regarding the realization of the code-switches, it appears that a minority of the inter-sentential switches was preceded by a hesitation (20%) or followed by a correction attempt (11%). Of these code-switches, one was interpreted as serving a sociolinguistic function and six appeared to have a metalinguistic function (Table 6). In switches with a metalinguistic function, participants switched to the other language to comment on their abilities in that language (Excerpt 6).

(6) INV: Dat u toch makkelijk wisselt naar het Duits.
That you easily switch to German.
Hugo: Ja **das ist kein Problem.**
Yes, THAT'S NOT A PROBLEM.

The majority of the inter-sentential code-switches were classified as having a psycholinguistic function (85%). In these cases, we assumed that the code-switch was the result of a difference in lexical accessibility, where the intended word was easier or faster to retrieve in the non-target language. Importantly, most of the inter-sentential switches were produced by one participant: Laura showed a substantial number of such switches (45 instances, contributing 74% of the total inter-sentential switches). These switches often concerned a shift from her L2 Dutch to her L1 English (Excerpt 7).

(7) INV: Dat is omdat u al zoveel van de wereld heeft gezien, bedoelt u?
That is because you have already seen so much of the world you mean?

Laura: Ja **because uh otherwise uh you think.**
Oh I wanted to do this and I want to do that.
And I had it.

Yes BECAUSE UH OTHERWISE UH YOU THINK.
OH I WANTED TO DO THIS AND I WANT TO DO THAT.
AND I HAD IT.

Importantly, Laura mentioned that she unconsciously switches to her L1 when trying to speak in Dutch. Furthermore, only seven (16%) of her inter-sentential code-switches were followed by an attempt to provide a correction to the target language. Her code-switching pattern in combination with the self-reports lead us to suggest that while many of Laura's code-switches are the result of a difference in lexical accessibility (i.e., a psycholinguistic function), she is unable to consciously monitor or suppress the more active non-target language. As such, her code-switches may in fact be a consequence of a control deficit.

Table 6. The postulated functions of the inter-sentential and intra-sentential code-switches, counts and percentages per position.

Position	**Function**			
	Metalinguistic	*Psycholinguistic*	*Sociolinguistic*	*Uncategorized*
Inter-sentential	6 (10%)	52 (85%)	1 (2%)	2 (3%)
Intra-sentential	21 (11%)	152 (83%)	8 (4%)	2 (1%)
Total	27 (11%)	204 (84%)	9 (4%)	4 (2%)

Intra-sentential code-switches

Most of the observed code-switches were intra-sentential (183 out of 244 code-switches, 75%). The intra-sentential switches mostly concerned content words (43%), followed by function words (30%) and phrases (27%, Table 5). Compared to the inter-sentential switches, more intra-sentential switches were preceded by hesitations (34%) and followed by attempts to correct to the target language (21%, Table 5). Of the intra-sentential switches, 21 (11%) were used as examples and their function can thus be interpreted as metalinguistic (Table 6). In these cases, participants seemed to switch to illustrate their language knowledge (Excerpt 8), explain how the languages they know differ (Excerpt 9), or provide an example of how their knowledge of multiple languages helped them (Excerpt 10).

(8) Tobias: Wel ehm eerste woord van eh op Frans **fromage**. Kaas!
Well ehm first word of eh on [g] French CHEESE. *Cheese!*

(9) Lars: Want ook een [gesture hand] andere uh **trött** bijvoorbeeld **trit**.
Because also another uh TIRED, *for example,* TIRED *[p].*
i(n) Holland is uh **trött** uh moe moe.
in Holland [s] is uh TIRED *uh tired tired.*

(10) Jasper: Ehm (.) ehm (.) ehm (.) heel vroeger, maar ja, vijf jaar geleden, dan eh logopedie geweest.
Ehm ehm ehm a long time ago, but yeah, five years ago, then eh speech therapy had [g].
Maar dan plaatje huis, maar dan eh **home home** maar dan ja.
But then picture house, but then eh HOME HOME, *but then yeah.*
Eh eh verst- ja begrijpen **home** maar dan eh huis ja.
Eh eh hea- [s] yes understand HOME *but then eh house yes.*

Code-switches that could be marked as serving a sociolinguistic function were scarce in the dataset. Bram is the only interviewee who showed multiple code-switches that could be explained in terms of emphasizing one's own identity. During the interview, Bram mentioned that he has been part of an international gaming community, where English is the lingua franca (Crystal, 2001). The code-switches he produced resemble those that have been observed in online writing of young Dutch people (Verheijen & Van Hout, 2022), and often concerned affective language (Excerpts 11 and 12) or discourse markers (Excerpt 13). The finding that most of the code-switches were not preceded by hesitations nor followed by correction attempts, adds to our interpretation of a sociolinguistic function of these switches. It must be noted, though, that Bram's insertions of English words could also be explained as *lexical borrowings*, an issue we return to in the Discussion.

(11) Bram: *Maar dat is wel **super cute** natuurlijk.*
But that's SUPER CUTE, *of course.*

(12) Bram: Dat is dan **annoying** zeg maar.
That's kind of ANNOYING, *you know.*

(13) Bram: Maar ehm ja **anyway** die dus ik ben tot begin van de corona…
But ehm, yeah, ANYWAY, *that so I was until the beginning of the corona…*

Consistent with the inter-sentential switches, we argue that most of the intra-sentential switches in the dataset served a psycholinguistic function and were the result of a difference in the ease of lexical access between the languages. Various factors may have contributed to these lexical access differences. First, participants encountered *word-finding difficulties*, exemplified by filled pauses or hesitations, and this may have prompted a switch to the other language in case the translation equivalent was easier to retrieve (Excerpt 14). Sometimes, such code-switches were followed by an attempt to correct with a translation to the target language (Excerpt 15). Secondly, the *absence of a translation equivalent* with the exact same meaning might also explain why words in the non-target language were easier to access (Excerpt 16). Thirdly, we assumed that the difference in lexical accessibility could have been driven by a more frequent use of specific words in one language than the other (Excerpt 17).

(14) Niels: Uh [four fingers up] vier m- m- **months** geleden krijg ik een beroerte [waves hand].
Uh four m- m- MONTHS ago I have [g] a stroke.

(15) Tobias: Ja ja ja en ook ehm **hörbucher** (.) hoorspelen.
Yes, yes, yes, and also, ehm, AUDIOBOOKS (.) radio plays [s].

(16) Arthur: i- is is niet zo uh uhm (.) uh **nip- nifty** en zo maar het het werkt uh voorlopig dus uh.
i- is is not like uh uhm (.) uh NIP- NIFTY and all, but it it works uh for now, so uh.

(17) Laura: And then I got a [points to head] **herse- herseninfarct**.
And then I got a BRAI- BRAIN INFARCTION.

Finally, some words may have been easier to access because they were cued by the preceding context. This was mainly the case for Laura, whose default language during the interview appeared to be English (L1). In some utterances, she inserted Dutch nouns that were included in the question (Excerpt 18). A likely explanation for these intra-sentential switches is that certain salient words in the immediately preceding context received an activation boost, making this specific word temporarily more accessible in Dutch than English. Importantly, as noted before, Laura indicated to have difficulties controlling her language choice. As such, these intra-sentential switches may be involuntary, and result from priming effects that reflect an activation process rather than an intentional switch to the target language.

(18) INV: Heeft u ook geen duidelijke herinneringen aan die eerste periode? Of?
You also don't have clear memories of that first period? Or?

Laura: **Uhm (..) i- uhm I know what uhm I was doing**.
UHM I- UHM I KNOW WHAT UHM I WAS DOING.

INV: Hmm.

Laura: **But I I don't have any** herinnering **that uh doing wrong** [g].

But I I don't have any memory that uh doing wrong [g].

More evidence for intra-sentential code-switches that could be the result of control difficulties were switches on function words (e.g., Muysken, 2000). Two participants code-switched frequently on function words: Olaf (13 instances) and Bren (29 instances). For Bren, the interview was conducted in his L3. His code-mixes predominantly concerned insertions of function words, most notably 'und' (*and*) in his L1 German (Excerpt 19). In only a few cases, his switches were corrected to Dutch (Excerpt 20). In line with this more marked code-switching pattern, Bren described that he cannot use his multiple languages to compensate for word-retrieval deficits, and that he experiences difficulties separating his languages, although this slowly improves over time. Olaf reported similar experiences and also showed intra-sentential code-switches of function words to his L2 English.

(19) Bren: **Und** Engels **und** ja zie die uh ja dat di- di-…

And English and ja see that uh yes that di- di…

(20) Bren: En dat s- uh het het uhm uhm uh ik w- weet niet **wo** waar w- w- wat we uh…

And that s- uh it it uhm uhm uh I d- don't know where where w- w- what we uh…

The results for the code-switching patterns show that most of the participants produced few instances of code-switching and adhered to the pragmatic context of the interview. Moreover, the majority of participants switched by inserting content words into the structure of Dutch sentence, which aligns with the literature on neurologically healthy bilinguals (e.g., Muysken, 2000). Finally, we saw that many code-switches appeared to be the result of differences in lexical access between languages (i.e., psycholinguistic function), and that there were some instances of metalinguistic or sociolinguistic reasons to code-switch.

2.3.3 Two case studies

The previous sections revealed variability in the participants' experiences and code-switching patterns. To further explicate language control mechanisms in bilinguals with aphasia, we focused on two interviewees with diverging experiences: Niels, who reported no control difficulties, and Olaf, who experienced problems suppressing his L2. We address their self-reports, code-switching, and repair initiation observed in the interviews.

Niels: Unimpaired language control?

Niels is a 65-year-old man with chronic aphasia and apraxia of speech due to an ischemic stroke in the left hemisphere eleven years ago. He is a non-fluent speaker with slightly slowed and staccato speech. His spontaneous language production is characterized by word-finding difficulties and simplified syntactic structure. His spontaneous speech was rated 22/30 on the AAT assessment scale (Graetz et al., 1992). Niels is a native speaker of Dutch and a late learner of English (L2) and French (L3). He acquired his L2 and L3 through formal instruction and immersion. Pre-morbidly, he was a highly proficient, balanced Dutch-English bilingual with frequent use of both languages. He currently still uses both languages daily.

Interview

Niels exclusively reported positive experiences regarding compensation and control during the interview. He said that he sometimes uses his other language to retrieve a word and answered "of course!" to the question whether this should be viewed as a strategy. Consequently, he indicated that he considers his knowledge of multiple languages beneficial. In similar vein, Niels reported that he does not mix his languages unconsciously and although mixing occasionally happens, he explains that he "knows the languages".

Code-switches

Niels produced 29 words (1.6%) in the non-target language. These words were part of 12 code-switches, one produced inter-sententially and 11 intra-sententially. Niels provided corrections to the target language for three of his code-switches, and nine switches were preceded by hesitations or filled pauses. The switches concerned, for example, interjections (*'whatever', 'oh wait'*) or idiomatic expressions (Excerpt 21). Moreover, Niels showed multiple code-switches that can be interpreted as self-cueing via his L2. In Excerpt 22, the code-switch is preceded by a filled pause and an explicit signal of a word-finding difficulty (*'What do you call that?'*), and is followed by the Dutch target word. Finally, there were examples of code-switches that were likely to have been primed by the preceding context. In Excerpt 23, the English title of the movie may have primed the code-switch to English on the word 'speech'.

(21) Niels: Nou niet uh mijn mijn **cup of tea** nee en uh Hazes ook niet maar…
Well, not uh my my CUP OF TEA*, no, and uh, Hazes neither, but...*

(22) Niels: Ik vind het uh i- i- i- i- i- ik uh mijn uh familie uit Frankrijk uh ja d- die uh schoonfamilie is uh…
I find it, uh, i- i- i- i- i- I, uh, my, uh, family from France, uh, yes, my i- uh in-laws are, uh...
Hoe noem je dat?
What do you call that?

Dead uh overleden.
DEAD, uh, deceased.

(23) Niels: Maar de eerste keer dat ik film zien uh na de beroerte was the King's Speech.
But the first time I see [g] a movie after the stroke was "The King's Speech."

INV: Oh oké!
Oh okay!

Niels: Geweldige film.
Great movie.

INV: Ja is een prachtige film.
Yes, is a wonderful film.

Niels: Dat gaat over de koning in Engeland die die uh stottert en dat is geweldig.
It's about the king in England who who uh stutters and that is fantastic.

INV: Ja.
Yes.

Niels: En de eerste keer dat ik- gaat over uh **speech** [points to mouth].
And the first time that I- it's about uh SPEECH.

Repair

Niels showed 73 instances of repair initiation during the interview, indicating that the percentage of repair behavior over total number of words during the interview was 4%. There were seven occurrences of signaling (Excerpt 22), two descriptions, and 64 gestures. Excerpt 24 illustrates how Niels used gestures to support the target word 'think'. In the same example, he gave a description of how he can use his knowledge of English to communicate a message.

(24) Niels: Ja tuurlijk want uh ja i- ik ik denk oh ja is beter [points to head].
Yes of course because, uh yes, I- I think, oh yes is better.
Ja uh wat is een l- l- uh misdaad dingen uh **crime crime** nee ja uh ja dan ga je [points to head]…
Yes uh what is a l- l- uh crime things, uh, CRIME, CRIME, no yes uh yes, then you go…

Olaf: Impaired language control?

Our second case is Olaf, a 54-year-old man who had a hemorrhagic stroke in his basal ganglia three years prior to the interview. Olaf is a non-fluent speaker with aphasia whose speech is mostly characterized by articulatory and phonemic difficulties, as he has concomitant apraxia of speech. He exhibits no clear syntactic impairment and his word-finding problems are not prominent in spontaneous speech, which was rated 24/30 on the AAT assessment scale (Graetz et al., 1992). Dutch is his first language, and he is a late learner of English (L2), which he acquired through formal instruction and immersion since he lived and worked abroad. He also learned German, French, and Cantonese, albeit to a more limited level of proficiency. Prior to his stroke, he was a highly proficient speaker of English and a balanced bilingual, who used his L2 reportedly 90% of the time. After his stroke, Olaf indicated that he wants to focus on improving his Dutch.

Interview

Olaf solely reported negative experiences with language control during the interview. He explained that his knowledge of English is no longer beneficial but interferes with speaking Dutch. When he intends to communicate a message in Dutch, the non-target English is automatically activated, and Olaf needs to deliberately translate each word before speaking (Excerpt 25).

(25)	INV:	Bedoelt u dat u dat nu nog steeds makkelijk spreekt? Makkelijker?
		Do you mean that you still find it easy to speak now? Easier?
	Olaf:	[shakes head] Ja makkelijker **but** want het komt als de eerste taal in mijn hoofd op.
		Yes, easier, BUT *because it comes up as the first language in my head.*
	INV:	Echt waar?
		Really?
	Olaf:	Dan dan Engels dan **to** Nederlands dan **to** paar- praten.
		Then, then English, then TO *Dutch, then* TO *a spe- speaking.*

Code-switches

Olaf used 21 words (2.4%) in the non-target language, and these were part of 18 code-switches that were all produced intra-sententially. His code-switches concerned four content words, thirteen function words, and one phrase. There were correction attempts in five code-switches and four were preceded by a hesitation or filled pause. Excerpt 26 illustrates a code-switch on a noun, which is preceded by false starts and followed by a correction to Dutch. In Excerpt 27, Olaf switched on pronoun "everything", which is subsequently corrected to Dutch. The most striking pattern is the code-switching on short function words (Excerpt 28). In line with his own reports, our interpretation is that these switches are caused by difficulties suppressing his L2.

(26) Olaf: En (.) wonen in een vreemd kl- l- kanty wonen in een vreemd gebied ook leuk.
And (.) living in a foreign c- c- COUNTRY [p], living in a foreign area, also fun.

(27) Olaf: i- parijt en de opelheid en de [waves hand] **everything** al- al- (..) alles.
i- parijt [n] and the opelheid [n] and the EVERYTHING ev- ev- everything.

(28) Olaf: Ja **it** gaat beter.
Yes IT gets better.
INV: Hmhm.
Olaf: Maar **still** maar st- **it** gaat stap voor stap.
But STILL, but st- IT goes step by step.

2

Repair
Olaf showed a total of 25 instances of repair, and the percentage of repair behavior over total number of words produced during the interview was 2.9%. His repair behavior included nine occurrences of signaling and sixteen gestures. One frequently observed repair is a gesture used to signal that he needed more time to verbalize his message (Excerpt 29). After this signal, he was generally able to produce the target answer.

(29) INV: En dus een grote retailer, is dat een kledingwinkel of…
And so, a big retailer, is that a clothing store or...
Olaf: Nee tis i- **it** o- ehm even wachten [holds up hand].
No, it's i- IT, ehm, wait a moment.
INV: Ja.
Yes.
Olaf: Het i- het is een schoenenbedrijf.
It i- it is a shoe company.

2.4 Discussion

This study aimed to provide new insight into the question why bilinguals with aphasia code-switch, and whether their code-switching should be considered the result of control deficits or as a strategy to enhance verbal effectiveness.

2.4.1 Self-reports about bilingual abilities

The self-reports indicated that many participants reported to recruit their bilingual language knowledge to compensate for word-retrieval deficits. Differences were described in the intentionality of these code-switches and whether they served as substitutions or aids in retrieving the target word in the intended language. The interviews also revealed that not all participants experienced difficulties controlling their languages, but when they did, it was considered disruptive for their daily communication. The reported control difficulties primarily concerned the automatic and involuntary co-activation of both languages, leading to problems separating and suppressing the languages. The stage at which the control difficulties arise, varied across participants. For some, the non-target language could not always be inhibited proactively but they were able to monitor their output. For one interviewee, inhibition could not be selectively applied to the non-target language, nor was it possible to monitor the language of the output. Previous research also reported variability in the presence and extent of control impairments in bilingual individuals with aphasia (e.g., Dash & Kar, 2014; Grunden et al., 2020). However, to our knowledge, this study is the first that corroborates these findings with self-reports of bilingual speakers with aphasia.

2.4.2 Typical code-switching patterns

The analysis of the code-switches revealed that most participants showed no or very few instances of code-switching. Instead, they answered almost exclusively in the target language. Notably, when code-switching did occur, it primarily involved switches to English, despite the participants having diverse language backgrounds encompassing various languages. Although not explicitly addressed before the interview, it is possible that participants made assumptions about the interviewer's language knowledge, as English use and proficiency is widespread in academia and in the Netherlands in general (Edwards, 2016). Consequently, most participants seemed to only switch to languages assumed to be shared between interviewer and interviewee, and thus adhered to the pragmatic context of the interview. These results corroborate earlier research that found no evidence for pragmatically inappropriate code-switching in bilinguals with aphasia (Chengappa et al., 2004; Goral et al., 2019; Paplikar, 2016; Riccardi, 2004).

Furthermore, the code-switching patterns generally aligned with those observed in neurologically healthy bilinguals, both in terms of switched elements and their functions. In most cases, code-switches involved the insertion of single content words, serving metalinguistic, sociolinguistic, or psycholinguistic functions (e.g., Muysken, 2000; Poplack, 1980). These findings confirm earlier studies that reported few qualitative differences between individuals with and without aphasia (Chengappa et al., 2004; Grosjean, 1985; Muñoz et al., 1999). However, the specific functions of code-switching in persons with aphasia had not been extensively studied, as previous research administered more constrained narrative elicitation tasks (Bihovsky et al., 2023; Goral et al., 2019; Lerman et al., 2019; Neumann et al., 2017), or focused on the structural properties of code-switches (Muñoz et al., 1999; Paplikar, 2016). Evidently, our results of the functions of the code-switches are based on interpretations of the observed behavior.

To improve replicability, we have consolidated our results by using a consensus rating of two coders, but future research could further investigate the functions of code-switches by bilinguals with aphasia in a more controlled setting.

Code-switches that served a metalinguistic function suggest that participants were able to intentionally access their other languages to convey a message. In addition, the participant who produced switches that appeared driven by sociolinguistic factors, showed switching patterns that resembled those seen in neurologically healthy bilinguals (Verheijen & Van Hout, 2022). Additionally, many code-switches were likely the result of differences in ease of lexical access, a key factor in code-switching among healthy bilinguals (Heredia & Altarriba, 2001). Individuals with aphasia may experience more pronounced lexical accessibility difficulties due to their language impairment, potentially resulting in increased code-switching frequency (Bihovsky et al., 2023; Chen, 2018; Goral et al., 2019; Lerman et al., 2019; Muñoz et al., 1999; Paplikar, 2016).

Furthermore, our results showed instances of explicit self-cueing via the other language. In such cases, participants encountered word-retrieval deficits, often accompanied by (filled) pauses, hesitations, or explicit signals. This was followed by a code-switch and, in some cases, by corrections to the translation equivalent in the target language. Notably, this realization of code-switches contradicts a control deficit interpretation (Abutalebi et al., 2000). Self-cueing is known to be an effective communicative strategy for individuals with aphasia in general (Berman & Peelle, 1967), and has also been used in an intervention to train switching back to the target language for a bilingual with aphasia who involuntarily switched to the non-target language (Ansaldo et al., 2010). Our results indicate that code-switching may be used as a self-cueing strategy and should therefore not always be discouraged in clinical practice (see also Hameau et al., 2022). Additional research into the effectiveness of self-cueing via the other language is an important direction for future research.

Subsequent studies could also elaborate on the specific words that are code-switched by individuals with aphasia. We adhered to a somewhat coarse classification of code-switched material, by dividing it into code-switches on function words, content words, and phrases. In doing so, we disregarded whether words functioned as discourse markers. Discourse markers are words that play a role in establishing relationships between different parts of a conversation, but do not contribute to the conceptual meaning of the sentence (Fraser, 1999). Because discourse markers are syntactically separable from the main sentence, they can easily be code-switched. A detailed analysis of the discourse markers in our data was beyond the scope of the current study, and this topic deserves further investigation (see also Bihovsky et al., 2023; Neumann et al., 2017; Neumann-Werth et al., 2010).

In addition, we excluded loanwords from our switching analysis because these words have become part of the Dutch lexicon. Our rather strict definition of loanwords excluded switches to another register that could have been considered *borrowed elements*, especially in the case of the code-switches with a sociolinguistic function. However, because the distinction between borrowings and true code-switches is problematic (Appel & Muysken, 1987), we decided to retain our strict operationalization.

2.4.3 Marked code-switching patterns

These results demonstrate that the majority of our participants exhibited typical code-switching patterns that were often driven by differences in lexical access. However, three participants displayed more marked code-switching: Laura, Bren, and Olaf. These patterns may be attributed to language control impairments. This interpretation was based on several factors, including their self-reported difficulties with language control, the characteristics of the code-switched elements, or the absence of corrections for switches.

Laura, who reported limited control over her languages, tended to answer questions in her L1 English, which was the non-target language of the interview. These inter-sentential code-switches have been associated with language control impairments (Fabbro, 2000; Perecman, 1984). Moreover, some of the observed intra-sentential code-switches to the target language were argued to result from automatic bottom-up activation of lexical items in the preceding context, rather than intentional switches. This pattern aligns with observations from neurologically healthy bilinguals, where code-switching can be *triggered* by priming from words in the context (Broersma & de Bot, 2006; Clyne, 2003). Investigating whether bilinguals with aphasia are more susceptible to triggered code-switching than neurologically healthy bilinguals, is a direction for future research.

For Bren, the interview also took place in his late-acquired L3. His language background and the severity of his language impairment might have contributed to his frequent and marked code-switching, often involving short function words – an uncommon pattern among healthy bilinguals (Muysken, 2000). Code-switching on function words has previously been attested in bilinguals with aphasia, and has been explained as an attempt to enhance fluency (Bihovsky et al., 2023). Bren reported difficulties in separating his languages. These observations together lead us to suggest that his code-switching patterns were, at least partially, caused by a problem with language control.

Olaf also code-switched frequently on short function words. Because he is a native speaker of Dutch residing in the Netherlands, it appeared unlikely that he code-switched to his L2 to compensate for language deficits, making a control deficit more plausible. This interpretation aligns with his self-reports and localization of his lesion in the basal ganglia, a subcortical brain structure that is part of a wider network hypothesized to be crucial for bilingual language control (Abutalebi et al., 2000; Aglioti et al., 1996; Ansaldo et al., 2010; Calabria et al., 2018; Green & Abutalebi, 2008; Van der Linden, Dricot, et al., 2018).

2.4.4 Highlighting variability in two cases

To illustrate the diversity within our participant group, we conducted a more in-depth analysis of two cases, Niels and Olaf. Despite their similar language backgrounds, these two cases reported diverging experiences with bilingual language control. Their self-reports during the interviews were consistent with the observed code-switching patterns. Both participants proved to be able to initiate conversational repair during the interview, taken as index of language control abilities in functional communication (Frankel et al., 2007; Penn et al., 2010; Spitzer et al., 2020), although Niels showed a higher occurrence of repair initiation as compared to Olaf.

This difference between Niels and Olaf could imply that the bilingual language control difficulties experienced by Olaf, that result in problems suppressing his L2, are part of a more general language control problem that may sometimes prevent him from initiating repair upon encountering communicative difficulties. However, these results should be regarded as exploratory, because the observed differences were small and repair initiation was analyzed in a relatively uncontrolled setting. Furthermore, these results also indicate that Olaf, despite experiencing pronounced difficulties with bilingual language control, was still able to initiate communicative repair in many cases. This could suggest that bilingual language control difficulties are, to a certain extent, distinguishable from language control problems expressed in the ability to initiate repair. Further research including a larger group is needed to elucidate this suggestion.

Another direction for future research is to elaborate on the various forms of compensatory strategies that persons with aphasia use. We focused on communicative repair, which included signals, descriptions, and iconic or deictic gestures. In doing so, we excluded other forms of strategic behavior, such as filled pauses to buy time or gestures that signify an enumeration. This was a methodological decision to make the analysis manageable, but a broader definition of compensatory behavior and how this behavior relates to the control abilities of individuals with aphasia is worth examining in subsequent studies.

2.5 Conclusion

This study showed that although many bilinguals with aphasia report to experience difficulties controlling their languages, they also report their knowledge of multiple languages to be beneficial in word retrieval. A similar variability was observed in their code-switching patterns, although many participants adhered to the pragmatic context of the interview and rarely code-switched. The observed code-switches often resembled those of healthy bilinguals in terms of realization and function. Three participants exhibited atypical code-switching patterns, both quantitatively and qualitatively. We argued that their code-switching was likely, at least partially, the result of difficulties with language control. Importantly, all three participants were able to accurately reflect on their abilities. A more detailed exploration of two participants with diverging control experiences further illustrated the variability in this population, and indicated that diverging reported bilingual language control experiences did not coincide with clear differences in the ability to initiate conversational repair. This study highlights that, despite variability, the majority of bilinguals with aphasia effectively manage their two languages. Control deficits appear to exist in a small number of bilinguals with aphasia and may result in marked code-switching behavior.

Appendices

Appendix A. Interview questions

Interview questions taken from the Dutch AAT (Graetz et al., 1992):

1. Can you tell me what happened to you?
   a) How are you doing now?
   b) How is your speech now?
   c) What speech problems were there in the beginning?
2. What is/was your profession?
   a) Where did you last work?
   b) What exactly did you have to do there?
   c) Can you tell me more about that?
   d) How did you come to that choice?
3. Where do you live? Can you tell me something about your family?
4. What do you like to do in your free time? Do you have any hobbies?

Questions about bilingualism:

1. Can you tell me about the languages you speak?
   a) What is your native language?
   b) Which other languages do you speak?
2. Where did you learn these languages?
3. When did you learn these languages?
4. How well do you speak these languages?
5. How often and where do you speak these languages?
6. Do you notice a difference between the two languages before and after your brain injury? If so, in what way?
7. What does being bilingual mean to you?
8. In which situations do/did you speak these languages?
9. How important is it for you to speak both languages?
10. Does your bilingualism have only advantages, or do you also encounter difficulties? Can you explain how that works?
11. Does knowing another language help you with speaking Dutch? If so, in what way?
12. Do you ever have trouble keeping your two languages apart? If so, in what way?
13. Do you feel that others understand you well when you mix two languages?
14. Did you practice both languages after your brain injury? If not, why not? If yes, how was that?

Appendix B. Codebook for reported experiences, instances of code-switching, and repair initiation during the interviews

Reports

Code	Definition	Example
Neutral experiences	**Any reports about current or past bilingual experiences that do not have a clear positive or negative interpretation.**	
Control	Neutral experiences about bilingual language control (e.g., switching, interference suppression).	"It is difficult to say if languages interfere."
Long-term post	Neutral experiences about the language abilities long-term post acquiring aphasia.	"Currently, I use Swedish with my neighbors."
Pre	Neutral experiences about the language abilities before acquiring aphasia.	"I used to speak Dutch in school."
Short-term post	Neutral experiences about the language abilities short-term post acquiring aphasia.	"Right after my stroke, Turkish recovered and then Dutch."
Negative experiences	**Any reports about current or past bilingual experiences that have a clear negative interpretation.**	
Compensation	Knowledge of other language cannot be used to compensate for language difficulties.	"I cannot use English as a trick to find a word."
Control	Negative experiences about bilingual language control (e.g., switching, interference suppression).	"Sometimes, my languages interfere."
Long-term post	Negative experiences about the language abilities long-term post acquiring aphasia.	"I can't find the words in French anymore."
Pre	Negative experiences about the language abilities before acquiring aphasia.	"I could understand but not speak German."
Short-term post	Negative experiences about the language abilities short-term post acquiring aphasia.	"Early after my stroke, I did not understand any German."
Positive experiences	**Any reports about current or past bilingual experiences that have a clear positive interpretation.**	

Reports		
Code	**Definition**	**Example**
Compensation	Knowledge of other language can be used to compensate for language difficulties.	"I use my Turkish when I can't find a word."
Control	Positive experiences about bilingual language control (e.g., switching, interference suppression).	"It costs me no time to switch between languages."
Long-term post	Positive experiences about the language abilities long-term post acquiring aphasia.	"Those are the languages I knew, and they are still here."
Pre	Positive experiences about the language abilities before acquiring aphasia.	"My English was as good as my Dutch and Somali."
Short-term post	Positive experiences about the language abilities short-term post acquiring aphasia.	"Initially, we could speak English and Dutch like we used to."
Languages	**Any information about the languages spoken by the interviewee.**	
L1	First-acquired language.	
L2	Not the first language.	
Cantonese, Czech, Danish, Dialect, Dutch, English, Finnish, French, German, Hebrew, Papiamento, Portuguese, Russian, Somali, Spanish, Swedish, Turkish.		
Modality	**Any reports about the modality of the language abilities.**	"Reading subtitles while watching English TV is okay."
Listening, reading, speaking, writing.		
Speech therapy	**Any reports about the language in which speech and language therapy was given.**	"We tried English in speech-therapy but that didn't work."

Code-switches			
Code		**Definition**	**Example**
Code-switches		**All other-language material produced by the interviewee.**	
Position	Inter-sentential	A switch between languages that happens at clause boundaries, between turns, or between utterances.	"Wat is er? What is wrong?"
	Intra-sentential	Insertion of lexical items or constituents from one language into structure of other language.	"I can't walk outside alleen."

Code-switches

Code		Definition	Example
Linguistic unit	Content	Switching on content words (nouns, main verbs, adjectives, adverbs).	"Die scholarship heb ik ingevuld."
	Function	Switching on function words (prepositions, determiners, auxiliary verbs, conjunctions, pronouns, interrogatives, interjections).	"Ja makkelijker but het komt als eerste omhoog."
	Phrase	Switching on a string of words.	"My man zegt something is wrong."
Realization	Preceded hesitation	Switch is preceded by a hesitation (repetition of target phonemes) or a filled pause ('uh').	"Uh uhm uh nip- nifty."
	Correction attempt	Switch is followed by an attempt to correct code-switch to target language.	"Mijn Klarheit – ik begreep meer."
Function	Metalinguistic	Switching to comment directly or indirectly on languages involved.	"Alleen wat ik weet is sortie."
	Sociolinguistic	Switching to express one's own identity.	"Dat vind ik echt super cute."
	Pragmatic	Switching that involves hearer directly, to include or exclude persons from conversation.	"Hola hermana, how are you?
	Psycholinguistic	Switching when there is a lack of knowledge of one language.	"En ook ehm hörbucher hoorspelen."

Repair initiation (two cases)

Code	Definition	Example
Repair	**Communicative behaviour signaling language control impairments or abilities, defined as the presence of repair initiation (regardless of success).**	
Signal	Communicative behaviour with which the interviewee signals (s)he encounters difficulties (and potentially asks for help)	"What do you call that?"
Description	Interviewee provides a description of the target word. Description should not be a synonym and should contain >2 words.	"Yes, it's a thing to put flowers in." (for vase)
Gestures	Interviewee provides a gesture to substitute or help retrieve a target word. Can be iconic (form a meaning related to the meaning articulated in speech) or deictic (pointing, showing, giving, and reaching).	"A big book [gesture size] Dick Swaab about the [points to head] uh the brain."

Appendix C. Definition of words used for the word count

The definition of words was based on Nicholas and Brookshire (1993) and Bihovsky et al. (2023). We counted all words or partial words that were intelligible in context. Words did not have to be accurate, relevant, or informative.

Included:

- All words or partial words that were intelligible in context, also if they were repeated, retraced, or revised.
- Words that contain sound substitutions, omissions, distortions, or additions if the word is intelligible in context, also if they result in a real word that was not the target.
- Sound combinations denoting a specific object or action.
- Filler words, phrases, interjections, and informal terms.
- Common contractions or simplifications of words.
- Each word in numbers.
- Compound words were counted as one word.
- Each word in proper names.
- Acronyms were counted as one word.

Excluded:

- Words or partial words that are not intelligible in context:
  - Neologisms
  - False starts
  - Vocalizations
  - Non-word fillers

3

Executive control in bilingual aphasia: A systematic review

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Abstract

Much research has been dedicated to the effects of bilingualism on executive control (EC). For bilinguals with aphasia, the interplay with EC is complex. In this systematic review, we synthesize research on this topic and provide an overview of the current state of the field. First, we examine the evidence for EC deficits in bilinguals with aphasia (BWA). We then discuss the domain generality of bilingual language control impairments. Finally, we evaluate the bilingual advantage hypothesis in BWA. We conclude that (1) EC impairments in BWA are frequently observed, (2) experimental results on the relationship between linguistic and domain-general control are mixed, (3) BWA with language control problems in everyday communication have domain-general EC problems, and (4) there are indications for EC advantages in BWA. We end with directions for experimental work that could provide better insight into the intricate relationship between EC and bilingual aphasia.

3.1 Introduction

With an ever-growing bilingual population, an increasing number of people who develop aphasia after neurological damage are bilingual (Ansaldo & Saidi, 2014). That is, they use or have used more than one language on a regular basis (Grosjean, 2013). Bilingualism has implications for the diagnosis and rehabilitation of aphasia. Treatment of both languages is not always feasible, and the likelihood of cross-linguistic transfer depends on many factors (Goral & Lerman, 2020). In addition, it is difficult to ascertain the premorbid level of proficiency in each language.

When a bilingual develops aphasia, this can result in different recovery patterns across languages (e.g., Fabbro, 2001; Paradis, 2001). Bilingual persons with aphasia (BWA) may have parallel impairments in both languages or selective impairments in one of their languages. Recovery patterns are determined by a multitude of factors, including age of acquisition, language use and history, premorbid language proficiency, and stroke-related variables such as time post-onset as well as size and location of the lesion (Lerman et al., 2020). A meta-analysis investigated the relationship between these factors (Kuzmina et al., 2019), and showed that the general pattern is that BWA perform better in their first-acquired language (L1) than in their second language (L2), an effect modulated by age of acquisition and, to a lesser extent, premorbid language proficiency and frequency of use (see Kuzmina et al., 2019, for a more extensive discussion).

Besides different recovery patterns, bilingual aphasia can lead to cross-language intrusions. Pathological language mixing is a rare phenomenon that refers to the unintended use of two languages within a single utterance, whereas switching happens between utterances (Fabbro, 2000). Although mixing and switching is frequently observed in all bilinguals, it becomes "a pathological behavior when it is inappropriately used within a context where speakers do not share both language codes" (Ijalba et al., 2004, p. 82). BWA have been found to switch more frequently and their switches result in miscommunication more often as compared to healthy bilinguals (Muñoz et al., 1999).

Involuntary mixing or switching is caused by an impairment *in bilingual language control*, the set of functions necessary to use more than one language effectively (e.g., Abutalebi & Green, 2007). There is compelling evidence that both languages are active and compete for selection, either directly (e.g., Costa et al., 1999; Hermans et al., 1998; Kroll et al., 2006; Van Heuven et al., 2008) or indirectly by activating competitors in the target language (Roelofs et al., 2016). One important model for bilingual language production is Green's Inhibitory Control model (1998), which argues that language selection is a competitive process in which interference is resolved by inhibitory control. This inhibition ability is hypothesized to be domain general, that is, it encompasses both linguistic and non-linguistic control.

Inhibition is one of the often-postulated *executive control* (EC) functions. *Updating* of working memory and *shifting* between mental sets are the other two components of an influential proposal about the taxonomy of EC (Friedman et al., 2008; Friedman & Miyake, 2017; Miyake, Friedman, et al., 2000; Miyake & Friedman, 2012), although other models of EC have been put forward (e.g., Braver, 2012; Duncan, 2010). In this proposal, inhibition is defined as the ability to suppress dominant or prepotent responses, shifting refers to the ability to switch between mental sets, operations, or tasks, and updating indicates the active manipulation of incoming information in working memory. Miyake et al. (2000) found that updating, inhibition, and shifting are clearly distinguishable on the behavioral level, but share underlying commonality. EC functions are components of the attention system in the brain (e.g., Posner, 2011; Posner & Raichle, 1994), and together, they allow for complex and goal-directed behavior.

