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A Case Study Investigating Executive Control Impairment in Fluent Bilingual Aphasia

The current literature on bilingual aphasia is limited, especially in investigating non-linguistic executive control (EC) impairment. Most studies suggest an EC deficit in bilingual aphasics known as bilingual People With Aphasia (bPWA). We used both linguistic and neuropsychological assessments, including the Bilingual Aphasia Test, Boston Naming Test, Rey Complex Figure B Test, Verbal Working Memory Test, and a Visual Working Memory Test, to evaluate EC impairments and to examine comprehension, fluency, and naming. We examined two bilingual (L1 Croatian- L2 Hungarian) post-stroke aphasics, both females over 70 years of age. They were diagnosed with anomic aphasia in the chronic phase. We compared their performance with a reference group consisting of 11 neurologically healthy elderly Croatian-Hungarian bilinguals. All participants were tested individually in several sessions. The results suggest moderate impairment in fluency and naming and mild impairment in working memory of the bPWA patients investigated. This study highlights the importance of investigating executive control deficits and their potential association with language performance in bPWA. These findings contribute to our understanding of the less explored domain of executive control in bilingual individuals with aphasia.

Keywords: bilingual aphasia, executive control, working memory, anomia, fluency

1. Introduction

The study of bilingualism has been a significant topic of interest in recent years, particularly in the field of language skills and disorders. Aphasia is a language disorder that impairs the individual's performance in many areas including understanding or producing intelligible speech and grammatical sentences, all due to brain damage. Brain incidents causing aphasia in bilingual individuals may present unique challenges in terms of language impairment and recovery. Although investigations of impaired executive control in bilingual aphasics emerged in the late 1990s and continued in the 2000s (Gitterman et al., 2012), the current data available in the literature is still limited, especially on anomia and working memory.

1.1. Aphasia

When defining aphasia, it is important to consider four factors: neurogenic and acquired nature, its impact on language, and the exclusion of general sensory and mental deficits. Neurogenic aphasia always results from brain damage, which can be caused by stroke, head injury, surgical removal of brain tissue, brain tumour, or infection (Goetz, 2007). Acquired aphasia is not a developmental disorder; it is not congenital. Rather, it is characterised by the partial or complete loss of language functions in an individual who had previously developed some language ability. Aphasia predominantly affects language functions and is often described as a disorder of symbolic processing, with difficulties in both producing and interpreting linguistic symbols. It can impact all forms of symbolic communication, including speaking, listening, reading, writing, and sign language. More importantly, aphasia is not associated with sensory, motor, or intellectual problems. These characteristics are crucial in distinguishing aphasia from other neurogenic disorders that affect language, speech, cognition, movement, and perception (Chapey, 2008). There are two post-stroke aphasia subtypes classified by the multidimensional view: fluent (Wernicke's, conduction, transcortical sensory and anomic) and non-fluent (Broca's, global, transcortical motor). Fluent aphasia is a condition where the ability to comprehend spoken words is impaired, while the ability to produce connected speech remains relatively unaffected. Non-fluent aphasia is a condition in which language production is severely impaired, while comprehension of spoken words remains relatively intact (Pléh & Lukács, 2014). The main characteristics of aphasia subtypes are presented in Table 1.

Table 1. Main characteristics of aphasia subtypes

Aphasia type	Speech	Comprehension	Repetition	Naming
Wernicke's	fluent speech without much meaning	poor	poor	poor
Conduction	fluent	good	poor	poor
Transcortical sensory	fluent	poor	good	poor
Anomic	fluent with circumlocutions	good	good	poor
Broca's	poor	good	poor	poor
Global	extremely poor	poor	poor	poor
Transcortical motor	little	good	good	poor

Anomic aphasia is regarded as the mildest and the most controversial aphasia subtype. Its status as a reliable syndrome of aphasia is disputed due to high variability in associated lesion sites (Fridriksson et al., 2018). Some frequently cited sites of lesions include the angular gyrus and the second temporal gyrus (Hedge, 2024). Anomia is a naming difficulty, and it is a common symptom observed across various aphasia types and may also persist as a residual symptom in individuals who have recovered from aphasia. Anomic aphasia is a form of aphasia that is characterised primarily by a persistent and severe naming deficit, even though overall language abilities remain relatively preserved. Their speech is generally fluent, apart from pauses due to deficiencies in word retrieval. Despite having the ability to engage in fluent, spontaneous conversation, their speech is empty. Individuals with anomic aphasia tend to exhibit good auditory comprehension, normal syntax, good articulation, preserved repetition, and normal or near-normal oral reading and writing. The specific symptoms of naming difficulties may vary depending on the location of the lesion. To illustrate, if the lesions are situated in the more frontal areas, phonemic cues may evoke a naming response. Additionally, the repetition of a word endlessly with no comprehension of its meaning is associated with lesions in the angular gyrus (Hedge, 2024).

1.2. Bilingual Aphasia

More than half of the global population is now considered to speak two or more languages (Fabbro, 2001), leading to a growing chance of bilingual aphasia. Individuals are deemed bilingual if they use or have used more than one language on a regular basis (Grosjean & Li, 2013). Bilingual aphasia is a condition in which an individual who is fluent in two or more languages experiences language deficits in both languages following brain damage. This condition presents unique challenges for assessment, diagnosis, and treatment due to the complex interaction between the two languages in the brain. The characteristics of bilingual aphasia are dependent on several factors, including the age of language acquisition, pre-morbid proficiency in each language, and the nature and location of brain damage. Bilingual aphasia can be classified into two types of impairments: parallel and selective. Parallel impairment occurs when both languages of a bilingual person are affected to a similar extent. In this case, the individual experiences difficulties in producing and understanding speech in both languages. The impairments observed in one language are mirrored in the other language, suggesting a parallel decline in language abilities. Selective impairment, on the other hand, refers to a situation where one language is more affected than the other. Here, the individual may have difficulty producing and understanding speech in one language, while the other is relatively unimpaired. This suggests a selective decline in language abilities, with one language being more impaired than the other (Gitterman et al., 2012).

Currently, there is no definitive answer to the question of which one of the two languages should be prioritised in aphasia therapy (Green, 2005; Paradis, 2004). Arguments for selecting a specific language for speech and language therapy suggest choosing according to the impairment's severity, the pre-morbid frequency of use, the immediate environment's language preference, and the stronger emotional connections. However, research indicates that simultaneous stimulation of both languages can aid in rehabilitation (Ansaldo & Marcotte, 2007; Kohnert, 2004). This is particularly relevant for proficient bPWA (Ansaldo & Marcotte, 2007), given that the bilingual language system consists of two language codes within a single system. Therefore, bPWA may encounter a variety of communication settings, ranging from entirely monolingual to completely bilingual, depending on the context, indicating a bilingual intervention approach may be a reasonable option to consider (Gitterman et al., 2012). In conclusion, when deciding which language to focus on during therapy, it is essential to consider which language is less impaired and which language is more important to the patient and their family.

