

The impact of working memory on the recovery from aphasia



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Abstract

Annamária Kiss

The impact of working memory on the recovery from aphasia

The classical aphasia literature has placed considerable emphasis on the language-centered understanding of aphasia and failed to consider the role of executive functions in the patients' performance, especially in bilinguals. Thus far in most cases current studies suggest deficit in executive functions in individuals diagnosed with mono- and bilingual aphasia, although the number of existing data is still limited.

The present study used various neuropsychological and linguistic batteries to examine the comprehension of grammatical phrases and language structures, fluency, repetition, planning, attention, inhibition, cognitive flexibility and working memory. Here, the aim of the study was to investigate whether impairment in executive functions has a negative effect (slowness in performance, increased response time and/or decreased accuracy) on naming. In addition, we examined whether poor performance in word fluency tasks correlate with similar performance in naming. To investigate this, the Boston Naming Test as well as a verbal semantic fluency test were employed. Furthermore, the study aimed to compare the assumed working memory impairments in individuals with mono- and bilingual aphasia. To examine this, both visual and verbal working memory tasks were employed, such as a Visual Sequential Memory Test, the Rey-Osterrieth Complex Figure B (ROCF-B) and an Auditory Sequential Memory Test. It was hypothesised that both aphasia groups would exhibit impairments in their visual and verbal working memory performance. Additionally, to investigate assumed cognitive flexibility impairments the study employed the Trail Making Test (TMT) as well as a Number and Letter Sudoku task. Auditory comprehension deficits were measured by The Token Test and the Hungarian versions of the Test for Reception of Grammar (TROG-H). In addition to investigating executive function impairments in linguistic and non-linguistic batteries, the study sought to investigate performance differences between fluent and non-fluent aphasia types, as well as the effect of age and education on performance. Finally, the study investigated assumed better performance in non-linguistic tests in individuals with bilingual aphasia in comparison with monolinguals with aphasia.

In our multiple case study, a total of 54 participants were recruited, including monolingual (N=10) and bilingual (N=8) individuals with aphasia and individuals without any neurological problems (N=36). The post stroke aphasic patients were investigated in the chronic phase of recovery. They were diagnosed with different types of aphasia. The performance of mono- and bilingual patients was compared with reference groups matched in terms of age, gender, educational background, age of acquisition as well as L1 and L2. All bilinguals have used parallel the two languages. The bilingual participants had their first language as Croatian or Hungarian and had acquired their second language, Hungarian or Croatian or Slovakian or German, at varying ages. All participants were tested individually in several sessions.

Results of the working memory tests (Auditory Sequential, Visual Sequential Memory, ROCF-B) and cognitive flexibility tests (TMT, Number and Letter Sudoku) performed by both mono- and bilingual aphasic patients indicated general slowness and decreased accuracy in all tasks in comparison with the reference groups. Moreover, the impairment of cognitive skills, such as inhibitory control, working memory, task switching, visual attention, visual memory, motor programming and planning did not depend on the aphasia type. All participants with aphasia demonstrated significant variability in all the non-linguistic tasks, with impairments noted in comparison to the

reference groups. Although the bilingual aphasia group had lower scores than the monolinguals, these differences were not statistically significant.

Furthermore, comprehension, repetition, fluency, and naming investigated by using linguistic tests (Token, TROG-H, BNT, fluency tasks) showed significant difference in comprehension, naming and fluency between both aphasia groups and the reference groups. Results indicated that all participants with aphasia performed significantly worse in the letter fluency task, due to higher executive control demands.

The investigation of difference between fluent and non-fluent aphasics revealed that non-fluent aphasics exhibited greater impairment in both the linguistic and non-linguistic tests in comparison with fluent aphasics. Furthermore, the study highlights the significant influence of age and education on linguistic and non-linguistic performance in both the aphasia and reference groups. While education has been shown to correlate positively with performance, the impact of age varied.

The study revealed that the impairment in executive functions might have a negative effect on naming, comprehension and fluency, so that the functional variations of the neural networks should be considered, and our interpretation should rely on psychophysiological data available in the aphasia literature. The findings contribute to our understanding of the less explored domain of executive function impairments in bilingual aphasia and highlight the need for tailored therapeutic interventions and further exploration of cognitive deficits in bilingual aphasia.

Keywords: *executive functions, working memory, cognitive flexibility, aphasia, bilingual aphasia, fluency, naming, multiple case study*

Doktori értekezés

Kivonat

Kiss Annamária

A munkamemóriának az afáziás betegek rehabilitációjára gyakorolt hatása

A klasszikus afáziairodalom nagy hangsúlyt fektetett az afázia nyelvközpontú értelmezésére, figyelmen kívül hagyva a végrehajtó funkciók szerepét, különösen kétnyelvű afázia esetén. A jelenlegi tanulmányok többsége a végrehajtó funkciók zavarára utal egy és kétnyelvű afázia esetén, bár a meglévő adatok száma igen csekély.

Jelen tanulmány különböző neuropszichológiai és nyelvi tesztek alkalmazott a nyelvtani és nyelvi szerkezetek megértésére, valamint a szófolyékonyság, ismétlés, tervezési folyamatok, figyelem, gátló-funkciók, kognitív flexibilitás és munkamemória vizsgálatára. A kutatás a végrehajtó funkciók zavarának lehetséges negatív hatásait vizsgálta megnevezés esetén (lassult teljesítmény, válaszüti növekedése és/vagy pontosságcsökkenés). Emellett megvizsgáltuk, hogy a szófolyékonyságot mérő feladatokban nyújtott gyenge teljesítmény korrelál-e a megnevezésben nyújtott teljesítménnyel. Ennek vizsgálatára a Boston Megnevezési Tesztet, valamint egy szemantikai szófolyékonyság tesztet alkalmaztunk. A vizsgálat célja továbbá az volt, hogy összehasonlítsuk az egy és kétnyelvű afáziás személyek feltételezett munkamemória károsodását. Ennek vizsgálatára vizuális és verbális munkamemória feladatokat alkalmaztunk, mint például a Vizuális Szekvenciális Memória Teszt, a Rey-Osterrieth Komplex B (ROCF-B) ábra és az Auditív Szekvenciális Memória Teszt. Feltételeztük, hogy mindkét afáziás csoport vizuális és verbális munkamemória teljesítménye sérülést mutat. Továbbá a feltételezett kognitív flexibilitási zavarok vizsgálatára a Trail Making Tesztet (TMT), valamint egy szám és betű sudoku feladatot is alkalmaztunk. A hallás utáni szövegértési hiányosságokat a Token teszttel és a TROG teszt magyar változatával mértük. A nyelvi és nem nyelvi tesztekben mért végrehajtó funkciók zavarának vizsgálata mellett a tanulmány a fluens és non-fluens afázia típusok közötti teljesítménybeli különbségeket, valamint az életkor és az iskolai végzettség teljesítményre gyakorolt hatását is vizsgálni kívánta. Végül, a tanulmány megvizsgálta a nem nyelvi tesztekben a kétnyelvű afáziás egyének feltételezett jobb teljesítményét az egy- és kétnyelvű afáziásokhoz képest.

A több esetet vizsgáló tanulmányban összesen 54 fő vett részt, köztük 10 egy- és 8 kétnyelvű afáziás, valamint 36 neurológiai problémákkal nem rendelkező egészséges személy. Az afáziás személyeket a stroke-ot követő krónikus felépülési szakaszban vizsgáltuk, különböző afázia típusokkal. Az egy és kétnyelvű afáziás személyek teljesítményét összehasonlítottuk a referenciacsoporttal, amely életkorban, nemben, iskolai végzettségben, nyelvsajátítási korban, illetve első és második nyelv ismeretében megegyezett. Minden kétnyelvű személy párhuzamosan használta a két nyelvet. A kétnyelvű résztvevők első nyelve a horvát vagy a magyar volt, a második nyelvet: a magyart, a horvátot, a szlovákot vagy a németet pedig különböző életkorban sajátították el. Minden résztvevő több alkalommal egyénileg került tesztelésre.

A munkamemória tesztek (Auditív és Vizuális Szekvenciális Memória Teszt, ROCF-B) és a kognitív flexibilitást mérő tesztek (TMT, szám és betű sudoku) eredményei a referenciacsoportokhoz képest általános lassúságot és csökkent pontosságot mutattak minden feladatban az egy és kétnyelvű afáziás személyek esetében. Ezenkívül a kognitív készségek, mint például a gátló-funkció, munkamemória, feladatváltás, vizuális figyelem, vizuális memória, motoros programozás és tervezés zavara nem függött össze az afázia típusával. Minden afáziás résztvevő jelentős eltérést mutatott minden nyelvi feladatban a referenciacsoportokhoz képest. Bár a kétnyelvű afáziás csoport jobban teljesített, mint az egy- és kétnyelvűek, ezek a különbségek statisztikailag nem bizonyultak szignifikánsnak.

Továbbá a nyelvi tesztek eredményei (Token, TROG, Boston Megnevezési Teszt, szófolyékonyságot mérő feladatok) szignifikáns különbséget mutattak mindkét afáziás csoport és a referenciacsoportok között hallás utáni megértésben, megnevezésben és szófolyékonyságban. Az eredmények kimutatták, hogy minden afáziás személy szignifikánsan rosszabbul teljesített a betű szófolyékonyság feladatban, a megnövekedett végrehajtó funkciók követelményei miatt.

A fluens és non-fluens afáziások közötti vizsgálat kimutatta, hogy a non-fluens afáziás személyek mind a nyelvi, mind a nem nyelvi tesztekben nagyobb mértékű sérülést mutattak a fluens afáziásokhoz képest. A tanulmány továbbá rávilágít az életkor és az iskolai végzettség jelentős hatásaira a nyelvi és nem nyelvi tesztek teljesítésében mind az afáziás, mind a referenciacsoport esetében. Míg az iskolai végzettség pozitívan korrelált a teljesítménnyel, az életkor hatása eltérő volt.