While Green (1998), among others, suggested that the mechanisms for resolving language interference rely on domain-general EC, there is considerable disagreement about the nature of bilingual language control. Another proposal is that bilingual language control relies on functions that are specific to the language domain. One line of research attempts to clarify this by looking for associations between tasks that rely on language control and domain-general EC. The findings of these behavioral studies are mixed. Some find that performance in the two domains correlates (Declerck et al., 2017; Prior & Gollan, 2011), suggesting overlap, while other evidence suggests that the overlap is only partial (Branzi et al., 2016; Calabria et al., 2012, 2015; Klecha, 2013). Secondly, evidence from neuroimaging research indicates that domain-general EC and language control share neural circuits (e.g., De Baene et al., 2015; De Bruin et al., 2014). A third approach is to investigate how bilingual language-control demands in everyday life affect EC. For example, language switching experience has been found to predict non-linguistic switching performance (Barbu et al., 2018; Prior & Gollan, 2011; Soveri et al., 2011; Verreyt et al., 2016).

The third approach is closely related to another lively debate in the bilingualism literature: The hypothesis that bilinguals exhibit enhanced EC due to a lifelong practice with managing two languages. Since the first article reporting evidence for improved performance on a non-linguistic inhibition task (Bialystok et al., 2004) dozens of studies have been published on this topic, but the results are often inconsistent. Review articles and meta-analyses come to varying conclusions: from full support for an advantage (Adesope et al., 2010), to partial support (Hilchey & Klein, 2011; Van den Noort, Struys, et al., 2019), to reviews concluding that there is no convincing evidence for an advantage (De Bruin et al., 2015; Donnelly, 2016;

Lehtonen et al., 2018; Paap et al., 2015). In other words, the status of the bilingual advantage hypothesis remains unclear to date.

Despite the inconclusive evidence, it could be argued that enhanced EC is especially beneficial for persons with aphasia. From monolingual populations with aphasia (MWA) it is already known that they often experience deficits in EC (e.g., Christensen et al., 2018; Fridriksson et al., 2006; Hunting-Pompon et al., 2015; Kuzmina & Weekes, 2017; Murray, 2012a; Olsson et al., 2019). The prevalence of such impairments has led some researchers to suggest that aphasia reflects non-linguistic attentional impairments that negatively impact language processing (Hula & McNeil, 2008; McNeil & Pratt, 2001) and that EC can — at least in part — explain the inter- and intra-subject variation that is frequently observed in aphasia (Kolk, 2007).

Impairments in EC may lead to more severe aphasia symptoms because it prevents PWA from *compensating* for linguistic difficulties, which involves continuously recruiting relatively spared verbal and nonverbal communication skills. Therefore, EC has been shown to be important for functional communicative abilities and recovery of linguistic skills after stroke (Fridriksson et al., 2006; Olsson et al., 2019; Ramsberger, 2005). Moreover, evidence from neuroimaging research indicates that activation of brain regions responsible for domain-general EC correlates with recovery and language performance of monolingual speakers with aphasia (Brownsett et al., 2014).

Research discussed thus far evidently reveals open questions. We know that MWA often suffer from non-linguistic EC impairments. For BWA, these impairments could be particularly noticeable if they rely on these functions to manage their two languages effectively. In the literature on neurologically healthy bilinguals, two prominent debates concern the domain generality of bilingual language control and the bilingual advantage hypothesis. Because there is an increasing bilingual population with aphasia and an apparent link between aphasic symptoms and EC, it is worthwhile to investigate these issues in BWA. In addition, advantages for bilinguals with aphasia could be particularly beneficial, as they may contribute to cognitive reserve and offer a protective effect (e.g., Craik et al., 2010). Various researchers have started to pursue this line of research in the past decade, but findings are not always clear-cut.

In the present study, we synthesize the research published on this topic thus far. We first address the question whether non-linguistic EC deficits have been observed in BWA. Secondly, we review the literature on domain generality of language control by investigating associations between impairments in bilingual language control and EC. Finally, we evaluate the evidence for bilingual advantages in EC for individuals with aphasia.

3.2 Methods

3.2.1 Literature search

Various bibliographic databases were searched: MLA International Bibliography, Linguistics and Language Behavior Abstracts, PubMed, CINAHL, Embase, MEDLINE, PsycINFO, ERIC, Web of Science. Construct- (*executive control*) and population-related (*aphasia* and *bilingualism*) search terms were used, which are presented in Appendix A. We included studies published between each database's coverage start date and March 2020. We inspected the *Aphasiology archives* separately for conference proceedings of the Clinical Aphasiology Conference. Lastly, bibliographies of previous reviews and studies were examined.

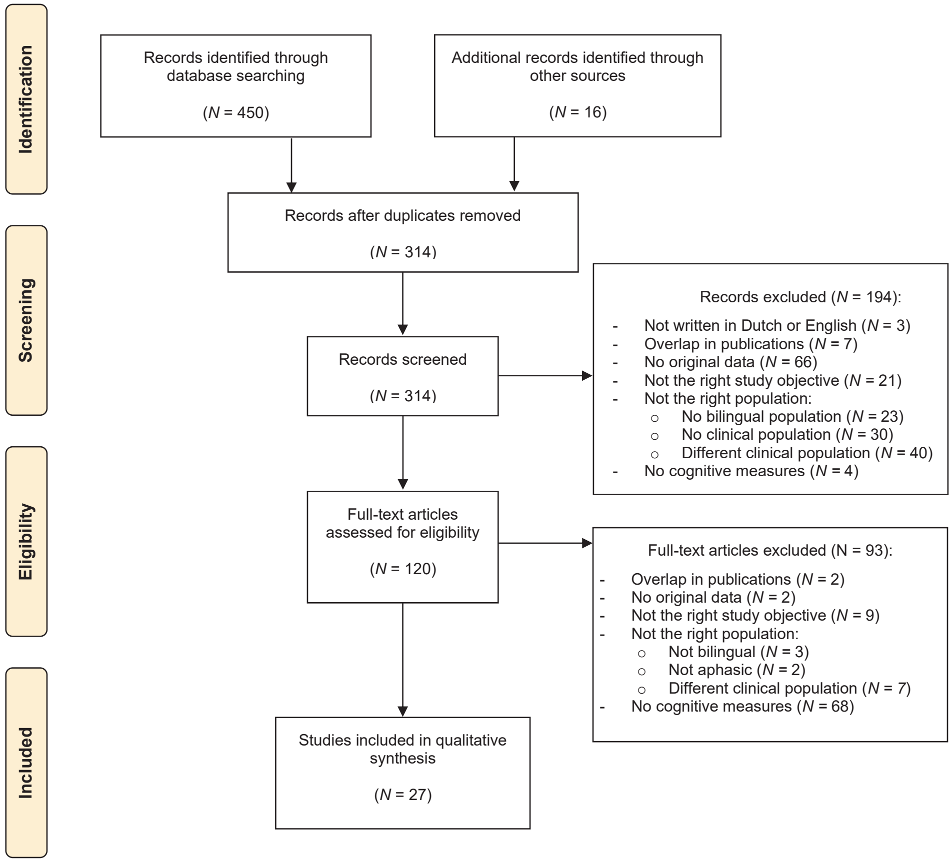
3.2.2 Inclusion and exclusion criteria

We included studies that reported on EC measures in bi- or multilingual individuals with aphasia. They were selected if they included participants who were adults (≥ 18 years) with non-progressive aphasia due to acquired neurological damage of any etiology. Presence and severity of aphasia was determined using a standardized aphasia test or based on a clinician's evaluation. Participants had to be bi- or multilingual, but there were no specific restrictions regarding the type of bilingualism (such as *age*, *manner of acquisition* or *premorbid proficiency*). The studies had to be peer reviewed and include a measure of EC, either with standardized tests or compared to a matched control group of healthy participants. Finally, the article had to be written in English or Dutch. Studies were excluded if they failed to meet these criteria, if they did not include original data (e.g., meta-analyses, reviews), or if participants were duplicated in multiple studies.

3.2.3 Selection procedure

The literature search yielded 466 results in total. We checked the results and removed duplicates, resulting in 314 articles. The remaining papers were screened and assessed on eligibility based on their titles and abstracts. We retrieved the full text of the articles that were left in the final selection. There were 27 articles that met all requirements. The entire selection procedure is illustrated in a PRISMA-flowchart (Moher et al., 2009) given in Figure 1.

Figure 1. PRISMA flowchart of the search process.



3.3. Results

3.3.1 Deficits in non-linguistic EC

All articles that included a comparison between BWA and a healthy control group or that used standardized measures were suitable to evaluate whether EC impairments are observed in BWA. Following Miyake et al. (2000), we divided EC into *inhibiting*, *updating*, and *shifting*, which have been shown to play a role in normal language performance (see Roelofs & Ferreira, 2019, for a review). The results for each study are presented in Table 1.

Inhibiting

Inhibition turned out to be the most-often researched EC component in the included studies. Twenty studies investigated inhibition abilities in BWA. Nine studies used the Stroop task

(Stroop, 1935), in which a deficit is typically operationalized as the relative difference in reaction time (RT) or accuracy between congruent and incongruent conditions (e.g., say "red" to the red ink color of the word *red* or *green*, respectively). The Stroop task is taken to be a measure of *prepotent response inhibition*, a component of inhibition that involves the ability to suppress dominant or automatic responses (Friedman & Miyake, 2004; Miyake, Friedman, et al., 2000; but see Roelofs, 2021; Shao et al., 2015; Sikora & Roelofs, 2018, for evidence against this interpretation).

A large majority (37/39) of BWA, reported on in eight studies, showed abnormally high interference in the Stroop task (Adrover-Roig et al., 2011; Faroqi-Shah et al., 2018; Green et al., 2010, 2011; Kambanaros et al., 2012; Kong et al., 2014; Mariën et al., 2017; Penn et al., 2017). Two BWA, on the other hand, exhibited normal interference (Penn et al., 2010). Most studies report a case (series) design, except for Penn et al. (2017) and Faroqi-Shah et al. (2018), who conducted group studies. The results of the Stroop task indicate that most BWA experience inhibition impairments. However, the linguistic nature of the task (i.e., naming and reading) complicates disentangling non-linguistic inhibition impairments from disordered language skills. In two studies, this validity issue is partially circumvented by administering an adapted version of the task, requiring a nonverbal response (Faroqi-Shah et al., 2018; Penn et al., 2017), but this does not reduce the reading demands. Moreover, the individuals who performed the adapted Stroop also showed impaired performance on this task.

The Eriksen flanker task (Eriksen & Eriksen, 1974) is another frequently used test. Here, participants manually respond to a visually presented target stimulus (e.g., >) while ignoring interference from flanked congruent (i.e., >>>>>) or incongruent (i.e., >><>>) non-target stimuli. This task is frequently used to assess *resistance to distractor interference*, a subcomponent of inhibition that involves the ability to resist or resolve interference from irrelevant information (Friedman & Miyake, 2004). Inhibition abilities in this task are operationalized as interference effects or ratios, which is the relative difference in RT or accuracy between incongruent and congruent conditions. A smaller difference typically points to more efficient conflict resolution. Therefore, impaired inhibitory control is generally defined as markedly larger conflict ratios. However, other authors have defined impaired inhibitory control as the absence of interference effects (Gray & Kiran, 2016, 2019).

BWA also show impairments on the flanker task: 21 BWA reported on in six studies experienced larger interference compared to healthy control participants (Dash et al., 2020; Green et al., 2010; Keane & Kiran, 2015; Van der Linden, Dricot, et al., 2018; Van der Linden, Verreyt, et al., 2018; Verreyt et al., 2013). However, a larger number of BWA shows unimpaired performance on this task: 44 participants in six studies (Calabria et al., 2019; Gray & Kiran, 2016, 2019; Green et al., 2010, 2011; Van der Linden, Verreyt, et al., 2018). The results of the putatively non-linguistic inhibition task thus show a more mixed pattern of impairments as compared to the Stroop task.

The results on the triad task, another test measuring resistance to distractor interference, were also found to be mixed. On this test, participants match stimuli on color or shape based on a cue while ignoring distractors. Eighteen BWA showed impaired performance (Dekhtyar et al., 2020), whereas 13 BWA did not (Gray & Kiran, 2019). It is important to note, however, that impaired performance was operationalized differently in these studies. Dekhtyar et al. (2020) compared performance of the BWA with a control group, whereas the presence of interference effects or ratios was indicative of unimpaired performance in Gray and Kiran (2019).

Four of the studies that did not find abnormal interference nevertheless found BWA to be significantly slower and/or less accurate overall on tasks (Calabria et al., 2019; Gray & Kiran, 2016, 2019; Van der Linden, Verreyt, et al., 2018).[5] This shows that while the specific ability to resist interference from distractors may be intact, other cognitive abilities necessary to perform the task, such as processing speed or sustained attention, may be below normal performance.

Finally, the studies discussed above included BWA who varied in their time post-onset and this may inform us about the transiency of inhibition impairments. The acute phase of recovery typically lasts two weeks, the subacute stage six months, followed by the chronic stage (Kiran, 2012). Three out of four studies that reported on inhibition in the *subacute phase* found abnormal scores (Mariën et al., 2017; Penn et al., 2017; Verreyt et al., 2013) and one study reported differences between BWA with parallel and selective impairments (Van der Linden, Verreyt, et al., 2018). In the subacute phase, spontaneous and guided recovery is still expected, and these impairments may therefore resolve over time. Notably, one study that conducted a comparison between six- and twelve-weeks post onset found that inhibiting impairments persisted (Penn et al., 2017). Moreover, the remaining studies investigated BWA with *chronic aphasia* and frequently observed inhibiting deficits, indicating that these impairments persist.

When we focus on inhibiting abilities, we can conclude that the majority of BWA show impairments when measured with the Stroop task. On flanker and triad tasks, the majority of BWA shows unimpaired inhibition abilities. These contradictory findings could be due to the difference in the linguistic demands of each task, or to the type of inhibition that was measured.

Updating

Four studies investigated *updating* abilities in BWA. Penn et al. (2010) found the performance of two chronic BWA on a self-ordered pointing task to be within the normal range. In this task,

5 For Gray and Kiran (2016, 2019), this claim is based on our calculation of *t*-scores and *p*-values based on the means, standard deviations, and samples sizes reported in these articles.

stimuli are arranged differently across trials, and participants point to a different item in each trial (Petrides & Milner, 1982). Conversely, three studies found updating to be impaired in 12 BWA. Adrover-Roig et al. (2011) and Lee et al. (2016) describe case studies in which patients showed impaired performance on backward digit and/or visual span tasks, in which stimuli must be recalled in reverse order. In a group study (*N* = 10), Penn et al. (2017) found that BWA were impaired on a non-linguistic *N*-back task, in which pictures are presented successively and participants manually indicate whether a new stimulus is the same as the one *N* back. At first sight, the majority (12/14) of BWA appear to have impairments in updating ability.

This observation, however, needs to be nuanced when we consider time post-onset. Most (11/12) BWA with impaired updating ability were in the subacute phase of recovery (Lee et al., 2016; Penn et al., 2017). Results by Penn et al. (2017) show that updating improved over time, though significant differences with control participants remained at 12 weeks post-onset. Therefore, as updating appears to be susceptible to improvement, we cannot rule out the possibility that updating impairments will recover toward the chronic phase of recovery.

Besides time post-onset, the operationalization of updating should call for cautious interpretation of the results. Firstly, backward span tasks tap a broader working memory capacity than the more specific updating ability (Diamond, 2013). Still, latent variable analyses have shown that working memory maintenance and updating appear to rely on similar underlying constructs (Schmiedek et al., 2009; Waris et al., 2015) and performances on the N-back and backward span tasks overlap considerably (Byrne et al., 2019). Secondly, only the self-ordered pointing and N-back task are non-linguistic in nature, as backward span tasks require some linguistic processing. Taking these considerations into account, updating impairments are observed in BWA, though the results appear to be mixed.

Shifting

Finally, there were nine studies that investigated *shifting* ability in BWA. Six studies, including 15 participants, found it to be impaired (Adrover-Roig et al., 2011; Kohnert, 2004; Kong et al., 2014; Lee et al., 2016; Marini et al., 2016; Penn et al., 2017), and three studies, including four participants, report unimpaired shifting abilities (Aglioti et al., 1996; Mariën et al., 2017; Penn et al., 2010).

Like the findings for updating, most (11/15) of the BWA with impaired switching ability were in the subacute phase of recovery, compared to one out of four BWA with unimpaired shifting abilities. Again, Penn et al.'s (2017) study showed that shifting improves during recovery, indicating that shifting impairments may diminish over time.

It is important to consider the tasks that were used to measure shifting ability. The studies reported here administered the Wisconsin Card Sorting Test (WCST; Grant & Berg, 1948) and the Trail Making Test (TMT; Army Individual Test Battery, 1944). Only the WCST can be characterized as a non-linguistic task, as the TMT requires sequencing of letters and therefore relies on linguistic knowledge. When we eliminate the linguistic demands and only focus on the outcomes of the WCST, the majority (13/17) of BWA are still found to be impaired.

Besides linguistic demands, both tasks require complex cognitive processing. Although shifting is an essential component of performance on the WCST (Miyake, Friedman, et al., 2000), it is a multifactorial task that also requires other functions such as conceptual ability, problem solving, and attentional processing (Greve et al., 2002; O'Donnell et al., 1994). The TMT is not only a measure of shifting ability, but also relies on visuo-perceptual abilities and working memory (Sánchez-Cubillo et al., 2009). As with the other EC components, operationalization of the constructs is challenging but crucial for the right interpretation of results. In conclusion, the literature suggests that most BWA experience shifting problems.

Table 1. Summary of studies reporting on non-linguistic EC impairments in bilingual aphasia.

Study	***N***	**Lesion**	**Aphasia: TPO, severity**	**Bilingualism: languages, AoA, usage, proficiency**	**Inhibition**	**Updating**	**Shifting**
Adrover-Roig et al. (2011)	1	Left basal ganglia	Chronic	Basque (L1) - Spanish (L2) Early, equal use, equal proficiency	Impairment (Stroop)	Impairment (digit span)	Impairment (TMT)
Aglioti et al. (1996)	1	Left basal ganglia	Chronic	Venetian (L1) - Italian (L2) L1 more frequent and proficient			No impairment (WCST)
Calabria et al. (2019)	11	Left hemisphere	Chronic Mild-moderate	Catalan – Spanish Early, equal use, equal proficiency	No impairment (flanker)		
Dash et al. (2020)	10	Left anterior regions	Chronic	French – English Varying AoA, usage and proficiency	Impairment (flanker)		
Dash & Kar (2014)	4	Left frontal/parietal	Chronic Mild/Moderate	Telugu, Hindi, Urdu (L1s) - English (L2) Varying AoA, usage and proficiency	Variable (flanker)		
Dekhtyar et al. (2020)	18	*Not specified*	Chronic	Spanish – English Highly proficient but English dominant	Impairment (triad task)		
Faroqi-Shah et al. (2018)	20	*Not specified*	Chronic Moderate	English (L1) – different L2s or Tamil (L1) – English (L2)	Impairment (manual Stroop)		
Gray & Kiran (2016)	10	Various	Chronic Varying severity	Spanish – English Varying AoA, usage and proficiency	No impairment (flanker)		
Gray & Kiran (2019)	13	*Not specified*	Chronic Mild-moderate/ Severe	Spanish – English Varying AoA, usage and proficiency	No impairment (flanker and triad task)		
Green et al. (2010)	2	Left subcortical/ parietal	Chronic	French/Spanish (L1s) - English (L2) Late, equal usage and proficiency	Both patterns (Stroop & flanker)		

3

Table 1. Summary of studies reporting on non-linguistic EC impairments in bilingual aphasia. *(Continued)*

Study	*N*	Lesion	Aphasia: TPO, severity	Bilingualism: languages, AoA, usage, proficiency	Inhibition	Updating	Shifting
Green et al. (2011)	1	Left temporo-parietal	Chronic	German-English-Spanish Early, equal usage and proficiency	No impairment (flanker), impairment (Stroop)		
Kambanaros et al. (2012)	1	Left parieto-occipital	Mild-moderate	Greek – English Simultaneous, L1 more frequent, equal proficiency	Impairment (Stroop)		
Keane & Kiran (2015)	1	Left frontal due to tumor	Chronic Moderate-severe	Amharic (L1) - English (L2) - French (L3) Early, L2 more frequent, equal proficiency	Impairment (flanker)		
Kohnert et al. (2004)	1	Left middle cerebral artery	Chronic Severe	Spanish (L1) - English (L2) Late, equal usage and proficiency			Impairment (WCST)
Kong et al. (2014)	1	Left frontal and temporoparietal	Severe	Cantonese (L1) - English (L2) - Mandarin (L3) Late, equal usage and proficiency	Impairment (Stroop)		Impairment (WCST)
Lee et al. (2016)	1	Right basal ganglia	Subacute Severe	Korean (L1) - Japanese (L2) Late, equal usage and proficiency		Impairment (digit span)	Impairment (TMT, WCST)
Leemann et al. (2007)	1	Left insula, upper temporal, frontal operculum	Subacute Severe	French (L1)-German (L2) Late, not frequent, not proficient	Impairment (not specified which test)		
Mariën et al. (2017)	1	Right cerebellum	Subacute Mild	English (L1), French (L2), German (L3), Slovene (L4), Serbo-Croat (L5), Hebrew (L6), and Dutch (L7). Late, variable proficiency and usage	Impairment (Stroop)		No impairment (WCST)

Table 1. Summary of studies reporting on non-linguistic EC impairments in bilingual aphasia. *(Continued)*

Study	*N*	Lesion	Aphasia: TPO, severity	Bilingualism: languages, AoA, usage, proficiency	Inhibition	Updating	Shifting
Marini et al. (2016)	1	Whole left hemisphere affected	Chronic Severe	Romanian (L1) - Italian (L2) Early, equal usage and proficiency	Impairment (Tower of London)		Impairment (TMT)
Penn et al. (2010)	2	Left fronto-parietal, left temporo-parietal	Chronic Moderate	English (L1)-Afrikaans (L2) & Multilingual	No impairment (Stroop, Tower of London)	No impairment (self-ordered pointing)	No impairment (TMT - ratio B-A, WCST)
Penn et al. (2017)	10	Various	Subacute Severe	English (L2 or L3), various first languages	Impairment (Stroop)	Impairment (N-back)	Impairment (WCST)
Van der Linden, Verreyt, et al. (2018)	7	Differential aphasia	Subacute Mild (L1) - Moderate (L2)	Dutch (L1)- French/English (L2s) Varying AoA, L1 more proficient	Impairment (flanker)		
	8	Parallel aphasia	Subacute Mild	Dutch (L1)- French/English (L2s) Varying AoA, L1 more proficient	No impairment (flanker)		
Van der Linden, Dricot, et al. (2018)	1	Left subcortical parietal	Chronic Severe	French (L1) -English (L2) Late, L2 more frequent, equal proficiency	Impairment (flanker)		
Verreyt et al. (2013)	1	Subcortical thalamic	Subacute	French (L1)-Dutch (L2) Early, equal usage and proficiency	Impairment (flanker)		

Note. Abbreviations used in the table: TPO: time post-onset (acute: ≤2 weeks, subacute: ≤6 months, chronic: ≥6 months), AoA: Age of acquisition, TMT: Trail Making Test, WCST: Wisconsin Card Sorting Test.

3.3.2 Domain generality of bilingual language control impairments

This section of our review is about the nature of bilingual language control in PWA. If bilingual language control impairments are consistently paired with EC impairments, this may have implications for recovery because the integrity of EC is crucial for aphasia recovery and treatment (Olsson et al., 2019; Simic et al., 2020). Similarly, if language control relies on domain-general EC, training of the latter could lead to improvements in language (Kiran & Gray, 2018). Another reason to investigate domain generality in BWA is that the selectivity of their impairments can inform us about associations and dissociations between cognitive functions (Calabria et al., 2018).

In what follows, we first examine studies that adopted an experimental design to compare EC and language control abilities. Next, we discuss studies that report problems with bilingual language control in functional communication, demonstrated by selective recovery or pathological switching and mixing of the two languages.

Domain generality: evidence from experiments

Nine studies directly investigated the relationship between EC and bilingual language control in controlled experiments (Table 2). The majority of studies focused on *receptive* language control abilities measured with lexical decision tasks (Green et al., 2010, 2011; Van der Linden, Dricot, et al., 2018; Van der Linden, Verreyt, et al., 2018; Verreyt et al., 2013), semantic judgment tasks (Gray & Kiran, 2016, 2019), or a linguistic version of the flanker task (Dash & Kar, 2014; Gray & Kiran, 2019). One study measured *expressive* language control abilities using language switching tasks or picture naming tasks (Calabria et al., 2019). The Stroop task, used by Green et al. (2010, 2011), is a peculiar case, as it requires receptive language abilities (i.e., reading), expressive language abilities (i.e., naming colors), but only limited lexical or semantic knowledge.

The first study to explicitly investigate the overlap between language control and EC was conducted by Green et al. (2010). Two BWA performed verbal lexical decision (LD), the Stroop task, and a non-linguistic flanker task. Their results indicated that, despite their parallel recovery pattern, both BWA had problems managing interference. However, one participant's impairments were limited to the verbal domain, whereas the other participant demonstrated an association between linguistic and non-linguistic control impairments. Green and colleagues argue that overlap between the two processes can be explained by the localization of lesions. The first BWA had left subcortical damage, which according to Green et al. (2010) is consistent with domain-specific language control problems. The other participant had extensive left parietal damage, explaining the domain-general control problems.

Subsequent studies also reported dissociations between language control and EC. Green et al. (2011) report on a case of a trilingual individual with parallel recovery of three languages.

The PWA showed impaired LD and Stroop performance, but performed within normal limits on the flanker task, demonstrating that her language control difficulties were dissociable from non-linguistic control issues. Gray and Kiran (2016) made a similar observation in one of the few group studies that have been conducted *(N* = 10). They administered a semantic relatedness judgment task, measuring bilingual language control, and a flanker task. On the non-linguistic task, both the BWA group and the control group showed interference effects. On the linguistic control task, though, the control group showed significant interference ratios whereas the BWA group did not. According to the authors, these dissociations are indicative of a domain-specific impairment in bilingual language control.

Dash and Kar (2014) investigated four BWA in a case series design. They relied on Braver's (2012) dual-mechanisms framework, in which variability in functions is explained in terms of the temporal dynamics of control. Braver distinguishes *proactive control*, measuring resistance to interference that is expected, and *reactive control*, measuring resistance to interference after it has occurred. These two forms of control were tested by looking at slow and fast trials, respectively. Dash and Kar used a non-linguistic negative priming task, and a linguistic (i.e., with letters instead of arrows) and non-linguistic version of the flanker task. RT analyses revealed that BWA were impaired in proactive control and primarily used reactive control on the negative priming task. The participants showed effective control mechanisms on the non-linguistic flanker task. For the linguistic version, however, results were more variable both between participants, and within participants between languages. This variability not only demonstrates the inter-subject variance, but Dash and Kar argue that it also stresses the difference between language control and EC mechanisms. These findings are at odds with the results of another research group (Van der Linden, Dricot, et al., 2018; Van der Linden, Verreyt, et al., 2018; Verreyt et al., 2013). The latter compared BWA's performance on flanker and LD tasks, and found that performances in both domains were associated.

Associations in impairments, however, may not be required to conclude that bilingual language control and executive control rely on the same underlying mechanism. Although the BWA *(N* = 11) in a study by Calabria et al. (2019) did not exhibit deviant interference ratios on inhibitory control tasks, their performance on these tasks was significantly correlated with linguistic control (see Gray, 2020, for converging evidence). Due to small sample sizes, however, findings of correlational analyses should be interpreted with caution.

A final issue we address here is *task complexity* as a potentially modulating factor for domain generality of language control. Gray and Kiran (2019) investigated this in a group of BWA *(N* = 13) by contrasting relatively easy linguistic and non-linguistic flanker tasks with more complex linguistic and non-linguistic triad tasks. They found that BWA and the control group scored similarly on easier tasks but performed differently on more complex tasks. On the non-linguistic triad task, both groups showed interference, but on the linguistic triad only the control group did. Furthermore, the control group showed significant interference ratios for all tasks, whereas the BWA showed significant ratios only for the non-linguistic tasks. Consequently, Gray and Kiran propose that BWA have selective impairments on complex tasks that require participants to manage and process more information simultaneously. This claim was supported by correlational analyses. However, it is important to note that on the linguistic flanker task, neither the control group nor the BWA showed interference effects, complicating the interpretation of these results. Nonetheless, task complexity appears to be an important factor to consider when investigating control abilities.

Our review of the experimental studies on the nature of bilingual language control reveals mixed findings. Several studies report dissociations between bilingual language control and EC impairments, suggesting that problems experienced by BWA are restricted to language control (Dash & Kar, 2014; Gray & Kiran, 2016, 2019; Green et al., 2011). Other studies report overlap (Van der Linden, Dricot, et al., 2018; Van der Linden, Verreyt, et al., 2018; Verreyt et al., 2013), although differing regarding the extent of the overlap (Calabria et al., 2019; Green et al., 2010).

Table 2. Summary of studies reporting bilingual language control and EC measures.

Study	*N*	Lesion	TPO	Bilingualism	BLC	EC	Conclusion
Calabria et al. (2019)	11	Left hemisphere	Chronic	Catalan - Spanish, early bilinguals and highly proficient. Parallel impairment.	Impairments in non-dominant language (semantically blocked cyclic naming, bilingual word-picture matching)	No impairment (flanker), but slower	Evidence for partial overlap
Dash & Kar (2014)	4	Left frontal/parietal	Chronic	Telugu, Hindi, Urdu (L1) - English (L2). Dominance comparable premorbidly. Parallel impairment	Two BWA impaired for L1, one for L2, one unimpaired (linguistic flanker)	Various: slower, but intact conflict cost (flanker and negative priming)	Varying patterns highlight dissociations
Gray & Kiran (2016)	10	Various	Chronic	Spanish - English, varying in dominance and proficiency. Parallel impairment.	Impairment (semantic relatedness judgment)	No impairment (flanker)	Dissociation between BLC and EC indicative of domain-specific BLC
Gray & Kiran (2019)	13	*Not specified*	Chronic	Spanish - English, varying in dominance and proficiency. Mostly parallel impairment.	Impairment (linguistic flanker and triad task)	No impairment (flanker) and impairment (triad task)	For complex tasks BWA show selective impairment in BLC
Green et al. (2010)	2	Left subcortical / parietal	Chronic	French/Spanish (L1s) - English (L2), late learner, highly proficient. Parallel impairment.	Impairment (lexical decision), mixed results (Stroop)	Opposite results (flanker)	Overlap between EC and BLC depending on localization of lesion
Green et al. (2011)	1	Left temporo-parietal	Chronic	German-English-Spanish, late L2, highly proficient. Parallel impairment.	Impairment (lexical decision and Stroop)	No impairment (flanker)	Domain-specific problems with BLC

Table 2. Summary of studies reporting bilingual language control and EC measures. *(Continued)*

Study	*N*	Lesion	TPO	Bilingualism	BLC	EC	Conclusion
Van der Linden, Verreyt, et al. (2018)	15	Various	Subacute	Dutch (L1)- French/English (L2s), highly proficient though not completely balanced. Differential and parallel impairment.	No impairment (generalized and selective lexical decision)	Impairment for differential BWA, no impairment for parallel BWA (flanker)	Preserved cross-language interactivity, but impaired EC for BWA with differential recovery
Van der Linden, Dricot, et al. (2018)	1	Left subcortical parietal	Chronic	French (L1) -English (L2), late learner but highly proficient. Differential impairment.	Impairment for high-control setting (generalized and selective lexical decision)	Impairment (flanker)	BLC and EC are at least closely related
Verreyt et al. (2013)	1	Subcortical (thalamic)	Subacute	French (L1)-Dutch (L2), early acquisition, equal usage, and proficiency. Differential impairment.	Impairment for high-control setting (generalized and selective lexical decision)	Impairment (flanker)	Deficit in EC may underlie differential language impairment

Note. Abbreviations used in the table: TPO: time post-onset (acute: ≤2 weeks, subacute: <6 months, chronic: ≥6 months), BLC: bilingual language control.

Domain generality: evidence from functional communication

Problems with bilingual language control can lead to symptoms such as translation difficulties or involuntary language switching, and differential recovery of languages. A frontal-basal ganglia connection, the *anterior control loop*, has been identified as a crucial circuitry for language control (Abutalebi & Green, 2007; Green & Abutalebi, 2008). It has been argued that language control impairments cause selective recovery patterns through inhibitory mechanisms (Green, 1986; Green & Abutalebi, 2008; Paradis, 1998). Languages can be inhibited to a similar degree (*parallel recovery*), one language can be inhibited more strongly (*selective recovery*), or inhibition can shift from one language to the other (*antagonistic recovery*). When inhibition cannot be selectively applied, this results in involuntary language switching and mixing. The question we address here is whether non-linguistic EC impairments are observed when BWA show deviant recovery patterns or language control impairments in functional communication.

First, some studies report differential recovery of the L1 or the L2. Four studies report cases showing better recovery of the L2 (Adrover-Roig et al., 2011; Aglioti et al., 1996; Lee et al., 2016; Van der Linden, Dricot, et al., 2018). Aglioti et al. (1996) report on a case of bilingual subcortical aphasia in which the participant's L2 was better preserved than her L1. In addition, translation abilities from L2 to L1 were worse than vice versa. This pattern is unexpected considering that premorbidly the L1 was used more frequently and proficiently. Aglioti et al. propose that a lesion in the left basal ganglia, a brain region also crucial for implicit memory systems, mainly impacts the L1. The L2, typically relying more heavily on explicit memory systems, is therefore better preserved. However, the BWA's performance on EC tasks (updating and shifting) were within normal range, leading the authors to suggest that the impairment is predominantly linguistic.

Other studies describe, however, that differential recovery patterns co-occur with EC problems. Adrover-Roig et al. (2011) report on a case with damage to the left basal ganglia showing worse L1 production compared to the L2 and translation difficulties from L2 to L1, despite being equally proficient in both languages premorbidly. The BWA also experienced problems on the TMT, showing that the language control problems were part of a wider ranging impairment. Likewise, Van der Linden, Dricot, et al. (2018) argue that their participant with subcortical damage shows differential recovery of the L2 due to a domain-general impairment, illustrated by deviant flanker task performance. Finally, Lee et al. (2016) describe differential impairment of the L1 in a case of crossed aphasia that resulted from subcortical damage to the right basal ganglia, which was accompanied by problems with EC. All four studies report selective recovery of the L2 following damage to subcortical areas. While Aglioti et al. (1996) did not find evidence for accompanying EC deficits, the other studies report that the participants in their studies experienced problems with EC.

Evidence for a more direct relationship between EC deficits and selective recovery of one language is provided by Verreyt et al. (2013) and corroborated by the group comparison of Van der Linden, Verreyt, et al. (2018). They investigated BWA's language control and EC abilities and found that BWA with differential recovery of their languages tentatively showed more difficulties with both linguistic control and inhibitory control, compared to BWA with parallel recovery. Therefore, the authors conclude that a deficit in EC may underlie selective recovery of one language. The importance of the control network in recovery of two languages is confirmed by findings from an fMRI experiment (Radman et al., 2016). They found that although improvements in language control functions alone were not sufficient to fully explain recovery patterns, the involvement of the control network in recovery was nevertheless essential.

Problems with bilingual language control can also lead to pathological mixing and switching. This has been reported in several studies, and more recent case studies allow us to investigate the relationship with EC. In one case, Leemann et al. (2007) observed involuntary switching to the L2, which had never been fluent nor used after late acquisition in school. The authors suggest that this switching pattern is due to reliance on explicit memory systems used for L2 processing. Kong et al. (2014) report on a highly proficient trilingual with damage to frontal regions who showed involuntary switching across three languages. Lastly, Mariën et al. (2017) describe a multilingual individual with aphasia who involuntarily switched between languages when speaking in one of his several second languages, but not in his L1. This patient suffered a cerebellar stroke, and the authors hypothesize that this damage led to functional disruption of the dorsolateral prefrontal areas, causing control impairments. Importantly, these three cases showed co-occurring deficits in non-linguistic EC, indicating a connection between impaired language control and EC.

Two treatment studies provide additional evidence for this connection. Firstly, Kohnert (2004) conducted a cognitive and cognate-based treatment study in which a BWA showed modest improvement on various language tests, after receiving training on a range of non-linguistic cognitive functions, including shifting and inhibiting. The transfer effect from the non-linguistic cognitive domain to the language domain is interpreted as indirect evidence for overlap between functions. Secondly, Keane and Kiran (2015) performed a semantic treatment study that further informs us on this relationship. The trilingual individual with chronic aphasia experienced lexical deficits that manifested as pathological switching during naming and, importantly, showed problems with EC. The individual received semantic treatment to improve naming deficits, which did not lead to cross-language generalization but instead resulted in an increase of cross-language intrusions from the treated language. Keane and Kiran argue that these are an effect of a failure to inhibit the non-target language and result from impairments in domain-general control mechanisms, which is supported by the finding that this person with aphasia had EC impairments.

In summary, a convincing majority of studies that report differential recovery profiles or involuntary language mixing or switching find co-occurring deficits in EC (except Aglioti et al., 1996), indicative of domain-general control issues. Another prominent finding is that many of the individuals who show this behavior suffer from lesions in subcortical or frontal areas of the brain, parts of the anterior control loop (Abutalebi & Green, 2007; Green & Abutalebi, 2008). Lastly, transfer effects of EC training to language performance and lack of crosslinguistic generalization due to inhibition impairments also point to overlapping control domains.