Recovery from aphasia can be divided into three phases: acute, subacute, and chronic. The acute phase of aphasia typically lasts for two weeks, followed by the subacute phase, which lasts up to six months after the incident. The chronic phase occurs after six months (Kiran, 2012). Recovery from bilingual aphasia is a complex process influenced by several factors, including the age of onset, the patient's language ability, and dominance, as well as the nature and severity of the underlying neurological condition (Lerman et al., 2019). Developing effective therapeutic interventions that aim at optimal language recovery and the improvement of functional communication requires a thorough understanding of the factors and their interactions involved. Fabbro's (1999) study found that the nature of recovery in bilingual individuals with aphasia is manifested in considerable variations. The research indicates that 40% of bPWA experience parallel recovery, where their recovery process occurs simultaneously in both languages. Within this group, 32% of the studies report a more significant recovery in their first language (L1), while 28% observe a more substantial improvement in their second language (L2). Furthermore, Kuzmina et al. (2019) also revealed better performance in L1 than in L2 among bPWA in their meta-analysis.

1.3. Executive control impairment in bilingual aphasia

Executive functions (EFs) are a set of top-down mental processes that are essential for tasks that require concentration and attention. These processes are particularly important when going on procedural automatism or relying on instinct or intuition would be insufficient or impossible (Diamond, 2013). The influential model proposed by Miyake and colleagues (2000) is comprised of three distinct components of executive functions such as updating, inhibition, and shifting. Updating refers to the ability to actively manipulate and monitor information in working memory. Inhibition involves the capacity to suppress prepotent responses, interfering stimuli, or irrelevant information. Shifting, on the other hand, refers to the ability to switch between mental sets or tasks flexibly. Miyake and colleagues argued that these components represent core processes underlying executive functions and can be measured separately (Miyake et al., 2000, 2008, 2012, 2017).

Executive control (EC) is a fundamental component of the executive function system. EC is believed to play an essential role in bilingual performance and language recovery (Abutalebi & Green, 2007; Green, 1986; Paradis, 2004). Issues with bilingual language control can manifest as difficulties in translation or involuntary switching between languages, as well as differential recovery of languages. It has been proposed that impairment in language control results in selective recovery patterns due to blocked inhibition (Abutalebi, 2008; Gitterman et al., 2012). Languages can be inhibited to a similar degree (parallel recovery), or one language can be inhibited more strongly (selective recovery). As the Green model (1998) proposes, the bilingual system consists of separate linguistic and control units. While the linguistic units belong to the lexical-semantic system, the control units serve the linguistic operations through activation and inhibition. The inhibition process is classified as domain-general: that is, it encompasses the procedural aspect of both the linguistic and non-linguistic control (Gitterman et al., 2012). However, there is considerable disagreement about the nature of bilingual language control. Some authors propose that bilingual language control relies on functions specific to the language domain (Mooijman et al., 2022), while others argue that the general and specific executive functions correlate and contribute to linguistic performance (Declerck et al., 2017; Prior & Gollan 2011), suggesting an existing overlap. Others suggest that the overlap is only partial (Klecha, 2013; Calabria et al., 2012; Branzi et al., 2016). Evidence from neuroimaging data indicates shared neural circuits of domain-general EC and language control (De Bruin et al., 2014; De Baene et al., 2015).

The existing research on healthy adults indicates that impairments in language control can have a significant impact on our understanding of language deficits in bilingual aphasia. This makes it challenging to differentiate between deficits in lexical access and deficits in language control when there is a potential interaction between language and cognitive control (Miller et al., 2018). Reported cases of bilingual aphasia patients demonstrate differential language impairments, deficits in executive functioning, and challenges in isolating loss of lexical representations from language control abilities (Munoz & Marquardt, 2003; Adrover-Roig et al., 2011). These findings highlight the association between linguistic and non-linguistic control mechanisms after brain damage. Bilingual individuals with aphasia can provide unique insights into the relationship between language and cognitive control, although limited research has investigated this topic (Dash & Kar, 2014; Gray & Kiran, 2015; Green et al., 2010; Verreyt, De Letter, Hemelsoet, Santens, & Duyck, 2013) with mixed results that underscore the complexity of this area of study. The findings of these studies are inconclusive. While some studies provide evidence for domain-general cognitive control (Verreyt et al., 2013), others provide evidence for domain-specific cognitive control in individuals diagnosed with bilingual aphasia (Dash & Kar, 2014; Gray & Kiran, 2015;).

It is already known from studies that monolingual aphasics (mPWA) often experience EF deficits (Purdy 2002; Murray, 2012; Szöllősi et al., 2015; Murray 2017; Marinelli et al., 2017; Schumacher et al., 2019; Ramsey et al., 2017; Christensen et al., 2018; Kuzmina & Weekes, 2017; Olsson et al., 2019). Impairment in executive functions may result in more severe aphasia symptoms as it prevents people with aphasia from compensating for linguistic difficulties (Mooijman et al., 2022). Therefore, EC is classified as a crucial factor in functional communicative abilities and the recovery of linguistic skills (Ramsberger, 2005; Fridriksson et al., 2006; Olsson et al., 2019). Most studies that have investigated the working memory (WM) abilities of mPWA have indicated updating impairment. However, it is notable that many of these studies have employed tasks that are linguistically demanding. In order to complete these tasks, individuals are required to engage in semantic processing and/or phonological processing, which enables them to understand the instructions and formulate an appropriate response. Some studies have focused on investigating non-linguistic working memory, with particular attention paid to ensuring the tasks were simple and 100% non-linguistic. For instance, in their 2010 study, Christensen and Wright examined linguistic and non-linguistic working memory in L2 monolingual individuals with varying degrees of post-stroke aphasia. The n-back task was employed with three stimulus categories: fruit (high linguistic load), Fribbles (semi-linguistic), and blocks (non-linguistic). While the performance of the aphasia group on tasks with varying linguistic loads was similar to that of a control group, it was generally at a lower level. Furthermore, accuracy decreased as the linguistic elements of the tasks were reduced.

Overall, the results demonstrated that verbal encoding has a significant impact on working memory in mPWA. Additionally, Christensen and colleagues (2018) investigated WM performance in mPWA (N=14) using verbal and spatial WM tasks. The verbal *n*-back task included letters, while the spatial tasks included an *n*-back task with black circles and the flanker test. The findings showed that mPWA performed worse than the control group on the verbal tasks, but there was no group difference on the spatial tasks. Their results suggest that although WM deficits are primarily evident in the verbal domain in mPWA, they are not exclusively the result of domain-specific verbal deficits. In addition to investigating non-linguistic WM in aphasia, recent studies have concentrated on the efficiency of WM training in mPWA. Zakariás et al. (2018) found that computerized WM training improved spoken sentence comprehension and everyday memory in a small group of participants (N=3), with some showing gains in working memory and functional communication. This result suggests that WM can be enhanced through training even in the chronic phase of recovery. Similarly, Nikravesh et al. (2021) studied the effects of WM training on a larger group (N=13) of individuals with mild to moderate language impairment and found significant improvements in both trained and untrained WM tasks, as well as in overall language performance.