A jelen tanulmány kimutatta, hogy a végrehajtó funkciók zavara negatív hatással lehet a megnevezésre, megértésre és a szófolyékonyságra. Az eredmények értelmezése során figyelembe kell vennünk a neurális hálózatok funkcionális változatait és az afázia szakirodalomban rendelkezésre álló pszichofiziológiai adatokat. Az eredmények hozzájárulnak a kétnyelvű afázia esetében a végrehajtó funkciók zavara kevésbé feltárt területének megértéséhez, illetve rávilágítanak a személyre szabott terápia és a kétnyelvű afázia esetén a végrehajtó funkciók zavarának további feltárásának szükségességére.

Kulcsszavak: *végrehajtó funkciók, munkamemória, kognitív flexibilitás, afázia, kétnyelvű afázia, szófolyékonyság, megnevezés, több esetet vizsgáló tanulmány*

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List of Abbreviations

- ACE-R-** Addenbrooke's Cognitive Examination Revised
- AoA-** Age of Acquisition
- AQ-** Aphasia Quotient
- ASMT-** Auditory Sequential Memory Test
- BNT-** Boston Naming Test
- bHP-** bilingual healthy participants
- bPWA-** bilingual people with aphasia
- EC-** executive control
- ECDF-** empirical cumulative distribution function
- EFs-** executive functions
- fMRI-** functional Magnetic Resonance Imaging
- KS-** Kolmogorov-Smirnov
- L1-** first language
- L2-** second language
- MCA-** middle cerebral artery
- mHP-** monolingual healthy participants
- mPWA-** monolingual people with aphasia
- MTA-** mixed transcortical aphasia
- PWA-** persons with aphasia
- RT-** response time
- ROCF-B-** Rey-Osterrieth Complex Figure B
- TBI-** traumatic brain injury
- TMA-** transcortical motor aphasia
- TROG-H-** Hungarian version of Test for Reception of Grammar
- TSA-** transcortical sensory aphasia
- TT-** Token Test
- TMT-** Trail Making Test
- VSMT-** Visual Sequential Memory Test
- WAB-** Western Aphasia Battery
- WCST-** Wisconsin Card Sorting Test
- WM-** working memory
- WMC-** working memory capacity
- WSR-** Wilcoxon signed-rank

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INTRODUCTION

The study of bilingualism has been a significant topic of interest in recent years, particularly in the field of language disorders. Aphasia, a language disorder resulting from brain damage, presents unique challenges in understanding the cognitive processes underlying language impairment. Traditionally, researchers in the field of neuropsychology and linguistics have focused on language deficits as the primary symptom of aphasia following a stroke. It is now evident that individuals diagnosed with aphasia do not only experience language impairments but also cognitive deficits (Purdy 2002; Murray 2012). Investigating the interactions between language and executive functions is crucial because cognitive impairments may worsen communication difficulties and slow down the rehabilitation process. Despite their significant influence on each other, the role of executive functions has not been extensively studied in the existing aphasia literature, neither in monolingual (Murray, 2017; Schumacher et al., 2019) nor in bilingual people with aphasia (Mooijman et al., 2022). Furthermore, brain incidents causing aphasia in bilingual individuals may present unique challenges in terms of language impairment and recovery. Although investigations of bilingual aphasia emerged in the late 1990s and continues in the 2000s (Gitterman et al., 2012), the current data available in the literature is still limited, especially on anomia and working memory. As a result, there is a significant gap in the relevant literature on the characteristics of their cognitive flexibility and working memory, a system responsible for temporal holding and manipulating information, crucial for language processing and communication. This study seeks to bridge this gap by providing data acquired by testing executive functions in monolingual and bilingual individuals with aphasia, thereby exploring the potential for a bilingual advantage in aphasia population. In addition, it aims to examine how executive functions and verbal fluency are linked in individuals with mono-and bilingual aphasia. It also uses verbal semantic and letter fluency tasks to understand impairments in aphasia and investigate the relationship between fluency and naming. The study hypothesises that impaired executive functions will negatively affect performance on fluency, auditory comprehension and naming as well as on non-linguistic working memory and cognitive flexibility tasks. Moreover, the paper investigates performance differences between aphasics and healthy counterparts, as well as between fluent and non-fluent aphasics. Finally, the thesis examines the effects of age and education on performance in both the aphasia and reference groups.

1 THEORETICAL BACKGROUND

1.1 Aphasia

Due to its variable manifestations, the study of aphasia is complex and, therefore, can be conceptualized in various ways. The definition of aphasia varies considerably across different scientific disciplines. From a functional point of view, aphasia can be characterized as a communication impairment that masks the individual's inherent language competence (Kagan, 1995). From a neurolinguistic perspective, aphasia can be seen as a breakdown in specific language areas resulting from a focal lesion (Lesser, 1987). From a cognitive perspective, aphasia is defined as a selective breakdown in language processing itself, underlying cognitive skills or necessary cognitive resources caused by a focal lesion (Ellis & Young, 1988; McNeil, 1982). The damage can lead to impairment in all aspects of language, for instance, phonology, morphology, syntax, semantics and pragmatics. Additionally, it can also affect all language modalities such as speaking, reading and writing (Papathansiou et al., 2013).

Despite these various perspectives, most researchers in the field agree that the following four factors should be considered when defining aphasia, its neurogenic and acquired nature, its impact on language as well as the exclusion of general sensory and cognitive deficits (Chapey, 2008). Neurogenic aphasia always results from brain damage, which can be caused by a stroke, head injury, brain tumour, infection or the surgical removal of brain tissue (Goetz, 2007). Acquired aphasia does not refer to the fact that an individual is born with aphasia but suggests it is characterized by the partial or complete loss of language functions. 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. Importantly, aphasia is not associated with sensory, motor or intellectual problems. These characteristics are crucial in distinguishing aphasia from other neurological disorders that affect language, speech, cognition, movement and perception (Chapey, 2008).

While the definition of aphasia may seem straightforward, there are numerous frameworks (e.g. propositional, concrete-abstract, thought process, unidimensional and multidimensional) that can be used to explore the intricacies of aphasia. A thorough

understanding of the fundamental differences between the various approaches is essential (Chapey, 2008).

In the propositional language frame, people with aphasia struggle to convey specific meanings and integrate words into appropriate contexts. They may habitually use words incorrectly and fail to incorporate them into a range of sentence structures despite being aware of the correct words (Chapey, 2008). In the concrete-abstract framework, individuals with aphasia rely on past experiences to regulate their actions and reactions with abstract language causing difficulties in symbolizing and embedding symbols. Consequently, their language may be comprised more of speech automation, emotional utterances, sounds and concrete words rather than propositional language (Chapey, 2008). According to Wepman's (1976) thought-process framework, aphasia is conceptualized as a thought-process disorder, leading to impaired semantic expressions and difficulty in spontaneous speaking. The impairment of lexical symbols may result in an inability to communicate specific propositional ideas (Chapey, 2008). The unidimensional framework views aphasia as a general language impairment affecting speaking, writing, reading and listening, rejecting the use of various dichotomies (Schuell et al., 1964). This framework proposes that aphasia is not modality-specific but rather represents an inability to recall or retrieve words and languages rules for speech production. Finally, the multidimensional framework suggests that aphasia can manifest in different forms based on distinct underlying lesion sites, resulting in each individual exhibiting unique symptoms who can be classified into different categories based on their specific expressions (Chapey, 2008).

1.1.1 Subtypes (fluent and non-fluent aphasia)

There are two subtypes of post-stroke aphasia: fluent (e.g. Wernicke's, conduction, transcortical sensory and anomic) and non-fluent (e.g. Broca's, global, transcortical motor and mixed transcortical). Fluent aphasia is a condition where the ability to comprehend spoken words is impaired, while the ability to produce connected speech remains relatively unaffected. However, speech is frequently incoherent and may contain irrelevant words, especially in severe cases (Hedge, 2024). The individual may also experience impairment in their reading and writing abilities (Chapey, 2008). Those with fluent aphasia are able to engage in spontaneous conversation but with the use of meaningful fillers and without prolonged pauses. Individuals demonstrate effortless

speech production characterised by good articulation, typical prosody and a normal phrase length of five to eight words per phrase (Hedge & Freed, 2022; Hickok & Poeppel, 2004). In contrast, non-fluent aphasia is a condition that is characterised by severely impaired language production, while the ability to comprehend spoken words remains relatively intact (Clough & Gordon, 2020). Individuals with non-fluent aphasia often exhibit a reduced rate of speech with some exhibiting nonverbal communication alone. Their speech is marked by excessive effort, slow rate, limited phrase length and complexity, abnormal prosody as well as difficulty imitating speech. Furthermore, their ability to read and write is typically impaired (Pléh & Lukács, 2014; Hedge, 2024). The main characteristics of subtypes (*non-fluent with Italic*) of aphasia are presented in Table 1.