3.3.3 Bilingual advantage for populations with aphasia

Research with healthy bilinguals suggests that their lifelong practice managing their languages may have favorable consequences for non-linguistic EC (e.g., Adesope et al., 2010; Bialystok et al., 2004). However, not all studies have replicated these results (e.g., Paap et al., 2015, 2017), leaving the status of the cognitive consequences of bilingualism uncertain. Here, we report on the studies that investigated whether BWA experience EC advantages relative to MWA. Therefore, only studies that included monolingual individuals with aphasia as a control group were reviewed.

Penn et al. (2010) were the first to conduct a study on the bilingual advantage for individuals with aphasia. EC abilities were measured with a test battery that included inhibition, updating, and shifting tasks. They compared two BWA with eight MWA. Penn et al. found that the bilinguals in their experiment had significantly better-preserved EC abilities and showed better conversation skills. While this is an important starting point for further enquiries, these findings should be regarded as preliminary due to the small sample size.

Perhaps more compelling evidence for a bilingual advantage in persons with neurological damage was provided by Alladi et al. (2016). They evaluated the protective effect of bilingualism for cognitive outcome after stroke by examining data of over 600 patients from a stroke registry. They found that the incidence of aphasia was similar for mono- and bilinguals (12% versus 11%). However, bilinguals showed unimpaired performance on cognitive measures more often than monolinguals (41% versus 20%). The authors measured cognitive performance with the Addenbrooke's Cognitive Examination revised (ACE-R; Mioshi et al., 2006). It is important to note that both the memory and attention tests of the ACE-R rely on verbal abilities (word repetition and recall, serial subtraction), which complicates separating non-linguistic cognitive abilities from language capacities. Alladi et al.'s results demonstrate that the protective effect of bilingualism for stroke survivors lies in the non-linguistic cognitive abilities rather than the linguistic domain.

If BWA have benefits in the non-linguistic domain, their aphasic symptoms could be less severe when compared to MWA. A recent study has demonstrated this pattern in a large group *(N*

= 68) of bilingual and monolingual persons with aphasia (Paplikar, Mekala, et al., 2018), who were at least three months post stroke. The BWA showed significantly better performance on language, attention, memory, and visuospatial subtests of the ACE-R. The authors conclude that bilingualism does not reduce the likelihood of developing aphasia after acquired neurological damage but can reduce impairment symptoms through enhanced EC. Strengthened EC may facilitate compensation for aphasic deficits. Paplikar et al.'s results point to the need to examine this relationship more systematically.

Faroqi-Shah et al. (2018) carried out an experimental investigation into the relationship between word retrieval and EC. They compared MWA *(N* = 18) with two groups of BWA *(N* = 10 in each group). One bilingual group was English dominant and had various L2s, the other bilingual group spoke Tamil as L1 and English as L2. Each group was matched for age and education level with healthy control groups. Their study showed a bilingual advantage in interference ratios on the Stroop task for the control groups and the English-dominant BWA, but not the Tamil-English BWA. The authors give two explanations for this difference. First, it could be due to opposing proficiency patterns for reading (necessary for the Stroop task) and speaking (necessary for word retrieval tasks). Tamil-English bilinguals may have stronger reading proficiency in their L2 and stronger speaking proficiency in their L1. The English-dominant bilinguals did not have such a potential confound. Second, the authors suggest that in Tamil-English BWA, the EC advantage does not surpass the EC impairments following aphasia. To conclude, Faroqi-Shah et al.'s (2018) results show the importance of cross-linguistic replications but are inconclusive about the bilingual advantages for individuals with aphasia.

Recently, two articles were published in which bilingual advantages were investigated with a similar approach. Dekhtyar et al. (2020) assessed inhibitory control abilities with a triad task in monolingual and bilingual groups with and without aphasia. The groups were matched on demographic variables, language abilities, and non-linguistic EC measured with a composite score of the Cognitive Linguistic Quick Test (CLQT; Helm-Estabrooks, 2001). The BWA *(N* = 18) in their study showed significantly shorter RTs on incongruent trials of the triad task, compared to MWA *(N* = 18). Such a difference was absent on congruent trials. Interestingly, bilingual advantages on the inhibitory control task were also absent in the healthy control group. Dekhtyar et al. (2020) suggest that bilingualism may contribute to cognitive reserve in BWA, whereas its advantages do not surface in healthy individuals. Finally, the authors found that shorter RTs were not correlated with language or executive function scores, suggesting that cognitive advantages are subtle and may not be picked up by standardized diagnostic tests.

Other attentional mechanisms, in addition to EC, were investigated by Dash et al. (2020). They used the Attention Network Task (ANT; Fan et al., 2002), an adaptation to the flanker task designed to disentangle alerting, orienting, and EC (i.e., resistance to interference) mechanisms of attention (Posner, 2011; Posner & Raichle, 1994) by providing warning cues for alerting or location cues for orienting. In addition to the analysis of the difference scores, Dash et al. (2020) examined the RT distributions with an ex-Gaussian analysis. While the group analysis did not reveal statistically significant differences in mean RT between the BWA and MWA groups *(N* =10 and N = 7), a comparison based on the RT distribution revealed significant differences for *alerting*. For the Gaussian part of the distribution (faster responses, automatic processing) bilinguals outperformed monolinguals, whereas the opposite pattern was observed for the exponential part (slower responses, controlled processing). The authors interpret this as evidence that for BWA, alerting is more automatized, whereas MWA are more helped by the alerting cue in controlled processing. Furthermore, Dash and colleagues found significant correlations between language scores and EC abilities for BWA, while this correlation was absent in the monolingual group. BWA experienced no clear benefits on the other attentional mechanisms.

When we recapitulate the findings of a bilingual advantage for populations with aphasia, all studies published thus far seem to point in the direction of confirmation of the bilingual advantage hypothesis. Nonetheless, there are also some caveats. Some report on small sample sizes (Penn et al., 2010), others included rather coarse measures of linguistic and cognitive abilities (Alladi et al., 2016; Paplikar et al., 2018), and in other cleverly designed group studies researchers have observed contradicting findings (Dash et al., 2020; Faroqi-Shah et al., 2018).

3.4 Discussion

In our review of the literature, it appeared that, at first glance, a majority of BWA shows impaired performance on inhibition tasks. However, some of these tasks partially rely on language processing, and when we only focused on studies that reported on an exclusively non-linguistic task, this pattern was weaker or absent. Studies including monolingual speakers with aphasia have also observed discrepancies between linguistic and non-linguistic EC, as the latter appears to be intact more often than the former (Christensen et al., 2018; Kuzmina & Weekes, 2017). Updating abilities, much less researched in this population, varied considerably between studies. Shifting impairments were found in most BWA; but here too, the employed tasks are likely to recruit other cognitive functions, including language. We can conclude that, despite the variability, BWA often suffer from deficits outside the linguistic domain. This is in accordance with the literature on MWA, in which EC impairments are frequently observed (Murray, 2012a; Olsson et al., 2019; Purdy, 2002).

Aphasia characteristics can partly explain the observed variability. Based on the available data on time post-onset, we found that inhibiting deficits are likely to persist, while most evidence for updating and shifting impairments was found in BWA in the subacute phase. Aphasia severity may impact performance on EC tasks that rely more heavily on language processing. In addition, persons with more severe aphasia may have suffered larger lesions and may therefore experience more extensive cognitive deficits. Evaluating the influence of aphasia severity proved to be difficult, as this is operationalized differently across studies. But at first sight, it appears that all studies that included patients with (moderate to) severe aphasia also report deficits in EC (Keane & Kiran, 2015; Kohnert, 2004; Kong et al., 2014; Lee et al., 2016; Leemann et al., 2007; Marini et al., 2016; Penn et al., 2017; Van der Linden, Dricot, et al., 2018).

However, severity of aphasia alone is not enough to predict EC performance, as the EC results for BWA with mild aphasia are more mixed. In addition, the studies that directly investigated the influence of aphasia severity on EC also report opposing results. Dash et al. (2020) found that BWA experience less interference if they have higher language scores. Other studies did not find performance on inhibition tasks to correlate with the degree of language impairment (Calabria et al., 2019; Dekhtyar et al., 2020; Gray & Kiran, 2019). Gray and Kiran (2019) found that aphasia severity did not correlate with the interference ratios for flanker and triad tasks, but it correlated with processing speed in the flanker task. More research on the relationship between aphasia severity and EC is needed to elucidate this matter.

Next, we discussed evidence for and against domain generality of bilingual language control, the set of mechanisms responsible for managing more than one language. An increasing number of studies investigated this by comparing performance on experiments tapping language control to tasks measuring EC. Results were found to be mixed, as the number of studies concluding overlap, partial overlap, or dissociations was essentially equally distributed. Contradicting findings are also reported in the literature on healthy participants (Branzi et al., 2016; e.g., Declerck et al., 2017; Prior & Gollan, 2011).

The conflicting results for BWA cannot resolve the debate about domain generality of bilingual language control. BWA may experience linguistic control problems in absence of non-linguistic control problems, which could be interpreted as evidence for a domain-specific nature of control in BWA (Gray & Kiran, 2016, 2019). However, Gray and Kiran also acknowledge that more research is needed to provide definite conclusions. In addition, the question arises whether a dissociation between linguistic control and EC is necessary to explain patterns of impairments, or whether a domain-general EC problem could explain both patterns, an issue also raised by Green et al. (2010). EC always interacts with another function: it "manages, integrates, regulates, coordinates, or supervises other cognitive processes" (Valian, 2015, p. 5). In this view, EC would interact with language in tasks measuring linguistic control. Aphasic impairments are most pronounced in the language domain and, therefore, tasks tapping linguistic control will be relatively harder for individuals with aphasia than tasks requiring non-linguistic EC. Consequently, if BWA have difficulties with linguistic control tasks, a domain-general EC impairment may underlie these problems even if the control issues may not surface outside the linguistic domain in less demanding tasks (cf. Spearman, 1927). This way, selective impairments in linguistic control could nonetheless be the result of a domain-general EC problem.

The variability in findings for domain generality of control impairments in BWA leads us to suggest a partial dissociation between language control and non-linguistic EC in BWA (Murray, 1999, 2012a; Villard & Kiran, 2017). This is supported by correlational analyses in Calabria et al. (2019), who also advocate partial overlap. More recently, Gray (2020) found an association between bilingual language control and non-linguistic EC for BWA, but not for healthy bilinguals. Gray (2020) argues that this association may be due to the increased cognitive load BWA experience in order to process language. Increased demands in language processing for BWA requires them to rely more heavily on non-linguistic EC.

A partial dissociation is in line with the view that relatively spared EC can facilitate compensation for language deficits of persons with aphasia. EC has been identified as an important mediator in compensating for linguistic deficits in monolingual persons with aphasia. For example, research involving monolingual speakers has found a relationship between functional communication abilities and EC (Fridriksson et al., 2006), especially for persons with severe aphasia (Olsson et al., 2019). In addition, Simic et al. (2019) carried out a systematic review and argue that baseline EC ability is an important indicator of language therapy outcome, independently of time post-onset.

We suspect that similar mechanisms are at play in bilingual populations. In addition, better-preserved EC could increase flexibility, efficient inhibition of the non-intended language, or more effective switching between languages – and, this way, improve functional communication. For example, it has been shown that language mixing in aphasia is associated with lexical retrieval problems (Lerman et al., 2019), and that individuals with more severe aphasia code-switch more often (Goral et al., 2019). Similarly, Muñoz et al. (1999) suggested that mixing is an (un)conscious strategy to access a lexical item and could be a compensatory approach.

Our review of the literature showed that language control problems in functional communication – most notably, selective impairments or involuntary language switching – are consistently paired with non-linguistic EC deficits (Adrover-Roig et al., 2011; Kong et al., 2014; Lee et al., 2016; Leemann et al., 2007; Mariën et al., 2017; Van der Linden, Dricot, et al., 2018; Van der Linden, Verreyt, et al., 2018; Verreyt et al., 2013). In most cases, such impairments follow damage to subcortical areas, part of the anterior control loop (Abutalebi & Green, 2007; Green

& Abutalebi, 2008). Involuntary language switching in absence of aphasic deficits has also been observed (Fabbro, 2000). In this case, the bilingual speaker suffered a lesion in parts of the anterior control loop, which resulted in a defective language control system while the rest of the language network remained intact. This is indicative of dissociations between aphasia in absence of involuntary switching (impairments to language network), aphasia with instances of involuntary switching (impairments to language and control network), and involuntary switching in absence of aphasia (impairments to control network). Considering that there is much variance in the specific lesion locations of these cases, more research is needed to shed light on this issue. However, it appears that in bilingual aphasia, if involuntary language switching is observed, it is often paired with EC deficits.

In the final part of the review, we addressed the bilingual advantage hypothesis for BWA. Only a few studies investigated this issue in populations with aphasia, but all provide indications for the existence of such an advantage for BWA. Yet, it is important to consider potential methodological weaknesses such as small sample sizes. In addition, in the literature on neurologically healthy bilinguals, researchers have started to cast doubt upon the validity of the bilingual advantage hypothesis, as there is evidence for a publication bias (De Bruin et al., 2015), an issue to consider when reviewing the aphasiology literature too. While there is controversy surrounding the bilingual advantage hypothesis, there are reasons to assume that beneficial effects may be larger for BWA. Age appears to be a modulating factor for the bilingual advantage (Van den Noort, Struys, et al., 2019) and advantages are more consistently demonstrated in older (Bak et al., 2014; Kavé et al., 2008; Perquin et al., 2013) and vulnerable populations (Alladi et al., 2017; Woumans et al., 2015). This is in line with Dekhtyar et al.'s (2020) results, who found evidence for a bilingual advantage in BWA, but not in matched control participants.

Reviewing bilingual advantages for populations with aphasia revealed promising findings. But how is superior performance on EC tasks helpful in a BWA's daily life? MWA with better EC show enhanced functional communication, recovery, and generalization of skills taught in therapy (Fridriksson et al., 2006; Helm-Estabrooks, 2002; Olsson et al., 2019). If EC is enhanced in bilinguals, this compensatory mechanism is more effective in BWA compared to MWA and, as a result, could lead to better functional communication. The results of Penn et al. (2010) can be regarded as first evidence: they showed that BWA performed better on EC tasks and exhibited better conversational skills than MWA. In summary, BWA appear to experience benefits as a consequence of their bilingualism and these benefits may have a positive impact on improvement of their language performance. Importantly, that is not the whole story. Findings in neurologically healthy populations show that bilinguals may be disadvantaged in lexical retrieval abilities (Bialystok, 2009). Similarly, Hope et al. (2015) assessed how suitable post-stroke prognostic models are to predict language impairments in BWA when these models are trained with monolingual data. They found that models tend to be over-optimistic; bilinguals had worse language skills than expected based on the model. Again, this stresses the importance of careful separation of linguistic and non-linguistic skills and warrants the need to further investigate the contributions of each of these in functional communication of bilinguals with aphasia.

Tackling this validity issue is our first suggestion of how research on EC in bilingual aphasia should advance. Our review showed that many of the administered EC tasks also engage language processing and/or other cognitive functions. This is referred to as the *impurity problem*, which has been particularly problematic in the investigation of EC (Burgess, 2004; Miyake, Emerson, et al., 2000). The fact that EC interacts with other cognitive functions makes it difficult, if not impossible, to fully isolate EC from other abilities, including language. When investigating individuals with aphasia, it is even more important to administer EC tests that allow for separation of linguistic and non-linguistic abilities, to ensure the possibility of drawing conclusions about the integrity of non-linguistic functions (Keil & Kaszniak, 2002). For example, the Stroop task measures prepotent response inhibition, but its verbal demands complicate administering and interpreting this task in populations with aphasia. In line with Miyake et al. (2000), we suggest using simpler EC tasks and making explicit which subcomponent of EC it is supposed to measure. Good examples of such tasks are flanker or triad tasks (tapping resistance to interference), while the WCST or the TMT are less suitable.

Furthermore, some studies found slower performance on EC tasks, in absence of impaired interference. Calabria et al. (2019) suggest that overall slower response speed indicates a deficit in conflict monitoring rather than resolution. However, being slower to perform any task may be caused by general cognitive slowing rather than a specific problem with EC (Purdy, 2002). Discrepancies between RTs and accuracy, as well as negative correlations between the two, can also be indicative of a difference in speed/accuracy trade-off. Participants may favor quick over accurate responding or vice versa. Faroqi-Shah et al. (2018) found that, in contrast to healthy participants, BWA's Stroop performance was characterized by a negative correlation between RTs and accuracy. Therefore, reporting both RTs and accuracy is recommended.

Inter-individual variability is a key feature of research into bilinguals as well as studies involving persons with aphasia. Bilingual experience and aphasia-related factors can have profound (combined) effects on recovery and linguistic and non-linguistic control abilities (e.g., Green, 1998; Kuzmina et al., 2019). For example, Calabria et al. (2019) found evidence for a relationship between language dominance and control abilities, and Dash and Kar (2014) found language proficiency to influence language control. Due to the variation in the included studies of the current review, a systematic analysis of these factors proved to be difficult. Therefore, we advise to report these factors consistently and take these into consideration when interpreting results of BWA.

Another recommendation for future research is to investigate expressive language control abilities. We have shown that many previous studies have focused on receptive linguistic control, for example, as involved in making lexical decisions. As anomia is one of the most pervasive problems for speakers with aphasia (e.g., Goodglass & Wingfield, 1997), a next step is to investigate bilingual language control in language production. A final way to advance research on bilingual aphasia is to investigate whether the positive findings for a bilingual advantage in individuals with aphasia can be replicated and extended to benefit everyday functional communication.

3.5 Conclusion

We systematically reviewed the literature on the role of EC in bilingual aphasia. Our first finding was that BWA's impairments are not limited to the linguistic domain and that non-linguistic EC impairments are frequently observed. Next, we examined domain generality of bilingual language control by reviewing whether linguistic control impairments were associated with EC impairments and found that the experimental results were mixed. However, BWA who show problems with bilingual language control in everyday communication, such as differential recovery or pathological switching and mixing, nearly always show problems with EC, indicative of overlapping mechanisms. Finally, research on bilingual advantages in BWA published thus far points to beneficial effects for this population.

Appendix A. Search strings

Construct-related terms	Population-related terms
executive function* OR executive control OR cognitive function OR cognition OR cognitive control OR inhibition OR inhibitory OR inhibitory control OR switching OR shifting OR memory OR attention OR updating	aphasia OR dysphasia bilingual OR multilingual OR polyglot OR bilingualism OR multilingualism OR trilingual OR quadrilingual

4

Voluntary and cued language switching in late bilingual speakers

A slightly adapted version of this chapter is published as a research article in:
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The data that support the findings of this study are openly available at https://osf.io/gd2wv/.

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Abstract

Previous research examining the factors that determine language choice and voluntary switching mainly involved early bilinguals. Here, using picture naming, we investigated language choice and switching in late Dutch-English bilinguals. We found that naming was overall slower in cued than in voluntary switching, but switch costs occurred in both types of switching. The magnitude of switch costs differed depending on the task and language, and was moderated by L2 proficiency. Self-rated rather than objectively assessed proficiency predicted voluntary switching and ease of lexical access was associated with language choice. Between-language and within-language switch costs were not correlated. These results highlight self-rated proficiency as a reliable predictor of voluntary switching, with language modulating switch costs. As in early bilinguals, ease of lexical access was related to word-level language choice of late bilinguals.

4.1 Introduction

Bilinguals need to monitor and regulate their languages when they communicate. They adjust their language choice according to their interlocutors and switch between their languages when this is required. In everyday situations, language choice is predetermined when the interlocutor only knows one of the languages. In contexts where interlocutors know both languages about equally well, the bilingual speaker may feel free to choose a language. In such settings, language choice may depend on the speaker's own relative proficiency or the momentary availability of words in each language.

Previous research into the factors that determine language choice and free switching[6] mainly examined balanced bilinguals. For instance, De Bruin et al. (2018, 2020) and Jevtović et al. (2019) studied Spanish-Basque bilinguals living in the Basque Country, where many people have acquired both languages early in life and are highly proficient in both. Moreover, the languages are ever-present in daily life, allowing speakers to freely switch between languages. Importantly, the motivation to switch languages and the effort involved in switching may be different for unbalanced bilinguals. In the Netherlands, for example, speakers typically acquire English relatively late, as a second language (L2) at school. In daily life, use of Dutch is predominant whereas English is only used in specific, well-defined settings. Thus, conclusions derived from findings on early balanced bilinguals living in bilingual contexts may not generalize to late unbalanced bilinguals in largely monolingual contexts.

In the present study, we examined language switching abilities and the factors contributing to switching behavior and language choice in late Dutch-English bilinguals living in the Netherlands. We first review the relevant evidence on cued and voluntary language switching and the mechanisms of switching, and then outline the present study. Next, we describe our methods and results, and end by discussing the implications of our findings.

4.1.1 Cued and voluntary language switching

Language switching is typically studied using a cued switching task, in which the bilingual participant is prompted to switch based on an external cue, or an alternating runs paradigm, in which switches follow a predictable pattern (e.g., Declerck & Philipp, 2015). Switch trials are those in which a speaker produces another language than in the previous trial. In a seminal paper, Meuter and Allport (1999) found that language switching is costly: Response time (RT) is longer on switch compared to repeat trials. In addition to this local, reactive switch cost, more global and proactive mixing costs have also been consistently found (e.g., Christoffels

6 The terms 'voluntary and 'free' switching are used interchangeably, as are 'mandatory' and 'cued' switching.

et al., 2007). Mixing costs refer to overall longer RTs in conditions requiring the use of two languages compared to one language.

The cost of language switching may be determined by various factors. *Language proficiency* has a central role in theoretical models of bilingual language processing, for example by influencing the amount of inhibition required (Green, 1998), by the relative strength of the connections between words and concepts (Kroll & Stewart, 1994), or by the resting level activations for each language (Dijkstra et al., 2018).

Behavioral support for the role of proficiency in switch costs was provided by Bonfieni et al. (2019), who showed that switch costs in both languages were smaller in bilinguals with higher L2 proficiency. However, *asymmetrical switch costs* are also frequently observed, wherein switching into the more dominant language is slower and more error-prone than switching into the less dominant language (Meuter & Allport, 1999). While there is ample evidence for the existence of asymmetrical switch costs (e.g., Costa & Santesteban, 2004; Gollan et al., 2014; Philipp et al., 2007), some studies failed to find such asymmetry (e.g., Christoffels et al., 2007), or observed a reversed asymmetry (e.g., Bonfieni et al., 2019; C. Liu et al., 2019; Timmer, Christoffels, et al., 2019). In short, both magnitude and symmetry of switch costs may vary depending on proficiency.

While switch costs are a consistent finding in the experimental literature, the ecological validity of cued switching paradigms has been questioned (Blanco-Elorrieta & Pylkkänen, 2018). Recent studies have started to investigate voluntary language switching, allowing participants to freely choose the language that first comes to mind. Most voluntary switching experiments still observed switch costs (De Bruin et al., 2018, 2020; Gollan et al., 2014; Gollan & Ferreira, 2009; Grunden et al., 2020; Jevtović et al., 2019; H. Liu et al., 2020; Sánchez et al., 2022; but see Blanco-Elorrieta & Pylkkänen, 2017). However, there is evidence that mixing costs are reduced (Gollan & Ferreira, 2009), or turn into benefits, such that voluntarily mixing languages leads to faster responses than single language conditions (De Bruin et al., 2018, 2020; De Bruin & Xu, 2023; Grunden et al., 2020; Jevtović et al., 2019).

When voluntary and cued switching are compared within the same task, cued switching has been found to result in slower overall responses and larger mixing and switching effects (Jevtović et al., 2019). Gollan et al. (2014) and De Bruin and Xu (2023) also reported (some) benefits in voluntary over cued language switching, whereas De Bruin et al. (2018) observed that both types of switching yielded comparable switch costs but overall faster responses for the voluntary than cued switching task.

Studies that investigated voluntary switching in balanced bilinguals who live in bilingual societies typically observe a voluntary switching rate of around 40%. Similarly high switching rates have been observed for many, though not all, late or unbalanced bilinguals (De Bruin & Xu, 2023; H. Liu et al., 2020; Sánchez et al., 2022; but see H. Liu et al., 2021). Across studies, bilinguals vary in their switching rate. Gollan and Ferreira (2009) reported that balanced bilinguals switch more frequently (35%) than unbalanced bilinguals (24%). Furthermore, the bilinguals in their study named the easiest items (regarding frequency, length, retrieval speed, and accuracy) in the non-dominant language, leaving the relatively more difficult items to be named in the stronger language. This shows that bilinguals may predominantly switch languages when items in the non-dominant language are relatively accessible.

Gollan and Ferreira (2009) presented first evidence for a relationship between language abilities and language choice. Additional support for this relation was provided by Sarkis and Montag (2021), who showed that lexical accessibility predicted code switches in a sentence production experiment. Furthermore, De Bruin et al. (2018) demonstrated that ease of lexical access, operationalized as item-level differences in naming latencies between the L1 and L2, was a predictor for language choice in the voluntary condition. Interestingly, participant's overall L2 proficiency or use, undoubtedly related to ease of lexical access, was not related to language choice or switching costs in this study.

While asymmetrical switch costs, interpreted as an index of the influence of relative language proficiency, are frequently observed in cued language switching, there is little evidence for an asymmetry in voluntary switch costs. Although larger switch costs into the dominant language were observed by H. Liu et al. (2021), the majority of studies did not find a relationship between language and magnitude of switch costs (De Bruin et al., 2018, 2020; Gollan et al., 2014; Gollan & Ferreira, 2009; Grunden et al., 2020; Jevtović et al., 2019), or found an asymmetry in the opposite direction (De Bruin & Xu, 2023; Sánchez et al., 2022).

4.1.2 Mechanisms of language switching

The ubiquity of switch costs in language switching suggests that top-down language control processes are involved. The extent to which bilingual language control abilities overlap with domain-general control processes has been debated in the literature. Several studies found commonalities between language switching and non-linguistic task switching, both in terms of correlations (Declerck et al., 2017; Prior & Gollan, 2011) and overlap in neural circuits (De Baene et al., 2015; De Bruin et al., 2014; Weissberger et al., 2015). Furthermore, language switching experience has been found to relate to non-linguistic task switching performance (Barbu et al., 2018; Festman & Münte, 2012; Timmer, Calabria, et al., 2019; Verreyt et al., 2016). However, other studies failed to find (complete) overlap between linguistic and non-linguistic switching (Branzi et al., 2016; Calabria et al., 2012, 2015; Klecha, 2013; Segal et al., 2019; Timmer et al., 2018; Weissberger et al., 2012). In short, the current literature is inconclusive regarding domain generality of bilingual language control abilities (see Declerck & Philipp, 2015; Jiao et al., 2022, for reviews). It has been argued that the conflicting results can, at least in part, be explained by task-related differences in response modality, stimuli type, and cues (Declerck et al., 2017; Declerck & Philipp, 2015).

Focusing on voluntary switching, De Bruin et al. (2018) found that voluntary language switching costs were related to linguistic, but not non-linguistic, inhibition. Gollan et al. (2014) compared voluntary and cued switch costs in linguistic and non-linguistic tasks and found that advantages for voluntary over cued switching may be more pronounced in non-linguistic switching than in language switching, especially when items were not repeated. The authors take this as evidence that language switching mostly relies on domain-specific mechanisms.

Importantly, switching is not exclusive to bilingual language production. Instead, every speaker needs switching skills to communicate effectively, for example by switching between registers or syntactic constructions (i.e., within-language switching). Declerck et al. (2020) compared control mechanisms in between- and within-language switching tasks. They found evidence for overlap between control processes but also saw that the switch costs were differentially influenced by manipulations of the interval between cues and stimuli.

Sikora and colleagues also studied within-language switching (Sikora et al., 2019; Sikora, Roelofs, & Hermans, 2016; Sikora, Roelofs, Hermans, & Knoors, 2016; Sikora & Roelofs, 2018). They designed a picture naming task in which participants produced short (e.g., *chair*) or long noun phrases (e.g., *green chair*) and were cued to switch between these phrases. Sikora, Roelofs, Hermans, and Knoors (2016) found no correlation between the overall within-language switch costs and switch costs in a non-linguistic switching task. However, the results of a reaction-time distribution analysis provided evidence for the engagement of domain-general switching ability in within-language switching.

Despite disagreement in the literature about the overlap between linguistic and non-linguistic switching, the two domains appear to have similarities when task demands are kept the same. In addition, switching can be measured between and within languages, and these types of switching tend to overlap and induce switch costs. This raises the question how cued within-language switching is related to cued and voluntary between-language switching when comparable methods are used.

4.1.3 Summary

To recapitulate, switching in voluntary contexts remains costly, although switch costs may be reduced. Switching may be motivated by language abilities when operationalized as language dominance. Bilinguals' language proficiency, on the other hand, was not found to be related to voluntary switching and mixing costs, although this was investigated in a group of early bilinguals with a high level of proficiency in both languages. For bilinguals with more varying language abilities, the effect of proficiency on voluntary switching costs may be larger. Moreover, late bilinguals may show asymmetry in their voluntary switch costs, but the direction and prevalence of this asymmetry is not yet established. Finally, the domain generality of bilingual language switching abilities remains controversial to date, and an approach to advance is by comparing tasks with highly similar characteristics.

4.1.4 Research questions

We aimed to replicate and extend earlier research into voluntary switching and systematically investigated the differences and commonalities between voluntary and cued between-language switching, and cued within-language switching. Specifically, we intended to contribute to the existing literature by (1) investigating a group of late bilinguals with varying degrees of L2 proficiency living in their L1 environment, (2) focusing on the role of proficiency and ease of lexical access on language switching, and (3) investigating the extent of overlap between different types of language switching. We addressed the following research questions:

1. Do late bilinguals switch between their languages in a voluntary switching task, and can their voluntary switching behavior be explained by relative ease of lexical access and/or L2 proficiency?
2. Do voluntary and cued language switching induce similar switch costs, and can these switch costs be explained by L2 proficiency and/or more general switching abilities as measured with a cued within-language switching task?
3. To what extent do cued between-language and within-language switching abilities overlap?

4.1.5 Testing language production in an online setting

We examined our research questions in a web-based setting. The COVID-19 pandemic resulted in closing of labs and social distancing measures, which made it impossible to conduct in-person experiments for a considerable period of time. Using web-based tools is a way to collect behavioral data when labs are closed. Web-based tools have advantages, such as ease, efficiency, flexibility of data collection, and remote testing. Yet, there are certain risks too, especially for language production studies like the current study, in which accurate measurement of latencies is crucial. Common objections to web-based testing are questionable quality of the speech recording and concerns about the timing, due to instabilities of the experimental program, operating system, internet browser and internet speed (Fairs & Strijkers, 2021; He et al., 2021). Several studies have demonstrated the feasibility and accuracy of web-based language production studies. Although overall latencies are longer in web-based than in lab-based experiments (Fairs & Strijkers, 2021), frequently-observed psycholinguistic effects that rely on precise and accurate measurement of naming latencies are replicated (Stark et al., 2022; Vogt et al., 2021).

4.2 Method

4.2.1 Participants

Forty native speakers of Dutch with English as their L2 took part in this study[7]. They were all students at Dutch universities or universities of applied sciences. To ensure variation in English proficiency, we recruited half of the participants from (under)graduate programs with English as the language of instruction. The remaining participants were enrolled in studies with Dutch as the language of instruction. Dutch proficiency was not assessed, but considering that all participants were native speakers of Dutch, lived in the Netherlands full-time, and qualified for higher education, it was assumed their Dutch proficiency was at the highest level. Participants' English proficiency was verified with self-ratings and a lexical test (LexTALE, Lemhöfer & Broersma, 2012). Visual inspection of the distribution of the proficiency measures showed that this way of recruiting participants resulted in a wide range of scores on the proficiency measures, but also revealed that the distributions between the two groups overlapped sufficiently to be treated as a single group.

We encountered technical issues in the final part of the experiment for one participant and we decided to exclude this participant from the analysis. All included participants had (corrected to) normal hearing and vision. Each participant read and signed an informed consent form prior to participation. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional Ethics committee (2019-5035) on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008. The participants' characteristics are presented in Table 1.

7 One participant was born outside of the Netherlands, but acquired Dutch before the age of five, and we therefore decided to leave this participant in the dataset.

Table 1. Characteristics of the participants.

Characteristic	Statistic			
Sex	*N*	*%*		
Female	32	82.1		
Male	7	17.9		
	M	*SD*	*Min*	*Max*
Age (years)	21.9	2.8	18.4	29.0
LexTALE English (%)	81.1	12.6	61.3	100.0
Daily language switching: 1 (*never*) – 5 (*very often*)	3.9	0.9	2	5
Age of acquisition English	9.9	1.9	4	14
Years usage English	10.9	3.0	6	18
Self-rated proficiency Dutch (0-100)				
Comprehension	98.0	3.7	90	100
Production	97.8	4.7	80	100
Reading	98.5	4.2	80	100
Writing	95.0	6.8	79	100
Self-rated proficiency English (0-100)				
Comprehension	84.6	13.9	41	100
Production	77.9	17.2	20	100
Reading	87.0	12.8	50	100
Writing	78.8	14.6	40	100
Frequency usage Dutch: 1 (never) – 5 (daily)				
Home	5.0	0.0	5	5
Family	4.9	0.4	3	5
Friends	4.8	0.6	2	5
Study	3.8	1.5	1	5
Frequency usage English: 1 (never) – 5 (daily)				
Home	2.4	1.5	1	5
Family	1.8	1.2	1	5
Friends	3.3	1.5	1	5
Study	4.3	0.9	2	5

4.2.2 Materials

Participants completed a questionnaire about demographic and language variables. The questions were based on the Language Experience and Proficiency Questionnaire (LEAP-Q, Marian et al., 2007) and the Language History Questionnaire (LHQ 2.0, Li et al., 2014). The questionnaire consisted of 30 questions and was administered using the Qualtrics platform (Qualtrics, 2005). Self-rated proficiency was assessed by using a sliding scale ranging from 0 ("poor") to 100 ("excellent"). The questionnaire ended with the LexTALE, a 60-item word recognition test for advanced learners of English that has been shown to correlate well with general English proficiency (Lemhöfer & Broersma, 2012).

In all naming tasks, the same thirty 8 × 8 cm colored line drawings from the MultiPic database were used (Duñabeitia et al., 2018). Pictures were named in Dutch or English, depending on the task instruction. The target words for the pictures were one- or two-syllabic non-cognate words (Appendix A). All target words were frequent (SUBTLEX log10 frequency ≥ 2.0), acquired early (age of acquisition ≤ 7.0), highly prevalent (rating ≥ 1.7/2) and concrete (rating ≥ 4.3/5). Word variables and ratings were based on various databases (Brysbaert et al., 2014, 2019; Brysbaert & New, 2009; Keuleers, Diependaele, et al., 2010; Keuleers et al., 2015; Kuperman et al., 2012). See Appendix B for mean values of the variables of the stimuli.

4.2.3 Design and procedure

The study involved an online testing procedure that lasted approximately 45 minutes per participant. The experimental tasks were administered in a peer-to-peer video call in Zoom (Zoom Video Communications Inc., 2012). This allowed the experimenter to monitor the test session in a way that was similar to lab-based settings. The experimental materials were shown using PowerPoint via screen sharing.

Experiments started with a familiarization task in which participants saw each picture with the two printed target words (in English and Dutch) and they were asked to read both words out loud. The four experimental tasks (further explained below) were presented in a fixed order: (1) picture naming in Dutch and English blocks, with the block order counterbalanced, (2) voluntary picture naming in Dutch or English, (3) cued picture naming in Dutch or English, and (4) cued within-language switching between phrase types in Dutch. Participants started with the single-language task to measure naming in each language separately. The voluntary switching task was administered before the cued between-language switching task to avoid priming switching behavior. The last task in the protocol was the cued within-language switch task, because this task only required naming in Dutch and it was a relatively new task compared to the more established between-language switching tasks. The tasks were not repeated to prevent fatigue, which was expected to be particularly probable in a web-based setting.

Each naming task started with an instruction and practice items, and consisted of 60 trials divided over blocks separated by short breaks. Instructions were given verbally by the experimenter and shown on the screen in Dutch, English, or a mix of both languages. Speed and accuracy of naming was emphasized in all instructions. The target pictures were presented twice in all tasks, randomized using Mix (Van Casteren & Davis, 2006), with a constraint that the repetition of each item did not follow within at least 10 trials. Two versions of the experiment were created to control for any effect of starting language of the first task, with a different starting language and a different randomization order of trials in each version. The versions were counterbalanced between participants. An overview of the experimental tasks and blocks is presented in Appendix C.

In the single-language task, participants named pictures in blocks of Dutch and English. The task consisted of four blocks of 15 trials each. The voluntary language switching task consisted of two blocks with 30 trials each, and participants were instructed to name the pictures in the language that first came to mind.