Individuals with bilingual aphasia may experience challenges with language selection, inhibition of interfering languages, and attentional control during language production and comprehension. The nature and severity of these impairments may vary depending on the location and extent of brain damage, language proficiency, and the specific demands of each language. Several studies confirm EC impairments in bPWA, although with rather mixed and contradictory results on the relationship between linguistic and domain-general control. Moreover, while most studies confirm that bPWA with language control problems in everyday communication shows domain-general EC problems, there are indications for EC advantages as well (for review, see Mooijman et al., 2022).

1.3.1. Inhibition

The comprehensive meta-analysis of Mooijman et al. (2022) examined studies investigating executive control impairment in bilinguals. The analysis included 27 articles investigating deficits in non-linguistic EC in bilingual aphasia. The results revealed that inhibition was the most frequently researched EC component. The Stroop task was primarily used in these studies to investigate prepotent response inhibition (Miyake et al., 2000; Friedman & Miyake, 2004). In the Stroop task (Stroop, 1935), participants are required to read three different tables as quickly as possible. Two of the tables represent the congruous condition, in which participants are required to read the names of colours printed in black ink and name different colour patches. Conversely, in the third table, named colour-word condition, colour words are printed in an inconsistent colour ink (e.g., the word 'red' is printed in green ink). In this incongruent condition, the participants are required to name the colour of the ink instead of reading the word (Scarpina & Tagini, 2017). The group studies conducted by Penn et al. (2017) and Faroqi-Shah et al. (2018) revealed that the majority of bPWA experience inhibition impairments in the Stroop task. However, it is difficult to distinguish between non-linguistic inhibition impairments and disordered language skills due to the nature of the task. The Eriksen flanker test is a commonly used assessment of resistance to distractor interference. In the flanker test, 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 (Eriksen & Eriksen, 1974). Several studies have shown that bPWA had impairments in the flanker test compared to healthy controls (Dash et al., 2020; Green et al., 2010; Keane & Kiran, 2015; Van der Linden et al., 2018; Verreyt et al., 2013). However, a significant number of bPWA show unimpaired performance in the flanker test (Calabria et al., 2019; Green et al., 2010, 2011). Most studies indicate that the majority of bPWA show impairments when measured with the

Stroop task and show unimpaired inhibition abilities in the flanker test. These contradictory findings could be due to the differences in the linguistic demands of each task or the type of inhibition that was measured (Mooijman et al., 2022).

Furthermore, it has been found that studies investigating inhibition impairment in bPWA produced differing results depending on the phase of recovery (acute, subacute, chronic). Specifically, some studies have reported abnormal scores during the subacute phase (Penn et al., 2017; Verreyt et al., 2013). It is important to note that during the subacute phase, spontaneous and guided recovery is still expected, and these impairments may, therefore, resolve over time. According to a study conducted by Penn and colleagues (2017), participants in both the acute and subacute phases were compared, and it was found that inhibiting impairments persisted. Additionally, studies investigating participants in the chronic phase also showed inhibiting deficits, suggesting that these impairments continue to persist (Mooijman et al., 2022).

1.3.2. Updating

The available research on updating in bPWA is limited and has produced mixed results. Two case studies (Adrover-Roig et al., 2011; Lee et al., 2016) found evidence of impairment in updating in participants with basal ganglia lesions. In a group study (N=10), Penn et al. (2017) investigated recovery profiles in the acute and subacute phases of recovery in post-stroke participants with bilingual aphasia. The study revealed impaired updating in a non-linguistic *n*-back task in bPWA. It is, however, noteworthy that the participants with aphasia showed impairment in updating in the acute and subacute phases of the recovery. It is worth considering that impairments in updating may have the potential to recover during the chronic phase of recovery.

1.3.3. Shifting

Similarly to the findings for updating, most of the bPWA with impaired switching ability were in the subacute phase of recovery. It has been suggested by Penn et al.'s (2017) study that shifting improves during recovery, indicating that shifting impairments may decrease over time. Studies investigating shifting involved the Wisconsin Card Sorting Test (WCST) and Trail Making Test (TMT). However, only WCST can be characterized as a non-linguistic test, as TMT requires the sequencing of letters and, therefore, relies on linguistic knowledge. Impaired shifting ability was also found in the case of the WCST. In addition to linguistic demands, both tasks require complex cognitive processes. It is worth noting that the TMT is not only a measure of shifting ability, but also relies on visual-perceptual abilities and working memory (Sánchez-Cubillo et al., 2009). In conclusion, based on the existing literature, the majority of bilingual individuals with aphasia may experience shifting problems in the subacute phase of the recovery (Mooijman et al., 2022).

1.4. Executive control in verbal fluency in bilingual aphasia

Verbal fluency tasks are frequently used to investigate the correlation between executive control and language function in healthy adults (Hughes & Bryan, 2002; Patra et al., 2019) and clinical populations (Bittner & Crowe, 2007; Henry & Crawford, 2004; Wauters et al., 2020; Carpenter et al., 2020; Faroqi-Shah et al., 2018). These tests are usually verbal fluency tasks (semantic and letter). In the semantic verbal fluency task (also called category fluency), participants are requested to produce as many unique words as possible from a given semantic category (e.g., animals, fruits, vegetables). In the letter condition, participants are requested to generate as many distinct words as possible that begin with a given letter (e.g., M) or phoneme (/b/) (Patra et al., 2020). In the semantic fluency task, participants are requested to access the pre-existing connections in their mental lexicon associated with the given category to produce words. To illustrate this, when participants are asked to generate words from the animal category, the word 'dog' may activate all the associated animal nodes in their mental lexicon that share features with 'dog' (Gruenewald & Lockhead, 1980). However, it is worth noting that in the letter fluency task, participants are required to produce words with a specific letter/phoneme while suppressing the activation of related semantic concepts. Studies have shown that such activation can have a detrimental effect (Friesen et al., 2014; Luo et al., 2010).

Studies comparing semantic and letter fluency tasks have revealed significant differences between the two. While most studies have found that the letter fluency task places greater demand on executive control (Patra et al., 2019; Shao et al., 2014; Thiele et al., 2016), further research is needed to investigate verbal fluency in the domain of bilingual aphasia. Faroqi-Shah et al. (2018) conducted a study to explore the relationship between word retrieval and executive control in bilingual aphasics. The study employed a semantic fluency task, picture naming, and the Stroop task. The results indicated that there was no correlation between semantic fluency and the Stroop task. However, a strong correlation was observed between picture naming and the semantic fluency task. It has been suggested that the absence of a correlation between inhibitory control and semantic fluency may be due to the impaired executive control abilities in aphasia, which are no longer able to support word retrieval. A recent study by Carpenter et al. (2020) found that bPWA were more vulnerable to the impact of EC demand on the verbal fluency tasks in comparison to the healthy controls. Moreover, it was observed by Patra et al. (2020) that individuals with aphasia who exhibited the most notable deficiencies in EC measures also demonstrated more pronounced impairment in the letter fluency task.

1.5. The present study

The primary objective of this study was to examine the relationship between impairments in language modalities and executive control in bilingual aphasia. To accomplish this, we employed a range of neuropsychological tests and non-linguistic working memory tests to identify deficits in executive control and further investigate these deficits in language modalities. Additionally, our study aimed to explore the effects of these impairments on performance in naming, verbal semantic, and letter fluency tasks.