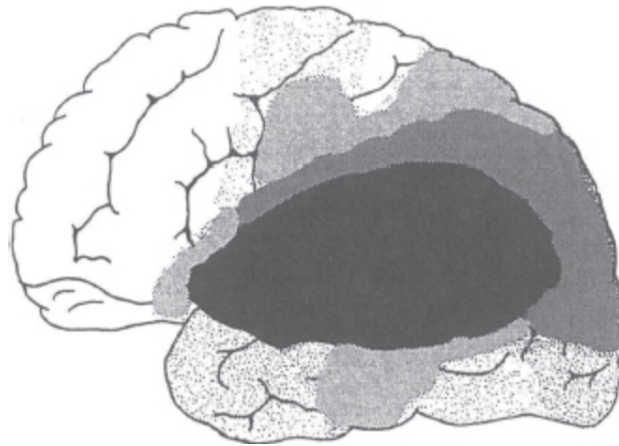
Table 1. Main characteristics of subtypes of aphasia

Aphasia type	Speech	Comprehension	Repetition	Naming
Wernicke’s	fluent, empty	poor	poor	poor
Conduction	fluent	good	poor	poor
Transcortical sensory	fluent	poor	good	poor
Anomic	fluent with circumlocutions	good	good	poor
<i>Broca’s</i>	<i>poor</i>	<i>good</i>	<i>poor</i>	<i>poor</i>
<i>Global</i>	<i>extremely poor</i>	<i>poor</i>	<i>poor</i>	<i>poor</i>
<i>Transcortical motor</i>	<i>little</i>	<i>good</i>	<i>good</i>	<i>poor</i>
<i>Mixed transcortical</i>	<i>extremely poor</i>	<i>poor</i>	<i>good</i>	<i>poor</i>

In 1874, Carl Wernicke, the prominent German neuropsychiatrist, first characterized a form of aphasia which he termed “sensory aphasia”. This clinical syndrome, now commonly known as Wernicke’s aphasia, is well-established in the field as it is one of the earliest identified subtypes of aphasia (Chapey, 2008). The condition is characterised by the production of fluent verbal output that is grammatically correct but contains paraphasias and neologisms. In contrast, auditory comprehension is severely impaired. The neuroanatomical basis of Wernicke’s aphasia is primarily localized to the posterior portion of the superior temporal gyrus in the left hemisphere (Hedge,2024). In some cases, the lesion may extend beyond this region (see Figure 1), affecting additional areas

such as the second temporal gyrus, the surrounding parietal lobe, the angular gyrus and the supramarginal gyrus (Fridriksson et al., 2018; Hickok & Poeppel, 2004).

Figure 1. Neuroanatomical basis of Wernicke’s aphasia. The darker region indicates the primary lesion site observed in most cases, while lighter shaded areas represent other potentially involved regions (Hedge, 2024, p. 125).

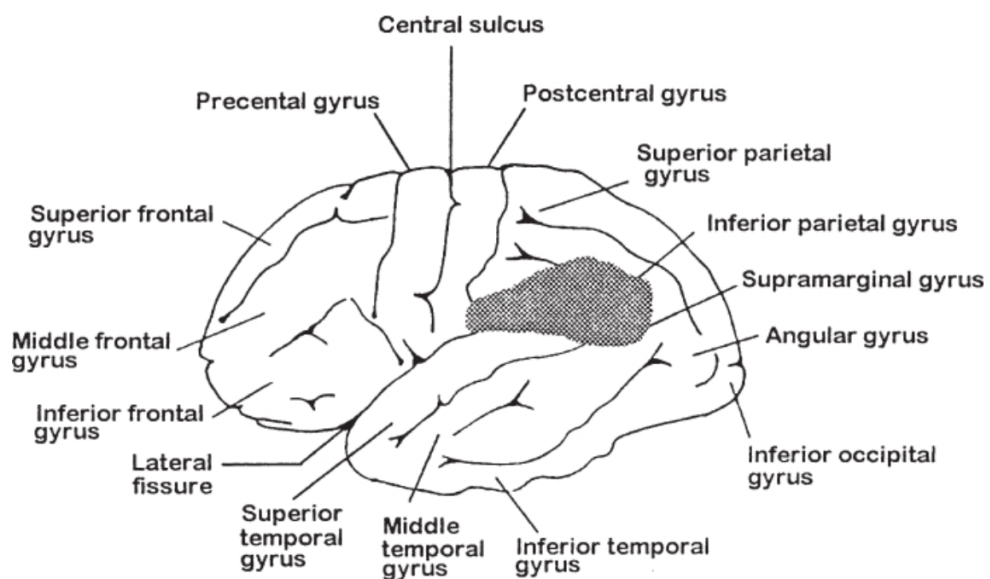


The regions impacted by damage related to the Wernicke’s area are provided with “a blood supply by the posterior branches of the left middle cerebral artery (MCA)” (Hedge, 2024, pp.123-125). Unlike individuals with Broca’s aphasia, sufferers tend to exhibit no paresis or paralysis. Individuals with Wernicke's aphasia exhibit relatively fluent speech with normal prosody and articulation as well as generally intact grammatical structures. However, they often struggle to recall words, frequently providing descriptions instead of naming objects. They may perform better at pointing to correct objects when the options are limited. Their speech is often empty, filled with semantic and literal paraphasias as well as meaningless words. Although the primary characteristic of Wernicke's aphasia is severely impaired auditory comprehension, the specific patterns of this deficit can vary. Additionally, these individuals typically exhibit impaired repetition, reading and writing skills. Furthermore, they may also display behavioural symptoms such as lack of awareness of their disability, depression and paranoia (Chapey, 2008; Hedge, 2024; Papathansiou et al., 2013).

Conduction aphasia is a rare type of fluent aphasia. Individuals with conduction aphasia share symptoms to those who have Wernicke’s aphasia, but their speech is less fluent (Hedge, 2024). A notable distinction is that their auditory comprehension is almost

normal with only structures that are grammatically more complex posing difficulties. The neuroanatomical basis of conduction aphasia is more controversial compared to other subtypes. Lesions along the left posterior temporal-parietal boundary are often cited as the causes of conduction aphasia with either the superior temporal gyrus, supramarginal gyrus or both potentially affected (Benson & Ardila, 1996; Hedge, 2024; Hedge & Freed, 2022; Hickok & Poeppel, 2004), please refer to Figure 2.

Figure 2. Neuroanatomical basis of conduction aphasia. The shaded area is the most common site of lesion (Hedge, 2024, p. 132).

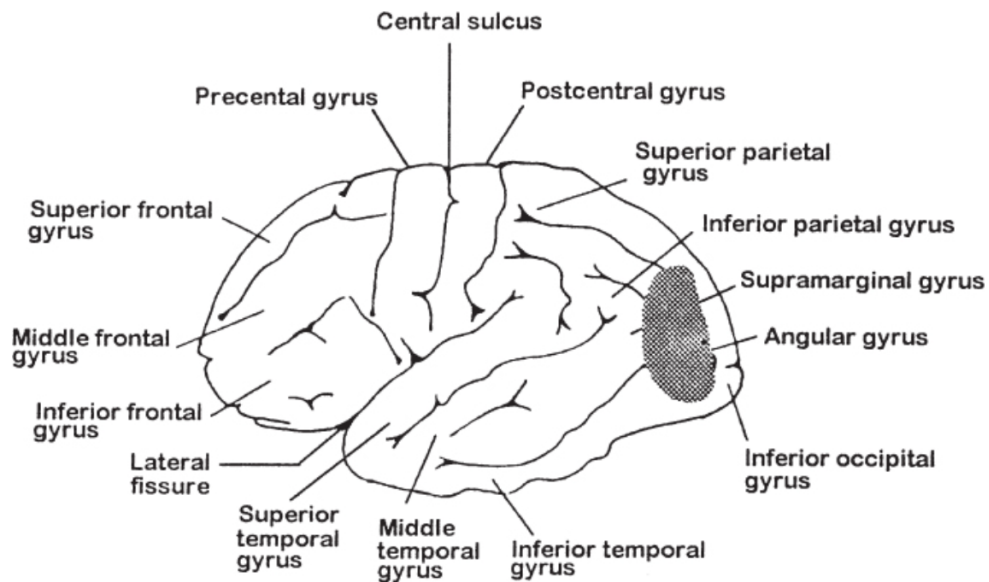


The language deficits for those with conduction aphasia include impaired repetition as well as fluent and paraphasic speech with naming difficulties (Papathansiou et al., 2013). These individuals often make the effort to correct their speech errors. Conduction aphasia is characterised by acceptable syntactic and prosodic features which distinguish it from Broca’s aphasia (Hedge, 2024).

Transcortical sensory aphasia (TSA) is classified as a fluent type of aphasia, sharing similarities with Wernicke’s aphasia. However, it can be distinguished from Wernicke’s aphasia by the preserved ability of sufferers to repeat words and phrases accurately. The primary cause of TSA is often attributed to a lesion in the temporoparietal lobe (Hedge, 2024). Damage to the posterior portion of the middle temporal gyrus is typical (Chapey, 2008). Additional involvement may occur in the lateral aspects of the occipital lobe, the angular gyrus as well as visual and auditory association cortices (Hedge, 2024). Notably, the Wernicke’s area, Broca’s area and arcuate fasciculus typically remain intact. The

cortical regions of the dominant hemisphere that are commonly impaired in TSA are located in the watershed areas of the MCA (Benson & Ardila, 1996; Hedge, 2024; Hedge & Freed, 2022). Figure 3 illustrates the neuroanatomical basis of TSA, with the shaded area indicating the most frequently affected region.