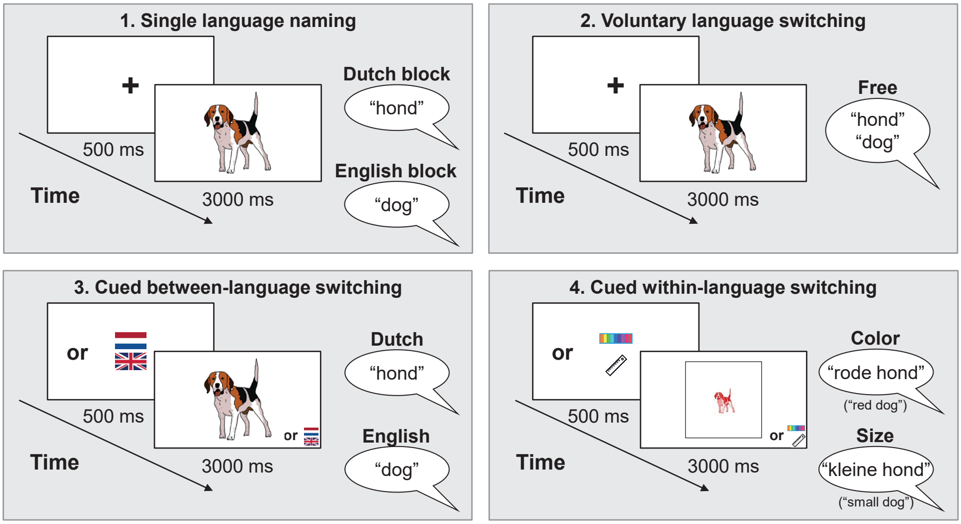
The two cued switching tasks (between-language and within-language) had the same design. Both tasks consisted of two blocks and involved cued and predictable switching in a *switch–repeat–switch–repeat* order, with a cue presented preceding and simultaneous with each item. Using *alternating runs* in a cued switching experiment has been found to elicit reliable switch costs (De Bruin et al., 2020; Declerck et al., 2015; Jackson et al., 2001; Rogers & Monsell, 1995). Furthermore, a predictable switch pattern eliminates having to manipulate potentially confounding factors associated with unpredictable cued switching, such as run length (Zheng, Roelofs, & Lemhöfer, 2018) and preparation time effects (see Jost et al., 2013; Kiesel et al., 2010; Koch et al., 2018, for discussions). Additionally, the need to rely solely on the cue signaling an upcoming switch has been argued to obscure the distinction between cue-encoding processes and task switching (Logan & Bundesen, 2003, 2004; Schneider & Logan, 2005). Therefore, we considered the alternating switching paradigm a reliable and pure measure of switch costs.

The cued between-language switching task involved participants naming pictures in either Dutch or English based on a visually presented country flag serving as a reminder. The pictures were separated across the two versions of the experiment, such that participants named an item in either English or Dutch, not both, to avoid potential interference effects resulting from translation equivalents (Kleinman & Gollan, 2018). Items were about equally divided based on word length, frequency, and visual complexity of the picture.

The design of the cued within-language switching task involved participants naming color or size properties of the depicted object, together with the target word, indicated by a color bar or ruler. All line drawings were edited such that they were in red or blue, and big (14 × 14 cm) or small (6 × 6 cm). The target language for this task was Dutch.

The trial structures of the four tasks are illustrated in Figure 1. Pictures were shown for maximally 3000 ms but when items were named before the end of the trial, the experimenter manually initiated the next trial at the offset of the participant's answer. Every trial was preceded by a 500 ms interval, during which a fixation cross (single-language and free switching tasks) or the visual cue (cued switching tasks) was shown. To enable annotation of the audio files and extraction of the response latencies later, a click sound was presented at the onset of each picture.

Figure 1. Illustration of the trial structures of the four naming tasks.



We tried to manage possible negative artefacts of web-based experiments in several ways. First, we used a live connection and participants carried out the experiment whilst being in a videocall with the experimenter. Therefore, we believe that the level of distraction was similar to an in-person experiment. Second, RTs were manually extracted and this way, we could evaluate each individual data point before entering it into the statistical analysis and discard trials affected by glitches. Any remaining glitches were expected to occur randomly across trials and would therefore not systematically affect the results. Overall slower internet connections of specific participants were accounted for in the statistical analysis by including random intercepts for participants.

4.2.4 Analyses

The experiment was recorded in Zoom (Zoom Video Communications Inc., 2012) and audio files were annotated manually in Praat (Boersma & Weenink, 2022) to extract naming latencies. RTs were operationalized as the time between the onset of the click sound and the speech onset of the participant's response. A portion of the data (i.e., 720 observations) was independently coded by two raters (the first author and a research assistant) to establish the inter-rater reliability of the RT annotation. We analyzed the inter-rater reliability using a single-measurement, consistency, two-way random-effects model using 'irr' package (Gamer et al., 2012) in R, version 4.1.2 (R Core Team, 2022) in RStudio version 2021.09.1 (RStudio Team, 2023). The Intraclass Correlation Coefficient (ICC) calculation showed excellent agreement between raters (ICC = .91, 95% confidence interval = .89 – .92) and the remainder of the data was annotated by a single coder. The responses were categorized based on the (adapted) classification by De Bruin et al. (2018), but due to the low error rates, only binary accuracy (correct/incorrect) was further analyzed (see Appendix D for the full classification scheme).

We statistically analyzed the data using packages 'lme4', 'lmerTest', 'emmeans', 'tidyverse' and 'ggplot2' (Bates et al., 2015; Lenth, 2022; Wickham, 2016; Wickham et al., 2019). We did not remove outliers, but RTs of < 500 ms or > 3000 ms and the first trials of a task or immediately after a break were excluded. For the RT analyses, incorrectly answered items were discarded. The trials preceded by a mistake were not removed because trial type (switch/repeat, L1/L2) was predetermined by the task demands or could still be established in all errors. There were missing data points (N = 196, 2.1%) due to technical glitches (e.g., inaudible clicks, problems with recording, or connection hiccups). In total, 689 data points (7.4%) were excluded from the RT analysis. In the accuracy analysis, we excluded 215 data points (2.3%) in total, 12 (0.1%) due to glitches and 203 (2.2%) first trials.

We ran multiple (generalized) linear mixed-effects regression models to answer our research questions. All models were fit with the theoretically informed maximal random structure that was possible without convergence issues (Barr et al., 2013) and we used the 'bobyqa' optimizer to prevent any convergence problems. To investigate factors related to voluntary switching, *switching behavior* (switch: yes/no and language choice: Dutch/English) was predicted by *objective l2 proficiency* (LexTALE scores), *subjective l2 proficiency* (self-rated L2 proficiency averaged across ratings for production, comprehension, reading, and writing), *lexical accessibility* (response-speed difference between Dutch and English items on the single-language task), and *switching abilities* (switch costs on the cued within-language switching task). In these models, all predictors were scaled (centered and standardized) to address convergence warnings.

To investigate differences between different types of switching, we ran (generalized) linear mixed-effects regression models with accuracy or RTs as outcome variables. *Task* (voluntary switching and cued switching), *language* (Dutch or English target items), *trial type* (switch or repeat trials), *objective proficiency*, *subjective proficiency*, and *switching abilities* were included in the voluntary versus cued between-language switching model. Lexical accessibility was not included because this predictor was operationalized as relative naming speed and thus resembled the outcome variable (naming speed on the same items, albeit in different tasks) too much to be a meaningful predictor. Through model comparison, we saw that trial number had a significant effect on RTs ($\chi^2(1) = 4.75$, $p = .029$) and we therefore included it as a covariate. In our model comparing cued between-language switching to within-language switching, we limited our predictors to *task*, *trial type*, and *trial number*.

The continuous predictors were centered around the mean and categorical predictors were sum-coded (-1 or +1). The interpretation of multi-level predictors was facilitated by an omnibus test and post-hoc pairwise comparisons with a Bonferroni-correction of the *p*-value. RTs were (natural) log transformed to reduce skewness. The model assumptions were checked visually (heterogeneity of variance and normally distributed residuals) and by inspecting Variable Inflation Factors for multicollinearity (all VIFs < 2.0).

Importantly, there was a moderate positive correlation between objective and subjective L2 proficiency ($r = .60$, $p < .001$). As this may be problematic for regression analyses, we decided to run separate models for each of the two measures of proficiency for every research question. Except for these two proficiency variables, the models were identical in terms of the remaining fixed- and random-effects structure. After fitting the models, we compared the Akaike Information Criterion (AIC) values of the two models. The main effects of objective and subjective L2 proficiency are always presented, but we only report the remaining fixed effects of the best fitting model.

4.3 Results

4.3.1 Descriptive statistics

Accuracy (in percentage correct) was highest in the free switching task ($M = 99$, $SD = 11$), followed by single-language naming across L1 and L2 ($M = 98$, $SD = 15$), cued language switching ($M = 97$, $SD = 17$), and within-language switching ($M = 90$, $SD = 30$). The RTs (in ms) showed a similar pattern. On average, RTs were shortest in free switching ($M = 968$, $SD = 280$), followed by cued switching ($M = 1037$, $SD = 309$), single-language naming ($M = 1041$, $SD = 322$), and within-language switching ($M = 1148$, $SD = 380$). The descriptive statistics of accuracy and RTs for task, language, and trial type are presented in Appendix E.

4.3.2 Free switching behavior

To answer the research question whether late bilinguals switch between their languages and what predicts their switching behavior, we analyzed the results of the free switching task. On average, participants switched on 41.5% of the trials (*range* 7-65%) and approximately half of the items (53.4%) were named in English, with considerable variation between participants (*range* 3-93%)[8].

Our first generalized linear mixed-effects model with switching (*yes* (1) or *no* (0)) as a dependent variable showed no significant effect of objective proficiency on switching behavior ($OR = 1.00$, $SE = 0.11$, $p = .982$). The second model, including subjective proficiency, was better fitting as indicated by a lower AIC value. This model showed that subjective proficiency was related to voluntary switching ($OR = 1.28$, $SE = 0.13$, $p = .021$). This indicates that participants who rated their own proficiency higher switched more, regardless of direction of the switches. There were no significant effects of any other predictors (Appendix F).

In the next step, we fitted the same predictors and included trial type in the model with language choice (*English* (1) or *Dutch* (0)) as outcome variable (Table 2 and Figure 2). Here too, we found that objective proficiency was not significantly related to language choice ($OR = 1.24$, $SE = 0.21$, $p = .201$, Figure 2A) and that the model including subjective proficiency better predicted language choice. There was a significant main effect of subjective proficiency, indicating that English was chosen more frequently by participants who rated their own L2 proficiency as higher ($OR = 1.87$, $SE = 0.23$, $p < .001$, Figure 2B). This factor interacted with trial type ($OR = 1.59$, $SE = 0.10$, $p < .001$), showing that the effect was driven by the repeat trials. Ease of lexical retrieval had a significant effect on language choice, as items that were retrieved more quickly in English in the single-language task, were named in English relatively more often than in Dutch (and vice versa) in the free switching task ($OR = 0.64$, $SE = 0.04$, $p < .001$, Figure 2C). Lexical accessibility did not significantly interact with trial type ($OR = 0.97$, $SE = 0.05$, $p = .613$), and we did not find a significant effect of within-language switch costs on language choice ($OR = 0.97$, $SE = 0.11$, $p = .799$, Figure 2D).

8 The observed variation between participants could not be explained by the two participant groups, as participants attending English instruction university showed similar switching rates compared to participants attending Dutch instruction university.

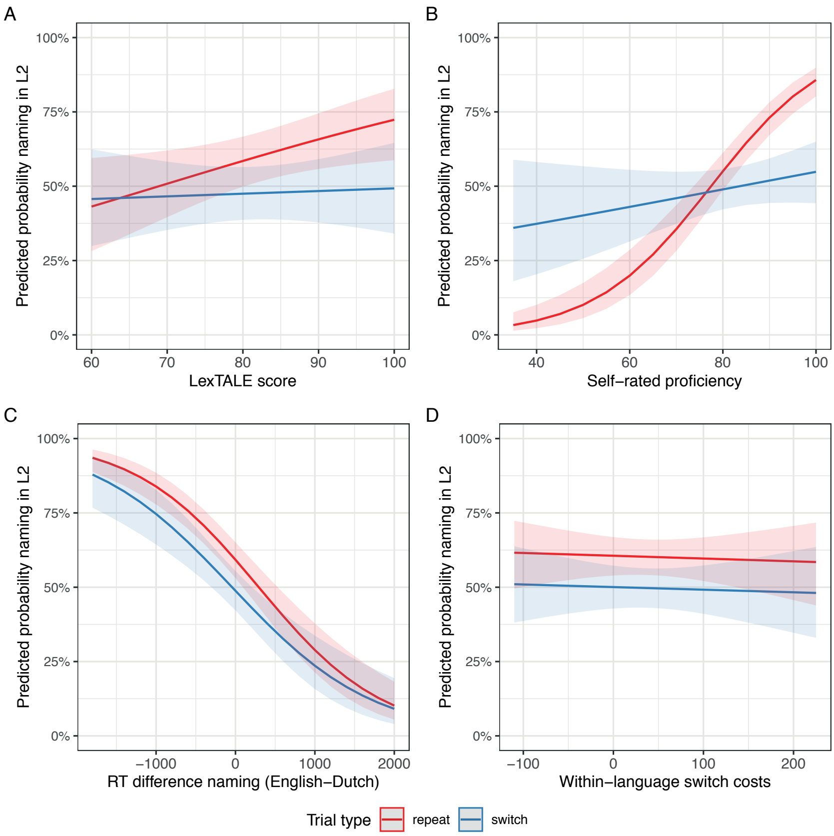
Table 2. Switch behavior analysis: language choice on free switching task.

Language choice (English/Dutch)				
Effect[a]	*Odds ratios*	*St. Error*	*95% CI*	*p-value*
Intercept	1.19	0.15	0.93 – 1.53	.174
Trial type	1.21	0.06	1.10 – 1.34	**<.001**
Self-rated proficiency	1.87	0.23	1.47 – 2.38	**<.001**
Lexical accessibility (RT Δ)	0.64	0.04	0.58 – 0.72	**<.001**
Within-language switch cost	0.97	0.11	0.78 – 1.21	.799
Trial type × Self-rated proficiency	1.59	0.10	1.40 – 1.80	**<.001**
Trial type × Lexical accessibility (RT Δ)	0.97	0.05	0.88 – 1.08	.613
Trial type × Within-language switch cost	1.00	0.05	0.90 – 1.10	.976

Note. Number of observations = 2117. [a]All predictors were scaled.

4

Figure 2. Predicted probabilities of language choice in switch and repeat trials as a function of objective (A) and self-rated proficiency (B), ease of lexical access (C), and within-language switch costs (D), including 95% confidence interval bands.



4.3.3 Factors predicting voluntary and cued between-language switching

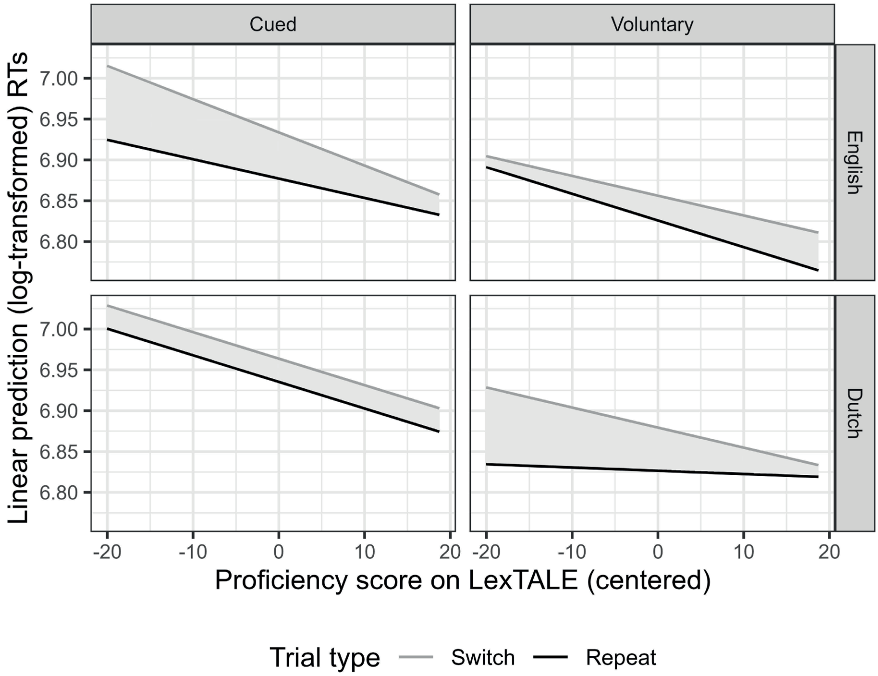
We compared switch costs in free and cued between-language switching and investigated whether both types of switching were equally predicted by proficiency and within-language switching abilities. The model output for accuracy showed no significant effect of subjective proficiency (*OR* = 0.99, *SE* = 0.20, p = .977) and the model including objective proficiency was a better fit. The results revealed higher accuracy on repeat trials than on switch trials (*OR* = 1.59, *SE* = 0.33, p = .025), indicative of an overall switch cost, and on the free task compared to the cued task (*OR* = 0.56, *SE* = 0.12, p = .005). Task and objective proficiency interacted (*OR* = 1.03, *SE* = 0.02, p = .040), indicating that participants with higher L2 proficiency had significantly higher accuracy only in cued switching. We did not find a significant effect of language or other interactions between predictors (Appendix G).

The RT models showed no significant effect of subjective proficiency (β = -0.001, *SE* = 0.002, p = .534), and the model including objective proficiency fitted the data better. We observed significant main effects of trial type, task, language, and trial number (Appendix H), but no significant main effect of objective proficiency (β = -0.003, *SE* = 0.002, p = .217) or within-language switching ability (β = 0.0004, *SE* = 0.0004, p = .316). A significant effect of trial number (β = -0.0004, *SE* = 0.0002, p = .029) indicates that participants became faster as the task progressed. The interpretation of the main effects of trial type, task, and language was complicated by the presence of a three-way interaction effect between these predictors (β = 0.006, *SE* = 0.003, p = .029), demonstrating that the trial type effect (i.e., switch cost) was differentially predicted by task and language. Furthermore, the predictors were part of a four-way interaction with objective proficiency (β = 0.0006, *SE* = 0.0002, p = .011). We first examined this four-way interaction effect by creating subsets of the data based on language.

For English trials (Figure 3, upper panels), there was an interaction between task and trial type (β = -0.008, *SE* = 0.003, p = .018), revealing that the RT difference between switch and repeat trials (indicated in light grey color) was larger in the cued than voluntary condition. Furthermore, we found a significant three-way interaction effect between task, trial type, and proficiency (β = 0.0006, *SE* = 0.0003, p = .024). This effect was mainly driven by cued switching, since there was a significant interaction between trial type and proficiency in the cued switching condition (β = 0.0009, *SE* = 0.0004, p = .033), but not in the voluntary condition (β = -0.0004, *SE* = 0.0004, p = .316). These results show that switch costs in English were smaller in the voluntary than cued condition, and that this difference was larger for participants with lower English proficiency.

For the Dutch items (Figure 3, lower panels), we failed to find a significant two-way interaction between trial type and task (β = 0.004, *SE* = 0.004, p = .413). This indicates that despite overall longer RTs for switch than repeat trials (β = -0.02, *SE* = 0.004, p <.001), and for items in the cued compared to the voluntary condition (β = 0.05, *SE* = 0.01, $p < .001$), the magnitude of the switch cost in Dutch did not differ significantly between tasks. Despite a trend visible in the graph, the interaction between task, trial type, and proficiency was not significant for Dutch (β = -0.0005, *SE* = 0.0004, $p = .140$).

Figure 3. Linear prediction of the four-way interaction effect of task, language, trial type, and proficiency (centered scores on the LexTALE) for RTs on the switch tasks.

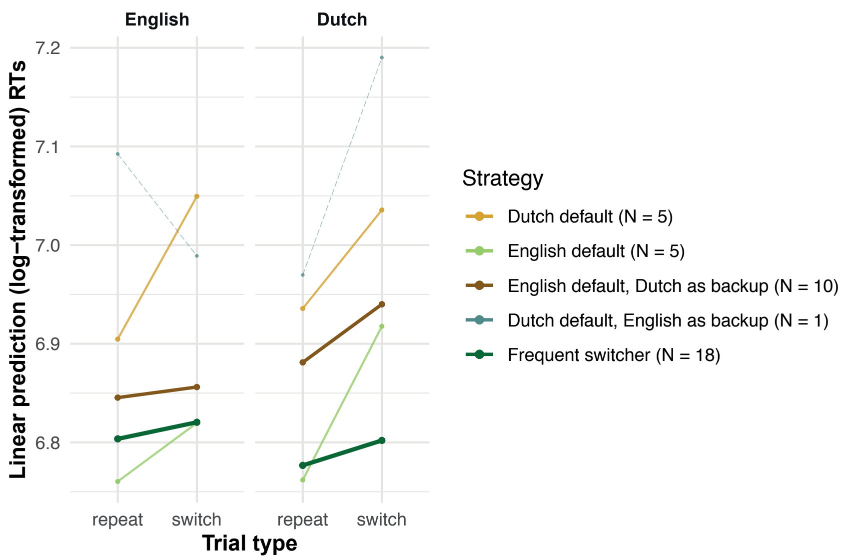


To evaluate switch cost asymmetries, we examined the interaction between task, trial type, and language by creating subsets of the data based on task. The results of the cued condition (Figure 3, left panels) confirmed that participants were slower on switch than repeat trials (β = 0.02, *SE* = 0.004, $p < .001$) and slower on Dutch items than English items (β = 0.02, *SE* = 0.008, $p = .006$), but there was no statistical evidence for a difference in switch costs between the two languages (β = 0.006, *SE* = 0.004, $p = .158$). For free switching (Figure 3, right panels), we corroborated the switch cost (β = 0.02, *SE* = 0.004, $p < .001$), but did not find a significant main effect of language (β = 0.006, *SE* = 0.007, $p = .418$). However, these predictors significantly interacted (β = 0.008, *SE* = 0.004, $p = .044$), with larger switch costs into the L1 than the L2.

To search for an explanation of this voluntary switch cost asymmetry, we inspected the strategies participants adopted in the free switching task. We evaluated the effect of *switching* *frequency* on switching costs. An interaction effect demonstrated that participants who switched more, experienced smaller voluntary switch costs ($\beta = 0.01$, $SE = 0.005$, $p = .003$). Focusing on individual participants, they appear to have implemented different approaches: (a) *Dutch as default* ($N = 5$), with a majority of items in Dutch and few switches into English; (b) *English as default* ($N = 5$), with a majority of items in English and few switches into Dutch; (c) *English default, Dutch as backup* ($N = 10$), with a majority of items in English and one-time switches into Dutch; (d) *Dutch default, English as backup* ($N = 1$), with a majority of items in Dutch and one-time switches into English; and (e) *frequent switchers* ($N = 18$), with many switches into both languages, and an equal number of switch and repeat trials.

When we included *individual strategy* in a linear model with trial type and language predicting the RTs in the voluntary switching task, we observed a significant interaction effect between these predictors ($\chi^2(4) = 11.32$, $p = .023$), implying that the strategies were differentially related to the switch costs into the L1 and L2 (Figure 4). These results suggest that participants who switched infrequently showed larger switch costs, and further show that the magnitude of switch costs depended on the language they switched into. Overall, the Dutch switch costs appear larger than the English switch costs. The participant with the 'Dutch default, English as backup' approach presents as an outlier in terms of strategy, overall RTs, and switch costs.

Figure 4. Visualization of the linear predictions of RTs by language, trial type, and individual strategy.



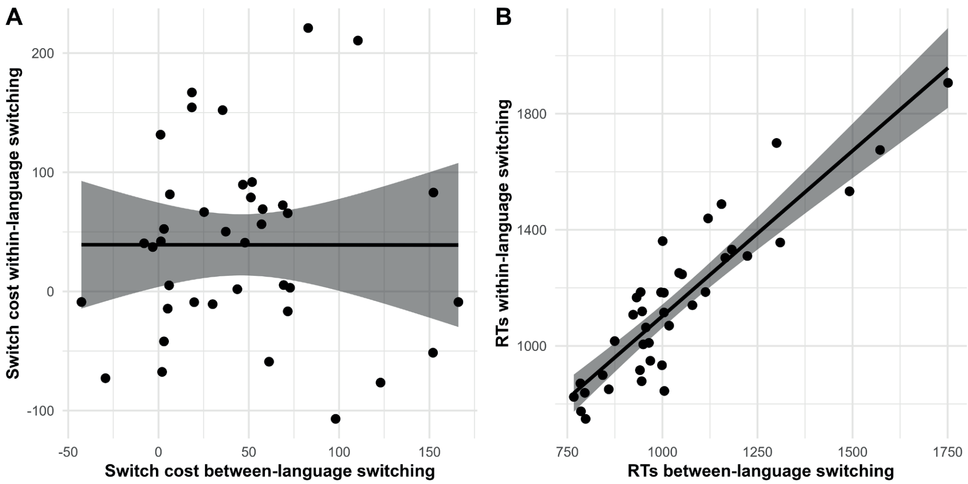
4.3.4 Comparison of cued between-language and within-language switching

We compared participants' performance on the cued between-language and cued within-language switching tasks (Appendices I and J). Accuracy was higher in the between-language than the within-language switch task (*OR* = 2.03, *SE* = 0.16, p <.001). There were switch costs in both tasks (*OR* = 1.46, *SE* = 0.11, p <.001), but there was no significant interaction between trial type and task (*OR* = 1.14, *SE* = 0.09, p = .099).

In correspondence with the accuracy results, RTs were longer in the within-language switch task as compared to the between-language switch task (β = 0.04, *SE* = 0.003, p <.001). We observed a significant switch cost across tasks (β = 0.02, *SE* = 0.003, p <.001), although there was no statistical evidence that these costs differed between tasks (β = 0.003, *SE* = 0.003, p =. 417).

Finally, we carried out a correlation analysis of the switch costs and RTs on the cued between-language and within-language switching tasks (Figure 5). There was no significant correlation of the switch costs between tasks (r = –.0006, p = .997), whereas the overall RTs showed a strong positive correlation (r = .90, p <.001).

Figure 5. Correlation plots of cued between-language and within-language switching costs (A) and overall RTs (B), including 95% confidence interval bands.



4.4 Discussion

We investigated voluntary and cued language switching abilities and the factors contributing to switching behavior and language choice in late Dutch-English bilinguals. In what follows, we elaborate on our main findings.

4.4.1 Language switching motivations

Our results of the voluntary switching task show that participants switched on 42% of the trials, which closely matches previous research on early balanced bilinguals (Blanco-Elorrieta & Pylkkänen, 2018; De Bruin et al., 2018, 2020; Grunden et al., 2020; Jevtović et al., 2019) and unbalanced bilinguals (De Bruin & Xu, 2023; H. Liu et al., 2020; Sánchez et al., 2022). The observed switching frequency is higher than reported by Gollan and Ferreira (2009), who showed that unbalanced bilinguals switched 24% of the time. This may be due to methodological differences between the studies, as Gollan and Ferreira used more difficult target items (with regards to word frequency and length) and did not repeat stimuli. At the same time, Gollan et al. (2014) observed similar switching rates in voluntary switching tasks with and without repetition of stimuli.

The similarity between switching frequencies may be surprising given the differences in type of bilinguals between the studies. The bilinguals in our study can be regarded as less balanced and show more variability in their proficiency levels compared to most previous studies, who generally included bilinguals with a lower age of acquisition, higher proficiency, more balanced use, and who live in bilingual societies in which everyday language switching is more common (i.e., the Basque country, Catalonia, Arabic-English bilingual community, southern California) or who currently live in their L2 environment (De Bruin & Xu, 2023). The studies by H. Liu et al. (2020, 2021) are exceptions. They investigated Chinese-English bilinguals living in an L1 context with limited English proficiency and observed varying switching rates, perhaps due to differences between the two experimental designs. Sánchez et al. (2022) investigated late unbalanced bilinguals (their current language context is not given) and observed high (47%) switching rates in voluntary switching between sentences.

The relatively high switching frequency we observed is remarkable given that code-switching is rather rare in everyday conversations in the Dutch society. A likely explanation is that the number of switches is experimentally induced by a high activation level of English and Dutch as a consequence of the task instructions and experimental set-up. Both languages are explicitly made equally appropriate in the voluntary switching task, and the familiarization and single-language task directly preceded the free switching task. This experimental set-up was also used in earlier studies involving late bilinguals (De Bruin & Xu, 2023; H. Liu et al., 2020, 2021). Contrary to Gollan and Ferreira (2009), the target language of the preceding block in the single-language task did not influence the switching rates, although methodological differences, particularly pre-exposure to the pictures, could have contributed to the diverging findings. Future studies could further explore how experimentally induced voluntary switching generalizes to more naturalistic settings (Blanco-Elorrieta & Pylkkänen, 2017). However, it is also possible that switching frequency is predominantly induced by the conversational situation rather than the language situation in the society at large. Future studies may examine this possibility by manipulating the utility of voluntary switching by varying the frequency of monolingual or bilingual contextual cues (e.g., Zheng et al., 2020).

Our results of the voluntary switching task further showed that bilinguals who rated their own L2 proficiency as higher, switched more often and chose to name items in English more frequently. This effect of proficiency was larger for language choice of the repeat than the switch trials, which indicates that participants with high self-rated proficiency were more inclined to produce repeat items in English. These participants may have adopted English as their default language, and thus switched less frequently overall. Objective proficiency, operationalized as the score on the LexTALE, did not significantly predict switching behavior nor language choice. The absence of a significant main effect of objective proficiency corresponds with earlier research (De Bruin et al., 2018), whereas the relationship between self-rated proficiency and language switching and choice is a new finding, as self-rated proficiency has not yet been considered as a potential predictor for language choice.

This outcome points to a possible role for *language attitude* as an important factor for language switching in this context, complementing research showing that personal language preference of balanced bilinguals may guide language choice (De Bruin & Martin, 2022). Effects of language attitude may be even more pronounced in the Dutch-English bilinguals in our study who, in some cases, have deliberately chosen to pursue their university degree in English. Language attitude can be regarded as a top-down, socio-psychological motivation to switch languages, and has long been established as an important reason to code switch in naturalistic settings (Ritchie & Bhatia, 2012). The question whether balanced bilinguals also choose a language according to their self-rated proficiency, is open for investigation.

Moreover, ease of lexical access predicted language choice: Items that were named relatively more quickly in English than in Dutch in the single-language tasks, were more likely to be named in English in the free switching task (and vice versa), regardless of whether it concerned switch or repeat trials. In other words, participants tended to name the item in the language that was easiest to retrieve, even if that required switching languages. This outcome is in line with earlier findings of switching in a sentence production task (Sarkis & Montag, 2021) and in a picture naming task for balanced bilinguals reported by De Bruin et al. (2018), although lexical access was operationalized slightly differently in both studies. These results imply that the bilinguals in our study encounter subtle differences in lexical retrieval speed and that this affects their language choice, which results in increased efficiency of picture naming. This matches findings for early balanced bilinguals and strengthens the evidence for the role of ease of lexical access in language choice, at least in experimental settings.

4.4.2 Comparing cued and voluntary switching

Our analyses showed that participants were overall faster and made fewer errors in voluntary switching than cued switching, but that both tasks induced switch costs. The comparison of RTs between the two tasks further showed larger cued than voluntary switch costs for the English items, whereas an opposite trend was observed for Dutch. Diminished switch costs in voluntary switching have been observed previously (Gollan et al., 2014; Gollan & Ferreira, 2009; Jevtović et al., 2019; Zhang et al., 2015), but differences in switch costs in the two languages between task types are not yet well established. Our observation is consistent with Jevtović et al. (2019), who found that switch costs in Basque (L2), but not Spanish (L1), were larger in cued than voluntary switching.

Relatedly, we observed an asymmetrical switch cost only in voluntary switching, where participants experienced larger costs for switching into the L1 than the L2. Asymmetrical voluntary switch costs have been observed in late unbalanced bilinguals before (H. Liu et al., 2021), whereas other studies report reversed asymmetrical switch costs (De Bruin & Xu, 2023; Sánchez et al., 2022). Differences in language development and context between bilinguals might underlie the variability in findings of asymmetrical voluntary switch costs. A direct comparison between bilingual groups is warranted to investigate this further.

Asymmetrical switch costs are often explained in terms of control, whereby more inhibition is required for the more dominant language (e.g., Meuter & Allport, 1999; Philipp et al., 2007). Control demands can also result in *reverse dominance effects*, which refer to worse performance in the dominant language compared to the non-dominant language when both languages are mixed (see Declerck & Koch, 2023; Goldrick & Gollan, 2023, for reviews). Proactive control is said to function as a preventative mechanism to minimize cross-language interference resulting from language non-selective activation (see Declerck, 2020, for a review). The finding that participants in our study were overall faster to name the English than Dutch items is in line with this account. Correspondingly, many participants adopted English as their default language in the voluntary switching task. They may have exerted more inhibition over their stronger L1 than L2, resulting in longer L1 naming latencies and asymmetrical voluntary switch costs. This interpretation is supported by the observation that reverse dominance effects started to emerge only in the later blocks of the single-language condition. In other words, repeated exposure to two languages caused interference and increased the inhibitory demands, resulting in reversed dominance effects.

However, an absence of asymmetrical switch costs in the cued switching task warrants an additional explanation for the large voluntary switch costs into Dutch. We tried to clarify this pattern by focusing on the strategies participants adopted in the free switching task. This showed that participants became more efficient switchers when they switched more frequently, and appeared to have implemented different strategies that impacted switch costs in each language. Frequent and flexible switchers showed small switch costs in both languages, while participants with a clear default language show relatively high voluntary switch costs into both languages, but more pronounced for their non-default language.

We tentatively take this as evidence for a role of ease of lexical access in explaining the voluntary language switch costs: Participants with a clear default language may decide to switch to the other language only when they encounter a lexical retrieval difficulty. This is time-consuming, which is subsequently interpreted as a large switch cost. Importantly, more participants used English as their default language ($N = 15$) than Dutch ($N = 6$). This could potentially contribute to the large voluntary switch cost observed for Dutch, which, in turn, eliminated the voluntary switching advantage for Dutch. The precise mechanism underlying this effect, and why it governs switching into the L1 more prominently than switching into the L2, should be investigated in future research.

Our experimental tasks were presented in the order that was deemed optimal given the methodological constraints. However, as a result of the item repetition and fixed order in which the tasks were presented, the mixing costs of the voluntary and cued switching task could not be compared. While the finding that participants were overall faster on voluntary switching than cued switching and single-language naming can be regarded as evidence in the direction of an overall processing advantage in the voluntary condition (i.e., mixing benefits), repetition effects cannot be ruled out entirely. Because the same set of pictures was used in all tasks and the tasks were presented in the same order, participants may have become faster with each repetition of an item. Speeding up in the voluntary switching compared to the single-language task could be due to repeating stimuli, and the effect of slowing down in the cued task would likely have been larger if items had not been repeated. To adequately assess mixing costs, a single-language block should have been added after the switching tasks (De Bruin et al., 2018; Grunden et al., 2020; Jevtović et al., 2019). The effects of item repetition on bilingual picture naming are detailed in Kleinman and Gollan (2018).

4.4.3 Contributors to language switching abilities

Our results showed that differences in switch costs between cued and voluntary switching appeared to be moderated by L2 proficiency. More specifically, L2 proficiency and task interacted only for the English items, and played a role in cued, rather than voluntary switching into English. This could suggest that cued switching into the L2 was particularly difficult for participants with relatively low proficiency. In other words, when you *must* switch to a language of relatively low proficiency, switching takes more time. This points to a role for lexical accessibility in explaining the cued switch costs into English. This interaction was not statistically significant for the Dutch items, which may be due to the relatively smaller number of voluntary trials named in Dutch. Because these results reflect a complex interaction effect, a replication in a larger group of participants is warranted.

A potential reason for the absence of a main effect of proficiency on the naming latencies may be that the experiments did not place high demands on lexical knowledge of the participants. The highly frequent target words were repeated throughout the experiment, and we familiarized participants with all items prior to the experiments. In addition, the LexTALE is a receptive vocabulary test and may therefore not directly relate to naming speed in the experiments.

In addition to proficiency, we examined the effect of more general switching abilities on cued and voluntary switching. We administered a picture naming task that required participants to make within-language switches, inspired by Sikora et al. (2019; 2016; 2018). We did not find evidence that within-language switch costs predicted voluntary or cued switching behavior or abilities. A separate analysis showed that participants experienced within-language switch costs, implying that the task was successful in capturing switching abilities. We found no statistical evidence for differences or associations between the between-language and within-language switch costs. At the same time, the overall RTs on the two tasks were strongly correlated. These results could suggest that the performance on the two picture naming tasks showed considerable overlap, but that the within-language switching costs specifically may play only a minor role in between-language switching, which could provide tentative evidence for a more domain-specific nature of bilingual language switching (Branzi et al., 2016; Calabria et al., 2012, 2015; Klecha, 2013; Prior & Gollan, 2011).

However, there are two alternative explanations for the absence of significant correlations between the switch costs. Firstly, concerns have been raised about the reliability of difference scores and this could explain the discrepancy in findings between the switch costs (a difference score) and overall RTs (e.g., Draheim et al., 2019; Segal et al., 2021). Secondly, methodological differences may hinder the comparison between types of switching (Declerck et al., 2017, 2020). We tried to make our switching tasks as comparable as possible (i.e., both tasks required a verbal response, had similar cue presentation, and an alternating-runs design), but the tasks inevitably diverged in some ways. For between-language switching, the target word in the competing language was the only response alternative, whereas within-language switching had the competing target property (color or size) as the most prominent response alternative, but participants could also omit the target property altogether and produce only the bare noun. In addition, the required responses were more complex in the within-language task (adjective and noun) than the between-language switch task (bare noun). These differences between task designs are difficult to avoid but complicate drawing firm conclusions about the domain specificity of bilingual language switching.

4.4.4 Testing language production online

Our study confirms that collecting language production data in a web-based setting is feasible (Fairs & Strijkers, 2021; Stark et al., 2022; Vogt et al., 2021). Our data were somewhat noisier compared to data gathered in the lab, but we consider less than 3% missing data due to technical glitches acceptable. In addition, the average RTs in our data (~1000 ms) were higher than typically reported for bilingual picture naming studies (~800–900 ms), but we were nonetheless able to capture switch costs. The switch costs were in the expected direction and resembled those gathered in lab-based settings in terms of relative magnitude. Furthermore, the online data collection process was efficient, easy to carry out, and required little technical equipment. Thus, our study contributes to the evidence that a web-based administration of language experiments is a suitable method of data collection for future research.