We hypothesized that impaired executive control has a negative effect on naming in the bPWA subjects investigated, and its impact results in slower performance, increased response time, and decreased accuracy. We assumed that the longer the time to complete the task was, the more mistakes were made. This assumption was thoroughly investigated in the Boston Naming Test.

Furthermore, we assumed that bilinguals with aphasia may have impaired working memory both in the visual and verbal domains. To identify visual working memory impairment, we employed the Visual Working Memory Test and the Rey Complex Figure Test. Additionally, we used the Verbal Working Memory Test to identify verbal working memory impairment.

The relationship between word retrieval and executive control in bilinguals with aphasia and bilingual healthy controls was investigated using verbal tasks, including semantic and letter fluency. We expected lower performance in bilinguals with aphasia in both fluency tasks because of a possible impairment in inhibitory control due to aphasia (Patra et al., 2020). We particularly expected poor performance in bilinguals with aphasia in the letter fluency task because it requires greater recruitment of executive control to compensate for lexical difficulties.

2. Methodology

2.1. Participants

The study involved two bilingual female participants (A0 and A1 given as anonymized code) over the age of 70 who suffered from aphasia following an ischaemic stroke. Both participated in the study in the chronic phase of stroke, several years after the incident. Their first language (L1) was Croatian, and the second (L2) was Hungarian, with the age of acquisition as six years. Participant A0 was diagnosed with anomic aphasia, and A1 with mild anomic aphasia. The individual A0 was recruited from the Sopron Medical Centre, Erzsébet Teaching Hospital and Rehabilitation Institute, Hungary (Soproni Erzsébet Oktató Kórház és Rehabilitációs Intézet). Written permission for the performance of the tests on participant A0, diagnosed with anomic aphasia, was granted by the hospital director of the Rehabilitation Institute in Sopron (reference number: 543-2/2023). The two participants with aphasia gave their written informed consent. Descriptive data of the aphasic participants is given in Table 2.

Table 2. Characteristics of the sample of individuals with bilingual aphasia

Participants with bilingual aphasia	Aphasia type	Status	Lesion site	Gender	Age	Education in years	L1	L1 age of acquisition	L2	L2 age of acquisition
A0	anomic	chronic	left	female	72	16	Croatian	from birth	Hungarian	6
A1	anomic	chronic	left	female	73	12	Croatian	from birth	Hungarian	6

Participant A0 is a 72-year-old female who has been diagnosed with anomic aphasia. She was born in Hungary in a Croatian town. Before attending school, the home language was Croatian only. The language of instruction at school was Hungarian, and Croatian language was also taught. Before the stroke, she used Hungarian daily and Croatian three to four times a week. Before as well as after the stroke, she was a member of a Croatian seniors' club. She was submitted to rehabilitation in 2021 at the Rehabilitation Institute in Sopron following an ischaemic stroke. The CT scan revealed a subacute ischaemic lesion at the border of the left Anterior Cerebral Artery (ACA) and the Middle Cerebral Artery (MCA).

Furthermore, the MR scan revealed recent frontal ischaemia on the left side. At the onset of the subacute phase, the speech therapist administered the Western Aphasia Battery (WAB) to the patient. According to the WAB performance in the subacute phase, the patient's spontaneous speech was found to be fluent, but lacking in substance. The patient's grammar, auditory comprehension, and repetition abilities were intact. However, she failed in the verbal semantic fluency task. Additionally, she made a considerable number of mistakes in complex commands. The patient received speech therapy exclusively in Hungarian for a year. The participant was enrolled in our study two years after the stroke. According to the WAB performance in the chronic phase, the participant's speech, comprehension, repetition, reading, and writing abilities were intact.

Participant A1 is a 73-year-old female who has been diagnosed with mild anomic aphasia. She was born in a small Croatian village in Hungary, where Croatian was her home language. At school, she learned Hungarian as the language of instruction, but also had Croatian language lessons. Before and after the stroke, she has been using both languages. In 2000, the patient suffered a left anterior stroke. In the subacute phase, she was diagnosed with Wernicke's aphasia. The patient received speech therapy exclusively in Hungarian and physiotherapy (due to hemiplegia) for several years. In 2017, the patient experienced speech impediments and numbness on the left side of her body. The CT scan revealed no bleeding. According to the WAB performance in the chronic phase, the participant was diagnosed with mild anomic aphasia with intact comprehension, speech, repetition, reading, and writing.

The baseline measures used as reference were performed by testing eleven elderly (mean age 69; SD 4,96) Croatian-Hungarian bilinguals with no sign of any neurological deviation. The reference group of bilingual participants acquired L2 between the ages of 3 and 6. While the language of instruction at school was Hungarian, Croatian language as a subject was included in their curriculum. All bilinguals have used parallel the two languages. All members of the reference group gave their written informed consent. Descriptive data of the neurologically healthy participants is presented in Table 3.

Table 3. Characteristics of the sample of bilingual reference group

Healthy bilinguals	Gender	Age	Education in years	L1	L1 age of acquisition	L2	L2 age of acquisition
A4	female	62	12	Croatian	from birth	Hungarian	3
A5	female	67	8	Croatian	from birth	Hungarian	6
A8	female	66	11	Croatian	from birth	Hungarian	3
A10	female	63	18	Croatian	from birth	Hungarian	3
A11	female	67	11	Croatian	from birth	Hungarian	6
A12	female	66	14	Croatian	from birth	Hungarian	6
A2	male	72	8	Croatian	from birth	Hungarian	3
A3	female	76	8	Croatian	from birth	Hungarian	6
A6	female	71	8	Croatian	from birth	Hungarian	3
A7	male	72	11	Croatian	from birth	Hungarian	6
A9	female	77	11	Croatian	from birth	Hungarian	6

2.2. Procedures

The present study included both linguistic and non-linguistic assessments. Participant A0 was assessed at the Rehabilitation Institute in Sopron. The hospital provided a speech therapist, as well as a bilingual psychologist for the Croatian tests, and a quiet and private room for the assessments. The speech therapist conducted the Hungarian tests, while the bilingual psychologist carried out the Croatian tests. Both the Hungarian and Croatian assessments were conducted in the presence of the authors of this study. Participant A1 and control bilinguals were tested in their homes or at the local seniors' club by the authors of this study and a Croatian-Hungarian bilingual interpreter. The assessments were conducted individually and multiple times due to their length.

2.3. Language tests

In this study, we assessed language and cognitive functions by implementing linguistic batteries such as the Bilingual Aphasia Test (BAT) and the Boston Naming Test (BNT). We used BAT to measure the severity of impairment in aphasia and to investigate parallel or selective impairment. Furthermore, we employed BNT to evaluate naming. The principal objective of applying these batteries in this study was to investigate cognitive control functions in terms of comprehension, fluency, and naming.