Figure 3. The neuroanatomical basis of TSA (Hedge, 2024, p, 129)

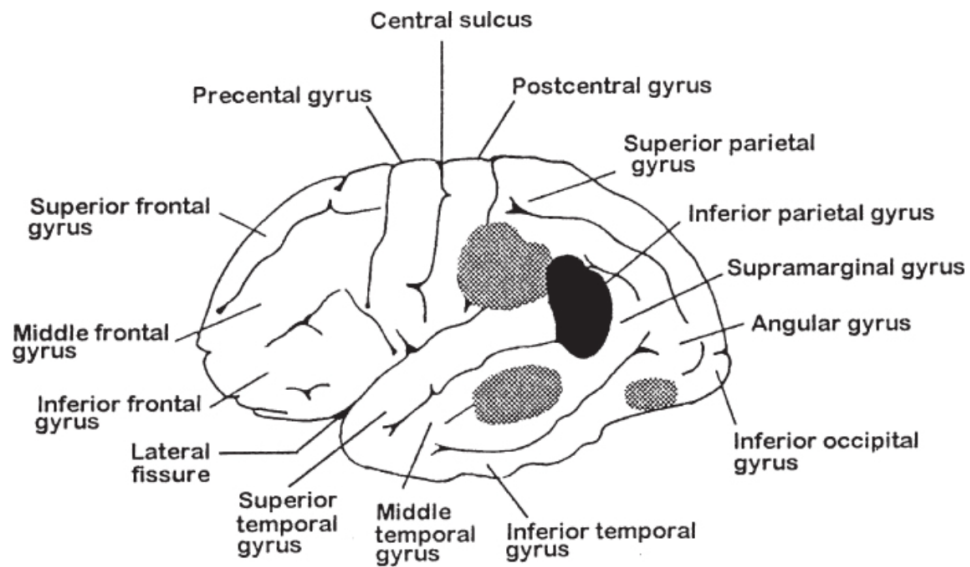


At the onset of TSA, individuals may experience hemiparesis, however, should they recover well, significant physical symptoms may not be exhibited later on (Hedge, 2024). Individuals with TSA typically exhibit good articulation as well as normal phrase length and prosody. Their speech may feature both semantic and neologistic paraphrasing, resulting in empty speech (Papathansiou et al., 2013). These individuals also demonstrate poor confrontation naming abilities, often providing descriptions instead of directly naming objects. In contrast to those with Wernicke’s aphasia, individuals with TSA can repeat words and phrases, although many struggle to understand even simple commands. Over time, some individuals with TSA may develop anomia, from which some may eventually fully recover (Hedge, 2024).

Anomic aphasia is also known as amnesic, amnesic aphasia or nominal aphasia (Papathansiou et al., 2013). Anomic aphasia is regarded as the mildest and most controversial subtype of aphasia. Its status as a reliable syndrome of aphasia is disputed due to the high degree of 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; Helm-Estabrooks & Albert, 2004), as shown in Figure 4.

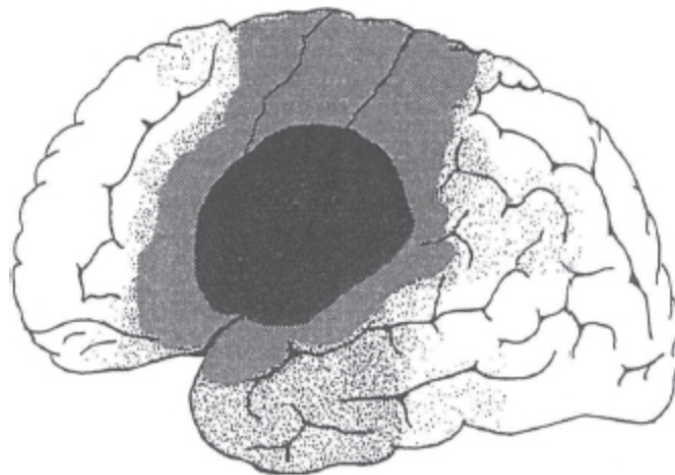
Figure 4. Potential brain areas involved in anomic aphasia. The darker and lighter-shaded areas represent several possible sites of lesion (Hedge, 2024, p. 135).



Anomia is a naming difficulty and is a common symptom observed across various subtypes of aphasia, moreover, may 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. It is therefore essential to distinguish between anomia as a symptom and anomia as a syndrome (Hedge, 2024). Their speech is generally fluent apart from pauses due to word-finding difficulties (Papathansiou et al., 2013). 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 as well as normal or near-normal oral reading and writing (Chapey, 2008). The specific symptoms of naming difficulties may vary depending on the location of the lesions. For example, if the lesions are situated in the more frontal areas, phonemic cues may evoke a naming response. Additionally, the endless repetition of a word with no comprehension of its meaning is associated with lesions in the angular gyrus (Hedge, 2024). Individuals are unable to produce certain words, especially common nouns, nor match words to their meanings and pronounce them correctly (Pléh & Lukács, 2014).

The neuroanatomical basis of Broca’s aphasia is classically associated with a lesion in “the posterior part of the inferior (third) frontal gyrus, the insula and the frontal operculum (the most posterior portion of the inferior gyrus [Broca’s area, also known as Brodmann’s area 44] is part of the operculum)” (Papathanasiou et al., 2013 p. 42). However, it is important to note that the precise location of the lesion in cases of Broca’s aphasia can be ambiguous (Ardila et al., 2016; Fridriksson et al., 2014; Hedge, 2024; Kim et al., 2019). In their 2018 study, Mirman and colleagues found that prevailing research indicates that phonetic errors may arise from impairments to the postcentral gyrus and supramarginal gyri. On the other hand, sentence production may be influenced by damage to the inferior and middle frontal gyri as well as the underlying white matter. Moreover, deficits in phonetic-articulatory planning and execution may result from damage to “the postcentral and supramarginal gyri, which are situated within the parietal regions” (Hedge, 2024, p. 111). Figure 5 presents possible brain areas that may be involved in Broca’s aphasia.

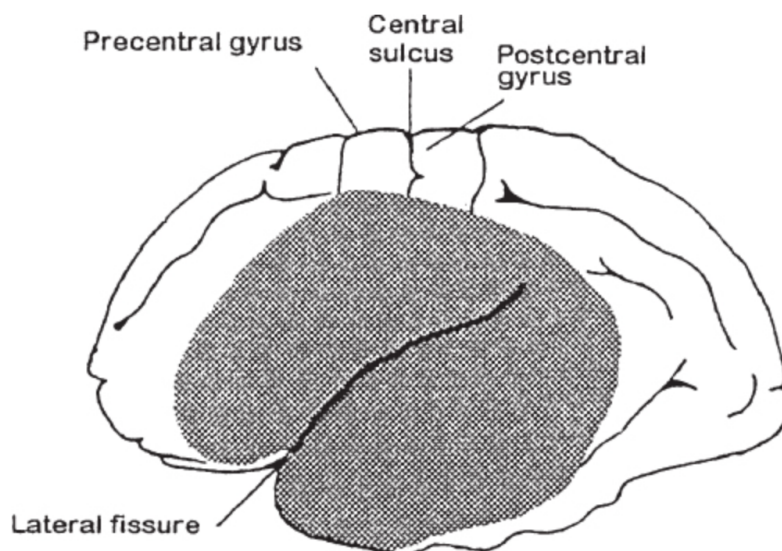
Figure 5. Potential brain areas involved in Broca’s aphasia. The darkest area is the most common location of damage, while lighter areas show other possible locations (Hedge, 2024, p. 113).



The language disorders commonly associated with damage to the Broca’s area are more prevalent during the acute phase of the recovery rather than in the chronic phase (Hedge, 2024). Some individuals diagnosed with Broca’s aphasia may have initially experienced global aphasia at the onset of a stroke. The clinical presentation of Broca’s aphasia may vary considerably, ranging from a complete loss of speech to a mild deficit characterised by simple word-finding difficulties (Chapey, 2008). Broca’s aphasia is

frequently accompanied by motor speech disorders such as apraxia and dysarthria. Apraxia refers to difficulty in initiating speech in the absence of weakness or paralysis of the speech musculature. Dysarthria, on the other hand, is caused by muscle weakness that impairs respiratory, phonatory and articulatory movements (Hedge, 2024). In Broca's aphasia, speech production is laborious, non-fluent and consists of short phrases or single words. Speech is often filled with many pauses (resulting in an uneven speech rate), revisions, sound and syllable prolongations as well as repetitions (Hedge, 2024). Broca's aphasia is particularly characterized by agrammatism (speech is limited to nouns and verbs) and awkward articulation (Goodglass et al., 2001). Individuals with this type of aphasia find repeating modelled utterances significantly difficult, for example, they often omit grammatical elements while repeating. Confrontation naming (e.g. "What is this?") is extremely impaired (Hedge, 2024). Auditory comprehension may be better than in individuals with Wernicke's aphasia. In general, writing and reading skills are similarly impaired to speech production. Writing is typically slow and agrammatic with many spelling errors. Oral reading is laborious and non-fluent, moreover, the comprehension of the written texts is impaired (Hedge, 2024). People with Broca's aphasia are typically aware of their communication difficulties and are more prone to depression than other people with different subtypes of aphasia (Chapey, 2008).

Figure 6. Neuroanatomical basis of global aphasia (Hedge, 2024, p. 122)



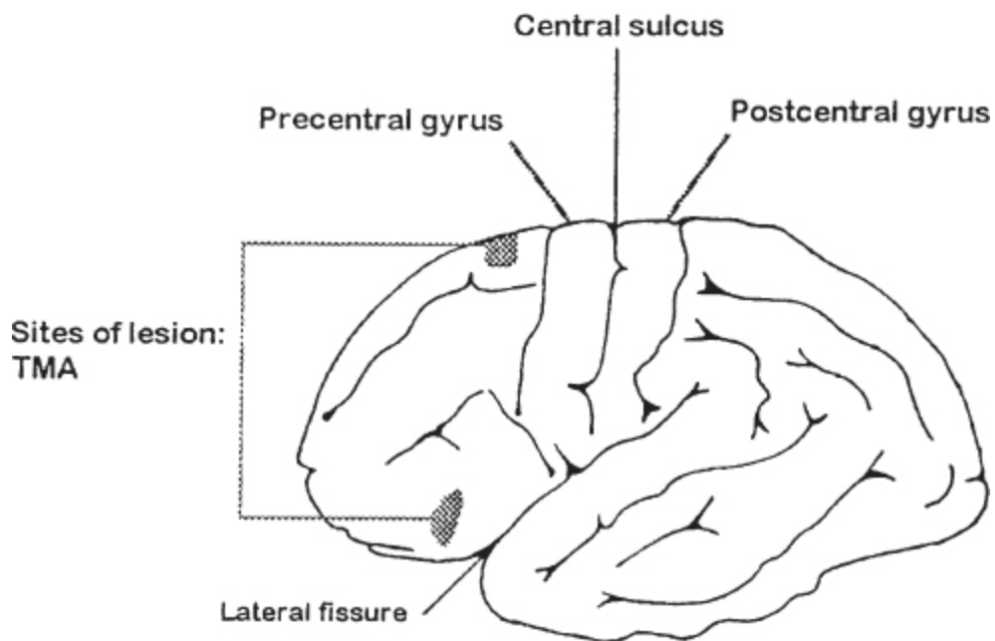
Global aphasia is widely acknowledged as the most severe form of aphasia (Hedge & Freed, 2022; Hedge 2024; Squire, 2009). The neuroanatomical basis of global aphasia is

commonly linked to lesions in the entire perisylvian region. Besides affecting the Broca's and Wernicke's areas, damage may extend further into the basal ganglia, internal capsule and thalamus (Bhatnagar, 2017). The affected regions are supplied by the middle cerebral artery. Figure 6 presents the neuroanatomical basis of global aphasia.