4.5 Conclusion

This study systematically investigated voluntary and cued language switching in late Dutch-English bilinguals, measured in a web-based setting. Our results suggest that late bilinguals behave similarly to early balanced bilinguals regarding several aspects of language switching. Their voluntary switching frequency resembled that of early balanced bilinguals, they experienced switch costs in cued as well as voluntary switching, and ease of lexical access contributed to their language choice. Moreover, our results demonstrated that self-rated proficiency rather than objective proficiency predicted voluntary switching behavior. Participants were overall slower to name pictures in cued switching than in voluntary switching. The magnitude of the switch costs for each task differed between the L1 and L2, which could partially be explained by individual approaches to voluntary switching adopted by participants. An interaction effect with proficiency revealed that switching into the L2 is particularly difficult if switching is not optional and proficiency is relatively low. Finally, there was considerable overlap in performance on between-language and within-language switching tasks, while the switch costs specifically were not significantly related. This study highlights the similarities in language switching between different types of bilinguals and provides insight into the factors that are related to voluntary language switching.

Appendices

Appendix A. Picture names in Dutch and English.

Dutch Target word	English Target word
munt	coin
eend	duck
hond	dog
kip	chicken
kraan	tap
kikker	frog
mand	basket
fiets	bike
riem	belt
touw	rope
jurk	dress
spiegel	mirror
stoel	chair
ketting	chain
sleutel	key
boom	tree
mes	knife
fles	bottle
wolk	cloud
knoop	button
haai	shark
dak	roof
hek	fence
bezem	broom
slak	snail
been	leg
pijl	arrow
paard	horse
lepel	spoon
wortel	carrot

Appendix B. Mean and range of word variables of stimuli.

	Dutch	**English**
	M (range)	M (range)
SUBTLEX log10 frequency	2.9 (2.0 – 3.9)	3.1 (2.0 – 4.0)
Age of acquisition	5.3 (3.7 – 6.9)	4.6 (2.7 – 6.8)
Prevalence (1.5 = 93% knows word)	1.9 (1.7 – 2.0)	2.4 (2.2 – 2.6)
Concreteness (rating scale 1-5)	4.8 (4.4 – 5.0)	4.9 (4.3 – 5.0)

Appendix C. Overview of the experimental tasks and blocks.

	Experiment version 1	**Experiment version 2**
Familiarization	Item familiarization L1 and L2	Item familiarization L1 and L2
1. Single-language naming		
Block 1	L1: Dutch (15 trials)	L2: English (15 trials)
Block 2	L2: English (15 trials)	L1: Dutch (15 trials)
Block 3	L1: Dutch (15 trials)	L2: English (15 trials)
Block 4	L2: English (15 trials)	L1: Dutch (15 trials)
2. Voluntary language switching		
Block 1	Free naming (30 trials)	Free naming (30 trials)
Block 2	Free naming (30 trials)	Free naming (30 trials)
3. Cued between-language switching		
Block 1	Cued switching (30 trials)	Cued switching (30 trials)
Block 2	Cued switching (30 trials)	Cued switching (30 trials)
4. Cued within-language switching		
Block 1	Cued switching L1 (30 trials)	Cued switching L1 (30 trials)
Block 2	Cued switching L1 (30 trials)	Cued switching L1 (30 trials)

Appendix D. The response categories with definitions and examples.

Label (Accuracy)	**Category**	**Definition/example (target word: *hond*, 'dog')**
A (1)	Correct response	Identical to target word in target language: *hond*
B (1)	Hesitation	Hesitation before correct answer: e*hh… hond*
C (0)	No or late response	No answer within 3000 ms
D (0)	Selection error	Target word in wrong language: *dog* Wrong competing adjective in within-language switching task: *small* instead of *red* Wrong adjective: *blue* instead of *red*; *big* instead of small Both target and competing word produced: *dog…hond*
E (0)	Semantic error	Meaning-based lexical error/semantically related with target: *kat* ('cat')
F (0)	Phonological error	Phonological overlap (and no semantic relation) with at least 2/3 of target word: *rond*
G (0)	Unrelated error	Error with no phonological or semantic overlap with target: *tafel* ('table')
H (0)	False start	Repetition of the first syllable or phoneme: *ho- hond* Repetition of the first adjective: *klein- kleine hond* ('small- small dog') Pause between adjective and noun: *kleine…hond* ('small…dog')
I (0)	Wrong language Wrong word	Language intrusion and error: *cat, table.*
J (0)	Mix of two languages	Combination of phonemes from target word in both languages: *hog*
GLITCH	Glitch	Technical hiccup that rendered measuring RT impossible

4

Appendix E. Descriptive statistics for the outcome measures grouped by the experimental conditions

Reaction Times						
Task	*Language*	*Trial type*	*Mean (ms)*	*SD*	*SE*	*N (trials)*
Single-language naming	English		1025.18	316.93	9.45	1124
	Dutch		1056.61	327.26	9.68	1142
Voluntary switching	English	Repeat	924.40	235.18	8.65	740
		Switch	988.29	297.67	13.79	466
	Dutch	Repeat	970.79	275.87	11.45	581
		Switch	1012.61	319.54	14.74	470
Cued between-language switching	English	Repeat	983.54	266.10	11.18	566
		Switch	1046.22	317.97	14.01	515
	Dutch	Repeat	1046.06	308.85	12.94	570
		Switch	1075.84	336.70	14.81	517
Cued within-language switching		Repeat	1130.70	368.45	11.46	1033
		Switch	1167.61	391.69	12.86	927

Accuracy						
Task	*Language*	*Trial type*	*Mean (proportion correct)*	*SD*	*SE*	*N (trials)*
Single-language naming	English		0.97	0.18	0.01	1167
	Dutch		0.99	0.12	0.00	1170
Voluntary switching	English	Repeat	0.99	0.07	0.00	749
		Switch	0.99	0.12	0.01	474
	Dutch	Repeat	0.98	0.13	0.01	597
		Switch	0.99	0.10	0.00	478
Cued between-language switching	English	Repeat	0.98	0.14	0.01	584
		Switch	0.96	0.21	0.01	543
	Dutch	Repeat	0.99	0.11	0.00	584
		Switch	0.96	0.19	0.01	542
Cued within-language switching		Repeat	0.92	0.27	0.01	1160
		Switch	0.88	0.32	0.01	1078

Appendix F. Model output for voluntary switching in the free switching task.

	Switching (yes/no)				
Effect[a]	*Odds Ratios*	*St. Error*	*LL 95% CI*	*UL 95% CI*	*p-value*
Intercept	0.67	0.07	0.55	0.82	**<.001**
Self-rated proficiency	1.28	0.13	1.04	1.57	**.021**
Ease of lexical access (Δ RT[b])	1.01	0.05	0.91	1.11	.796
Switch cost	0.95	0.10	0.78	1.16	.618

Note. Number of observations = 2117. [a] All predictors were scaled. [b] Ease of lexical access was operationalized as difference score in RTs between the L1 and L2.

4

Appendix G. Model output for accuracy analyses of cued and free switching.

	Switch model – Errors				
Predictors	*Odds Ratios*	*St. Error*	*LL 95% CI*	*UL 95% CI*	*p-value*
Intercept	85.79	20.82	53.31	138.04	**<.001**
Trial type	1.59	0.33	1.06	2.39	**.025**
Task	0.56	0.12	0.37	0.84	**.005**
Language	1.28	0.27	0.85	1.92	.239
LexTALE	1.00	0.02	0.97	1.03	.866
Trial type × Task	1.04	0.22	0.69	1.56	.862
Trial type × Language	1.31	0.27	0.87	1.97	.198
Task × Language	0.70	0.15	0.47	1.06	.090
Trial type × LexTALE	0.97	0.01	0.95	1.00	.066
Task × LexTALE	1.03	0.02	1.00	1.06	**.040**
Language × LexTALE	1.00	0.02	0.97	1.029	.948
Trial type × Task × Language	0.68	0.14	0.45	1.03	.066
Trial type × Task × LexTALE	1.03	0.02	1.00	1.06	.066
Trial type × Language × LexTALE	0.98	0.02	0.95	1.01	.143
Task × Language × LexTALE	1.02	0.02	0.99	1.05	.319
Trial type × Task × Language × LexTALE	1.02	0.02	0.99	1.05	.194

Note. Number of observations = 4551.

Appendix H. Model output for RT analyses of cued and free switching.

	Switch Model - RTs[a]				
Effect	*Estimate*	*St. Error*	*LL 95% CI*	*UL 95% CI*	*p-value*
Intercept	6.88	0.03	6.83	6.94	**<.001**
Trial type	-0.02	0.003	-0.03	-0.02	**<.001**
Task	0.04	0.01	0.02	0.06	**<.001**
Language	-0.01	0.01	-0.03	-0.002	**.019**
LexTALE	-0.003	0.002	-0.01	0.002	.217
Switch cost	0.0004	0.0004	-0.0003	0.001	.316
Trial number	-0.0004	0.0002	-0.001	-0.00004	**.029**
Trial type × Task	-0.001	0.003	-0.006	0.004	.731
Trial type × Language	0.0003	0.003	-0.005	0.006	.919
Task × Language	-0.007	0.003	-0.01	-0.002	**.01**
Trial type × LexTALE	0.0004	0.0002	-0.0001	0.001	.107
Trial type × Switch cost	-0.00002	0.00004	-0.0001	0.0001	.613
Task × LexTALE	-0.001	0.001	-0.002	0.001	.316
Task × Switch cost	-0.00001	0.0001	-0.0002	0.0002	.933
Language × LexTALE	-0.0004	0.0004	-0.001	0.0004	.340
Language × Switch cost	0.0000	0.0001	-0.0001	0.0001	.938
Trial type × Task × Language	-0.01	0.003	-0.01	-0.001	**.029**
Trial type × Task × LexTALE	0.0001	0.0002	-0.0004	0.001	.791
Trial type × Task × Switch cost	0.00004	0.00004	-0.00003	0.0001	.297
Trial type × Language × LexTALE	-0.0002	0.0002	-0.001	0.0003	.506
Trial type × Language × Switch cost	-0.0001	0.0000	-0.0001	0.00002	.161
Task × Language × LexTALE	0.0004	0.0002	-0.0001	0.001	.110
Task × Language × Switch cost	-0.00004	0.00004	-0.0001	0.0000	.265
Trial type × Task × Language × LexTALE	0.001	0.0002	0.0001	0.0010	**.011**
Trial type × Task × Language × Switch cost	-0.00001	0.00004	-0.00001	0.00004	.771

Note. Number of observations = 4425. [a] Reaction times were (natural) log transformed.

4

Appendix I. Model output accuracy between-language and within-language switching

	Cued model – Errors				
Effect	*Odds Ratios*	*St. Error*	*LL 95% CI*	*UL 95% CI*	*p-value*
Intercept	24.67	4.20	17.97	34.74	**<.001**
Trial type	1.46	0.11	1.25	1.69	**<.001**
Task	2.03	0.16	1.74	2.36	**<.001**
Trial type × Task	1.14	0.09	0.98	1.32	.099

Note. Number of observations = 4491.

Appendix J. Model output RTs between-language and within-language switching

	Cued model - RTs[a]				
Effect	*Estimates*	*St. Error*	*LL 95% CI*	*UL 95% CI*	*p-value*
Intercept	6.96	0.03	6.89	7.02	**<.001**
Trial type	-0.02	0.003	-0.02	-0.01	**<.001**
Task	-0.06	0.01	-0.08	-0.05	**<.001**
Trial number	-0.02	0.01	-0.04	-0.01	**.001**
Trial type × Task	-0.002	0.003	-0.01	0.004	.440

Note. Number of observations = 4128. [a] Reaction times were (natural) log transformed.

4

5

Benefits of free language choice in bilingual individuals with aphasia

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Abstract

Forced switching between languages poses demands on control abilities, which may be difficult to meet for bilinguals with aphasia. Freely choosing languages has been shown to increase naming efficiency in healthy bilinguals, and lexical accessibility was found to be a predictor for language choice. The overlap between bilingual language switching and other types of switching is yet unclear. This study aimed to examine the benefits of free language choice for bilinguals with aphasia and to investigate the overlap of between- and within-language switching abilities.

Seventeen bilinguals with aphasia completed a questionnaire and four web-based picture naming tasks: single-language naming in the first and second language separately; voluntary switching between languages; cued and predictable switching between languages; cued and predictable switching between phrase types in the first language. Several results point to benefits of voluntary language switching for bilinguals with aphasia. Freely mixing languages improved naming accuracy and speed, and ease of lexical access affected language choice. There was no statistical evidence for overlap of between- and within-language switching abilities. This study highlights the benefits of free language choice for bilinguals with aphasia.

5.1 Introduction

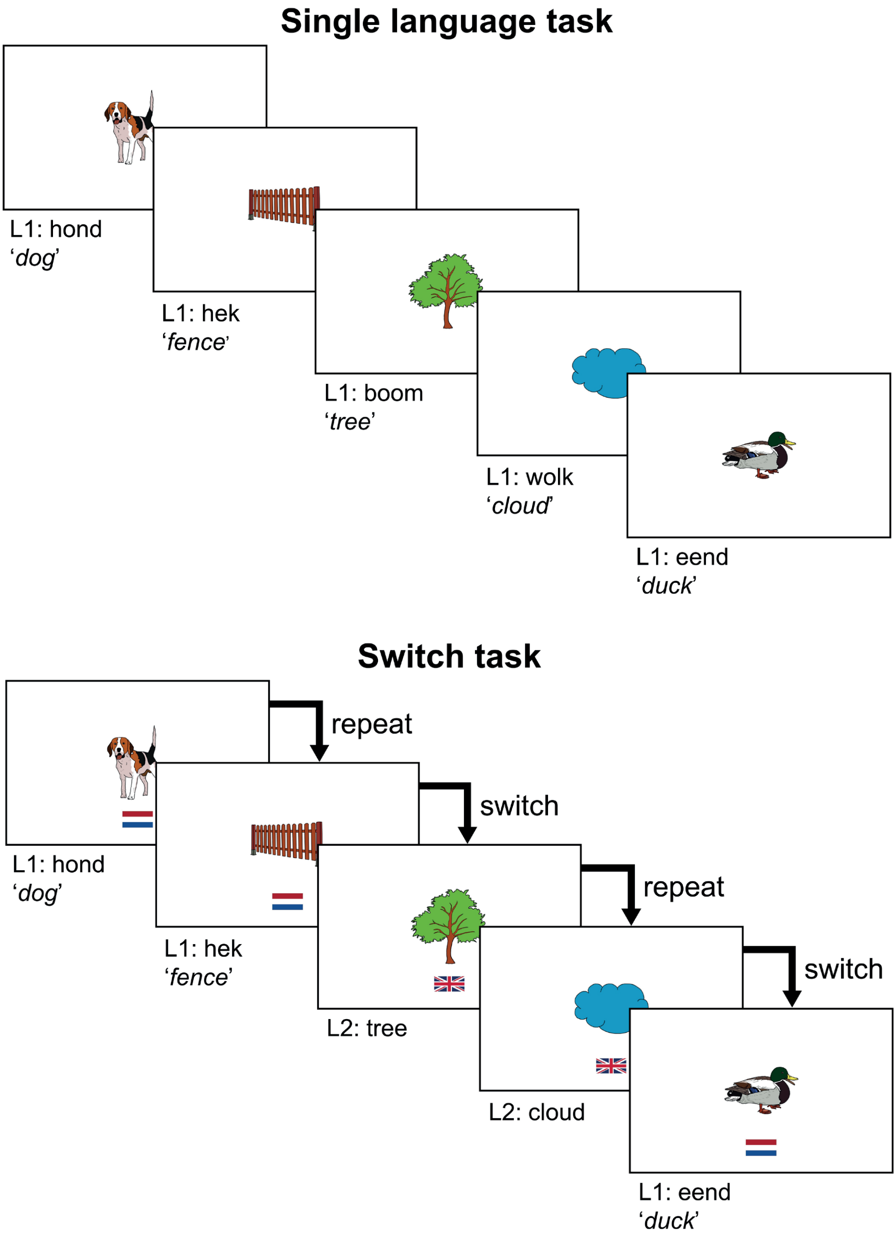
Despite a long history of research, it is still unclear whether knowing two languages may help individuals with aphasia. In his epoch-making article, Lichtheim (1885) reported on a person with aphasia who "spoke German and French fluently before the injury; but German rather the better of the two. As the aphasia diminished, German words returned before French" (p. 448). The individual experienced word-finding difficulties in both languages. In French, mostly he finds "the French equivalents of the words he can say in German" (p. 449). When words in the two languages are instead differently available, free language choice should improve naming. A bilingual speaker with aphasia may then choose the word that is most readily accessible from either language, and knowledge of two languages could thereby provide a way to bypass lexical retrieval difficulties.

At the same time, managing two languages presents a range of cognitive control demands to bilingual individuals. These demands could be difficult to meet for bilingual persons with aphasia when they have co-occurring impairments in language control. The aim of the present study was to investigate the efforts and benefits involved in bilingual language choice for bilinguals with aphasia.

To determine whether free language choice is beneficial for bilingual individuals with aphasia, we examined their picture naming abilities in conditions requiring a single language, and in conditions where language choice was free or externally cued. We also compared switching between and within languages. In the free condition, we assessed whether ease of lexical access in the languages affected language choice. In what follows, we first briefly review the extant evidence on cued and free language switching in healthy bilingual speakers and individuals with aphasia. Next, we report our new study.

Previous research has shown that language switching in a cued switching paradigm is effortful: healthy bilinguals perform worse on trials in which they have switched languages compared to trials in which the language is repeated (*switch cost*), and in blocks where they mix languages compared to single-language blocks (*mixing costs*) (e.g., Branzi et al., 2016; Calabria et al., 2012; Christoffels et al., 2007; Klecha, 2013; Meuter & Allport, 1999; Verhoef et al., 2009). Switch costs are operationalized as the reaction time (RT) or accuracy difference between naming pictures in switch and repeat trials, whereas mixing costs refer to the difference between language switching conditions and "pure" language conditions (Figure 1).

Figure 1. An illustration of a 'pure' language condition (left panel) and a typical language switching paradigm using alternating runs (right panel).



The switch costs and mixing costs imply that bilinguals need top-down *control* abilities to switch between their languages. Bilinguals with aphasia (BWA) may encounter challenges in meeting these control demands if they have impairments in control abilities. Several studies have demonstrated reduced performance on language control tasks (e.g., Dash & Kar, 2014; Gray, 2020; Gray & Kiran, 2016, 2019; see Chapter 3 for a review), but studies focusing on cued language switching abilities of BWA yielded mixed results (Calabria et al., 2014, 2019, 2021). When language switching by bilinguals with aphasia is investigated with verbal fluency tasks, it appears that BWA perform worse than neurologically healthy control participants when executive control demands are higher (Carpenter et al., 2020, 2021; Patra et al., 2020).

Further evidence for the presence of control impairments comes from reports of *pathological* code-switching (Abutalebi et al., 2000; Ansaldo et al., 2010; Calabria et al., 2014; Fabbro, 2000; Kong et al., 2014; Leemann et al., 2007; Mariën et al., 2017). Language switching is considered 'pathological' when it occurs in pragmatically inappropriate contexts (Ansaldo et al., 2008). In these cases, BWA may switch to a language not shared with their interlocutor, or to a language in which they are not proficient.

Pathological language switching has been found to co-occur with impaired non-linguistic control abilities (Calabria et al., 2014; Kong et al., 2014; Leemann et al., 2007; Mariën et al., 2017). Various studies therefore propose that a breakdown in the domain-general control system, particularly in *inhibition* abilities, may be responsible for involuntary code-switching (Abutalebi & Green, 2007; Green & Abutalebi, 2008; Kohnert, 2004). However, empirical studies that investigated whether language control impairments of BWA overlap with non-linguistic executive control impairments returned inconsistent results, as there is evidence for dissociations (Dash & Kar, 2014; Gray & Kiran, 2016, 2019; Green et al., 2011), but also for (partial) overlap (Calabria et al., 2019; Green et al., 2010; Van der Linden, Dricot, et al., 2018; Van der Linden, Verreyt, et al., 2018; Verreyt et al., 2013).

The conflicting findings may be due to methodological dissimilarities (Declerck et al., 2017), and examining switching abilities within the linguistic domain could reduce these differences. Previous research has shown considerable overlap in switching between and within languages in healthy bilinguals (Declerck et al., 2020), although discrepancies between the two domains have also been found (Chapter 4). Whether BWA show overlap in within- and between-language switching, is not yet established.

Despite the aforementioned challenges, being bilingual also has benefits. Knowledge of two languages allows a bilingual to choose the most accessible language when the context allows for the use of both languages. As such, *voluntary* language switching has been found to reduce mixing costs in healthy bilinguals (Gollan & Ferreira, 2009). Indeed, several studies have demonstrated that when healthy bilinguals are free to switch between languages, they may even show mixing *benefits*: they make fewer errors and are overall faster than when they have to stay in one language (De Bruin et al., 2018; Jevtović et al., 2019). Crucially however, voluntary switching still appears to generate switch costs, although these may be diminished.

Additionally, previous research has suggested that ease of lexical access is related to voluntary switching (De Bruin et al., 2018), such that bilinguals choose the language that is easiest to access at a particular point in time. Considering that persons with aphasia have lexical retrieval problems (e.g., Goodglass & Wingfield, 1997), language switching could function as a compensatory approach for word-finding difficulties (Riccardi, 2012).

Recent studies have investigated the potential benefits of language mixing for BWA more directly. Goral et al. (2019) and Lerman et al. (2019) examined language mixing in multilinguals with aphasia, and observed more frequent mixing in more demanding contexts (with regard to aphasia severity, language proficiency levels, type of target word, and required language output). The authors found no evidence for inappropriate language mixing. Consequently, they argue that BWA may mix their languages to circumvent word-retrieval difficulties, which could be interpreted as a strategy to improve communication. Results of a recent case report support this view (Hameau et al., 2022), while Paplikar (2016) did not find that increased instances of language mixing led to higher communicative success for BWA.

In short, previous research has shown that cued switching between languages is challenging for healthy bilinguals. Language control deficits could thus imply that cued switching between languages is particularly difficult for BWA. Studies involving healthy bilinguals showed that freely mixing language may increase naming efficiency and that ease of lexical access may affect language choice and switching (De Bruin et al., 2018; Jevtović et al., 2019; Chapter 4).

In the current study, we aimed to investigate whether voluntarily mixing languages is beneficial for BWA, leading to mixing benefits and providing a way to circumvent word-retrieval difficulties. To this end, we compared performance on three picture naming tasks: (1) naming pictures in a single language, (2) voluntarily switching between languages, and (3) cued switching between languages. These naming tasks were expected to place varying demands on control abilities. The adaptive control hypothesis of Green and Abutalebi (2013) states that the level of control necessary for bilingual language production depends on the context. In this view, the single-language naming task requires goal maintenance and interference control, and places moderate demands on control. In voluntary switching, languages can be in a cooperative relationship and this task therefore could require less language control (De Bruin et al., 2018). The cued switching tasks mirror Green and Abutalebi's (2013) dual-language context, and are assumed to evoke the highest control demands. In addition to comparing these three tasks, we sought to examine whether between-language switching abilities of BWA overlap with noun-phrase switching within one language, in order to contribute to the debate regarding the degree of overlap between various language control demands. Our research objectives were:

1. Investigate the potential benefits of language mixing, by:
   a) Analyzing voluntary and cued language *mixing* costs,
   b) Comparing voluntary and cued language *switching* costs,
   c) Examining the relationship between ease of lexical retrieval and voluntary language choice.
2. Examine how cued between-language switching costs relate to switching abilities within a language.

5.2 Methods

5.2.1 Participants

Nineteen BWA initially participated in the study. Two participants were excluded because the experiment was too challenging. The remaining participants (*N* = 17) were native speakers of Dutch (L1) with English or German as their second language (L2). Some participants spoke a third or fourth language (Appendix A). All participants indicated to have used or still use their L2 frequently and that they had acquired their L2 up to good-excellent levels of proficiency. However, their language history differed regarding age of acquisition and self-rated pre- and post-morbid proficiency and use.

Participants had aphasia caused by acquired brain damage due to hemorrhagic stroke (*N* = 10), ischemic stroke (*N* = 5), or traumatic brain injury (*N* = 2). Their aphasia was confirmed by their (former) speech-language therapist. The participants were all in the chronic stage of recovery (≥ 6 months, *range* 9-144 months). Six participants had motor speech impairments (apraxia of speech and/or dysarthria) in addition to aphasia, but their speech was sufficiently intelligible to participate in the study.

To get an indication of the aphasia severity and characteristics, two authors (SM and MR) qualitatively analyzed the semi-spontaneous speech collected with an adapted version (Ruiter et al., 2023) of the Amsterdam-Nijmegen Everyday Language Test (ANELT; Blomert et al., 1995) using the spontaneous speech assessment scale of the Dutch Aachen Aphasia Test (Graetz et al., 1992). The latter includes multiple language-processing levels (communicative behavior; articulation and prosody; automatized language; semantic structure; phonemic structure; syntactic structure), each scored on a six-level scale. Demographic and clinical characteristics are presented in Table 1.

Prior to participation, all participants received information about the study and gave their informed consent. The institutional ethics committee approved of the study (2019-5035).

Table 1. Individual demographic and clinical characteristics.

PWA	Age	Sex	Education[a]	Etiology	TPO[b]	ANELT Effectiveness[c]	ANELT Efficiency[d]	Fluent	Motor speech impairments	Total score classification[e]
P01	37.6	Male	6	Hemorrhagic CVA	89	81%	15.2	Yes	No	27
P02	47.8	Male	5	Ischemic CVA (*recurrent*)	23	71%	21.7	Yes	No	28
P03	53.7	Female	6	Ischemic CVA	18	50%	8.2	No	Yes	22
P04	41.0	Female	7	Hemorrhagic CVA	35	81%	11.4	No	Yes	25
P05	54.0	Male	5	Hemorrhagic CVA	65	67%	11.3	No	No	26
P06	36.4	Male	5	Traumatic Brain Injury	65	52%	4.5	No	No	23
P07	54.2	Male	7	Hemorrhagic CVA	35	78%	10.2	No	Yes	24
P08	64.5	Male	5	Ischemic CVA	129	60%	10.7	No	No	22
P09	55.7	Female	6	Hemorrhagic CVA	26	75%	10.8	No	No	26
P10	54.6	Female	5	Ischemic CVA	120	30%	4.5	No	No	17
P11	56.4	Female	6	Hemorrhagic CVA	22	71%	16.6	No	Yes	20
P12	61.6	Female	7	Hemorrhagic CVA	74	79%	10.3	Yes	No	28
P13	55.8	Male	7	Hemorrhagic CVA	9	59%	15	No	Yes	25
P14	48.8	Male	7	Ischemic CVA (*recurrent*)	89	54%	13.9	No	No	22
P15	29.2	Male	6	Hemorrhagic CVA	30	63%	10	No	No	24
P16	22.4	Male	7	Traumatic Brain Injury	27	57%	4.7	No	Yes	19
P17	63.3	Male	5	Hemorrhagic CVA	144	56%	7.2	Yes	No	24

Note. [a] *Education based on Verhage (1964) on scale 1-7;* [b] *TPO: time post-onset in months;* [c] *ANELT effectiveness: percentage essential information conveyed;* [d] *ANELT efficiency: average number of essential information units produced per minute;* [e] *Total score classification: based on Aachen Aphasia Test classification of spontaneous speech on scale 0-30.*

5.2.2 Materials

An adapted version of the TeleTaalTest-NL (Satoer et al., 2020) was used to screen whether the verbal comprehension and word-finding difficulties were not too severe (cut-off scores <4/5 and <5/6, respectively) to hinder participation in the study. Next, participants completed a web-based questionnaire on the Qualtrics platform (Qualtrics, 2005), including questions about demographic information, handedness, clinical variables, language background, and (perceived) language and executive control abilities. Handedness was established using the Edinburgh Handedness Inventory (Oldfield, 1971).

The language background questions were based on the Language Experience and Proficiency Questionnaire (LEAP-Q; Marian et al., 2007) and the Language History Questionnaire (LHQ 2.0; Li et al., 2014), adapted to ensure appropriateness for individuals with aphasia. Age and context of acquisition, and pre- and post-morbid self-rated language proficiency and frequency of use of all languages spoken by the participant were addressed, although we only report scores of the relevant L1 and L2. Afterwards, the average pre- and post-morbid self-rated proficiency in the L1 and L2 was calculated as the mean score for comprehension and production. Writing and reading were omitted because it was not the focus of the present study. The final part of the questionnaire consisted of questions targeting self-rated language control and executive control abilities on a scale of 1-100. The language control questions were newly created and the executive control questions were adapted from Derryberry and Reed (2002).

We made efforts to make completion of the questionnaire feasible for persons with aphasia (e.g., Herbert et al., 2019). We used visual support to help interpret the instructions and questions: pictograms from an open-source database (Sclera vwz, 2019) were added to the EHI and color coding was used to illustrate levels of proficiency. The language was adapted such that only short and simple sentences were used, and we included audio recordings of the questions and instructions. Participants could take as many breaks as needed.

We administered an adapted version (Ruiter et al., 2023) of Version-I of the ANELT (Blomert et al., 1995), which includes two practice items and ten test items that require the participant to verbally respond to an everyday scenario. We used the scoring proposed by Ruiter et al. (2011), in which *verbal effectiveness* is quantified by counting produced content units related to the preamble and request of each scenario. Afterwards, the proportion of produced content units over required content units was calculated. In addition, *verbal efficiency* was operationalized as the average number of content units produced per minute (Ruiter et al., 2011). Timing started at the offset of the scenario and ended when participants finished their answer.

We designed four picture-naming tasks that closely resemble those reported in Chapter 4. All naming tasks included the same thirty 8 × 8 cm colored line drawings from the MultiPic

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database (Duñabeitia et al., 2018). Pictures had to be named in Dutch (L1) and English or German (L2), depending on the language background of the participant. The target words were frequent, early acquired, prevalent, and concrete non-cognate words (see Appendix A). Word variables were based on various databases (Birchenough et al., 2017; Brysbaert et al., 2011, 2014, 2019; Brysbaert & New, 2009; Keuleers, Brysbaert, et al., 2010; Keuleers et al., 2015; Kuperman et al., 2012; Schröder et al., 2012).

5.2.3 Design and procedure

Due to the COVID-pandemic, in-person testing was not possible and the procedure took place remotely, using telephone and web-based tools. To ensure reliable measurements, we conducted the experiment using a live connection with participants, mimicking an in-person testing situation and minimizing distraction. In addition, we manually annotated the answers, allowing for an evaluation of each data point before including it in the analysis. Any remaining glitches were expected to be random and not systematically impact the results. Finally, we controlled for differences in internet connection speed by including random intercepts for participants in the statistical analysis.

Participants were recruited through online communities, aphasia centers, speech-language therapists, or (if granted permission) previous studies belonging to the same research project. A screening was administered to assess feasibility of participation. Eligible participants filled in the informed consent form and the questionnaire in Qualtrics. Thereafter, the experimental tasks were administered in a peer-to-peer video call in Zoom (Zoom Video Communications Inc., 2012), using a secure connection via the institution's license. The experiments were shown using PowerPoint via screen sharing. The experiments were recorded in Zoom, stored locally, and the audio recordings were used in the analysis.

The experimental procedure started with a familiarization task in which participants were shown each picture. They were asked to read aloud the two printed target words in their L1 and L2 or to repeat the target words after an auditory prompt. After familiarization, four picture-naming tasks were administered in a fixed order: single-language picture naming in separate L1 and L2 blocks, voluntary language switching between L1 and L2, cued language switching between L1 and L2, and cued switching between phrase types within the L1. Our motivation to choose for this particular fixed order was as follows. The single-language task was presented first to obtain a measure of naming performance in each language separately. Voluntary switching was administered before cued switching to avoid priming language switching. The within-language switch task came last because of its relative novelty. We found that completion of the four naming tasks took approximately 30 minutes including familiarization but excluding breaks and instructions.

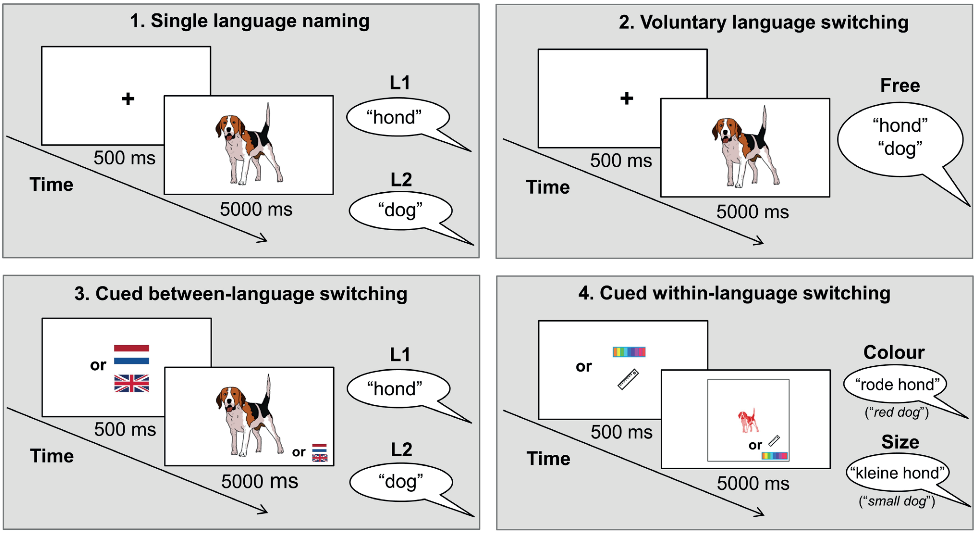
Participants were given written and (pre-recorded) verbal instructions in the target language of the block that followed: L1, L2, or a mix of both languages. The instructions emphasized speed and accuracy of naming. Participants saw four practice items before single-language naming and voluntary switching, and ten (or more, if requested by the participant) practice items before the two cued switching tasks. Each task consisted of 60 trials, with short breaks between the tasks. The target pictures were presented twice in each task, and order of the items was randomized using Mix (Van Casteren & Davis, 2006), with the constraint that the repetition of items was at least 10 trials apart. We created two versions of the experiment, each with a different starting language in the single-language naming task and a different randomization of the trials.

In the single-language naming task, participants named pictures in two blocks of trials for each language. In the voluntary switching task, participants were instructed to name pictures in whichever language first came to mind, completing two blocks. The two cued switching tasks also consisted of two blocks and had the same design: cued and predictable switching between languages or noun phrases in a *switch-repeat-switch-repeat* order. This order required participants to switch based on alternating runs, in an *AABBAA* pattern (e.g., L1-L1-L2-L2-L1-L1). A cue was presented preceding and simultaneous with each item. In the cued between-language switching task, participants named pictures in their L1 or L2 depending on a visually presented country flag. The pictures were separated across the two versions of the experiment, such that participants named an item in L1 or L2, not both, to avoid interference.

The cued within-language switching was inspired by Sikora et al. (2016, 2016, 2019) and Sikora and Roelofs (2018) and involved switching between naming color or size properties of the depicted object in the L1. All line drawings were edited such that they were red or blue, and big (14 × 14 cm) or small (6 × 6 cm). If the participants saw a color bar, they were required to name the color of the depicted object (e.g., *red dog* or *blue dog*). When a ruler was presented as a cue, participants named the size of the depicted object (e.g., *small dog* or *big dog*). As with the between-language switching task, participants switched in alternating runs (i.e., *size-size-color-color-size-size*, etc.).

The trial structure of each task is illustrated in Figure 2. Pictures were shown for maximally 5000 ms, or shorter if the participant named the item before the end of the trial. If the participant had not completed the response before the trial ended, a blank screen was shown such that the response could be finished. The experimenter manually started the next trial, to reduce time pressure for participants and potential spill-over effects of errors or long naming latencies. A click sound was presented at the onset of each picture to enable annotation of the audio files and extraction of the response latencies. The trials were preceded by a fixation cross (single language and voluntary switching tasks) or by the visual cue (cued switching tasks), which was always shown for 500 ms.

Figure 2. Experimental set-up of the four picture naming tasks in Dutch and English.



5.2.4 Analysis

Error categorization

The audio recordings of the experiments were annotated manually in Praat (Boersma & Weenink, 2022). The error categorization was based on the classification of De Bruin et al. (2018), adapted to make it suitable for the analysis of aphasic spoken language by including categories for phonemic, semantic, and unrelated errors. Additionally, categories for specific errors made in the within-language switch task were added (i.e., between- and within-dimensional selection errors). Appendix C presents the full classification scheme. The first author coded the errors, and any unclear cases were discussed with the co-authors until consensus was reached.

Reaction times

To get a complete picture of the participants' naming abilities, we also assessed naming latencies (Evans et al., 2020). RTs were extracted in Praat (Boersma & Weenink, 2022) and operationalized as the time between the onset of the click sound and onset of the participant's response. Inaccurate answers were not included in the RT analysis. Correct answers were included if they were started within 5000 ms, also if they were preceded by filled pauses (the naming latency included the filled pause and ended at the start of the target word) or hesitations (the naming latency ended at the start of the hesitation). For within-language switching, correct answers that were realized with long breaks (≥ 250 ms) between the target adjective and noun were coded as such, qualified as correct but not included in the RT analysis.