The Bilingual Aphasia Test (BAT) is a measure designed specifically for the purpose of evaluating the relative recovery of a bilingual individual's languages, utilizing criterion referencing (Paradis, 1989). We used some parts of the test, such as pointing, simple and semi-complex commands, verbal auditory discrimination, and repetition both in Hungarian and Croatian. Furthermore, the letter and semantic fluency tests were also used from the BAT to investigate fluency impairment in bPWA. The semantic fluency tasks were conducted both in Hungarian and Croatian. The participants were required to name as many animals as they could in one minute. The letter fluency task was applied in Hungarian, in which the participants had to name as many words as they could with the letter 'M,' except names, cities, and countries in one minute. We investigated potential impairment in inhibition, working memory, cognitive flexibility, monitoring and planning and organization in bPWA. The maximum available score is 7 in both tests. See Table 4 for details of the scoring system.

Table 4. The scoring system of the letter and semantic fluency tests

Letter Fluency	Semantic Fluency	Score
> 17	> 21	7
14-17	17-21	6
11-13	14-16	5
8-10	11-13	4
6-7	9-10	3
4-5	7-8	2
< 4	< 7	1

The Boston Naming Test (BNT) is a comprehensive assessment tool that includes both formal and informal confrontation naming tasks. The test consists of 60 black-line drawings, which are ordered based on their level of difficulty (Gitterman et al., 2012). By administering the test, valuable information can be obtained about an individual's responsiveness to phonemic cues, types of errors, and their ability to recognize correct responses from a set of four choices (Gitterman et al., 2012). While it primarily assesses language and semantic memory, it also involves certain executive functions, for example, inhibition, working memory, cognitive flexibility, attention, planning, and organization. The participants, whose accuracy and response time were measured, had to access their internal dictionary to be able to name a word.

2.4. Neuropsychological tests

The present study investigated the accuracy, speed, and efficiency of participants in neuropsychological tests designed to assess cognitive flexibility and non-linguistic working memory. Several tests were employed, including the Rey-Osterrieth Complex Figure B Test, a Verbal Working Memory Test, and a Visual Working Memory Test using software (Afázia app). These tests are designed to evaluate working memory and cognitive flexibility aimed at achieving goals. Non-linguistic tests, such as the Visual Working Memory Test and the Rey-Osterrieth Complex Figure B Test, were added to minimise the impact of language impairments on participants' performance. The assessment only began after the participants demonstrated a clear understanding of the task.

The Rey-Osterrieth Complex Figure B Test (ROCF-B) is a valuable tool for assessing cognitive impairment, especially in individuals with aphasia (Lezak et al., 2012). The test evaluates a range of cognitive functions, including visuospatial skills and visual memory. It involves copying and recalling a complex geometric figure. The copying phase primarily assesses visuospatial skills, perceptual organization, and motor planning. After a delay of three minutes, participants are required to draw the figure from memory. This recall phase assesses visual memory, organizational strategies and planning, monitoring, and inhibitory control (Kirkwood et al., 2001). The maximum score to achieve is 31.

In the Verbal Working Memory Test (Choinski et al., 2020), the participant is required to match words with corresponding pictures. A trial test should be conducted to determine if the participant understands and can perform the task. If successful, a sequence of unrelated words will be read aloud, and the participant will be asked to reproduce the sequence by pointing to the corresponding pictures. The test begins with a sequence of two words and gradually increases to a maximum of nine. The maximum score to achieve is 44.

A Visual Working Memory Test was used by a Hungarian rehabilitation software made specifically for post-stroke patients (called Afázia App, created by Katalin Nádudvari and Ali Baharev, PhD available online at https://afazia.app/). The task involves coloured sticks and requires the participant to memorise the order of 12 sticks (Cseh & Hegyi, 1995). Each section contains two colours, such as red and green, but the subject must choose from four different colours: red, green, yellow, and blue. The software instantly provides feedback to the user, indicating whether the selected colour is correct or incorrect. All participants completed the task on the same tablet to ensure a consistent assessment environment. Response time was measured to investigate performance differences between aphasics and neurologically healthy individuals.

3. Results

The findings presented in this study are based on the test results of bilingual aphasics compared with the bilingual participants' performance in the reference group. See Table 5 for detailed information about the test results.

Table 5. Results of the linguistic and non-linguistic tests in the aphasia and the reference group

Participants		BNT-HU (max score 60)	BNT-CRO (max score 60)	ROCF-B (max score 31)	Visual WM Test median RT (in ms)	Verbal WM Test (max score 44)	Letter Fluency (max score 7)	Semantic Fluency-HU (max score 7)	Semantic Fluency - CRO (max score 7)
Aphasia group	A0	25	7	20	1620	34	1	2	2
	A1	51	27	26	3089,5	34	4	6	3
The range of scores (min-max)		25-51	7-27	20-26	1620-3089,5	34	1-4	2-6	2-3
Median score		38	17	23	2354,75	34	2,5	4	2,5
Reference group	A2	59	37	31	835,5	35	2	6	5
	A3	45	27	25	1128	38	4	7	5
	A4	46	22	21	1102	42	5	6	5
	A5	47	36	26	975	35	5	6	5
	A6	46	36	15	989	29	2	6	4
	A7	45	39	26	1261	36	6	4	4
	A8	56	43	21	1105,5	44	5	7	6
	A9	49	39	27	1485,5	34	4	6	4
	A10	57	39	31	1005	44	4	7	6
	A11	58	41	31	1101	42	5	7	6
	A12	59	33	31	1013	44	6	7	6
The range of scores (min-max)		45-59	22-43	15-31	835,5-1485,5	29-44	2-6	4-7	4-6
Median score		49	37	26	1101	38	5	6	5

3.1. The impact of executive control impairment on naming

In the Boston Naming Test (BNT), 60 pictures were presented to investigate the assumed naming impairment of individuals with aphasia. Only answers provided by the participants or with the aid of the semantic cues were accepted. We believed that a potential impairment in executive control (e.g., attention, working memory, inhibitory control, cognitive flexibility) might negatively influence the overall performance in bPWA, resulting in increased response time (RT) and decreased accuracy. It was expected that a greater number of mistakes would lead to a longer RT required to complete the test. Therefore, a correlation was established between the number of accurate responses and the RT to test the hypothesis that an increased completion time would result in a greater number of errors (see Figure 1-2). The performance of the reference group was used as a baseline measure to determine the impact of aphasia on naming abilities.