Strong neurological symptoms include right-sided hemiparesis or hemiplegia as well as right-sided sensory loss (Hedge, 2024). It is predominantly characterised by the impaired comprehension and expression of language, moreover, is often regarded as a combination of Wernicke's and Broca's aphasia (Chapey, 2008). Individuals with global aphasia tend to have little or no understanding in all modalities and their ability to communicate is severely impaired as they are only able to produce a few utterances (Papathanasiou et al., 2013). They are deficient in terms of speech production and language processing, moreover, repetition, naming, reading and writing are all impaired (Goetz, 2007; Squire, 2009). Nevertheless, it is possible that some individuals may still be able to produce automatic phrases and overlearned expressions (Papathansiou et al., 2013). The symptoms of this condition may evolve over time. For example, global aphasia at the onset may develop into Broca's, Wernicke's, anomic or conduction aphasia. Although, the prognosis is generally poor, there is potential for improvement in communication skills through the implementation of an appropriate treatment plan (Hedge, 2024).

Transcortical motor aphasia (TMA) is another type of non-fluent aphasia in which the ability to repeat words is intact. Otherwise, language impairments are like those seen in Broca's aphasia. The neuroanatomical basis of TMA is usually associated with lesions outside the Broca's area with the anterior superior frontal lobe most commonly involved. Lesions are often located "in deep parts of the left frontal lobe (impacting the prefrontal and premotor cortices) or below or above the Broca's area" (Chapey, 2008, p. 32). The areas supplied by the anterior cerebral artery and the anterior branch of the middle cerebral artery are often affected, moreover, the watershed region between the middle cerebral and anterior cerebral arteries may also be impacted (Hedge, 2024). Hemiparesis is common (legs more affected than arms). Figure 7 shows the most common lesion sites of TMA.

Figure 7. Most common neuroanatomical lesion sites of TMA (Hedge, 2024, p. 117)



Individuals with TMA often exhibit language characteristics such as muteness, echolalia (repetition of heard speech) and preservation (multiple repetitions of one’s own utterances) (Hedge, 2024). They also often struggle to imitate and form responses in conversations (Damasio, 1998). The most distinctive feature of TMA is a remarkably preserved repetition skill, even if the individual can only provide single-word responses. They can correctly repeat a long and complex sentence (Goodglass et al., 2001). Persons with TMA tend to lack interest in verbal communication. Recovered speech in TMA sufferers resembles that of Broca’s aphasia with the absence of complex and precise syntactic structures. Confrontation naming difficulties may improve with various cues (e.g. semantic and phonemic cues) but auditory comprehension is impaired (Chapey, 2008). Comprehension is generally preserved with regard to simple conversations but may be impaired during complex speech. Word fluency is limited. Ultimately, the preserved repetition skills serve as the most prominent distinguishing factor between TMA and Broca’s aphasia (Hedge, 2024).

Mixed transcortical aphasia (MTA) is a rare variety that includes features of both fluent and non-fluent varieties (Benson & Ardila, 1996; Hedge, 2024; Hedge & Freed, 2022). MTA is characterised by a combination of symptoms of transcortical motor and transcortical sensory aphasia. The condition is defined by relatively preserved repetition

skills despite significant impairment in both language comprehension and production. In this regard, MTA shares similarities with global aphasia as both syndromes are characterised by extensive and often severe language impairment. Nevertheless, MTA is different from global aphasia because of the relatively preserved repetition skills like in TMA. The neuroanatomical basis of MTA is associated with the cerebral border zone or the watershed area (Hedge, 2024). This region is positioned between the areas supplied by the MCA on the one hand and the anterior as well as posterior cerebral arteries on the other. Additionally, the Broca's and Wernicke's areas may remain intact but become isolated from the rest of the brain (Benson & Ardila, 1996; Hedge & Freed, 2022). The arcuate fasciculus- "a crucial neural pathway that connects the frontal, parietal and temporal lobes"- may also remain unaffected (Hedge, 2024, p. 119). Individuals with MTA exhibit severely limited spontaneous speech, echolalia as well as markedly impaired fluency and naming. They also demonstrate extremely weak reading and writing skills (Papathanasiou et al., 2013).

1.1.2 Assessment of and recovery from aphasia

The assessment process requires not only the use of aphasia batteries but neuropsychological and cognitive assessments as well due to the fact that this information is fundamental in clarifying the breakdown in language and communication. Assessment is an organized, goal-directed evaluation of the principal components of communication with regard to cognitive, linguistic and pragmatic components (Chapey, 2008). According to Byng et al., "the nature of the language impairment indicates what aspects of language performance are more appropriate for treatment" (Byng et al., 1990, p. 67). A thorough, specific and detailed assessment is required in order to provide the best-quality treatments for individuals with aphasia. The general purposes of the assessment are to describe communicative strengths and weaknesses, identify existing problems, set goals as well as define factors related to language use, comprehension and production (Murray & Chapey, 2011). In the case of complex issues, the assessment varies according to the phase (acute, subacute or chronic) as well as the severity of the communication, physical or emotional disorder.

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 stroke incident. The chronic phase occurs after six

months (Kiran, 2012). The longest period for language recovery following the onset of aphasia is typically within the first three months. Since the rate of spontaneous recovery declines after six to seven months and ceases after one year (Kertesz & McCabe, 1977; Vignolo, 1964), the rate of recovery slows down after the first month and then remains constant for approximately 6 to 12 months. Most patients with aphasia reach a point where their language function does not improve any more within 2 to 6 weeks following the stroke. After 3 months, their language abilities are like those measured after 12 months (Chapey, 2008). Although the process of long-term recovery following a stroke may continue for a period of months or even years, the extent of recovery observed in individual patients can vary considerably. Some patients demonstrate significant improvement, whereas others exhibit stabilization or even regression, particularly those with relatively mild aphasia symptoms (Chapey, 2008). In conclusion, the existing literature suggests that aphasia therapy may be advantageous during both the acute and chronic phases of recovery (Brady et al., 2016; Cicerone et al., 2011; Faroqi-Shah et al., 2010; Simmons-Mackie et al., 2016). However, the longstanding clinical and scientific observation persists that some individuals either fail to demonstrate improvement or are unable to sustain gains achieved through therapy (Chapey, 2008).

Despite extensive research, the evidence on aphasia recovery is inconclusive. Age, lesion location and aphasia severity are significant variables, but their relationships are complex, and outcomes can vary considerably. The brain's neuroplastic properties tend to diminish with age, implying age may significantly impact aphasia recovery, however, this effect could be confounded by aphasia severity, as older patients are more prone to severe aphasia (Kristinsson et al., 2022). Furthermore, research indicates that the location and severity of the brain lesion can predict language recovery. Individuals with more severe aphasia at the onset of their stroke tend to demonstrate smaller improvements in the initial stage and poorer long-term outcomes, with greater language difficulties. Nevertheless, some studies have found that individuals with severe aphasia can benefit from therapy and achieve significant improvement in their language abilities during both the acute and chronic phases of recovery (Simic et al., 2020). Another important factor in aphasia recovery is neuroplasticity. Studies show that the most significant changes in the neural structures for language occur in the acute and subacute phases of recovery. Neuroplasticity continues to play a role even in the chronic phase of recovery (Kiran & Thompson, 2019).

1.1.3 Post-stroke aphasia

A stroke, also known as a cerebrovascular accident, is the most common cause of aphasia. "A stroke occurs when blood flow to an area of the brain is interrupted by the blockage of a blood vessel or artery or by the rupture of an artery" (Chapey, 2008, p. 10). The transport of vital nutrients, particularly glucose and oxygen, which are crucial for the sustenance of brain cells, occurs through the bloodstream. As brain cells lack the capacity to store these essential nutrients, they depend on a continuous supply of blood. Consequently, even brief periods of interruptions in the blood supply to the brain can result in long-lasting and devastating effects on brain tissue (Chapey, 2008).

The classification of strokes is based on their vascular pathology with the categorisation as either ischemic or haemorrhagic. Ischaemic strokes are caused by the complete or partial blockage of arteries (Hedge, 2024). When blood flow to a specific area falls below a critical threshold required for the maintenance of cellular function and elimination of toxic waste, cell death occurs, resulting in the development of an infarct as well as the subsequent necrosis and loss of tissue (Plum & Posner, 1980; Raichle, 1983). In regions affected by ischaemic conditions, a central area of infarction is typically observed surrounded by an ischaemic zone known as the penumbra (Schlaug et al., 1999). The primary objectives of treatment are to implement early intervention to prevent infarction as well as ensure the ischaemic zone is safeguarded to restrict the expansion of the infarct and minimise functional impairment (Chapey, 2008). As stated by Hedge (2024, p. 77), "Haemorrhages cause the second most common variety of strokes. Haemorrhagic strokes are those that result from ruptured cerebral blood vessels that cause cerebral bleeding, as contrasted with ischaemic strokes resulting from occlusion of blood vessels." Patients who have experienced either ischaemic or haemorrhagic strokes tend to demonstrate divergent patterns of recovery. In the case of ischaemic stroke, recovery is more pronounced and occurs more rapidly, with the initial stage of recovery being most evident within the first few weeks. Conversely, in the case of a haemorrhagic stroke, recovery is minimal in the initial 4 to 8 weeks, followed by a more rapid recovery that eventually slows down and stabilises, resulting in significant residual deficits (Hedge, 2024).