Statistical analysis

The statistical analyses were carried out in R (R Core Team, 2022) using RStudio (RStudio Team, 2023), with packages 'lme4', 'lmerTest', 'emmeans', 'tidyverse', 'ggplot2', 'corpcor', 'GPArotation', and 'psych' (Bates et al., 2015; Bernaards & Jennrich, 2005; Lenth, 2022; Revelle, 2022; Schafer et al., 2021; Wickham, 2016; Wickham et al., 2019). In the accuracy analysis, we excluded trials with technical glitches ($N = 3$), errors that made it impossible to judge the language choice of that item ($N = 15$), and the first trials of a task or after a break ($N = 78$). In total, we excluded 96 data points (2.5%) from the accuracy analysis.

In the RT analysis, we discarded the incorrectly answered items ($N = 834$) and answers with latencies of <500 ms ($N = 7$) and >5000 ms ($N = 208$). We removed trials with technical glitches that rendered measuring naming latencies impossible or unreliable ($N = 84$). Finally, the first trials of a task or block were excluded ($N = 61$). This led to the exclusion of 1194 data points (31.3%) in the RT analysis.

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Seven participant-related variables needed to be included in the statistical models: age, education level, both ANELT effectiveness and efficiency, spontaneous speech classification, self-rated L1 and L2 proficiency. To reduce the number of variables and decrease the risk of multicollinearity, a principal components analysis (PCA) was conducted on these predictors (see Appendix D for details). The PCA showed that the five language (dis)ability scores meaningfully contributed to one principal component. We calculated a factor score of this component ('aphasia factor') and included this score in the analyses. The remaining variables (i.e., age, educational level, and self-rated L2 proficiency) were included separately.

We ran multiple (generalized) linear mixed-effects regression models to answer our research questions (an overview of the models and their parameter estimates are given in Appendix E). In addition to the participant-related predictors, relevant task-related variables were included in each model. These predictors were: *task* (single-language naming, voluntary switching, cued between-language switching, and cued within-language switching), *language* (L1 and L2), and *trial type* (switch and repeat trials). The descriptive statistics for accuracy and RTs of these variables are presented in Appendix F.

The variable *trial type* reflects the switch costs because accuracy and RT differences on switch and repeat trials were compared. For cued switching, switch and repeat trials were predetermined by the trial order. For voluntary switching, switch and repeat trials were determined based on the participants' language choice. When they chose to name an item in the same language as the preceding trial, it was coded as a repeat trial. When language choice was different from the preceding item, the trial was coded as a switch. Consequently, the number of switch and repeat trials in the voluntary task differed between participants.

All models were fit with the maximal theoretically-informed random structure that was possible without convergence issues (Barr et al., 2013). Continuous predictors were standardized, and categorical predictors were sum-coded (-1 or +1). The interpretation of three-level predictors was facilitated by an omnibus test and post-hoc pairwise comparisons with a correction for multiple comparisons of the p-values. RTs were (natural) log-transformed to reduce skewness. The model assumptions of heterogeneity of variance, residual distribution and multicollinearity were checked.

5.3 Results

5.3.1 Questionnaire

Pre- and post-morbid self-rated language proficiency

Table 2 provides a summary of the language background questions. The included participants had differing levels of self-rated L2 proficiency. Pre-morbidly, ten participants considered their L1 and L2 proficiency to be balanced, whereas seven participants estimated their L1 skills to be higher. All participants rated their L1 and L2 proficiency higher pre-morbidly compared to post-morbidly (Figure 3). Overall, participants judged their proficiency decline to be larger in their L2 (mean difference = -1.4) than their L1 (mean difference = -1.2).

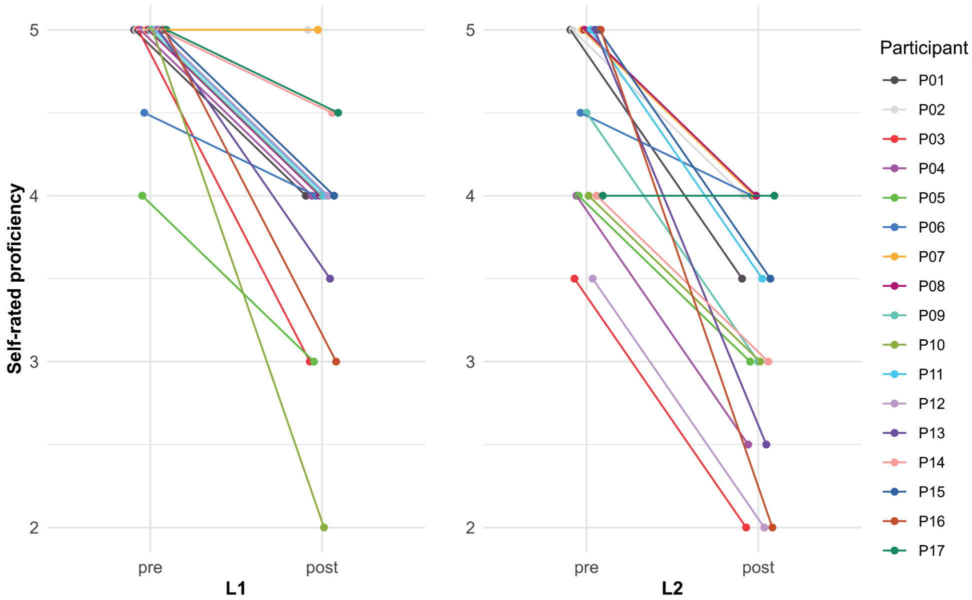
Table 2. Summary of the bilingual variables.

Second language (L2)	***N***	**%**							
English	12	71%							
German	5	29%							
Age of acquisition	***N***	**%**							
Early	4	24%							
Late	13	76%							
	Pre-morbidly				**Post-morbidly**				
	Mean	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Average difference**
Self-rated L1 proficiency									
Comprehension	4.9	0.3	4	5	4.2	0.8	2	5	-0.7
Production	4.9	0.2	4	5	3.5	0.9	2	5	-1.4
Reading	4.9	0.3	4	5	3.8	0.9	2	5	-1.1
Writing	4.7	0.8	2	5	3.1	1.0	2	5	-1.6
Self-rated L2 proficiency									
Comprehension	4.5	0.5	4	5	3.6	0.6	3	5	-0.9
Production	4.4	0.7	3	5	2.6	1.2	1	4	-1.8
Reading	4.5	0.5	4	5	3.4	0.8	2	5	-1.1
Writing	4.2	1.0	2	5	2.3	1.2	1	5	-1.9
Self-rated L1 frequency of use									
Home	4.8	0.8	2	5	5	0	5	5	0.2
Family	4.6	0.8	2	5	4.8	0.4	4	5	0.2
Friends	4.7	0.6	3	5	4.6	0.8	2	5	-0.1
Work	4.9	0.3	4	5	4.5	1.1	2	5	-0.4

Table 2. Summary of the bilingual variables. *(Continued)*

	Mean	SD	Min	Max	Mean	SD	Min	Max	Average difference
Self-rated L2 frequency of use									
Home	3.4	1.4	1	5	2.8	1.3	1	5	-0.6
Family	2.9	1.1	1	5	2.6	1.3	1	5	-0.3
Friends	3.2	1.5	1	5	2.6	1.3	1	5	-0.6
Work	3.7	1.4	1	5	2.1	1.0	1	4	-1.5

Figure 3. Self-rated pre- and post-morbid proficiency in the L1 and L2.



Language and executive control questionnaire

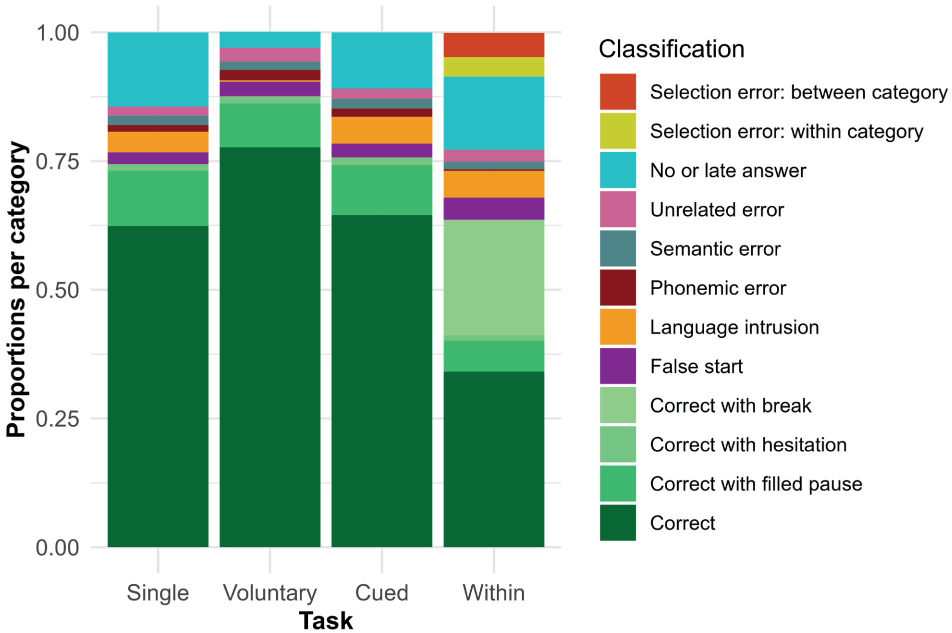
We highlight the main results of the language and executive control questionnaire. The average score on the question whether participants use their knowledge of another language to circumvent word-retrieval difficulties was 62.5/100 (*SD* = 29.8, *range* 9-100). The average self-rated code-switching frequency within a conversation was 37.1/100 (*SD* = 28.0, *range* 0-98). The lowest average score on the language-control questions was given for *language inhibition* ('It is easy to suppress one language when I am speaking in the other.'), averaging at 40.4/100 (*SD* = 27.9, *range* 5-100). *Switching awareness* ('I notice myself switching between my languages.') received the highest average score of 79.6/100 (*SD* = 21.6, *range* 32-100). Regarding the executive-control questions, participants rated their *divided attention* lowest ('I have no trouble following two conversations at the same time.'), averaging at 39.4/100 (*SD* = 29.1, *range* 0-100). Participants scored highest on their *task-switching* abilities ('I can easily switch between two different tasks.'), with an average score of 65.6/100 (*SD* = 27.8, range 25-100), closely followed by *refocusing* ('After being distracted, I can easily refocus my attention on what I was doing.'), averaging at 65.3/100 (*SD* = 31.3, *range* 10-100).

5.3.2 Experimental tasks

Task-related error patterns

The distributions of error types are visualized in Figure 4. The bars represent participant responses, and the colors illustrate the proportion of answers in each category. Participants provided correct answers (in green colors) most frequently in the voluntary switching task (including *correct*, *hesitations*, *pauses*: 88%) and least frequently in the within-language switch task (64%). In the single-language condition, 74% of answers was correct, compared to 76% in the cued switching condition. Task-specific effects contributed to some of the differences in the error distributions. The small number of *language intrusions* in voluntary switching can be attributed to the fact that both languages were considered correct in this condition. The *selection* errors, concerning the choice of the target property of the adjective, could only occur in the within-language switching condition. Besides the task-specific demands, the distribution of errors in the single-language and cued switching condition are rather similar, although participants made more language intrusions in the switching task. Notably, there were markedly fewer instances of no or late answers in the voluntary switching task as compared to the other conditions.

Figure 4. Classification of all observed answers divided over task. Correct answers in green colors, various errors in the other colors.



Costs and benefits of language mixing

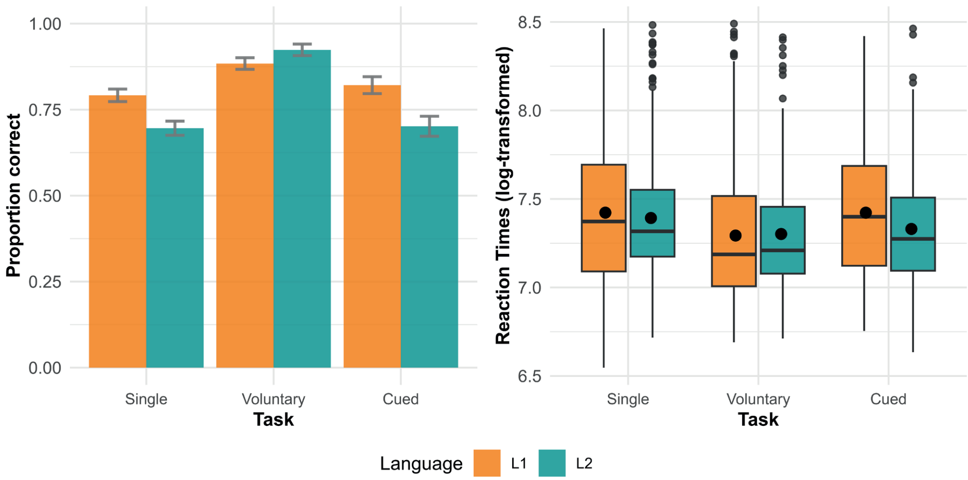
In this part of the analysis, we investigated the costs and benefits of cued and voluntary language mixing by comparing the single-language task to the repeat trials in the voluntary and cued switching tasks. We were interested in the effect of task, potentially modulated by language, while controlling for aphasia factor, L2 proficiency, age, and education level. The results are visualized in Figure 5 and the model outputs are presented in Appendix E-1 and E-2.

Accuracy. There was a significant effect of task ($\chi^2(2) = 24.8$, $p < .001$) and post-hoc pairwise comparisons showed that participants had higher accuracy in the voluntary condition compared to single-language naming ($OR = 3.29$, $SE = 0.67$, $p_{adj} < .001$) and cued switching ($OR = 0.32$, $SE = 0.07$, $p_{adj} < .001$). There was no significant difference between single-language naming and cued switching ($OR = 1.04$, $SE = 0.16$, $p_{adj} = .967$). Furthermore, participants made more errors in their L2 than their L1 ($OR = 1.27$, $SE = 0.14$, $p = .035$).

There was a main effect of L2 proficiency ($OR = 1.83$, $SE = 0.46$, $p = .015$), and an interaction with task and language indicated that higher L2 proficiency positively influenced the naming accuracy of the L2 items in single-language naming and cued switching. There was a significant interaction between task and education level ($OR = 0.66$, $SE = 0.13$, $p = .033$), as accuracy differences between tasks were particularly large for participants with lower levels of education.

Reaction times. The RT results mirrored the accuracy outcomes. There was a significant effect of task ($\chi^2(2) = 18.5$, $p < .001$), as participants were faster on voluntary switching compared to single-language naming ($\beta = -0.10$, $SE = 0.02$, $p_{adj} < .001$) and cued switching ($\beta = 0.07$, $SE = 0.02$, $p_{adj} = .013$). The latter two did not differ significantly ($\beta = -0.04$, $SE = 0.02$, $p_{adj} = .225$). There were no other relevant main effects, although task was involved in three-way interactions with language and L2 proficiency, age, education, and aphasia factor. These interaction effects did not alter the interpretation of the main effect of interest (see Appendix E-2). 5

Figure 5. Accuracy and response times single-language naming, voluntary switching, and cued switching tasks. Error bars in the accuracy plot represent the standard error and black dots in the boxplots represent mean RT.



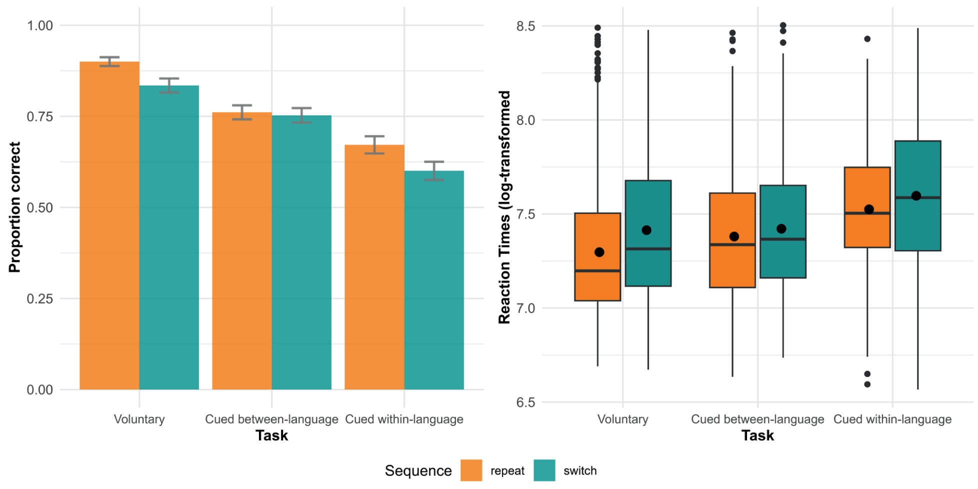
Costs of voluntary and cued language switching

Here, we aimed to determine whether switch costs can be reduced when switching is voluntary. We were thus interested in the effect of trial type in voluntary and cued switching, potentially modulated by language of the items. We controlled for aphasia factor, L2 proficiency, age, and education level. The results are visualized in Figure 6 and the model output is given in Appendix E-3 and E-4.

Accuracy. The accuracy analyses revealed a significant effect of trial type, indicative of a switch cost ($OR = 1.18$, $SE = 0.09$, $p = .028$), and showed that participants made more errors in cued than voluntary switching ($OR = 0.66$, $SE = 0.05$, $p <.001$). Moreover, these factors significantly interacted ($OR = 0.85$, $SE = 0.06$, $p = .034$), indicating that the switch costs were larger in voluntary than cued switching. Post-hoc pairwise comparisons showed that there were significant voluntary switch costs ($OR = 1.93$, $SE = 0.48$, $p_{adj} = .016$), in contrast to cued switching, where we did not observe a significant difference between switch and repeat trials ($OR = 1.02$, $SE = 0.18$, $p_{adj} = .994$).

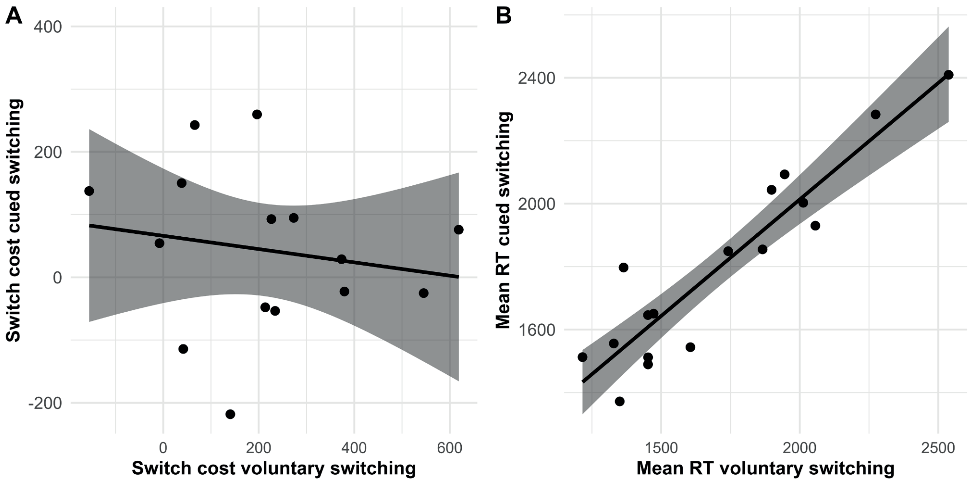
Reaction times. The RT analysis demonstrated that participants were slower on switch than repeat trials ($\beta = 0.03$, $SE = 0.01$, $p <.001$), and on cued switching compared to voluntary switching ($\beta = 0.03$, $SE = 0.01$, $p <.001$). There was no significant interaction effect between trial type and task ($\beta = 0.01$, $SE = 0.01$, $p = .230$).

Figure 6. Switch costs (accuracy and RT difference) on tasks voluntary, cued between-language switching, and cued within-language switching. Error bars in the accuracy plot represent the standard error and black dots in the boxplots represent mean RT.



Correlations. Next, we carried out a correlation analysis to investigate whether voluntary and cued switching were related (Figure 7). The results showed that the switch costs of the two tasks were not significantly correlated ($r = -.17$, $p = .544$), whereas the mean overall RT on these tasks were strongly positively correlated ($r = .93$, $p < .001$).

Figure 7. Correlation plots of voluntary and cued language switching, including 95% confidence interval bands.



Lexical accessibility and language choice

In the following part, we investigated whether ease of lexical retrieval could predict language choice in the voluntary task. Ease of lexical access was operationalized in two ways: (1) *accuracy difference*, by subtracting item-level accuracy in the L2 from the L1 based on the items of the single-language naming task (*-1* for items that were named correctly only in the L2, *0* for equal scores in both languages, *+1* for items that were named correctly only in the L1), and (2) *RT difference*, by subtracting item-level RTs in the L1 from the L2, again including only items of the single-language naming task (negative values indicate a retrieval advantage for the L2, positive values an advantage for the L1). The RT difference score could therefore only be calculated for items that were correctly named in both languages. We used these difference scores in two models with language choice as binary outcome, while controlling for aphasia factor, L2 proficiency, age, and education level (Appendices E-5 and E-6 present the models).

The voluntary switching data show that participants switched on average in 36% of the trials (*range* 0% - 53%) and that they used their L2 on 44% of the trials (*range* 0% - 90%). The outcomes of the first model reveal that language choice in the voluntary task was significantly related to ease of lexical access operationalized as accuracy difference ($OR = 0.30$, $SE = 0.06$, $p < .001$). This suggests that items that were more often accurately named in the L1 than the L2

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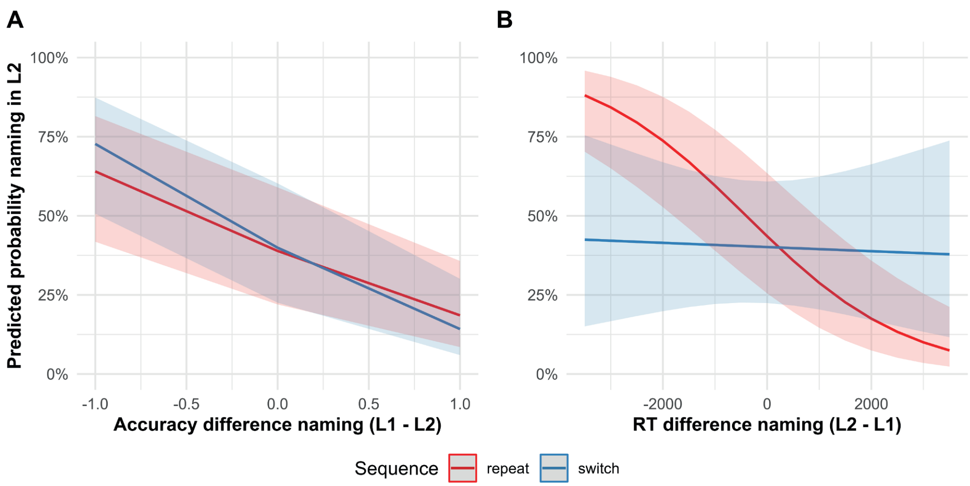
in the single-language condition, were also more likely to be named in the L1 in the voluntary switching condition, and vice versa (Figure 8A). This effect was obtained regardless of whether it concerned switch or repeat trials ($OR = 1.19$, $SE = 0.23$, $p = .356$).

Our second model demonstrated that ease of lexical access as measured with RT difference was also significantly related to language choice in the voluntary task ($OR = 0.68$, $SE = 0.10$, $p = .006$). Importantly, lexical access interacted with switching ($OR = 0.72$, $SE = 0.10$, $p = .014$), suggesting that participants were more inclined to stay in, but not switch to, a language in which the word was easier to retrieve (Figure 8B). Aphasia factor, age, and education level also affected voluntary language choice, but these effects were independent of ease of lexical access.

To assess whether the language of the final block of the single-language task impacted performance in the subsequent voluntary switching task, we conducted a post-hoc analysis examining the effect of experiment *version* on voluntary switching behavior. We observed no significant effect of this variable on overall language choice ($OR = 0.75$, $SE = 0.36$, $p = .537$), indicating that the language in which the participants finished the single-language task, did not significantly affect their voluntary language choice. Similarly, there was no significant effect of version on the likelihood of switching in the voluntary task ($OR = 0.94$, $SE = 0.32$, $p = .847$).

Figure 8. The model plots of the probability of naming an item in the L2 in the voluntary switching task, predicted by the accuracy difference (A) and RT difference (B) in naming items in the L1 and L2, including 95% confidence interval bands.



Relationship cued between- and within-language switching

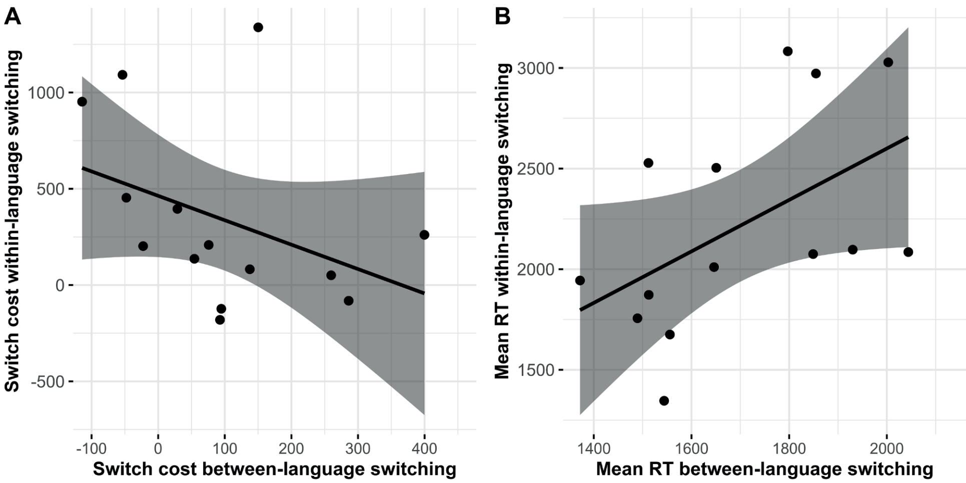
Finally, we explored the differences and commonalities between cued between-language and within-language between adjectival phrase switching. Our main interest was the interaction between task and switch costs, while controlling for aphasia factor, age, and education level (see Appendix E-7 and E-8 for the models). The accuracy and RT results are visualized in Figure 6.

Accuracy. The accuracy analyses revealed that participants made significantly more errors in the within-language switching task compared to the between-language switching task (OR = 1.57, SE = 0.10, p <.001). Task interacted with aphasia factor (OR = 0.63, SE = 0.05, p <.001), as aphasia severity negatively impacted accuracy on the within-language, but not the between-language switch task. An interaction between task and L2 proficiency indicates that L2 proficiency only impacted accuracy on the between-language switch task (OR = 1.37, SE = 0.11, p <.001). Finally, it appears that higher education level negatively affected accuracy in the within-language switch task, but not in the between-language switch task (OR = 1.42, SE = 0.12, p <.001). Despite a trend visible in Figure 6, the accuracy difference between switch and repeat trials across tasks was not significant (OR = 1.09, SE = 0.06, p = .128), nor was the interaction between switching and task (OR = 0.93, SE = 0.05, p = .189).

Reaction times. In correspondence with the accuracy results, participants were slower to respond to items in the within-language switch task as compared to the between-language switch task (β = 0.10, SE = 0.01, p <.001). Here, we observed a significant switch cost across tasks (β = 0.03, SE = 0.01, p = .007), although there was no statistical evidence that these costs differed between tasks (β = 0.01, SE = 0.01, p =. 474).

Correlations. A correlation analysis showed that there was no significant correlation between the switch costs in cued between-language and within-language switching (r = -.39, p = .170), and that the moderate positive correlation of the overall RTs between the tasks also did not reach significance (r = .51, p = .062).

Figure 9. Correlation plots of cued between-language and within-language switching, including 95% confidence interval bands.



5.4 Discussion

The aim of this study was to investigate whether voluntary language mixing can be helpful for bilingual individuals with aphasia. We investigated this by focusing on mixing and switching costs associated with voluntary and cued language switching and by examining the influence of lexical accessibility on voluntary language choice. Additionally, we explored whether the costs associated with bilingual language switching coincide with switching between noun phrases in the first language.

5.4.1 Benefits of voluntary language mixing

Several results point to benefits associated with voluntarily mixing languages. Our analyses revealed that voluntary switching was easier than single-language naming in the L1 and L2, and cued language switching between both languages. Participants had higher accuracy and higher naming speed on the voluntary task compared to the other conditions. These results corroborate voluntary mixing benefits observed for healthy bilinguals (De Bruin et al., 2018, 2020; De Bruin & Xu, 2023; Gollan & Ferreira, 2009; Jevtović et al., 2019) and BWA (Carpenter et al., 2020), but contrast the results of Grunden et al. (2020), who did not observe any mixing effects for BWA.

Our results are consistent with Carpenter et al. (2020), who found that BWA performed better on a verbal fluency task when they were free to switch between their languages. The authors argue that this result can be explained by the low control demands associated with this condition, or because BWA can benefit from their knowledge of multiple languages when the language constraints are not predetermined by the context. Following up on this question, we propose that several of our findings highlight a greater influence of bottom-up lexical retrieval processes over top-down control mechanisms in voluntary language switching by BWA.

The errors patterns specifically showed that the BWA in our study provided fewer 'no or late' responses in the voluntary switching task as compared to the other tasks. This suggests that when it is difficult to access an item in one language, the other language is recruited. The results of the questionnaire confirmed that most participants reported that their knowledge of multiple languages was useful when encountering a word-retrieval problem. These results are in line with research suggesting that language mixing may function as a compensation for anomia (Hameau et al., 2022; Goral et al., 2019; Lerman et al., 2019; Riccardi, 2012). More evidence for compensation came from our observation that relative ease of lexical access in the L1 and the L2 was a reliable predictor for language choice in voluntary switching. These results correspond with studies involving early and late healthy bilinguals (De Bruin et al., 2018; Chapter 4).

Importantly, lexical accessibility and switching interacted in predicting language choice. When ease of lexical access was operationalized as the *accuracy* difference between naming items in the L1 and L2, it predicted voluntary language choice in both switch and repeat trials. This suggests that participants were inclined to choose the item in the more accessible language, also if that meant having to make a switch. However, when lexical accessibility was investigated with the *RT* difference, we observed that it predicted language choice of only the repeat trials. In other words, items that surfaced more quickly in one language, were more likely to be named in that language, except when that implied having to make a switch. This divergence could be indicative of an (unconscious) cost-benefit analysis: The accuracy difference implies that participants were *unable* to name an item in one of the languages, whereas the RT difference merely signifies that one of the languages was *faster* to retrieve. In the latter case, participants accepted a longer retrieval time to avoid having to switch, suggesting a 'threshold' for switching.

A potential reason that participants avoided switching is that it was found to be costly, even when made voluntarily. The observed voluntary and cued switch costs corroborate research involving healthy bilinguals (De Bruin et al., 2018, 2020; De Bruin & Xu, 2023; Gollan et al., 2014; Gollan & Ferreira, 2009; Jevtović et al., 2019) and the BWA in Grunden et al. (2020). However, contrary to our predictions, we observed *smaller* switch costs in cued compared to voluntary switching. We tentatively explain these effects as follows. In voluntary switching, BWA may decide to switch languages upon encountering a word-finding failure. This failed word-retrieval process is time consuming and therefore, the associated voluntary switch costs also reflect lexical retrieval time in the other language. Cued switching, on the other hand, is prompted by a predictable and external cue, and is thereby governed more prominently by top-down control (Green & Abutalebi, 2013). Similar results were found for healthy bilinguals in Chapter 4. This explanation aligns with the results of the correlation analysis of voluntary and cued switching, which showed that overall RTs on these tasks were strongly correlated, indicative of an overlap in the abilities required to perform these tasks. However, the switch costs were not correlated, adding to our suggestion that the voluntary switch costs may specifically reflect bottom-up lexical access processes more strongly than top-down control processes.

The findings discussed thus far revealed that voluntary language mixing leads to higher naming accuracy and speed, that ease of lexical access is related to language choice, and that voluntarily mixing languages comes at relatively high switch costs that may originate from retrieval difficulties. These results agree with the literature on the potential benefits of bilingualism for persons with aphasia. Several studies found that BWA mixed their languages more frequently in more demanding contexts (Goral et al., 2019; Lerman et al., 2019), indicative of a compensatory reason to code-switch. Similarly, Muñoz et al. (1999) report that differences in code-switching patterns between healthy bilinguals and BWA were quantitative rather than qualitative. Considering that BWA likely encounter more word-retrieval difficulties than healthy bilinguals, increased code-switching rates could be the result of a strategy to access the word in either language (Muñoz et al., 1999). Our results provide additional evidence that subtle differences in ease of lexical access may be a motivation to choose a particular language, and thus add to the growing evidence that language switching can be recruited as a strategy to improve verbal functional effectiveness in persons with aphasia (Goral et al., 2019; Hameau et al., 2022; Lerman et al., 2019; Muñoz et al., 1999; Riccardi, 2012).

Promoting language switching as a strategy to manage lexical retrieval difficulties could serve as a starting point for clinical practice. The effectiveness of encouraging language switching may depend on the pragmatic context: If a bilingual individual frequently interacts in contexts where both languages are understood by interlocutors, code-switching may be a more effective strategy than when someone mostly operates in monolingual settings. At the same time, we agree with Hameau et al.'s (2022) proposal that code-switching could be useful even in situations where not all languages are shared, as this could nevertheless provide a way to self-cue and retrieve a word in the target language. This proposal is in line with the notion of "translanguaging", which is used to refer to the idea that bilinguals fluidly use all their linguistic resources to communicate (e.g., Wei & García, 2014). The value of promoting flexible use of the entire linguistic repertoire and explicitly training language switching to increase communicative effectiveness for individuals with aphasia needs to be tested in future studies.

Contrary to our expectations, we did not obtain statistical evidence for cued mixing costs. We propose two, not mutually exclusive, accounts for the absence of significant differences between single-language naming and cued language switching. Firstly, item repetition may have facilitated naming performance in the cued switching task, thereby eliminating the effects of the increased demands evoked by having to switch languages based on a cue. Secondly, cross-language interference effects, caused by the familiarization and alternating language blocks, may have already negatively impacted naming performance in single-language naming. Future studies should further examine the effects of item repetition and task order for bilingual individuals with aphasia.

5.4.2 Domain specificity of bilingual language switching

We also examined the generalizability of cued between-language switching abilities of BWA. Because previous research on this topic has been inconclusive, we limited the comparison to the language domain. We evaluated performance on a cued between-language switching task (between the L1 and L2) to a within-language switching task (between naming color and size). While the within-language switching task appeared to be more demanding than between-language switching, as demonstrated by lower accuracy and longer RTs, we did not find statistical evidence for differences in switch costs between the tasks. At the same time, our correlation analyses did not show a significant relationship between the switch costs or overall reaction times on the tasks. An absence of significant correlations between switching tasks has been observed previously in the literature on healthy bilinguals (Branzi et al., 2016; Calabria et al., 2012, 2015; Klecha, 2013; Segal et al., 2019; Timmer et al., 2018; Weissberger et al., 2012).

In one view, this could be interpreted as indicative of a domain-specific ability involved in switching between two languages. However, it is problematic to interpret null findings, especially since trends were visible and our sample size was small. We also recognize that despite our efforts to match the tasks as closely as possible (the same pictures were used, both tasks required a verbal response and used an alternating-runs design and a comparable cue presentation), they inevitably differed in some ways. The response alternatives between the two tasks differed and the within-language switch task required a more complex response (a correctly inflected adjective and the target noun) than the between-language switch task (the target noun). Perhaps as a result, participants experienced more difficulties in the within-language switching task. These differences could also explain the absence of significant correlations between the switching tasks.

The performance in between- and within-language switching was differentially influenced by participant-related factors. The aphasia factor, measured in the L1, had a greater impact on the within-language switch task, which required complex noun-phrase production in the

L1, than on the between-language switch task, which required producing bare nouns. This was expected because aphasia severity is likely to negatively impact the production of more complex phrases. Conversely, L2 proficiency had a stronger effect in the between-language switching task, which involved naming in both languages.

5.4.3 Limitations

Our study has several limitations. Firstly, we observed that individual differences between the participants in our sample impacted performance on the picture naming tasks. Individuals with aphasia vary in lesion characteristics (size, etiology, localization) and aphasia characteristics (severity, type, time post-onset). Additionally, bilinguals differ in age and manner of acquisition, proficiency level, frequency and context of language use, and linguistic similarity between their languages (e.g., Marian & Hayakawa, 2021). These differences certainly affect performance on picture naming and switching experiments, as confirmed by several interaction effects observed in our analysis. However, due to our small sample size, we cannot draw definitive conclusions regarding these interactions. Importantly, the interaction effects generally did not alter the interpretation of the main effects of interest. Future studies with larger sample sizes may explore individual differences related to bilingualism and aphasia in more detail.

Secondly, the order in which the tasks were administered and the repetition of items may have affected task performance. This has potential drawbacks, because picture naming may have become easier with each item repetition, although increasing interference or fatigue as the experiment progressed could have had detrimental effects on the participants' performance. Importantly, errors were never corrected by the experimenter during the experiment, and the pattern of the mixing costs (i.e., a decrease in RTs in voluntary switching and an increase in RTs in cued switching) shows that participants were sensitive to experimental manipulation despite repeating items. Another limitation regarding the design of the experiment was the difference in task complexity between the cued switching tasks. This difference was inevitable, but complicated comparing the two tasks.

A final limitation concerns the lack of equated tests in both languages of participants. The web-based setting and the characteristics of the included population made it difficult to administer elaborate tests, and we preferred a brief protocol over more detailed information of both languages. The combination of the ANELT, the assessment of the semi-spontaneous speech, and the results of the single-language naming test in both languages appears to have given a valid indication of the severity of the language disorder.