Figure 1. Number of correct answers in the Hungarian and Croatian versions of the BNT in the two bilingual aphasics and the bilingual reference group (N=11, 2 males)

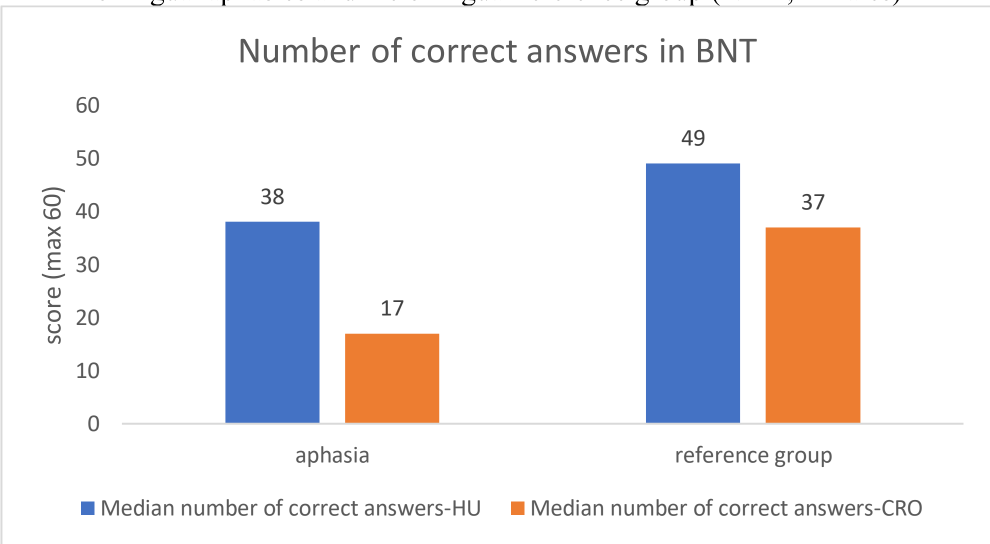
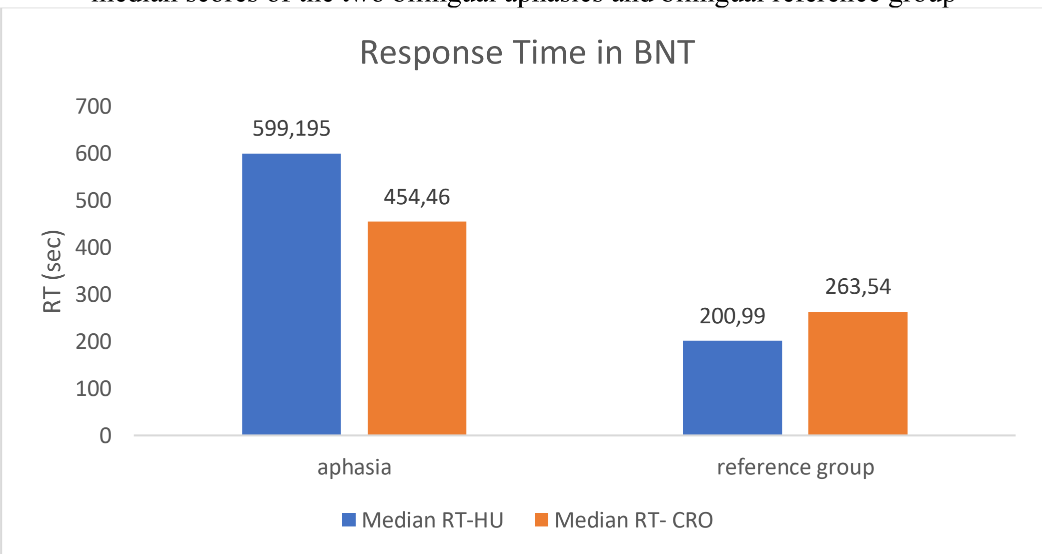


Figure 2. Response time in seconds in the Hungarian and Croatian versions of the BNT between the median scores of the two bilingual aphasics and bilingual reference group



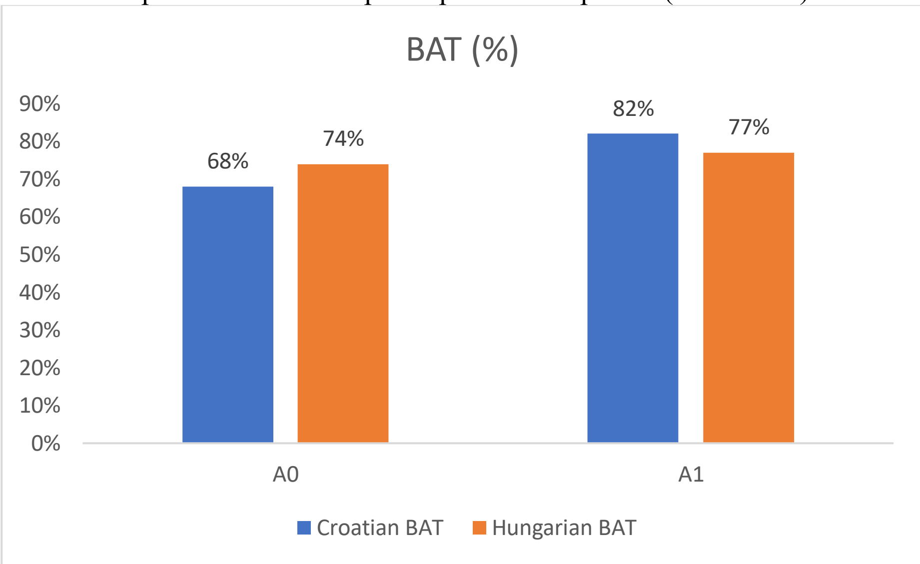
In the BNT, the participants in the reference group performed well in general, as shown in Figures 1 and 2. The number of correct answers was a median score (M) of 49 in the Hungarian version and 37 in the Croatian version. The response time was longer in the Croatian version when more mistakes were made, with M=263,54 seconds compared to M=200,99 seconds in the Hungarian test. In the aphasia group, the individuals with aphasia performed slower and less accurately compared to the reference group, as shown in Figures 1 and 2. The number of correct answers was a median score of 38 in the Hungarian and the Croatian version. The RT was M=599,195 seconds in the Hungarian version and M=454,46 in the Croatian version.

Both groups performed better in the Hungarian than in the Croatian version. However, there was a difference in response time. The aphasic participants required more time to complete the task in the Hungarian version despite having better performance in terms of the number of correct answers. Conversely, in the Croatian version, bPWA performed poorly, but they required less time as they skipped unknown items faster than in the Hungarian version. As expected, individuals with aphasia exhibited slower performance compared to the reference group. This reduced speed may be attributed to the effects of the stroke and potential impairment in executive control. EC impairment in aphasics may occur as difficulties in initiating and maintaining a systematic strategy for retrieving and producing the correct names of objects, resulting in hesitations, word-finding difficulties, and errors in naming objects. In bPWA, the struggle with inhibitory control may contribute to difficulties in suppressing irrelevant or competing responses when attempting to retrieve the correct word.

3.2. Parallel impairment in comprehension and repetition

We investigated parallel or selective impairment in bPWA using the Hungarian and Croatian versions of the BAT test. A shorter version was employed, including pointing, simple and semi-complex commands, verbal auditory comprehension, and repetition. Figure 3 represents the tests' total scores in percentage. Parallel impairment was observed in comprehension and repetition in both aphasic participants. Based on the available data from the speech therapist and the participants with aphasia, their Croatian improved over the years after the stroke, despite receiving therapy only in Hungarian. The level of impairment in comprehension and repetition was modest in both languages, supporting mild parallel impairment in the chronic phase for both participants.