Furthermore, it is important to note that aphasia is a significant long-term consequence for 10-38% of post-stroke patients (Lee et al., 2015). Beyond linguistic deficits, individuals with aphasia frequently experience emotional and psychological changes and the condition is a strong predictor of emotional distress and social isolation (Thomas & Lincoln, 2008). Consequently, it is crucial for tailoring effective therapy, which could improve overall quality of life for post-stroke patients.

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 likelihood of bilingual aphasia. Individuals are considered 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, premorbid proficiency in each language as well as the nature and location of brain damage. Questions concerning bilingual aphasia, e.g. the nature of impairment, remain unanswered (Gitterman et al., 2012).

1.2.1 Subtypes (parallel and selective)

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 (Gitterman et al., 2012). 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).

1.2.2 Assessment of and recovery from bilingual aphasia

Studying bilingual aphasia provides a unique opportunity to examine how two languages are affected within the brain. This allows for a systematic investigation of various aspects of this complex and dynamic process. However, studying these individuals presents several challenges. Each person has a unique language learning experience and the amount of exposure to each language determines how their language impairment manifests. Unlike monolingual aphasia, where the individual's proficiency in the language is presumed to be complete before the stroke, in bilingual aphasia, it is not possible to assume that the level of proficiency in both languages is 100% (Miller et al., 2018). Consequently, the proficiency levels in each language must be assessed through a language use questionnaire. Furthermore, this information is obtained after a stroke and is only an estimate of proficiency prior to the event. The dynamic nature of bilingualism and aphasia means that research on bilingual aphasia can yield a wide variety of findings. The factors that affect the interpretation of a bilingual individual's language abilities before a stroke can make it challenging to accurately assess their language impairment after a stroke. As a result, patients with similar pre-stroke language learning profiles may exhibit markedly different language impairment profiles, while those with diverse post-stroke language learning profiles may display strikingly similar language impairment profiles (Gray & Kiran, 2015; Kiran & Roberts, 2012). The age of acquisition and the extent of language proficiency are key factors that shape bilingual language representation in healthy individuals. When considered alongside other variables such as the site and size of the lesion, which are specific to aphasia and brain damage (Fabbro, 2001; Lorenzen & Murray, 2008), understanding the nature of bilingual aphasia represents a significant challenge (Miller et al., 2018).

To gain a better understanding of the nature of language impairment in bilingual aphasia, several tests have been developed such as the Aachen Aphasia Test (Huber et al., 1983), the Western Aphasia Battery (Kertesz, 2006), the Boston Diagnostic Aphasia Examination (Goodglass et al., 2000) and the Bilingual Aphasia Test (Paradis, 1989), facilitating cross-linguistic comparisons of language impairment (Miller et al., 2018). However, these standardised assessments are based on norms for healthy monolingual individuals and patients, making it difficult to establish a normative framework for bilinguals diagnosed with aphasia (Kiran & Roberts, 2012). In addition, it is difficult to

accurately determine pre-stroke language skills in bilingual individuals due to a significant degree of variability in healthy bilingual adults. Moreover, the translation of these tests may introduce biases in terms of the items and difficulty levels, resulting in unequal performance between the two languages (Miller et al., 2018). For instance, this has been demonstrated in the case of the Boston Naming Test (Kohnert et al., 1998; Roberts et al., 2002). Instead of relying on standardized norms, researchers can employ tasks such as category generation and narrative production to assess language abilities in both languages of bilingual patients. Category generation tasks require individuals to list words belonging to a specific category, and by comparing the number of words produced in each language, researchers can estimate any disparities in language performance (Miller et al., 2018). Research has demonstrated that this approach can effectively identify language impairment in bilingual patients (Kiran et al., 2013). Moreover, discourse production tasks can provide insights into a bilingual individual's fluency and complexity in both languages as these tasks not only reveal vocabulary usage but also the structure and coherence of language, thereby enhancing our understanding of the specific areas affected by an impairment (Rivera Mindt et al., 2008). Although further research is required to examine the processes of category generation and narrative production in bilingual aphasia, these represent an important future research direction.

Currently, there is no definitive answer to the question concerning 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 language preference of the immediate environment and the stronger emotional connections. However, research indicates that simultaneous stimulation of both languages can aid rehabilitation (Ansaldo & Marcotte, 2007; Kohnert, 2004). This is particularly relevant for proficient bilingual individuals with aphasia (Ansaldo & Marcotte, 2007), given that the bilingual language system consists of two language codes within a single system. Therefore, persons with bilingual aphasia may encounter a variety of communication settings, ranging from completely monolingual to completely bilingual depending on the context, so that a bilingual intervention approach may be a reasonable option to consider (Gitterman et al., 2012). In conclusion, when deciding which language to focus on in aphasia therapy, it is important to consider which language is less impaired and more important to the patients and their families.

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 to achieve an optimal language recovery, and the improvement of functional communication requires a thorough understanding of the factors and how they interact. Fabbro's (1999) study found that the nature of recovery in bilingual individuals with aphasia manifests in a variety of ways. The research indicates that 40% of persons with bilingual aphasia experience parallel recovery, where the 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) (Fabbro, 1999). Furthermore, Kuzmina et al. (2019) also revealed better performance in the L1 than in L2 among persons with bilingual aphasia in their meta-analysis.

In summary, the results of studies on bilingual aphasia vary greatly due to the dynamic nature of bilingualism as well as the individual factors that can influence language abilities before and after a stroke. Factors such as the age of acquisition of a language and proficiency in each language can impact how a language impairment is exhibited in bilingual individuals after a stroke. This complexity makes it challenging to interpret and compare language impairments in different bilingual patients (Miller et al., 2018).

1.2.3 Language processing in bilingual aphasia

Research in bilingualism has yielded important insights into how the brain processes multiple languages, which has significant implications for understanding aphasia in bilingual individuals. Language processing in bilinguals is a dynamic process influenced by factors like the age of acquisition, proficiency and language dominance (Abutalebi, 2008; De Keyser & Larson-Hall, 2005; Hernandez & Li, 2007). This dynamic interplay between languages can result in unique recovery patterns in bilingual aphasia. For instance, one language might recover better than the other or there might be a simultaneous improvement in both (Millet et al., 2018).

The limitations of our understanding of bilingual aphasia are obvious (Miller et al., 2018) as our knowledge is primarily based on the frequency of different language disorders occurring independently in each language. However, a deeper insight into the

underlying reasons for these occurrences is lacking. There are many influencing factors that make it difficult to draw clear conclusions, e.g. an individual's fluency prior to suffering from aphasia, the age at which they acquired a language and the type of brain injury they suffered, which all contribute to the complexity of the situation. Recent studies have begun to shed light on the processes by which bilingual people with aphasia access and retrieve words (Gray & Kiran, 2013; Kiran et al., 2014; Kiran & Tuchtenhagen, 2005; Kong, et al., 2014; Roberts & Deslauriers, 1999). It appears that an individual's language skills prior to the onset of aphasia have a significant impact on the language difficulties they experience afterwards. Bilingual people with aphasia tend to find it easier to name words that are similar in sound and meaning in their languages, a phenomenon known as the 'cognate advantage' (Roberts & Deslauriers, 1999). Despite the challenges posed by aphasia, the types of errors made by bilingual individuals are often similar to those made by healthy bilinguals (Kiran et al., 2013), suggesting that although bilingual patients with aphasia show lexical retrieval deficits, the underlying mechanism supporting lexical retrieval in naming tasks for bilingual patients with aphasia still reflects bilingual language processing used by healthy bilinguals (Miller et al., 2018).

In 2013, Gray and Kiran conducted a study examining the language disorders in 19 Spanish-English bilingual adults with aphasia. This was the first large-scale study to analyse patient data and identify patterns of language processing disorders across two languages. The researchers created a framework to understand bilingual language processing, including on different levels like comprehension, expression and translation. They validated this framework using standardized tests in Spanish and English. The results demonstrated strong correlations between the language understanding and production of the patients in both languages (Gray & Kiran, 2013). Additionally, the study also revealed that an individual's language ability prior to a stroke could predict their post-stroke communication skills. The researchers identified two groups of patients: one with similar deficits in Spanish and English, and one with varying levels of deficits in both languages. In other words, some individuals exhibited comparable language difficulties in both languages, whereas others demonstrated greater challenges in one language rather than in the other. The capacity to utilise a language prior to the onset of aphasia was identified as a reliable indicator of the extent of recovery (Gray & Kiran, 2013). Overall, the study elucidated that bilingual individuals with aphasia can manifest diverse patterns of language disorders, offering insights into the impact of bilingual

language processing. The significance of this study lies in its demonstration that aphasia can impact bilingual individuals in diverse ways, underscoring the vital importance of understanding their linguistic history to achieve effective rehabilitation (Miller et al., 2018).

Several studies on bilingual aphasia have employed a similar methodology to that used in the investigation of lexical and semantic processing (Miller et al., 2018). This approach has been used to examine the grammatical category as well as morphological performance of nouns and verbs across a range of language pairs (Hernandez et al., 2008; Kambanaros et al., 2012; Tschirren et al., 2011). In general, these studies have demonstrated an association between grammatical categories across languages (e.g., poorer performance in naming verbs compared to naming nouns across languages), indicating that languages share information regarding grammatical categories (Faroqi-Shah & Waked, 2010; Kambanaros et al., 2012). For a partial overview of research on grammatical categories and morphological processes, see a study by Miozzo et al. (2009).