5.5 Conclusion

This study reveals that when two languages are equally appropriate, bilinguals with aphasia frequently mix their languages. Moreover, freely mixing languages leads to fewer errors and higher naming speed compared to single-language naming or cued switching. The finding that ease of lexical retrieval was related to language choice supports the idea that the knowledge of two languages can be recruited to increase naming efficiency. At the same time, voluntary language switching was found to be costly as illustrated by relatively high switch costs. The voluntary switch costs are attributed to lexical retrieval difficulties, as BWA may be inclined to switch when they are unable to access a word in a language. These retrieval difficulties are time-consuming and are subsequently interpreted as high switch costs. Despite these costs, voluntarily mixing languages appears to be helpful for BWA as demonstrated by the mixing benefits. In contrast, cued language switching induced only modest switch costs, and we did not find statistical evidence of a relationship between bilingual language switching and within-language switching abilities of BWA. Overall, our findings contribute to the growing body of evidence that bilingual individuals with aphasia can harness their knowledge of two language to compensate for word-retrieval difficulties.

Appendices

Appendix A. Information about the additional languages spoken by participants

PWA	L1	L2	L3	L4
P01	Dutch	English	German	
P02	Dutch	German	English	
P03	Dutch	English	German	
P04	Dutch	English	German	
P05	Dutch	English		
P06	Dutch	German		
P07	Dutch	English	French	German
P08	Dutch	English	German	French
P09	Dutch	English	French	German
P10	Dutch	German	English	French
P11	Dutch	English	German	
P12	Dutch	English	French	German
P13	Dutch	German	English	
P14	Dutch	German	English	
P15	Dutch	English	German	French
P16	Dutch	English	German	
P17	Dutch	English		

Appendix B. Stimuli lists

Experiment version Dutch – English		Experiment version Dutch – German		
Dutch	**English**	**Dutch**	**German**	*English translation*
Been	Leg	Aardappel	Kartoffel	*Potato*
Bezem	Broom	Broek	Hose	*Trousers*
Boom	Tree	Dobbelsteen	Würfel	*Die*
Dak	Roof	Eiland	Insel	*Island*
Eend	Duck	Fiets	Fahrrad	*Bike*
Fiets	Bike	Geit	Ziege	*Goat*
Fles	Bottle	Golf	Welle	*Wave*
Haai	Shark	Hek	Zaun	*Fence*
Hek	Fence	Jurk	Kleid	*Dress*
Hond	Dog	Kast	Schrank	*Closet*
Jurk	Dress	Kikker	Frosch	*Frog*
Ketting	Chain	Kip	Huhn	*Chicken*
Kikker	Frog	Krant	Zeitung	*Newspaper*
Kip	Chicken	Kwast	Pinsel	*Brush*
Knoop	Button	Mand	Korb	*Basket*
Kraan	Tap	Mier	Ameise	*Ant*
Lepel	Spoon	Pak	Anzug	*Suit*
Mand	Basket	Peer	Birne	*Pear*
Mes	Knife	Pompoen	Kürbis	*Pumpkin*
Munt	Coin	Potlood	Bleistift	*Pencil*
Paard	Horse	Riem	Gürtel	*Belt*
Pijl	Arrow	Schilderij	Bild	*Painting*
Riem	Belt	Slak	Schnecke	*Snail*
Slak	Snail	Stropdas	Krawatte	*Tie*
Sleutel	Key	Touw	Seil	*Rope*
Spiegel	Mirror	Trein	Zug	*Train*
Stoel	Chair	Ui	Zwiebel	*Onion*
Touw	Rope	Vlinder	Schmetterling	*Butterfly*
Wolk	Cloud	Vork	Gabel	*Fork*

Appendix C. Error classification (adapted from De Bruin et al. 2018)

Category	Definition/example (target word: hond, 'dog')
Incorrect items (not included in response-time analysis)	
No answer	No (complete) answer within 5000 ms (includes late but correct answers, incomplete answers)
False start	Wrong word-initial sound, corrected: *ro- hond* Excluding sounds that share ≥2 word-initial phonemes with target word in competing language Excluding sounds that share ≥2 word-initial phonemes with target adjective of competing property
Intrusion	Target word in competing language: *dog* ≥2 Target phoneme(s) of word in competing language: *do- hond*
Selection: between-dimensional	Competing adjective of non-target dimension in within-language switching task: *small* instead of *red* Both adjectives produced: *small red dog*
Selection: within-dimensional	Wrong adjective of target dimension in within-language switching task: *blue* instead of *red*; *big* instead of *small* Both adjectives within the same dimension produced: *small big dog*
Semantic	Meaning-based lexical error: *cat*, or for adjectives: *green, long*
Phonemic	Sound-based lexical error, the given answer has phonological overlap with 2/3 phonemes of target word; is a non-word but is not realized with correct syllable onset: *zond*.
Unrelated	Error with no phonological or semantic relation to target: *table*
Correct items (not included in response time analysis)	
Break	Long pause (>250 ms, filled or not) between adjective and noun in within-language switch task: *small…dog*. Onset of target noun needs to be within 5000 ms limit.
Correct items (included in response time analysis)	
Correct	Answer matches target word in target language: *dog*
Correct: Identical	Identical to target word in target language
Correct: Phonemic	Correct with phonemic deviation: the given answer is realized with correct syllable onset (i.e., target consonant, cluster, or vowel); has phonological overlap with 2/3 phonemes of target word; is a non-word.
Correct: Grammatical	Correct with slight grammatical deviations (e.g., diminutive, plural, word order, wrong conjugation adjective)
Correct: Semantic	Correct with slight semantic deviations (e.g., dialect variant, synonym)
Pause	Filled pause before correct answer: *eh… dog*
Hesitation	Repetition of the word-initial target phoneme(s): *d- dog* Repetition of the first adjective: *small- small dog*

Appendix D. Details of the Principal Component Analysis

To reduce the number of variables and reduce the risk of multicollinearity, we conducted a principal components analysis (PCA) on the seven participant-related variables (i.e., ANELT effectiveness, ANELT efficiency, spontaneous speech classification, age, education level, self-rated L1 and L2 proficiency). The Kaiser-Meyer-Olkin (KMO) measure rejected the sampling adequacy for the analysis, leading to the exclusion of education *level* (*KMO* = .25) and *L2 proficiency* (*KMO* = .30). Bartlett's test of sphericity, $\chi^2(10) = 24.0$, $p = .008$, indicated that the correlations between the items were sufficiently large for PCA. We ran an initial analysis to obtain eigenvalues for each component in the data. Two components had eigenvalues above Kaiser's criterion of 1 and together explained 75% of the variance. These components were retained in the final analysis. The standardized factor loadings after rotation ("varimax") are presented below:

Variable	Item	RC1	RC2	h2	u2	com
ANELT effectiveness	3	0.89		0.80	0.20	1.0
Spontaneous speech classification	2	0.85		0.73	0.27	1.0
Self-rated L1 proficiency	5	0.80		0.64	0.36	1.0
ANELT efficiency	4	0.75		0.62	0.38	1.2
Age	1		0.99	0.97	0.03	1.0
		RC1	RC2			
Eigenvalue		2.72	1.04			
Proportion Variance		0.54	0.21			
Cumulative Variance		0.54	0.75			
Proportion Explained		0.72	0.28			
Cumulative Proportion		0.72	1			

Note. *RC1*: Principal component 1, *RC2*: Principal component 2, h^2: proportions of common variance, u^2: amount of unique variance, *com*: item complexity.

There was one *meaningful* component, tapping language ability. *Age* as a sole variable contributed to the other component. Therefore, we only included principal component 1 and calculated factor scores ('aphasia factor') for this component.

Appendix E. Model output of regression models

1. Accuracy language mixing

Generalized linear mixed-effects regression model: accuracy outcome predicted by task (single/voluntary/cued), language (L1/L2), aphasia factor, age, education level, L2 proficiency. Random slope for language over participants and item. Three-level predictor task was sum-coded, such that Contrast 1: cued (1), free (0), single (-1), and Contrast 2: cued (0), free (1), single (-1).

	Accuracy			
Predictors	*Odds Ratios*	*St. Error*	*95% CI*	*p-value*
(Intercept)	5.77	1.14	3.91 – 8.52	**<.001**
Task contrast 1	0.69	0.07	0.56 – 0.85	**<.001**
Task contrast 2	2.18	0.29	1.68 – 2.83	**<.001**
Language	1.27	0.14	1.02 – 1.58	**.035**
Aphasia Factor	0.84	0.19	0.54 – 1.30	.424
L2 proficiency	1.83	0.46	1.13 – 2.98	**.015**
Age	1.26	0.22	0.89 – 1.78	.199
Education	1.20	0.31	0.73 – 1.99	.471
Task contrast 1 × Language	1.19	0.13	0.97 – 1.46	.102
Task contrast 2 × Language	0.87	0.12	0.67 – 1.13	.307
Task contrast 1 × Aphasia Factor	1.13	0.16	0.86 – 1.48	.386
Task contrast 2 × Aphasia Factor	1.04	0.20	0.71 – 1.52	.843
Task contrast 1 × L2 proficiency	1.05	0.15	0.79 – 1.39	.743
Task contrast 2 × L2 proficiency	0.80	0.14	0.57 – 1.12	.198
Task contrast 1 × Age	0.84	0.09	0.68 – 1.03	.095
Task contrast 2 × Age	1.18	0.15	0.93 – 1.52	.178
Task contrast 1 × Education	1.13	0.18	0.83 – 1.54	.428
Task contrast 2 × Education	0.66	0.13	0.45 – 0.97	**.033**
Language × Aphasia Factor	1.32	0.18	1.01 – 1.74	**.044**
Language × L2 proficiency	0.93	0.13	0.70 – 1.23	.620
Language × Age	0.94	0.10	0.77 – 1.15	.575
Language × Education	1.03	0.15	0.77 – 1.38	.849
Task contrast 1 × Language × Aphasia Factor	1.02	0.14	0.77 – 1.34	.910
Task contrast 2 × Language × Aphasia Factor	0.76	0.15	0.52 – 1.12	.167
Task contrast 1 × Language × L2 proficiency	1.06	0.15	0.80 – 1.40	.708
Task contrast 2 × Language × L2 proficiency	1.45	0.25	1.03 – 2.04	**.035**
Task contrast 1 × Language × Age	1.06	0.11	0.86 – 1.31	.589
Task contrast 2 × Language × Age	1.16	0.15	0.91 – 1.49	.238
Task contrast 1 × Language × Education	1.05	0.17	0.77 – 1.43	.780

	Accuracy			
Predictors	*Odds Ratios*	*St. Error*	*95% CI*	*p-value*
Task contrast 2 × Language × Education	1.24	0.24	0.84 – 1.82	.275
Observations	2104			
Marginal R^2 / Conditional R^2	0.179 / 0.356			

2. Reaction times language mixing

Linear mixed-effects regression model: RTs predicted by task (single/voluntary/cued), language (L1/L2), aphasia factor, age, education level, L2 proficiency. Random slope for language over participants and item. Three-level predictor task was sum-coded, such that Contrast 1: cued (1), free (0), single (-1), and Contrast 2: cued (0), free (1), single (-1).

	Reaction Times (log-transformed)			
Predictors	*Estimates*	*St. Error*	*95% CI*	*p-value*
(Intercept)	7.38	0.03	7.33 – 7.43	**<.001**
Task contrast 1	0.01	0.01	-0.02 – 0.03	.478
Task contrast 2	-0.06	0.01	-0.08 – -0.03	**<.001**
Language	0.04	0.02	-0.00 – 0.07	.068
Aphasia Factor	-0.05	0.03	-0.11 – 0.01	.117
L2 proficiency	-0.04	0.03	-0.10 – 0.03	.289
Age	0.03	0.02	-0.02 – 0.08	.186
Education	0.07	0.04	0.00 – 0.14	**.046**
Task contrast 1 × Language	0.02	0.01	-0.01 – 0.04	.189
Task contrast 2 × Language	-0.01	0.01	-0.03 – 0.02	.513
Task contrast 1 × Aphasia Factor	0.02	0.02	-0.02 – 0.05	.344
Task contrast 2 × Aphasia Factor	-0.03	0.02	-0.06 – 0.01	.153
Task contrast 1 × L2 proficiency	0.01	0.02	-0.03 – 0.04	.775
Task contrast 2 × L2 proficiency	-0.03	0.02	-0.06 – 0.00	.068
Task contrast 1 × Age	-0.02	0.01	-0.05 – 0.01	.132
Task contrast 2 × Age	0.00	0.01	-0.03 – 0.03	.972
Task contrast 1 × Education	0.00	0.02	-0.03 – 0.04	.822
Task contrast 2 × Education	-0.00	0.02	-0.04 – 0.03	.898
Language × Aphasia Factor	-0.02	0.02	-0.07 – 0.02	.309
Language × L2 proficiency	0.01	0.02	-0.04 – 0.06	.659
Language × Age	0.05	0.02	0.01 – 0.08	**.009**
Language × Education	0.02	0.03	-0.03 – 0.07	.500
Task contrast 1 × Language × Aphasia Factor	-0.01	0.02	-0.04 – 0.03	.741
Task contrast 2 × Language × Aphasia Factor	0.06	0.02	0.02 – 0.09	**.002**
Task contrast 1 × Language × L2 proficiency	0.03	0.02	-0.00 – 0.06	.091
Task contrast 2 × Language × L2 proficiency	-0.06	0.02	-0.09 – -0.03	**<.001**
Task contrast 1 × Language × Age	0.01	0.01	-0.01 – 0.04	.283

	Reaction Times (log-transformed)			
Predictors	*Estimates*	*St. Error*	*95% CI*	*p-value*
Task contrast 2 × Language × Age	-0.04	0.01	-0.07 – -0.02	**.002**
Task contrast 1 × Language × Education	0.03	0.02	-0.00 – 0.07	.068
Task contrast 2 × Language × Education	-0.05	0.02	-0.08 – -0.01	**.009**
Observations	1655			
Marginal R^2 / Conditional R^2	0.149 / 0.285			

3. Accuracy voluntary and cued switching

Generalized linear mixed-effects regression model: accuracy (0/1) predicted by switching (switch/repeat), task (voluntary/cued), language (L1/L2), aphasia factor, age, education level, L2 proficiency. Random slope for language over participants and over item.

	Accuracy			
Predictors	*Odds Ratios*	*St. Error*	*95% CI*	*p-value*
(Intercept)	6.12	1.15	4.23 – 8.85	**<.001**
Switch	1.18	0.09	1.02 – 1.37	**.028**
Task	0.66	0.05	0.57 – 0.76	**<.001**
Language	1.22	0.15	0.97 – 1.55	.096
Aphasia Factor	0.87	0.18	0.58 – 1.30	.495
L2 proficiency	1.77	0.40	1.14 – 2.76	**.011**
Age	1.05	0.17	0.76 – 1.45	.752
Education	1.11	0.26	0.70 – 1.76	.654
Switch × Task	0.85	0.06	0.73 – 0.99	**.034**
Switch × Language	0.99	0.08	0.85 – 1.14	.845
Task × Language	1.13	0.09	0.97 – 1.31	.105
Switch × Aphasia Factor	1.08	0.11	0.88 – 1.32	.461
Switch × L2 proficiency	0.99	0.10	0.81 – 1.20	.898
Switch × Age	1.12	0.08	0.97 – 1.30	.127
Switch × Education	0.94	0.10	0.75 – 1.17	.571
Task × Aphasia Factor	0.93	0.10	0.75 – 1.14	.474
Task × L2 proficiency	1.09	0.11	0.89 – 1.33	.386
Task × Age	0.88	0.07	0.76 – 1.03	.105
Task × Education	1.12	0.13	0.89 – 1.39	.332
Language × Aphasia Factor	1.21	0.17	0.91 – 1.60	.183
Language × L2 proficiency	1.05	0.16	0.78 – 1.40	.765
Language × Age	0.88	0.10	0.71 – 1.10	.262
Language × Education	0.97	0.15	0.71 – 1.32	.844
Switch × Task × Language	1.09	0.08	0.94 – 1.26	.273
Switch × Task × Aphasia Factor	1.06	0.11	0.86 – 1.30	.605
Switch × Task × L2 proficiency	1.04	0.11	0.85 – 1.27	.678
Switch × Task × Age	1.01	0.08	0.87 – 1.17	.921
Switch × Task × Education	1.19	0.13	0.95 – 1.48	.124
Switch × Language × Aphasia Factor	0.85	0.09	0.69 – 1.04	.123
Switch × Language × L2 proficiency	1.17	0.12	0.96 – 1.43	.125
Switch × Language × Age	1.15	0.09	0.99 – 1.33	.063

	Accuracy			
Predictors	*Odds Ratios*	*St. Error*	*95% CI*	*p-value*
Switch × Language × Education	1.26	0.14	1.01 – 1.57	**.039**
Task × Language × Aphasia Factor	1.20	0.13	0.97 – 1.48	.092
Task × Language × L2 proficiency	0.87	0.09	0.71 – 1.06	.168
Task × Language × Age	0.92	0.07	0.78 – 1.07	.258
Task × Language × Education	0.98	0.11	0.78 – 1.22	.836
Switch × Task × Language × Aphasia Factor	1.07	0.11	0.87 – 1.32	.496
Switch × Task × Language × L2 proficiency	0.98	0.10	0.80 – 1.19	.811
Switch × Task × Language × Age	1.00	0.08	0.87 – 1.16	.950
Switch × Task × Language × Education	0.96	0.11	0.77 – 1.19	.701
Observations	1939			
Marginal R^2 / Conditional R^2	0.157 / 0.339			

4. Reaction times voluntary and cued switching

Linear mixed-effects regression model: RTs predicted by switching (switch/repeat), task (voluntary/cued), language (L1/L2), aphasia factor, age, education level, L2 proficiency. Random slope for language over participants, only random intercept for item (convergence issues).

	Reaction Times (log-transformed)			
Predictors	*Estimates*	*St. Error*	*95% CI*	*p-value*
(Intercept)	7.39	0.03	7.33 – 7.46	**<.001**
Trial type	-0.03	0.01	-0.05 – -0.02	**<.001**
Task	0.03	0.01	0.01 – 0.04	**.001**
Language	0.03	0.02	-0.00 – 0.06	.077
Aphasia Factor	-0.05	0.04	-0.12 – 0.03	.208
L2 proficiency	-0.05	0.04	-0.13 – 0.03	.260
Age	0.01	0.03	-0.04 – 0.07	.621
Education	0.08	0.04	-0.01 – 0.16	.079
Trial type × Task	0.01	0.01	-0.01 – 0.03	.230
Trial type × Language	0.00	0.01	-0.01 – 0.02	.797
Task × Language	0.00	0.01	-0.01 – 0.02	.682
Trial type × Aphasia Factor	-0.01	0.01	-0.03 – 0.02	.628
Trial type × L2 proficiency	-0.01	0.01	-0.04 – 0.01	.270
Trial type × Age	0.00	0.01	-0.01 – 0.02	.665
Trial type × Education	-0.00	0.01	-0.03 – 0.02	.954
Task × Aphasia Factor	0.01	0.01	-0.01 – 0.04	.282
Task × L2 proficiency	0.02	0.01	-0.01 – 0.04	.190
Task × Age	-0.01	0.01	-0.03 – 0.01	.179
Task × Education	-0.00	0.01	-0.03 – 0.02	.919
Language × Aphasia Factor	-0.00	0.02	-0.04 – 0.04	.988
Language × L2 proficiency	-0.01	0.02	-0.05 – 0.04	.744
Language × Age	0.03	0.02	-0.00 – 0.06	.051
Language × Education	0.01	0.02	-0.04 – 0.05	.700
Trial type × Task × Language	0.01	0.01	-0.01 – 0.03	.356
Trial type × Task × Aphasia Factor	0.00	0.01	-0.02 – 0.02	.882
Trial type × Task × L2 proficiency	0.01	0.01	-0.02 – 0.03	.572
Trial type × Task × Age	0.00	0.01	-0.02 – 0.02	.955
Trial type × Task × Education	0.01	0.01	-0.02 – 0.03	.516
Trial type × Language × Aphasia Factor	-0.00	0.01	-0.02 – 0.02	.950
Trial type × Language × L2 proficiency	0.00	0.01	-0.02 – 0.03	.841
Trial type × Language × Age	0.00	0.01	-0.01 – 0.02	.641

	Reaction Times (log-transformed)			
Predictors	*Estimates*	*St. Error*	*95% CI*	*p-value*
Trial type × Language × Education	0.00	0.01	-0.02 – 0.03	.912
Task × Language × Aphasia Factor	-0.02	0.01	-0.04 – 0.00	.065
Task × Language × L2 proficiency	0.03	0.01	0.01 – 0.06	**.003**
Task × Language × Age	0.02	0.01	-0.00 – 0.03	.077
Task × Language × Education	0.04	0.01	0.01 – 0.06	**.002**
Trial type × Task × Language × Aphasia Factor	-0.00	0.01	-0.03 – 0.02	.707
Trial type × Task × Language × L2 proficiency	0.01	0.01	-0.01 – 0.03	.442
Trial type × Task × Language × Age	0.01	0.01	-0.01 – 0.03	.219
Trial type × Task × Language × Education	0.00	0.01	-0.02 – 0.03	.910
Observations	1573			
Marginal R^2 / Conditional R^2	0.144 / 0.297			

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5. Language choice: accuracy-difference model

Generalized linear mixed-effects regression model: language choice (L1/L2) in voluntary switching task predicted by accuracy difference score, switching (switch/repeat), aphasia factor, age, education level, L2 proficiency. Random intercepts for participant and item (no slope for language as this was the outcome in this model).

	Language choice (L1/L2)			
Predictors	*Odds Ratios*	*St. Error*	*95% CI*	*p-value*
(Intercept)	0.67	0.28	0.30 – 1.50	.330
Accuracy difference	0.30	0.06	0.20 – 0.44	**<.001**
Trial type	0.97	0.09	0.80 – 1.16	.716
Aphasia Factor	0.45	0.24	0.16 – 1.27	.134
L2 proficiency	1.44	0.81	0.48 – 4.32	.518
Age	1.12	0.46	0.50 – 2.51	.777
Education	1.42	0.85	0.44 – 4.58	.554
Accuracy difference × Trial type	1.19	0.23	0.82 – 1.74	.356
Accuracy difference × Aphasia Factor	0.94	0.24	0.57 – 1.57	.820
Accuracy difference × L2 proficiency	0.94	0.25	0.55 – 1.59	.811
Accuracy difference × Age	1.20	0.22	0.83 – 1.73	.329
Accuracy difference × Education	0.57	0.17	0.31 – 1.04	.065
Trial type × Aphasia Factor	1.47	0.18	1.15 – 1.88	**.002**
Trial type × L2 proficiency	0.87	0.11	0.68 – 1.11	.271
Trial type × Age	1.36	0.13	1.12 – 1.64	**.002**
Trial type × Education	0.67	0.09	0.51 – 0.87	**.002**
Accuracy difference × Trial type × Aphasia Factor	1.12	0.28	0.68 – 1.84	.659
Accuracy difference × Trial type × L2 proficiency	0.76	0.20	0.45 – 1.28	.308
Accuracy difference × Trial type × Age	0.77	0.14	0.53 – 1.11	.158
Accuracy difference × Trial type × Education	0.84	0.25	0.47 – 1.51	.563
Observations	853			
Marginal R^2 / Conditional R^2	0.182 / 0.549			

6. Language choice: reaction-time difference model

Generalized linear mixed-effects regression model: language choice (L1/L2) in voluntary switching task predicted by RT difference score, switching (switch/repeat), aphasia factor, age, education level, L2 proficiency. Random intercepts for participant, but not for item due to convergence issues.

	Language choice (L1/L2)			
Predictors	*Odds Ratios*	*St. Error*	*95% CI*	*p-value*
(Intercept)	0.74	0.30	0.33 – 1.64	.455
RT difference	0.68	0.10	0.52 – 0.89	**.006**
Trial type	1.13	0.14	0.88 – 1.44	.347
Aphasia Factor	0.76	0.39	0.28 – 2.09	.593
L2 proficiency	1.09	0.62	0.36 – 3.30	.878
Age	0.96	0.39	0.43 – 2.13	.918
Education	1.01	0.59	0.32 – 3.19	.984
RT difference × Trial type	0.72	0.10	0.55 – 0.93	**.014**
RT difference × Aphasia Factor	0.97	0.20	0.65 – 1.44	.863
RT difference × L2 proficiency	0.99	0.19	0.68 – 1.43	.949
RT difference × Age	1.06	0.15	0.80 – 1.41	.681
RT difference × Education	0.89	0.17	0.61 – 1.29	.530
Trial type × Aphasia Factor	1.69	0.27	1.23 – 2.31	**.001**
Trial type × L2 proficiency	0.87	0.16	0.61 – 1.25	.459
Trial type × Age	1.21	0.16	0.93 – 1.57	.154
Trial type × Education	0.57	0.10	0.40 – 0.81	**.002**
RT difference × Trial type × Aphasia Factor	1.15	0.22	0.79 – 1.68	.468
RT difference × Trial type × L2 proficiency	0.78	0.14	0.55 – 1.12	.175
RT difference × Trial type × Age	1.22	0.17	0.93 – 1.59	.152
RT difference × Trial type × Education	0.85	0.15	0.60 – 1.21	.371
Observations	505			
Marginal R^2 / Conditional R^2	0.140 / 0.506			

7. Accuracy cued between- and within-language switching

Generalized linear mixed-effects regression model: accuracy (0/1) predicted by switching (switch/repeat), task (cued/within), aphasia factor, age, education level, L2 proficiency. Random intercepts for participant and item.

	Accuracy			
Predictors	*Odds Ratios*	*St. Error*	*95% CI*	*p-value*
(Intercept)	2.34	0.39	1.69 – 3.26	**<.001**
Task	1.57	0.10	1.39 – 1.78	**<.001**
Trial type	1.09	0.06	0.97 – 1.22	.128
Aphasia Factor	1.21	0.24	0.82 – 1.78	.329
L2 proficiency	1.27	0.27	0.84 – 1.92	.265
Age	1.06	0.16	0.79 – 1.43	.696
Education	0.89	0.21	0.56 – 1.40	.609
Task × Trial type	0.93	0.05	0.83 – 1.04	.189
Task × Aphasia Factor	0.63	0.05	0.55 – 0.73	**<.001**
Task × L2 proficiency	1.37	0.11	1.16 – 1.60	**<.001**
Task × Age	0.94	0.06	0.83 – 1.06	.306
Task × Education	1.42	0.12	1.20 – 1.68	**<.001**
Trial type × Aphasia Factor	1.06	0.07	0.92 – 1.21	.441
Trial type × L2 proficiency	1.10	0.08	0.95 – 1.28	.191
Trial type × Age	1.09	0.06	0.98 – 1.22	.126
Trial type × Education	1.13	0.09	0.96 – 1.33	.129
Task × Trial type × Aphasia Factor	1.10	0.08	0.96 – 1.26	.181
Task × Trial type × L2 proficiency	0.93	0.07	0.80 – 1.07	.311
Task × Trial type × Age	1.00	0.06	0.90 – 1.12	.982
Task × Trial type × Education	0.95	0.08	0.80 – 1.11	.494
Observations	1743			
Marginal R^2 / Conditional R^2	0.112 / 0.223			

8. Reaction times cued between- and within-language switching

Linear mixed-effects regression model: RTs predicted by switching (switch/repeat), task (cued/within), aphasia factor, age, education level, L2 proficiency. Random intercepts for participant and item.

	Reaction Times (log-transformed)			
Predictors	*Estimates*	*St. Error*	*95% CI*	*p-value*
Intercept	7.52	0.03	7.46 – 7.58	**<.001**
Trial type	-0.03	0.01	-0.06 – -0.01	**.007**
Task	-0.10	0.01	-0.13 – -0.08	**<.001**
Aphasia Factor	-0.03	0.04	-0.11 – 0.04	.404
L2 proficiency	-0.04	0.04	-0.12 – 0.04	.323
Age	0.02	0.03	-0.04 – 0.07	.586
Education	0.09	0.04	0.00 – 0.18	**.038**
Trial type × Task	0.01	0.01	-0.02 – 0.03	.474
Trial type × Aphasia Factor	-0.00	0.01	-0.03 – 0.02	.814
Trial type × L2 proficiency	0.00	0.02	-0.03 – 0.03	.933
Trial type × Age	0.01	0.01	-0.01 – 0.04	.313
Trial type × Education	0.01	0.01	-0.02 – 0.04	.446
Task × Aphasia Factor	-0.00	0.02	-0.03 – 0.03	.937
Task × L2 proficiency	0.02	0.02	-0.02 – 0.05	.339
Task × Age	-0.01	0.01	-0.04 – 0.02	.442
Task × Education	-0.01	0.02	-0.04 – 0.02	.353
Trial type × Task × Aphasia Factor	-0.00	0.01	-0.03 – 0.03	.958
Trial type × Task × L2 proficiency	-0.01	0.02	-0.04 – 0.02	.721
Trial type × Task × Age	-0.00	0.01	-0.03 – 0.02	.741
Trial type × Task × Education	-0.00	0.01	-0.03 – 0.03	.905
Observations	1036			
Marginal R^2 / Conditional R^2	0.152 / 0.249			

5

Appendix F. Descriptive statistics for the outcome measures grouped by the experimental conditions

Reaction Times						
Task	*Language*	*Trial Type*	*Mean (ms)*	*SD*	*SE*	*N (trials)*
Single-language naming	L1		1824.35	820.23	41.43	392
	L2		1728.01	692.42	37.39	343
Voluntary switching	L1	Repeat	1604.29	764.71	42.75	320
		Switch	1878.78	898.89	71.97	156
	L2	Repeat	1577.26	644.43	42.68	228
		Switch	1749.72	801.81	65.69	149
Cued between-language switching	L1	Repeat	1790.40	697.56	49.20	201
		Switch	1819.22	702.92	52.25	181
	L2	Repeat	1621.49	639.39	48.90	171
		Switch	1743.72	684.11	52.94	167
Cued within-language switching		Repeat	1969.59	713.99	55.58	165
		Switch	2152.93	873.55	71.09	151

Accuracy						
Task	*Language*	*Trial Type*	*Mean (proportion correct)*	*SD*	*SE*	*N (trials)*
Single-language naming	L1		0.79	0.41	0.02	499
	L2		0.70	0.46	0.02	500
Voluntary switching	L1	Repeat	0.88	0.32	0.02	362
		Switch	0.83	0.38	0.03	189
	L2	Repeat	0.92	0.27	0.02	249
		Switch	0.84	0.37	0.03	180
Cued between-language switching	L1	Repeat	0.82	0.38	0.02	246
		Switch	0.79	0.40	0.03	229
	L2	Repeat	0.70	0.46	0.03	248
		Switch	0.71	0.45	0.03	236
Cued within-language switching		Repeat	0.67	0.47	0.02	396
		Switch	0.60	0.49	0.02	388

6

General discussion

The aim of this dissertation was to investigate the involvement of control in bilingual language use in speakers with and without aphasia. To this end, I assessed self-reports and instances of code-switching in semi-structured interviews (Chapter 2). In addition, I conducted a systematic review of the research literature on this topic (Chapter 3). Finally, I carried out an experimental study that investigated language switching in neurologically healthy bilinguals (Chapter 4) and bilinguals with aphasia (Chapter 5). The combination of these research methods led to new insights into the role of control in bilingual language processing. In the following sections, I briefly summarize the key findings of each chapter. Then it is discussed which of these results can be attributed to control processes. Furthermore, I address the question whether bilingualism should be viewed as a benefit or an additional challenge for individuals with aphasia. The clinical implications of my findings are described at the end of the discussion.

6.1 Summary of the main findings

Chapter 2 reports on semi-structured interviews that were held with bilingual individuals with aphasia. The results highlighted the variability among bilinguals with aphasia, as participants reported diverging experiences regarding the impact of their aphasia on their bilingual language use. Interviewees often noted that they considered their knowledge of multiple languages beneficial in compensating for word-retrieval deficits. However, most participants also indicated experiencing difficulties controlling their languages. These control problems mostly concerned automatic and involuntary co-activation of the two languages, which could result in difficulties separating languages and suppressing the non-target language. I examined instances of code-switching during the interview, which also revealed variability among participants. Most participants showed very few instances of code-switching, and the characteristics of their code-switches generally aligned with the literature on code-switching in neurologically healthy bilinguals. Nonetheless, a small number of participants exhibited more marked code-switching patterns, which were attributed to difficulties in language control and could be interpreted as pathological code-switching.

In **Chapter 3**, I systematically reviewed the existing research literature on the intersection of executive control, bilingualism, and aphasia. The evidence for non-linguistic executive control impairments in bilinguals with aphasia was evaluated, and this showed that the majority of bilinguals with aphasia were reported to have impaired inhibition and shifting abilities, while results for updating varied considerably. Additionally, I reviewed the literature on the associations between impairments in bilingual language control and non-linguistic executive control. The studies that compared tasks measuring bilingual language control and executive control reached contradictory conclusions. However, those reporting bilingual language control impairments expressed in selective recovery of one language or involuntary switching between languages, described concurrent deficits in non-linguistic executive control in most cases. Finally, I evaluated whether bilingualism is associated with enhanced executive control abilities in individuals with aphasia, finding that all included studies provided (some) evidence for better executive control of bilinguals compared to monolinguals.

Chapter 4 describes a series of web-based bilingual picture naming tasks administered to a neurotypical group of late Dutch-English bilinguals. The experiment involved picture naming in separate L1 and L2 blocks, voluntary switching between the L1 and L2, cued switching between the L1 and L2, and cued switching between color and size properties of the depicted object in the L1. The findings showed that when given the choice, the late bilinguals in the study frequently switched between their languages. In addition, the relative ease of lexical access between the L1 and L2 contributed to voluntary language choice. Moreover, I observed significant switch costs in all types of switching, although the magnitude of these costs depended on several factors. First, it was found that switching into the L2 was more costly in cued switching than in voluntary switching, while the opposite was true for the L1. Second, voluntary switch costs were larger for the L1 than the L2, whereas such a difference was not observed for cued switch costs. I explained the difference in voluntary switch costs between the languages by evaluating the individual strategies that participants adopted in this task. This revealed that participants who frequently switched in the voluntary condition experienced smaller switch costs, whereas participants with a clear default language exhibited larger switch costs.

The same experimental paradigm was administered to a group of bilinguals with aphasia, the results of which are presented in **Chapter 5**. Here, the focus was on the question whether voluntarily mixing languages could be considered helpful for bilingual individuals with aphasia. The results showed that the participants frequently switched between their L1 and L2 in the voluntary condition. Perhaps as a result, they made fewer naming errors and became faster at naming the items in voluntary language switching compared to the single-language naming task. It was found that ease of lexical access was related to voluntary language choice. Both voluntary and cued language switching yielded switch costs, but contrary to the predictions, the voluntary switch costs were larger. This effect was explained in terms of lexical retrieval, as it was proposed that bilinguals with aphasia may voluntarily switch when they encounter a word-retrieval problem. This way, the voluntary switch cost also encompasses the failed lexical retrieval process prior to the switch.

6.2 The involvement of control

In this section, I examine the results that indicate the involvement of control in bilingual language processing of speakers with and without aphasia. In doing so, I differentiate between *proactive* and *reactive* control mechanisms (Braver, 2012). Reactive control is transient and recruited after interference has occurred, whereas proactive control involves sustained and anticipatory control of potential interference. Bilingual language control is generally assumed to rely on both mechanisms, with proactive control associated with mixing costs and reactive control with switching costs (e.g., Declerck, 2020; Declerck & Koch, 2023; Ma et al., 2016).

6.2.1 Results indicating the involvement of reactive and proactive control

In mixed language contexts, bilinguals may exert more inhibition on their dominant language compared to their non-dominant language. As a result, performance in the dominant language could fall behind, a phenomenon known as *dominance reversal effects* (e.g., Goldrick & Gollan, 2023). Here, proactive control is hypothesized to be engaged in anticipation of language interference (e.g., Declerck, 2020). In Chapter 4, several results point in the direction of such language dominance reversal effects. First, although all participants were native speakers of Dutch who had acquired English as an L2, many showed a preference for English in the voluntary naming condition. Moreover, participants were overall faster to name items in English compared to Dutch in the cued language switching condition. In single-language naming, these dominance reversal effects started to emerge in later blocks, indicating that participants became slower in naming items in Dutch only after prior exposure to both languages. Such differences in naming latencies between the L1 and L2 were not observed in the voluntary condition. These results can be interpreted in terms of control: reversed language dominance effects were visible in contexts with high control demands (i.e., cued language switching, final two blocks of single-language naming) but not in low control contexts (i.e., voluntary language switching). These results support earlier findings of dominance reversal effects (Verhoef et al., 2009; Christoffels et al., 2007; Peeters & Dijkstra, 2018; Zheng et al., 2020; Costa & Santesteban, 2004), although many other studies did not find these effects (see Declerck & Koch, 2023; Gade et al., 2021; Goldrick & Gollan, 2023, for reviews)

In the results of the bilinguals with aphasia (Chapter 5), a different picture emerges. In voluntary switching, six out of seventeen participants chose to name a majority (≥ 60%) of the items in their L2. This shows that, contrary to the neurotypical bilinguals, relatively few participants adopted the L2 as their default language in the voluntary condition. Furthermore, participants made more errors and were slower in naming items in their L2 than their L1. This pattern aligns with the presumed lexical accessibility of each language (with the dominant L1 being easier to retrieve than the non-dominant L2) but contradicts the dominance reversal effects observed in Chapter 4. This finding is consistent with findings of a case study reported by

Hameau et al. (2022), who also demonstrated better naming performance in the dominant compared to the non-dominant language in a bilingual with aphasia.