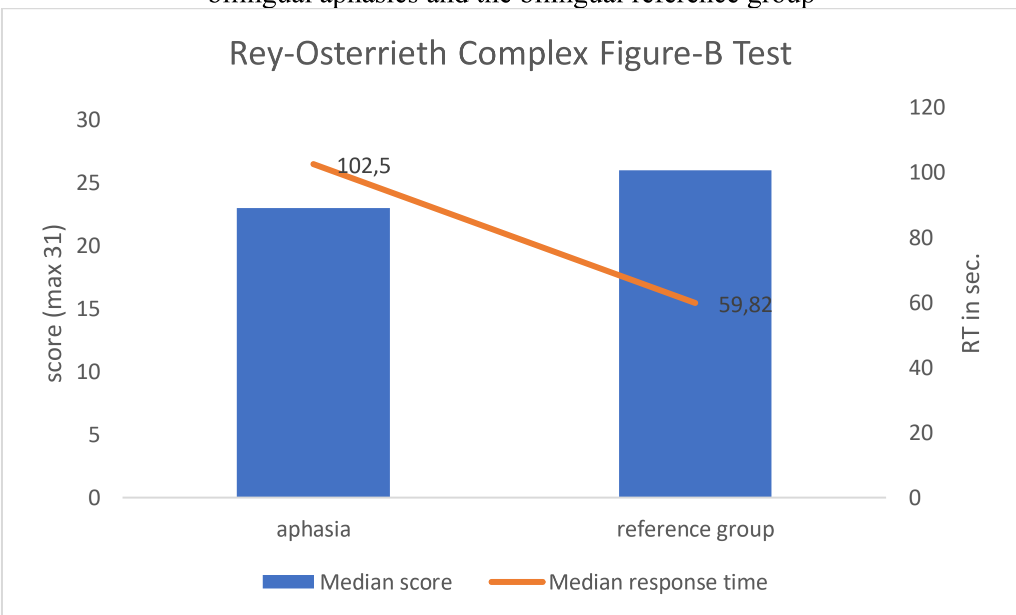
Figure 3. Results of the BAT tests indicating parallel impairment in comprehension and repetition in the two participants with aphasia (A0 and A1)



3.3. Visual and verbal working memory impairment

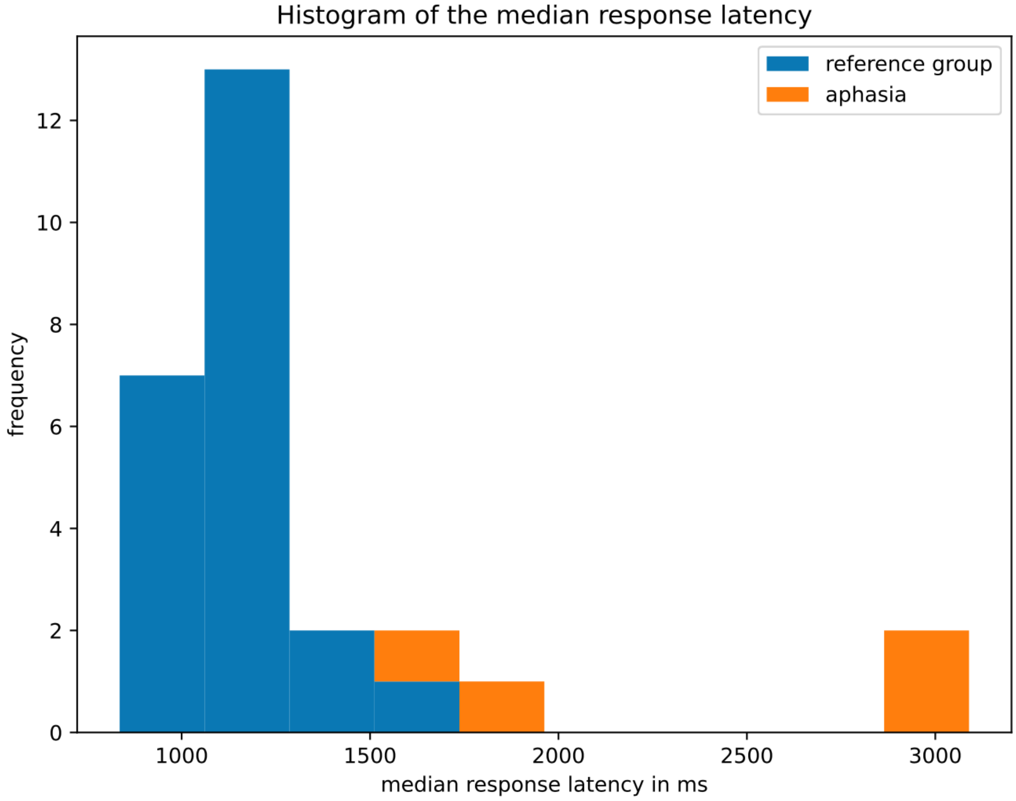
The study examined impairment in both non-linguistic and linguistic working memory through a variety of tests. To identify visual working memory impairment, the ROCF-B test and the Visual Working Memory Test were employed, with any linguistic aspects excluded to evaluate only non-linguistic working memory impairments. Furthermore, the Verbal Working Memory Test was also employed to investigate the possible impairments and to compare non-linguistic and linguistic working memory performance in bPWA.

Figure 4. Results of the ROCF-B test used to investigate non-linguistic WM impairment in the two bilingual aphasics and the bilingual reference group



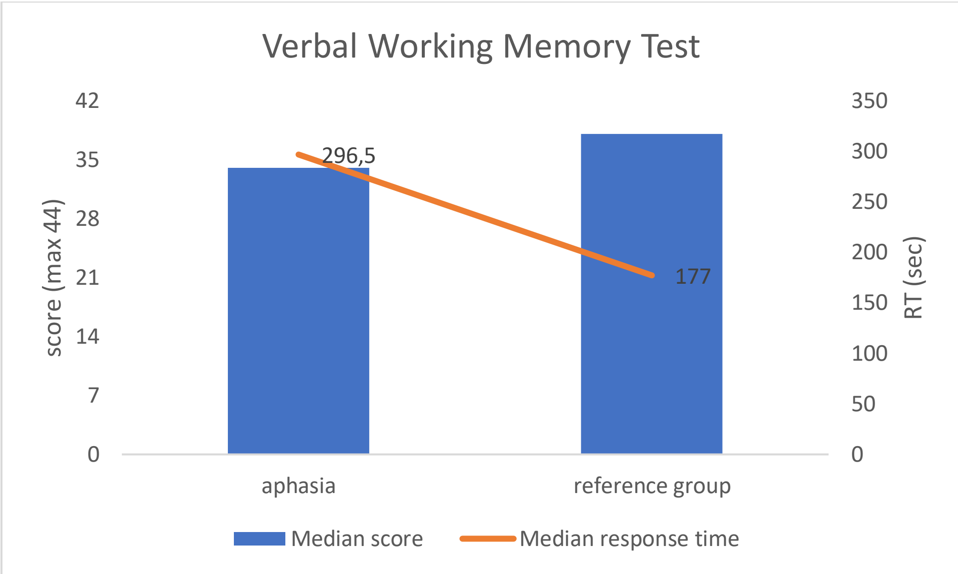
The ROCF-B test consisted of two parts: a copying phase and a drawing from memory phase. All participants completed the copying phase successfully. In the drawing from memory section, the reference group had a median score of 26 in M=59,82 seconds, whereas the participants with aphasia achieved a median score of M=23 in 102,5 seconds (see Figure 4). The reference group achieved a score of 84%, and the aphasics achieved 74%. This result suggests a mild impairment in visual memory, inhibitory control, monitoring, and planning. However, a difference in response time was identified as bPWA took almost twice as long as the reference group. This delay may be attributed to the general slowness caused by stroke and/or the mild impairment in EC.