The extant research on bilingualism has consistently demonstrated that the non-target language remains active during language processing, which has been identified as a key factor in language co-activation (Costa et al., 2006; Guo & Peng, 2006; Hoshino & Thierry, 2011; Marian et al., 2003; van Hauen et al., 2008). Nevertheless, the precise mechanisms by which bilinguals resolve this activation in the non-target language remain a topic of debate (Kroll et al., 2008; Costa, 2005; Green 1998). Some studies have proposed an attention mechanism that ignores competitors of the non-target language (Costa, 2005; Finkbeiner et al., 2006), while others have put forth an inhibitory mechanism that influences both the target and non-target languages, allowing bilinguals to access the target language while suppressing the non-target one (Green, 1986; 1998). This ongoing discussion highlights the complexity of bilingual language processing and underscores the need for further investigation into the cognitive strategies utilized by bilinguals to navigate their dual-language environments, particularly in relation to the implications for language impairment assessments in clinical settings (Fricke et al., 2018; Kroll et al., 2015).

1.2.4 Cognitive consequences of bilingualism in aphasia

One of the key findings in the field of bilingualism research is the impact of bilingualism on brain processing and the management of competing information (van den Noort et al., 2019). In case of neurologically healthy bilingual adults, it has been demonstrated that repeated practice in language selection and control can also impact other domains of cognitive control (Kroll & Bialystok, 2013). Early research by Bialystok and colleagues (2004), investigating the bilingual advantage, first demonstrated that bilingual adults exhibited more effective controlled processing than monolinguals, potentially mitigating age-related losses in certain executive processes. In a later study, Bialystok and colleagues (2008) found that bilingualism provides cognitive advantages as evidenced by higher performance in non-linguistic executive function tasks. Furthermore, they found that this advantage was stronger in the older group as the study included both young and elderly participants. Further studies on attentional networks and conflict monitoring tasks have demonstrated that bilingual individuals exhibit enhanced cognitive performance in non-verbal tasks when compared to monolinguals (Costa et al., 2008; 2009). This suggests that the constant management of language activation and control results in an advantage in terms of non-linguistic cognitive control, which may confer lifelong benefits for bilinguals, including protection against neurological decline (Craik et al., 2010; Bialystok et al., 2012). Since the early studies on this topic, dozens of studies have been published, but the results are often inconsistent (Mooijman et al., 2022). Some studies have not been able to reproduce the bilingual cognitive advantage, indicating that bilinguals may not necessarily exhibit more efficient cognitive processing (Gathercole et al., 2014; Kousaie & Phillips, 2012; Paap & Greenberg, 2013). This inconsistency is also present in review articles and meta-analysis as some support fully for an advantage (Adesope et al., 2010; Grundy, 2020), while other only support it partially (Hilchey & Klein, 2011; van den Noort et al., 2019). Moreover, some reviews even suggest that there is no convincing evidence for an advantage (de Bruin et al., 2015; Donnelly et al., 2019; Lehtonen et al., 2018; Paap et al., 2015). In addition, the diversity of tasks, linguistic environments, participant profiles, and selection criteria included across these studies may contribute to the lack of clear resolution on the issue of bilingual advantage as combining these in broader analyses may hide the distinct features linked to better bilingual performance (Bialystok, 2021).

It is also important to note that studies comparing the brain structure of monolingual and bilingual healthy older adults have also reported mixed findings. For instance, some studies found greater grey matter volume in bilinguals (Abutalebi et al., 2014; 2015). While others found no differences (Gold et al., 2013; Olsen et al., 2015) or even poorer volume in bilinguals compared to monolinguals (Anderson et al., 2018). However, participants across these studies performed similarly on cognitive tasks. One potential explanation is that the differences in brain structure between bilinguals and monolinguals may be age-related, as bilinguals tended to show better brain structure around the age of 60, but comparable structure in older age groups (Bialystok, 2021), while Abutalebi and colleagues (2015) found poorer white matter microstructure in bilinguals. In case of older bilinguals around 75 years old Anderson et al. (2018) found that bilinguals had poorer grey and white matter brain structure compared to monolinguals. While studies including young bilingual adults revealed that they generally have greater grey matter volume than monolinguals (Del Maschio et al., 2018; Heim et al., 2019; Li et al., 2014; Pliatsikas et al., 2020).

Task demands should also be considered when examining the bilingual advantage hypotheses in healthy population. The comprehensive review of van den Noort et al. (2019) describes the most frequently employed tasks in bilingual advantage research, revealing that most studies employ the Simon task, attention network test, Flanker task, the classical Stroop task, as well as switching tasks to examine the bilingual advantage in cognitive control and the findings across these various measures are inconsistent. For instance, the Stroop task consistently demonstrates a bilingual advantage across the majority of studies (Blumenfeld & Marian, 2014; Bialystok et al., 2008; Kousaie et al., 2014; Kousaie & Phillips, 2017). The Flanker task also generally supports the bilingual advantage, indicating improved accuracy and processing speed (Emmorey et al., 2008; Costa et al., 2009; Poarch & Bialystok, 2015; Xie, 2018) although some studies report mixed (Kousaie & Phillips, 2017) or null findings (Paap & Greenberg, 2013; van der Linden et al., 2018). Similarly, the attention network test predominantly reveals a bilingual advantage, with faster processing and enhanced performance scores (Costa et al., 2008; Tao et al., 2011; Woumans et al., 2015; Desideri & Bonifacci, 2018), while others reveal no evidence (Bialystok et al., 2010). Findings on task-switching are also mixed, with some studies indicating a bilingual advantage (Marzecová et al., 2013) while others do not (Paap & Greenberg, 2013). Among all these studies, the results for the

Simon task are more ambiguous, with a balance of studies showing the bilingual advantage, mixed results (van den Noort, 2019), and evidence against it, potentially due to the task's simplicity and a ceiling effect (Paap, 2023). According to van den Noort (2019), a potential explanation for the observed results may lie in the fact that both bilingual and monolingual participants, predominantly comprising undergraduate students and young adults, achieved maximum scores in the less challenging cognitive control tasks. Consequently, no significant differences were discernible between the two groups when both had performed at or near the upper limits of their capabilities. This phenomenon may also further elucidate why evidence supporting a bilingual advantage is frequently found among older adults (Schroeder & Marian, 2012; Bak et al., 2014). According to Paap (2023), the variability in task demands across studies may also contribute to the mixed findings in the literature regarding the cognitive advantages of bilingualism.

Studies investigating the effect of age of acquisition on bilingual advantage found that both early and late bilinguals were better in conflict resolution compared to monolinguals, with early bilinguals showing the most benefits (Tao et al., 2011). Furthermore, studies investigating early balanced bilinguals and trilingual individuals, found that trilingual individuals had advantages in inhibitory and attentional control, while bilinguals only showed an advantage in inhibitory control compared to monolinguals (Hsu, 2014). In a later research, Hsu (2017) indicated that unbalanced bilinguals performed better in non-contextual reading tasks compared to balanced bilinguals and monolinguals, suggesting that task context and language proficiency influence bilingual advantages. Further investigations into bilingual advantages have identified cognitive control benefits across different bilingual groups, including balanced, unbalanced and interpreters (Woumans et al., 2015). Additionally, bilinguals with interpreting experience have been shown to perform better in task-switching and updating tasks (Dong and Liu, 2016). Conversely, some studies indicate no cognitive benefits for interpreters or highly proficient L2 teachers (van der Linden et al., 2018). While other studies found mixed results, for instance Yudes and colleagues (2011) found that highly skilled interpreters outperformed unbalanced late bilinguals and monolinguals in cognitive flexibility, but not in inhibition. Furthermore, socioeconomic status has also been identified as a potential confounding factor, Naeem and colleagues (2018) noted faster response times in bilinguals, but this disappeared when socioeconomic status was considered. Finally, Paap and Greenberg

(2013) found no evidence for consistent cross-task advantages in executive functions. Overall, bilingual advantages may appear in specific tasks but not across all measures of executive processing (van den Noort et al., 2019).

In the context of aphasia, the number of studies investigating the potential bilingual advantage regarding non-linguistic executive functions is limited and the results remain inconclusive. These studies adopt a comparative approach, examining the performance of mono- and bilingual people with aphasia with varying subtypes of aphasia and phases of recovery (Mooijman et al., 2022).

Penn et al. (2009) were the first researchers in the field to investigate the potential bilingual advantage for individuals with aphasia. Their preliminary study included two female post-stroke patients with bilingual aphasia (aged 54-57) and eight monolingual participants with aphasia (three males and five females, aged 40-67) in the chronic phase of recovery. The two groups differed regarding their subtypes of aphasia. The bilingual individuals with aphasia were diagnosed with anomic and conduction aphasia, while the monolingual group included two with anomic aphasia, two with Broca's aphasia, three with conduction aphasia and one participant with right hemisphere disorder. The study employed a battery of neuropsychological tests, including the Stroop Colour and Word Test, Trail Making Test, Working Memory Self-Ordered Pointing Test, Wisconsin Card Sorting Test, Tower of London and Raven's Progressive Matrices. The results demonstrated that bilingual individuals with aphasia exhibited no impairment in these tasks, suggesting that their executive function abilities were significantly better preserved and that they displayed better conversation skills (Penn et al., 2009). However, it is essential to consider these findings with caution due to the limited sample size and the inclusion of individuals with different subtypes of aphasia.

In a study conducted by Alladi et al. (2016), the impact of bilingualism on cognitive outcome was investigated in 608 post-stroke patients. Of these patients, 30 out of 255 monolinguals and 37 out of 353 bilinguals were diagnosed with aphasia. The study was conducted in the subacute and chronic phases of recovery. The researchers observed that the incidence of aphasia was similar between monolingual and bilingual individuals (11.8 versus 10.5%, respectively). However, bilinguals demonstrated unimpaired performance with regard to cognitive measures more frequently than monolinguals (40.5 versus 19.6%, respectively). The authors employed the Addenbrooke's Cognitive Examination Revised

(ACE-R) as their assessment tool. It is important to note that both the memory and attention tasks of the ACE-R rely on verbal abilities such as word repetition and recall serial subtraction, making it challenging to distinguish between non-linguistic cognitive abilities and language capacities. The findings indicate that the protective influence of bilingualism on post-stroke patients is attributable to non-linguistic cognitive abilities rather than linguistic capabilities (Alladi et al., 2016). However, it is important to note that the results include participants with and without aphasia.