Considering that proactive control is hypothesized to be recruited to prevent interference in mixed language contexts, language selection errors could occur when proactive control temporarily falls short (Gollan et al., 2011; Zheng, Roelofs, Farquhar, et al., 2018; Zheng, Roelofs, & Lemhöfer, 2018). The results for the neurologically healthy bilinguals in the current study revealed that they made language selection errors in only 1.3% of the trials in the cued between-language switching condition. For the bilinguals with aphasia, language selection errors were observed in 5.2% of the cued switching trials, and slightly more when switching into the L2 (3.2%) than L1 (2.0%). These language selection errors can potentially be explained by lapses in proactive control, where the interference caused by the task demands could not be solved anticipatorily (Zheng et al., 2020; Zheng, Roelofs, Farquhar, et al., 2018). Importantly, participants provided corrections for their errors in some of their responses. These corrections might indicate that, despite being unable to proactively prevent an error, participants were sometimes able to monitor and initiate a correction of their language output. An investigation of errors and the likelihood of correction attempts is a direction for future research.

In both experimental studies, I observed switch costs in voluntary switching, cued between-language switching, and cued within-language switching, illustrating that the tasks were effective in tapping reactive language control in both populations. Furthermore, I observed asymmetrical voluntary switch costs in the neurotypical group, with larger switch costs into the L1 than the L2. Asymmetrical switch costs are often attributed to inhibitory mechanisms (e.g., Green, 1998; Meuter & Allport, 1999; but see Bobb & Wodniecka, 2013). Since inhibition is believed to be proportional to the level of activation (Green, 1998; Green & Abutalebi, 2013), more inhibition of L1 is required when naming items in the less dominant L2. This makes it challenging to overcome this inhibition upon switching back into the L1, resulting in asymmetrical switch costs. Asymmetrical switch costs are frequently reported in the cued switching tasks with (unbalanced) neurologically healthy bilinguals (e.g., Costa & Santesteban, 2004; Gollan et al., 2014; Meuter & Allport, 1999; Philipp et al., 2007), but their existence is not undisputed (e.g., Christoffels et al., 2007; Declerck et al., 2012). Moreover, evidence for asymmetrical *voluntary* switch costs is scarce, as most studies found symmetrical voluntary switch costs (De Bruin et al., 2018, 2020; Gollan et al., 2014; Gollan & Ferreira, 2009; Grunden et al., 2020; Jevtović et al., 2019), except for Liu et al. (2021). Other studies reported an asymmetry in the opposite direction, with larger costs for switching from L1 to L2 (De Bruin & Xu, 2023; Sánchez et al., 2022).

The lack of empirical evidence for asymmetric voluntary switch costs in previous research, along with my own observation that cued switching did not result in asymmetric switch costs, prompted me to explore other explanations for the observed asymmetry. I proposed that the relative ease of lexical access in either language is a likely alternative explanation for the observed switch costs pattern. In the voluntary switch task, participants seemed to have adopted different strategies for using both languages. The majority switched frequently and showed small switch costs. However, many participants appeared to have taken English as their default language. I suggested that they primarily switched back to their L1 when they encountered difficulty retrieving the lexical item in the L2. This time-consuming retrieval process was subsequently reflected in the voluntary switch costs. I therefore argued that processes related to lexical accessibility, rather than control mechanisms, were responsible for the large voluntary switch costs (see also De Bruin et al., 2018).

In line with these findings for neurologically healthy bilinguals, I observed larger overall voluntary than cued switch costs in the bilinguals with aphasia. Again, I attributed these large switch costs to lexical retrieval difficulties, as the participants may have decided to switch languages when they were unable to retrieve an item in the non-switch language. Correspondingly, ease of lexical access was a solid predictor for voluntary language choice in both studies. Therefore, it was argued that the voluntary switch costs patterns we observed Chapters 4 and 5 likely reflect bottom-up lexical retrieval processes rather than top-down control mechanisms.

6.2.2 Language control impairments in bilinguals with aphasia

Because I did not directly compare the aphasia group with a matched control group, firm conclusions cannot be drawn about the integrity of the language control abilities in bilinguals with aphasia. However, if we examine the qualitative patterns of the performance on the experimental paradigms (Chapters 4 and 5), multiple key findings overlap between the group of bilinguals with aphasia and the neurologically healthy young adults. Both groups experienced switch costs in all switching tasks, ease of lexical access was related to voluntary language choice of both groups, and there were no significant correlations between the switch costs of cued between-language switching and cued within-language switching in either group.

When zooming in, differences start to emerge. Contrary to the neurologically healthy group, I did not find evidence for reversed language dominance effects in the bilinguals with aphasia. Instead, naming speed and accuracy were in line with presumed ease of lexical access, with lower accuracy and speed for items in the non-dominant L2 (see also Hameau et al., 2022). Furthermore, while there was a strong positive correlation between the overall response speed on the cued between-language and within-language switching tasks in the healthy bilinguals, this correlation was weaker and did not reach significance in the bilingual speakers with aphasia. I tentatively explain these diverging findings as an effect of the language impairment rather than problems with control. Larger impairments in the L2 over the L1 in bilinguals with aphasia are frequently reported (see Kuzmina et al., 2019, for a meta-analysis), and the results of Chapter 5 also show that bilingual individuals with aphasia made more errors when naming in their L2 compared to their L1. More severe language impairments in the L2 than the L1 may reduce the likelihood of observing language dominance reversal effects. In addition, the severity of the language impairment could explain the absence of statistical evidence for an association between the naming latencies of the between-language and the within-language switching tasks. The within-language switching task required participants to produce more complex noun phrases, which is likely to be negatively impacted by aphasia severity more strongly than bare picture naming. Thus, the presence of a language impairment may have resulted in some qualitative differences between neurotypical bilinguals and bilinguals with aphasia. Importantly, I did not find evidence for reduced performance by the bilinguals with aphasia that can be reliably attributed to language control impairments specifically.

That said, several individuals with aphasia reported difficulties in controlling their languages during the interview. These difficulties resulted in atypical code-switching patterns in some cases, but most interviewees showed code-switches with similar form and function as known from the literature on neurologically healthy bilinguals (e.g., Muysken, 2000; Poplack, 1980). These results contrast with various case studies reporting pathological switching in bilinguals with aphasia (Abutalebi et al., 2000; Ansaldo et al., 2010; Calabria et al., 2014; Fabbro, 2000; Kong et al., 2014; Leemann et al., 2007; Mariën et al., 2017), but align with other studies reporting no evidence for pragmatically inappropriate code-switching in individuals with aphasia (Chengappa et al., 2004; Goral et al., 2019; Paplikar, 2016; Riccardi, 2004). In summary, while it should be noted that I did not directly compare bilinguals with aphasia to neurotypical bilinguals, I conclude that control impairments in bilinguals with aphasia may exist, although the presence of such impairments may be restricted to a relatively small group.

6.2.3 Domain generality of bilingual language control

One of the initial research goals of this project was to investigate the domain generality of bilingual language control (dis)abilities of individuals with aphasia. Therefore, one of the questions addressed in the systematic review concerned the evidence for domain-general control impairments in persons with aphasia. The literature including experimental investigations yielded inconclusive results, but it appeared that bilinguals with aphasia who showed selective recovery of one language, unintended code-switching between languages, or absence of cross-language therapy generalization – all hypothesized to be related to bilingual language control – (Green & Abutalebi, 2008), almost always showed concurrent non-linguistic executive control deficits (Adrover-Roig et al., 2011; Kong et al., 2014; Lee et al., 2016; Leemann et al., 2007; Mariën et al., 2017; Van der Linden, Dricot, et al., 2018; Van der Linden, Verreyt, et al., 2018; Verreyt et al., 2013). This provides (circumstantial) evidence for a relationship between bilingual language control and nonverbal executive control.

In the empirical chapters (Chapters 2, 4, and 5), the question of domain generality of bilingual language control was also addressed. Importantly, I had to limit my comparison to the language domain, a methodological decision that was made because of practical reasons[9], which prevents drawing any conclusions about the overlap between bilingual language control and *non*-linguistic executive control abilities. At the same time, the overlap of bilingual language control abilities with other types of language control (i.e., outside the bilingual domain), could still be examined. In the interviews, I explored the generality of bilingual language control impairments in two bilingual individuals with aphasia who reported diverging experiences with language control. One participant encountered no difficulties controlling his languages, while the other reported that his L2 automatically surfaced when trying to speak in his L1. Their self-reports appeared consistent with their code-switching patterns. However, the participants did not demonstrate clear differences in their ability to initiate conversational repair, which was considered an indicator of more general (language) control capabilities. Although exploratory, this might suggest that problems with bilingual language control do not necessarily coincide with difficulties in other forms of language control.

The extent to which bilingual language control was related to more general language control, was further investigated in the experiments involving neurologically healthy bilinguals (Chapter 4) and bilinguals with aphasia (Chapter 5). This was done by comparing their performance in picture naming tasks that required participants to switch between their languages, and within their first language between different types of noun phrases (based on Sikora et al., 2019; Sikora, Roelofs, Hermans, et al., 2016; Sikora & Roelofs, 2018). The switch costs on the two tasks were not significantly correlated, neither in the neurotypical group nor in the aphasia group. These findings seemingly contradict a more domain-general foundation for bilingual language switching. However, it is risky to draw conclusions based on null results, as the absence of significant correlations between the tasks could also be explained by factors such as differences in task complexity (especially for the aphasia group), limited sample sizes, and the fact that difference scores are inherently noisy (e.g., Draheim et al., 2019; Segal et al., 2021). Additionally, because all the domain-generality of language switching was only investigated within the linguistic domain, the overlap with non-linguistic switching abilities should be further explored in future research.

6.3 Bilingualism in aphasia: A help or a hindrance?

The second question addressed here, is whether a command of multiple languages should be considered beneficial for individuals with aphasia. The systematic review of the literature

9 Due to the COVID-19 pandemic, data collection took place in a web-based setting. For that reason, only verbal responses were collected.

showed that all included studies reported evidence that bilinguals with aphasia outperformed monolinguals on various nonverbal executive control tasks. More specifically, several large-scale studies indicated that, despite a comparable incidence of aphasia following stroke, bilinguals exhibited more favorable cognitive outcome after stroke compared to monolinguals (Alladi et al., 2016; Paplikar, Alladi, et al., 2018). More recently, two studies reported that the initial aphasia severity of bilinguals was lower than that of monolinguals, and that bilingualism was found to have a favorable effect on aphasia recovery (Ardila et al., 2021; Lahiri et al., 2020). The results based on large groups are promising, and add to the evidence that bilingualism may be one of the factors that offer a protective effect for neurological damage or decline (see Antoniou & Wright, 2017; Bialystok, 2021; Calvo et al., 2016; A. Grant et al., 2014; Guzmán-Vélez & Tranel, 2015; Van den Noort, Vermeire, et al., 2019, for reviews).

Another line of research aims to pinpoint the specific executive control domains that may be positively impacted by bilingualism. This is a highly-researched topic in the literature on neurologically healthy bilinguals (for reviews: Adesope et al., 2010; De Bruin et al., 2015; Donnelly, 2016; Hilchey & Klein, 2011; Lehtonen et al., 2018; Paap et al., 2015; Van den Noort, Struys, et al., 2019; Ware et al., 2020), but has also been examined in bilinguals with aphasia. The review of the literature showed that some, but not all, bilinguals with aphasia may outperform monolinguals on measures of inhibitory control (Dekhtyar et al., 2020; Faroqi-Shah et al., 2018) and attention (Dash et al., 2020).

The review thus examined the evidence for bilingual advantages for aphasia severity, cognitive outcome after stroke, and executive control. Importantly, bilingualism yields another obvious advantage: the ability to express oneself in more than one language. As such, bilingualism provides a means to convey an idea in multiple ways. Given that individuals with aphasia have impairments in the abilities necessary for language processing, knowledge of an additional language may offer an opportunity to compensate for these communicative difficulties. In Chapter 2, I explored whether bilingual knowledge could be recruited to enhance verbal effectiveness. It was found that the interviewees often reported that they could use their knowledge of another language to compensate for a word-retrieval deficit. These self-reports were supported by instances of code-switching that appeared to serve a self-cueing strategy. This indicates that not all language switching in this population is a marker of pathological behavior, and that many of the code-switches may fulfill a compensatory goal (Bihovsky et al., 2023; Chen, 2018; Goral et al., 2019; Hameau et al., 2022; Lerman et al., 2019; Muñoz et al., 1999; Paplikar, 2016).

The results of the language switching study in Chapter 5 further support these findings. I found that relative ease of lexical access of words in the L1 and L2 contributed to voluntary language choice. Specifically, when items were easier to retrieve in one language, participants were inclined to choose that language to name an item when both languages were equally appropriate. Such an effect of lexical accessibility on voluntary language choice was also observed in the neurotypical group in Chapter 4, as well as in previous research (De Bruin et al., 2018; Sarkis & Montag, 2021). This suggests that bilinguals with (and without) aphasia encounter differences in ease of lexical access between their languages, and that these differences may contribute to language choice.

As a consequence, language production may be more efficient in contexts where both languages are equally appropriate. I observed that participants with aphasia were quicker and made fewer errors in the voluntary switching condition compared to the conditions in which the target language was predetermined by the context. Similar voluntary mixing benefits have been reported in the literature involving neurologically healthy bilinguals (De Bruin et al., 2018, 2020; De Bruin & Xu, 2023; Gollan & Ferreira, 2009; Jevtović et al., 2019). This indicates that less restrictive language contexts may result in more productive or efficient language output by bilinguals with and without aphasia (cf. Paplikar, 2016). Whether this is due to decreased language demands (when the less dominant language can be avoided) or decreased control demands (when language choice does not need to be restricted or monitored) remains an open question.

The outcomes provide evidence that bilingual language knowledge *can* be harnessed to enhance communicative effectiveness. However, the effectiveness of code-switching as a word-retrieval strategy crucially depends on the language knowledge and background of a bilingual speaker, and whether languages are shared between interlocutors. Another point to note is the interindividual variability of bilinguals with aphasia, as demonstrated in the interviews. Whether a speaker can successfully employ their bilingual knowledge to their advantage depends on their language impairments, control difficulties, and the context.

6.4 Clinical implications

Based on the results reported on in this dissertation, I have argued that in certain contexts, bilingualism can be employed to improve verbal effectiveness of persons with aphasia. These findings hold potential clinical implications for clinical practice, and approaching bilingualism as a potential compensatory source for communicative effectiveness could be a starting point for therapy. It is important to bear in mind that bilingualism, irrespective of aphasia, may negatively affect lexical access in one language, for example leading to less accurate or slower picture naming in each language separately (Bialystok, 2009; Gollan et al., 2005; Roberts et al., 2002). However, I also found that free language choice may eliminate disadvantages or even turn into a benefit. These results align with the concept of 'translanguaging', which posits that bilingual individuals flexibly draw upon their entire linguistic repertoire for effective communication (Vogel & García, 2017; Wei & García, 2014). Correspondingly, Gollan et al. (2007) observed that neurologically healthy aging bilinguals benefitted from the option to choose the language that first came to mind in naming the items of the Boston Naming Test (Kaplan et al., 2001). Consequently, bilinguals with aphasia are likely to score higher on communicative measures when their output in either language is considered correct (Lerman et al., 2020). Therefore, the specific instructions of a naming task administered during treatment can be tailored based on the objectives of the clinical assessment (i.e., to differentiate the naming abilities in each language separately, or estimating word retrieval abilities in *any* language).

In the current research, I obtained no evidence to suggest that language switching should be discouraged in clinical practice. Indeed, depending on the pragmatic contexts, language mixing can be encouraged to enhance communicative effectiveness. If a bilingual individual frequently interacts in a context where both languages are understood by the interlocutors, code-switching may be an effective strategy to compensate for word-finding difficulties (Lerman et al., 2020; Goral et al., 2019; Fyndanis & Lehtonen, 2022). Moreover, I follow Hameau et al.'s (2022) proposal that code-switching may even be useful in situations where not all languages are shared. Code-switching to a language that is not shared with the interlocutor has often been considered "pathological code-switching", and could indicate a loss of control (e.g., Abutalebi et al., 2000; Ansaldo et al., 2008). However, when a bilingual with aphasia encounters a lexical retrieval deficit, switching to the other language may provide a way to self-cue and indirectly retrieve the target word in the intended language, even if their interlocutor does not speak that language. The current results provide a first indication, although the effectiveness of promoting or explicitly training language mixing to enhance communicative effectiveness through self-cueing needs to be examined in future research.

Many of the results obtained in this dissertation have suggested the involvement of control in bilingual language processing of individuals with aphasia. Processes of activation and inhibition have been proposed to play a role in assessment, treatment, and recovery of bilinguals with aphasia (e.g., Ansaldo et al., 2010; Goral & Lerman, 2020; Green & Abutalebi, 2008). For example, selective recovery of one of the languages is sometimes explained in terms of control impairments, making one of the languages temporarily inaccessible due to (over) inhibition of that language (Green & Abutalebi, 2008; Paradis, 1998; Pitres, 1895). Furthermore, executive control is important for new, complex and goal-directed behavior and as such, it is important for compensating for language impairments or facilitating therapy generalization (Helm-Estabrooks, 2002; Keil & Kaszniak, 2002). Consequently, executive control abilities have been found to enable learning and generalization of treatment in monolinguals (e.g., Fillingham et al., 2006; Lambon Ralph et al., 2010; Simic et al., 2019, 2020) and bilinguals with aphasia (Abutalebi et al., 2009; Radman et al., 2016).

Notably, it is not always feasible to provide treatment in the language of choice, let alone in both languages. This makes cross-language generalization effects an important outcome for treatment of bilinguals with aphasia. Fortunately, there is considerable evidence for the existence of such effects (see Faroqi-Shah et al., 2010; Goral et al., 2023; Kohnert, 2009, for reviews). However, intact control abilities have been postulated as a necessary condition for cross-language generalization effects. For cross-language generalization to occur, activation needs to spread from the treated to the untreated language, and appropriate levels of inhibition must be applied to the right language (Goral & Lerman, 2020; Kiran et al., 2013).

If control processes are important for recovery of two languages, the question arises whether training control abilities could lead to better recovery of both languages. Kiran and Gray (2018) posited that a combined treatment targeting executive control and language might yield positive outcomes for language control of bilinguals with aphasia, although there is currently no empirical evidence to support this proposal. However, there is first evidence from the literature on monolingual individuals with aphasia that could suggest a beneficial effect of interventions targeting nonverbal executive control abilities. For instance, training of cognitive flexibility in a conversation was found to enhance language and communication abilities (Spitzer et al., 2021). Additionally, nonverbal computer-assisted executive control training combined with speech and language therapy resulted in improvements for language outcomes of individuals with aphasia (M. Liu et al., 2022). While these results are tentative and require further substantiation in clinical settings, they could serve as a starting point for investigating the potential effectiveness of integrating executive control training in the treatment of bilingual individuals with aphasia.

6.5 Conclusions

Bilingual speakers cannot simply "switch off" one of their languages. When speaking in the second language, the first language always lingers subtly in the background. This requires bilinguals to exert control over their languages, allowing them to suppress the irrelevant language, reactivate it when needed, or to switch languages as desired. Given that individuals with aphasia often suffer from control impairments alongside their language difficulties, the knowledge of an additional language could potentially entail an extra demand on their cognitive abilities. Conversely, they may also experience benefits from their bilingualism: Lifelong practice with bilingual language control might result in enhanced control skills, and being able to rely on an additional language could be helpful when the other language is momentarily inaccessible.

Throughout this dissertation, the involvement of control in bilingual language processing was examined in various ways. The findings elucidated the control processes implicated in switching between languages by individuals with and without aphasia. In addition to top-down control, it was demonstrated that bottom-up lexical accessibility plays a key role in voluntary switching and language choice, particularly for persons with aphasia. Although individuals with aphasia may experience difficulties controlling their languages, their bilingual knowledge can also be harnessed to their advantage. Language switching can be used as a compensation for lexical access difficulties and may increase verbal output and enhance the efficiency of naming abilities. Consequently, the advantages of bilingual language knowledge for individuals with aphasia should not be overlooked.

References

Research data management

Author contributions

Summary in English

Nederlandse samenvatting

Acknowledgments

About the author

List of publications

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Research data management

Use of existing datasets

The research as described in this dissertation did not make use of existing datasets.

Creation of new datasets

Data were collected for Chapters 2, 4, and 5.

Chapter 2: Interviews

In this chapter, web-based interviews were conducted. This resulted in the following data: Personal data: names and contact information to schedule the interview appointment and to keep participants informed about the outcomes or future projects (if granted permission). This is *critical* data.

- Demographic variables: age (in years and months), level of education, and sex. These data can count as *standard*.
- Clinical variables, such as time post-onset, extent and location of lesion, potential co-morbidity. These data are considered *sensitive personal data*.
- Video/audio recordings of the interview. These data should be considered *critical* and *sensitive personal data*.
- Annotations of the recorded interview. Although all directly identifying information such as names or places were removed, the contents of the interviews may contain facts that allow for identification of the interviewee. Therefore, it should be considered *critical* data.

Chapter 4: Web-based experiments with healthy bilinguals

Forty neurologically healthy individuals participated in a web-based language switching study. For this study, we collected the following data:

Personal data: names and contact information of the participants, necessary to schedule the experiment. This is *critical* data.

- Demographic variables: age (in years and months), country of origin, and sex. When sufficiently anonymized and coded, these data can count as *standard*.
- Questionnaire results: information about the language background. These are *standard* data.
- Test scores (i.e., experimental outcome), consisting of scores on a language test, answers on the naming tasks, numerical values for accuracy and reaction times. These are *standard* data.
- Audio recordings of the experimental procedure, which were necessary for data processing. The audio recordings fall in the category of *critical* data.

- Annotations of the relevant parts of the audio recordings (i.e., the answers on the experimental tasks). Because these do not include identifying information, it should be considered *standard* data.

Chapter 5: Web-based experiments with bilinguals with aphasia
In this chapter, the same experimental procedure as in Chapter 4 was administered to a group of bilingual speakers with aphasia. This resulted in the following dataset:

- Personal data: names and contact information to schedule the experiment appointment and to keep participants informed about the outcomes or future projects (if granted permission). This is *critical* data.
- Demographic variables: age (in years and months), level of education, and sex. These data can count as *standard*.
- Clinical variables, such as time post-onset, extent and location of lesion, potential co-morbidity. As these are medical details, these data are *sensitive personal* data.
- Test scores (i.e., experimental outcome), consisting of scores on the Amsterdam-Nijmegen Everyday Language Test (ANELT), answers on the naming tasks, numerical values for accuracy, and reaction times. These are *standard* data.
- Video/audio recordings of the experimental procedure, necessary for data processing. The video/audio recordings fall in the category of *critical* data.
- Annotations of the relevant parts of the video/audio recordings (i.e., the answers on the experimental tasks, the ANELT, and any other relevant comments made during the interview). Because these do not include identifying information, it should be considered *standard* data.

Personal data and privacy
As described above, personal and critical data (i.e., data that enables identification of an individual) were collected in Chapters 2, 4, and 5. Contact information was necessary to collect to keep the participant informed about ongoing and potential future studies (if granted permission to approach them for future studies) or schedule an appointment for the experiment. The clinical variables were collected because these were expected to have an influence on the experimental results. The video and/or audio recordings were necessary to assess the functional communication abilities (Chapter 2 and 5) or to annotate and process the data (Chapter 4 and 5). The critical data will be retained for minimally ten years, in line with the university's policy.

Security of critical data
The data were collected outside the university facilities but on a Radboud University (RU) laptop. The data were always stored in RU folders. A RU file folder was created to share the

data with (only) the supervisors of the project. These file folders are automatically backed-up. The data were collected using BigBlueButton or Zoom, and the Ethics Assessment Committee Humanities approved both collection methods. Importantly, a RU licensed version of Zoom was used, such that the default privacy and security settings were optimal.

Privacy of critical data

The personal data (names and contact information) were separated from the research data and stored in a separate password protected table with pseudonymization keys to link the identifying information to the research data. Both files were stored separately in the RU file folder. Audio and video data could not be anonymized, because the voice and pictures contain identifying information. Participants have given explicit consent to collect these data. Participants had the option to approve the use of these video and/or audio files for educational purposes. In the transcripts of the interviews and the annotation of the experiments, all identifying information was removed.

Ethics assessment

Before assessment by the Ethics Assessment Committee Humanities, a preapplication was submitted to the Medical Ethics Assessment Committee, who decided that the research was not subject to the "Medical Research Involving Human Subjects Act" (*Wet medisch-wetenschappelijk onderzoek met mensen, WMO*). The research project was subsequently assessed and approved by the Ethics Assessment Committee Humanities under ETC-GW 2019-5035 on 26-09-2019. A first amendment, regarding web-based data collection in healthy bilinguals, was approved on 08-07-2020. The second amendment, regarding the web-based interview, was approved on 21-09-2020. A third amendment, regarding web-based data collection in bilinguals with aphasia, was approved on 30-03-2021. The data collection required the informed consent of participants. The standard informed consent procedure as specified by the Centre for Language Studies Lab was followed, and informed consent was obtained digitally.

Data storage and accessibility

In accordance with the university's policy on research data management, the data will be archived for at least ten years for reasons of scientific integrity, together with their accompanying metadata and documentation necessary to understand the data. The data are stored in RU file folders, which are safe and automatically backed up. The first author of each chapter was responsible for archiving the data.

During research, the data were shared with the supervisors of the research project, who had access to the data via the RU file folders. Four research assistants had temporary and restricted access to the data, necessary for their research activities. After completion of the research project, an anonymized dataset of Chapter 4 was made openly accessible and published on the Open Science Framework (OSF) under the CC-BY license: https://osf.io/gd2wv/. The data in Chapters 2 and 5 will only be reused for future research on the topic of bilingualism and cognition by the researchers who were involved in the current research project and only if the participant agreed to this. Because of the vulnerability of the participant group, the data will not be shared with researchers outside the project group.

Author contributions

Chapter 1 and 6
Saskia Mooijman (SM) wrote these chapters and revised them based on feedback provided by Ardi Roelofs (AR), Marina Ruiter (MR), and Rob Schoonen (RS).

Chapter 2 is a slightly modified version of an article submitted for publication: Mooijman, S., Schoonen, R., Goral, M., Roelofs, A., & Ruiter, M. B. (*submitted*). Why do bilingual speakers with aphasia alternate between languages? A study into their experiences and mixing patterns.

The study was designed by SM in collaboration with AR, MR, and RS. SM recruited the participants and collected the data. The interviews were partially transcribed by student-assistant Elynn Vollebregt, SM transcribed the remaining interviews. The data were re-coded by student-assistants Annemarie Bijnens and Geanne Hardeman. Data analysis was performed by SM and supervised by AR, MR, and RS, with valuable feedback provided by Mira Goral (MG). SM and MR evaluated the aphasia characteristics of the participants. SM is the lead author of this chapter, and AR, MG, MR, and RS provided multiple rounds of feedback.

Chapter 3 is a slightly modified version of a published article, with only minor formatting changes: Mooijman, S., Schoonen, R., Roelofs, A., & Ruiter, M.B. (2022). Executive control in bilingual aphasia: A systematic review. *Bilingualism: Language and Cognition, 15*(1), 13–28. https://doi.org/10.1017/S136672892100047X

The study was designed by SM, in collaboration with AR, MR, and RS. SM conducted the literature search and assessed the articles for eligibility. SM is the lead author of this manuscript, and AR, MR, and RS provided multiple rounds of feedback. The manuscript was subsequently submitted for publication as research article, and further revised based on feedback from reviewers. These revisions were discussed with AR, MR, and RS, and implemented by SM.

Chapter 4 is a slightly modified version of a published article, with only minor formatting changes: Mooijman, S., Schoonen, R., Ruiter, M.B., & Roelofs, A. (2023). Voluntary and cued language switching in late bilingual speakers. *Bilingualism: Language and Cognition*. Advance online publication. https://doi.org/10.1017/S1366728923000755

The study was designed by SM, in collaboration with AR, MR, and RS. SM recruited the participants and collected the data. Data were annotated by student-assistant Rivka van den Berg and partially re-coded by SM. Data analysis was performed by SM and supervised by AR, MR, and RS. SM is the lead author of this manuscript, and AR, MR, and RS provided multiple rounds of feedback. The manuscript was subsequently submitted for publication as research article, and further revised based on feedback from reviewers. These revisions were discussed with AR, MR, and RS, and implemented by SM.

Chapter 5 is a slightly modified version of a published article, with only minor formatting changes: Mooijman, S., Schoonen, R., Roelofs, A., & Ruiter, M.B. (2024). Benefits of free language choice in bilingual individuals with aphasia. *Aphasiology*. Advance online publication. http://dx.doi.org/10.1080/02687038.2024.2326239

The study was designed by SM, in collaboration with AR, MR, and RS. SM recruited the participants and collected the data. The data were annotated, coded, and analyzed by SM, under supervision of AR, MR, and RS. SM and MR evaluated the aphasia characteristics of the participants. SM is the lead author of this manuscript, and AR, MR, and RS provided multiple rounds of feedback. The manuscript was subsequently submitted for publication as research article, and further revised based on feedback from reviewers. These revisions were discussed with AR, MR, and RS, and implemented by SM.

Summary in English

Speaking and managing multiple languages requires continuous monitoring of those languages, being able to suppress one language, and switching between languages. All these abilities involve executive control, higher-order cognitive functions that are necessary for complex and goal-directed behavior. Persons with aphasia may have deficits in executive control. In these cases, being bilingual could pose additional demands that are difficult to meet. At the same time, having knowledge of multiple languages might provide a way to compensate for difficulties in one language, as experienced by individuals with aphasia. The aim of this dissertation was to investigate the involvement of control in bilingual language use in speakers with and without aphasia.

Chapter 2 reports on the experiences of bilinguals with aphasia, which were discussed in semi-structured interviews. Their reports showed that participants often experienced difficulties controlling their languages, which could concern unintentional mixing of languages, difficulties separating languages, or problems suppressing the non-target language. The study also looked at instances of language switching during interviews. This showed that most participants adhered to the language context of the interview and rarely switched to another language. When they did switch, their switching patterns often resembled those seen in neurotypical bilinguals. A small number of participants displayed more marked language switching patterns, which were argued to be related to control difficulties.

In **Chapter 3**, the existing research on executive control, bilingualism, and aphasia was reviewed. This showed that the impairments of bilinguals with aphasia were not limited to the language domain, and that non-linguistic executive control impairments were often observed. The overlap between non-language and language control deficits was also investigated, but these results proved to be mixed. However, bilinguals with aphasia who experience problems in everyday language control, such as involuntary language mixing, often experience non-language control impairments too. Finally, all studies published at that point reported some evidence for enhanced control abilities in bilinguals compared to monolinguals.

Chapter 4 reports on a series of picture naming tasks conducted with neurotypical bilinguals. The study involved naming in the first and second language separately, voluntary and cued language switching, and cued switching between different properties of the depicted objects. The findings revealed that late bilinguals frequently switched between languages, and that the ease of accessing words influenced their language choice. Switch costs were observed in all types of switching, with differences in costs based on factors like switching direction and individual strategies. Participants with a clear default language showed larger switch costs

in voluntary switching, while speakers who frequently switched between their languages experienced relatively small switch costs.

In **Chapter 5**, the same tasks as used in Chapter 4 were administered to bilinguals with aphasia. The focus was on the question whether voluntarily mixing languages could be beneficial for individuals with aphasia. The results revealed that the participants often mixed their languages when both were appropriate in the context. Freely mixing languages resulted in higher efficiency of picture naming. In addition, the ease of accessing words was related to language choice, such that participants tended to switch when they had difficulties finding a word in one language. However, voluntary language switching came at a relatively high cost. These large voluntary switch costs were attributed to lexical retrieval processes, where bilinguals may decide to switch upon facing a word-retrieval problem.

The results in this dissertation clarified how bilinguals, both with and without aphasia, exert control over their languages. Besides top-down control, the ease of accessing words also plays a role, especially for individuals with aphasia. Lexical accessibility may influence language choice when both languages are equally appropriate. Despite potential challenges with language control, individuals with aphasia can still benefit from their knowledge of multiple languages.

Nederlandse samenvatting

Het spreken van meer dan één taal vergt continue monitoring van de talen, het onderdrukken van de irrelevante taal en het kunnen schakelen tussen talen. Deze vaardigheden doen een beroep op de zogenaamde executieve controlefuncties van een tweetalige spreker. Dit zijn cognitieve functies die belangrijk zijn voor het plannen en het uitvoeren van complex of nieuw gedrag. Door bijkomende stoornissen in het executief functioneren zou dit een extra belasting kunnen betekenen voor meertalige personen met afasie. Personen met afasie kunnen hun kennis van een tweede taal echter ook inzetten als compensatie voor woordvindstoornissen die ze ondervinden in de eerste taal. In deze dissertatie is de rol van taalcontrole onderzocht in het tweetalige taalgebruik van sprekers met en zonder afasie.

Hoofdstuk 2 rapporteert over de ervaringen van tweetalige personen met afasie die besproken werden in interviews. De deelnemers, allen twee- of meertalige sprekers met afasie, rapporteerden problemen met taalcontrole, zoals onvrijwillig wisselen tussen talen, moeite met het uit elkaar houden van talen, of problemen met het onderdrukken van de niet-doeltaal. Daarnaast werd onderzocht of deze participanten tussen hun talen wisselden tijdens de interviews. Daaruit bleek dat veel deelnemers zich hielden aan de taalcontext van het interview en zelden overschakelden naar een andere taal. Wanneer ze dat wel deden, leek de manier waarop ze wisselden tussen hun talen doorgaans op die van tweetalige sprekers zonder afasie. Een klein aantal deelnemers vertoonde een meer afwijkende manier van wisselen, wat werd verklaard door problemen met taalcontrole.

In **Hoofdstuk 3** werd het bestaande onderzoek naar de interactie tussen executieve controle, tweetaligheid en afasie besproken middels een review van de literatuur. Daaruit kwam naar voren dat de stoornissen van tweetalige personen met afasie niet beperkt zijn tot het talige domein, maar dat niet-talige executieve controleproblemen vaak worden geobserveerd. De overlap tussen niet-talige en talige controleproblemen werd ook onderzocht, maar deze resultaten bleken niet eenduidig. Echter, als personen met afasie problemen ervaren in dagelijkse taalcontrole, zoals onvrijwillig wisselen tussen hun talen, vertonen ze vaak ook niet-talige controleproblemen. Tenslotte gaven alle tot dan toe gepubliceerde studies enig bewijs voor verbeterde controlevaardigheden bij tweetalige in vergelijking met ééntalige sprekers met afasie.

Hoofdstuk 4 bespreekt de resultaten van een reeks benoemtaken afgenomen bij gezonde tweetalige sprekers. Eerst benoemden de participanten afbeeldingen apart in hun eerste en tweede taal, daarna terwijl ze vrijwillig mochten wisselen tussen hun talen, vervolgens wisselden ze tussen hun talen afhankelijk van een teken en tot slot wisselden ze tussen het benoemen van de kleur en grootte van het afgebeelde object. De resultaten laten zien dat, als deelnemers de vrije keuze hadden, ze er vaak voor kozen om te wisselen tussen hun talen. Hoe gemakkelijk een woord toegankelijk was in één van beide talen, was van invloed voor hun taalkeuze. Het wisselen kostte moeite bij alle wisseltaken, waarbij de hoeveelheid moeite werd beïnvloed door factoren zoals de richting waarin gewisseld werd en de strategieën die participanten hadden. Zo ondervonden deelnemers met een duidelijke voorkeur voor een taal meer moeite met het vrijwillig wisselen dan participanten die vaak schakelden tussen hun talen.

In **Hoofdstuk 5** werden dezelfde taken als in Hoofdstuk 4 afgenomen bij tweetalige personen met afasie. De focus lag op de vraag of vrijwillig wisselen tussen talen nuttig kon zijn voor personen met afasie. De resultaten lieten zien dat de participanten vaak schakelden tussen hun talen als de context dat toeliet. Bovendien konden deelnemers afbeeldingen sneller en met minder fouten benoemen als ze vrij mochten wisselen. Hoe makkelijk woorden toegankelijk waren in een taal was van invloed op de taalkeuze, waarbij participanten naar de andere taal overschakelden als ze moeite hadden met het ophalen van een woord. Tegelijkertijd ging het vrije wisselen gepaard met relatief hoge wisselkosten. Deze kosten werden verklaard door de tijd die het kost om woorden uit het mentale woordenboek op te halen.

De resultaten in deze dissertatie geven meer informatie over hoe tweetaligen met en zonder afasie controle uitoefenen over hun talen. Naast de controleprocessen speelt het ook een rol hoe toegankelijk een woord is in één van de talen, zeker voor personen met afasie. In situaties waarin beide talen even geschikt zijn, kan deze toegang tot de woordenschat de taalkeuze beïnvloeden. Ondanks mogelijke extra uitdagingen die bestaan bij het beheersen van meerdere talen, kunnen personen met afasie ook profiteren van hun meertalige kennis.

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About the author

Saskia Mooijman was born in 1992 in Alphen aan den Rijn (the Netherlands). She graduated cum laude from the University of Groningen in 2015, completing bachelor's degrees in Linguistics and Communication and Information Studies. After a gap year, Saskia continued with a Research Master Linguistics at the University of Amsterdam, which she completed in 2018 (cum laude). During her studies, she spent a semester at Queen's University in Kingston (Canada), did an internship at Stellenbosch University (South Africa), and held various student-assistant positions. Upon finishing her master, Saskia began her doctoral research at the Centre for Language Studies of the Radboud University in Nijmegen, resulting in this dissertation. During this PhD project, she presented her research at various (inter)national conferences and conducted research visits to Boston University and the City University of New York. Alongside her PhD research, Saskia held a part-time position as a clinical linguist and researcher at the Department of Neurosurgery of the Erasmus University Medical Center in Rotterdam. After completing her PhD, Saskia took a break to hike the Fisherman's Trail and Camino Portugues. Currently, she works as a researcher in the Multilingualism and Education research group at HU University of Applied Sciences Utrecht.

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