Figure 5. Comparing response latency in milliseconds in the Visual Working Memory Test in the two bilingual aphasics and the bilingual reference group



The Visual Working Memory Test required the participants to memorise the order of 12 coloured sticks. Figure 5 presents the measured response time in milliseconds. RT was defined as the time taken to choose the correct sticks. We investigated potential impairment in the executive control functions by using the Visual Working Memory Test, which includes attention deficit, working memory limitations, inhibition difficulties, task-switching problems, and cognitive flexibility. While the median response latency for the bilingual reference group was between 835,5 and 1485,5 milliseconds, the bPWA participants completed the task between 1620 and 3089,5 milliseconds. All participants were able to solve the test. However, bPWA performed at a slower pace as compared to the group of healthy participants. These results indicate mild impairment in attention, inhibition, task switching, working memory, and cognitive flexibility in bPWA.

Figure 6. Results of the Verbal Working Memory Test. Median score and response time in seconds are given for the two bilingual aphasics and the bilingual reference group



The Verbal Working Memory Test consisted of a range of picture sets, from two to nine pictures, and response time was measured from the start of the test until its end. While the reference group completed the task with a median score of M= 38 with an RT of 177 seconds, the aphasic participants completed the task in M= 296,5 seconds with M=34 scores (see Figure 6). The results indicate a difference in response time between people with and without aphasia. Specifically, bPWA required almost twice as much time to complete the task. However, it is noteworthy that the bPWA participants could complete the task successfully.

3.4. Impairment in fluency

Table 6. Performance showed in the letter and semantic verbal fluency tests by the two bilingual aphasics and the reference group

	Aphasia (N=2)	**Reference group (N=11)**
Letter Fluency-HU	M= 2,5	M=5
Semantic Fluency-HU	M= 4	M=6
Semantic Fluency-CRO	M=2,5	M=5

Table 6 presents the fluency test results of bPWA and, in comparison, with the reference group in letter (Hungarian) and semantic (Hungarian and Croatian) tasks. Both groups performed better in the Hungarian semantic fluency task. The reference group achieved a median score of M=6 in the Hungarian semantic fluency task as compared to M=5 in the Croatian version. The aphasic participants achieved a median score of M=4 in the Hungarian fluency task and achieved M=2,5 in the Croatian version. In the letter fluency tasks, both groups showed lower performance in comparison to the semantic tasks. While the reference group of bilinguals achieved a median score of M=5, bPWA had a lower median score of M=2,5. The results of the semantic and letter fluency tasks suggest moderate impairment in bPWA.

4. Discussion

This study aimed to investigate the potential impairment of executive functions in fluent bilingual aphasics in the chronic phase by using linguistic tests with a particular focus on naming, fluency, and non-linguistic working memory tests.

The results of our study indicated mild parallel impairment in comprehension and repetition in the two bPWA participants when assessed by the Bilingual Aphasia Test. However, it was found that they performed better in the Hungarian version of the Boston Naming Test (BNT) and fluency tests, despite parallel impairment in word retrieval. Better performance in Hungarian was also observed in the bilingual reference group, which may be attributed to the fact that Hungarian was the more frequently used language among the participants. In addition, the assumed correlation between poor performance and increased response time in bilingual aphasics was also investigated in the BNT. Bilinguals with aphasia exhibited slower performance both in the Croatian and Hungarian versions of the BNT as compared to the reference group's performance, suggesting a moderate impairment in naming.

In terms of fluency, both groups performed better in the Hungarian semantic tasks than in the Croatian version. As expected, all participants performed better in the semantic fluency than in the letter fluency task. In the letter fluency tasks, participants were required to produce words using a specific letter ('M') while suppressing the activation of related semantic concepts. Studies have shown that such activation can have detrimental effects (Friesen et al., 2014; Luo et al., 2010; Patra et al., 2020). Comparisons between the semantic and letter fluency tasks have found that the letter fluency task placed a great demand on executive control (Patra et al., 2019, 2020; Shao et al., 2014; Thiele et al., 2016). Our results suggest a moderate impairment in the semantic fluency tasks and greater impairment in the letter fluency task due to a higher load on EC in bPWA.

Furthermore, the ROCF-B and Visual Working Memory Test, excluding all linguistic aspects, were also investigated. The number of studies aiming at better understanding the role of updating in impaired functions of bPWA is minimal.

Most of the available studies include tests that involve numbers or letters, such as the Trail Making Test (Mooijman, 2022). To the best of our knowledge, studies investigating the non-linguistic working memory exclusively without numbers and/or letters in bPWA are rather limited. The results we got in the ROCF-B and Visual Working Memory tests show good performance in the aphasic participants, similar to the healthy controls, with the exception of low scores in response time. The two aphasic participants needed almost twice as much time to complete the tasks than the participants in the reference group. Similarly, in the Verbal Working Memory test, the performance of bPWA was good enough, though with increased response time as compared to the reference group. These results indicate that fluent bilingual aphasics in the chronic phase exhibit mild impairment in WM. It is important to note that the chronic phase might influence the recovery process, as the recovery phase could affect the improving or persisting impairment of executive control. Previous studies have shown that while impaired inhibition might persist in the chronic phase of aphasia, updating tended to improve (Penn et al., 2017). In our study, the aphasic participants investigated completed the tasks successfully but were slower than the reference group. This slowness may be attributed to the impact of aphasia and/or potential impairment of executive control.

5. Conclusion

In conclusion, our results of the word-retrieval tests (BNT and fluency) and non-linguistic WM tests showed moderate impairment in word retrieval and mild impairment in WM in bilinguals with aphasia. This finding was unexpected, as we assumed similar impairment in non-linguistic EC suggested by the aphasia literature as poor performance in naming and fluency can also be attributed to EC impairment (Faroqi-Shah et al. 2018). As our study showed, linguistic aspects included in testing might lead to more difficulties for bPWA, and excluding them could contribute to better performance. However, the performance of participants with aphasia required at least twice as much time as the reference group did to achieve similar results, and this might be attributed to the impact of aphasia or the impaired EC. While this study provides valuable insights into the impaired executive control in bilingual people with aphasia in the chronic phase, it is important to acknowledge the limitations of the study, such as the limited number of patients and the lack of well-matched controls. Although investigating an ageing group of bilinguals served as a reference measure, it provided baseline data with limited possibility to draw more decisive conclusions. Future studies should include multiple case studies with a broad range of testing for aphasics and patient-focused matching as control. Nevertheless, this study may serve as a starting point for exploring non-linguistic working memory impairment in fluent bilingual aphasia in the chronic phase and highlight the need for further research in this area.

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