The 65 participants (aged 25-78) who were diagnosed with aphasia in Alladi et al.'s (2016) study were further investigated in 2018 by Paplikar et al. who focused on the relationship between bilingualism and the severity of language impairment in post-stroke aphasia. Paplikar et al.'s (2018) study included 38 bilingual and 27 monolingual participants diagnosed with aphasia in the subacute and chronic phases of the recovery. The findings indicate that bilingual individuals with aphasia performed better in the attention, memory and visuospatial domains of ACE-R compared to monolingual aphasic subjects. The authors posit that bilingualism may mitigate the impact of aphasia in post-stroke patients through the enhancement of executive functions.

In a study published in 2018, Faroqi – Shah et al. investigated the relationship between cognitive control, word retrieval and bilingual aphasia. The study included participants with monolingual (N=18) and bilingual aphasia (divided into two subgroups, N=10 in each group) in the chronic phase of recovery as well as a matching control group comprised of neurologically healthy monolingual and bilingual participants of corresponding ages, sex and educational backgrounds. The bilingual aphasia group included 10 participants with Tamil (L1)- English (L2) language background who resided in India, while the other 10 participants had English as L1 and Russian/ French/ Hungarian/ Spanish as L2 residing in the United States. The participants with aphasia had experienced a single left hemisphere stroke resulting from the middle cerebral artery. All bilingual participants demonstrated a high level of proficiency in bilingualism. The results of the Western Aphasia Battery (WAB) indicated that participants with bilingual aphasia exhibited parallel impairment with regard to their L1 and L2. All participants with aphasia were assessed using the WAB. Based on the WAB results, both the monolingual and bilingual aphasics exhibited a moderate degree of impairment. The findings suggest that bilingualism may offer a cognitive advantage in healthy adults and in one group of

bilingual speakers with aphasia but not in the other group. No correlation was observed between word retrieval in individuals with aphasia and performance in the Stroop task. These findings demonstrate that cognitive control performance as assessed by the Stroop task is impaired in individuals with aphasia, irrespective of their bilingual status (Faroqi-Shah et al., 2018).

In 2020, Dekhtyar et al. assessed inhibitory control abilities in their study in monolingual (N=18) and bilingual (N=18) participants with aphasia with matched control groups in terms of age and educational background. The aphasic participants included 30 participants who suffered a stroke, three with a traumatic brain injury (TBI) and three with a brain tumour, all of which were in the chronic phase of recovery. The bilingual participants were all highly proficient Spanish-English language users but English was their dominant language. The subtypes of aphasia were not included in the study, neither were lesion sites specified. All the participants were required to complete a non-linguistic cognitive control task, which included both congruent and incongruent conditions. The findings indicate that no bilingual cognitive control advantage was observed in terms of reaction times among the healthy adult groups. However, the group of bilinguals with aphasia demonstrated faster reaction times than the group of monolinguals with aphasia, indicating that bilingualism may contribute to cognitive reserve in adults with aphasia. These findings indicate that the utilisation of multiple languages throughout the lifespan of an individual may confer a protective effect following an acquired brain injury. Moreover, the authors discovered that shorter reaction times were not associated with language or executive function scores, indicating that cognitive advantages may be subtle and may not be identified by standardized monolingual diagnostic assessments (Dekhtyar et al., 2020).

Dash et al. (2020) investigated the attentional mechanism on three specific components of attention in individuals with aphasia: alerting, orienting and executive control. The study aimed to examine three key research questions: (1) whether individuals with aphasia show evidence of an attention deficit in comparison to their language-matched healthy peers; (2) whether there is evidence of a bilingual advantage in attentional mechanisms; and (3) whether there is a relationship between bilingualism and subcomponents of attention. The group of aphasics included seven monolinguals, and ten French-English bilinguals diagnosed with different subtypes of aphasia (anomic, Broca's

and TMA). The control group included 16 neurologically healthy bilingual individuals and 16 neurologically healthy monolinguals who were matched in terms of their age, educational background and language use. The bilingual participants had varying ages of acquisition, as well as language usage and proficiency. All participants with aphasia were in the chronic stage of recovery and had suffered a stroke with varying lesions such as in the left anterior regions, the left MCA and Sylvian territory. The authors employed the Attention Network Task which is an adaptation of the flanker test. The main findings indicate that the bilingual advantage in terms of attention observed in healthy populations is also evident in bilingual speakers with aphasia, particularly regard to cue-driven performance in the alerting ability. This finding provided further evidence of the cognitive benefits of bilingualism and may explain the superior recovery patterns observed in bilingual individuals with aphasia compared to their monolingual counterparts. The better-preserved attentional abilities in bilingual individuals may be support language therapy. In conclusion, these findings suggest that rehabilitation strategies for bilingual and monolingual individuals with aphasia should take into consideration their attentional abilities (Dash et al., 2020).

The literature review on the bilingual advantage of populations with aphasia reveals a consistent pattern of findings that supports the bilingual advantage hypothesis. Nevertheless, it is important to acknowledge some potential limitations. Some studies employed small sample sizes (Penn et al., 2009), while others utilised rather limited measures of linguistic and cognitive abilities (Alladi et al., 2016; Paplikar et al., 2018). Additionally, in studies employing group designs, researchers have observed contradictory findings (Dash et al., 2020; Faroqi-Shah et al., 2018). Furthermore, it is essential to note that the majority of these studies included participants with different subtypes of aphasia in both monolingual and bilingual groups.

1.2.5 Domain generality of bilingual language control impairments

Bilingual individuals constantly resolve competition between their two activated languages (Kroll et al., 2014), yet they rarely make language selection errors (Gollan & Goldrick, 2018). This is believed to be due to bilingual language processing recruiting domain-general attentional processes that enable focus on the target language and avoid interference from the other (Bialystok, 2017). This explanation is supported by the overlap between bilingual language selection and non-verbal selection processes (Luk et

al., 2011). However, it has been suggested that these domain-general attention processes decline with healthy aging (Bialystok, 2021).

Recent research has focused on understanding the specific mechanisms underlying the bilingual cognitive advantage. These studies examined evidence for two distinct types of cognitive control processes: domain-general and domain-specific (Mooijman et al., 2022). “Domain-general cognitive control suggests that language control mechanisms and cognitive control mechanisms are associated and exhibit some overlap in processing..... In contrast, domain-specific cognitive control suggests that language control mechanisms and cognitive control mechanisms are independent from each other and do not overlap in processing” (Miller et al., 2018, pp. 387-388). Cognitive control is a fundamental component of the executive function system and is believed to play an important role in bilingual performance and language recovery (Abutalebi & Green, 2007; Green 1986; Paradis, 2004). Language control is crucial because blocked inhibition in one language or sufficient activation in the other during speech production may lead to the selective loss of language (Abutalebi, 2008; Gitterman et al., 2012). As proposed by Green’s model (1998), 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 linguistic and non-linguistic control (Gitterman et al., 2012). However, the nature of bilingual language control is very much questionable. Findings of behavioural studies are inconsistent. Some authors propose that bilingual language control relies on functions specific to the language domain (Calabria et al., 2012; Weissberger et al., 2012), while others argue that the general and specific executive functions correlate as well as contribute to the linguistic performance (Declerck et al., 2017; Prior & Gollan 2011), suggesting the existence of an overlap. Others suggest that the overlap is only partial (Branzi et al., 2016; Calabria et al., 2012; Klecha, 2013). Evidence from neuroimaging data indicates shared neural circuits of domain-general cognitive control and language control (De Baene et al., 2015 ; de Bruin et al., 2014).

Research on healthy adults indicates that impairments in language control can have a significant impact on our understanding of language deficits in bilingual aphasia, making it challenging to differentiate between deficits in lexical access and deficits in language

control when language and cognitive control potentially interact (Miller et. al., 2018). Reported cases of bilingual aphasia demonstrate differential language impairment, deficits in executive functioning and challenges in isolating loss of lexical representations from language control abilities (Adrover-Roig et al., 2011; Munoz & Marquardt, 2003). These findings highlight the association between linguistic and non-linguistic control mechanisms following brain damage. Although bilingual individuals with aphasia can provide unique insights into the relationship between language and cognitive control, a limited amount of research has investigated this topic (Dash & Kar, 2014; Gray & Kiran, 2015; Green et al., 2010; Verreyt et al., 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;).

In conclusion, these conflicting results underscore several key considerations in the study of bilingual aphasia: the complex interplay between cognitive control and bilingual language processing, the complicated nature of bilingual aphasia as well as the challenge of designing comparable studies that employ similar measures of inhibitory control and interference (Miller et al., 2018). It is evident that further research is required to investigate control mechanisms in bilingual aphasia, as this could provide valuable insights into the operation of linguistic and non-linguistic control mechanisms in the brain. To systematically explore these mechanisms in bilingual aphasia, future research should employ a methodical approach to the selection of linguistic and non-linguistic tasks, ensuring that they correspond appropriately to one another. Furthermore, larger samples of bilingual individuals with aphasia should be examined in order to account for the considerable differences between patients and their language profiles, facilitating more robust group-level interpretations (Miller et al., 2018).

1.3 The role of executive functions in 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 et al. (2000) is comprised of three distinct components of executive functions, namely

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 flexibly switch between mental sets or tasks. Miyake et al. argues that these components represent core processes underlying executive functions and can be measured separately (Miyake et al., 2000, 2012; Friedman et al., 2008; Friedman & Miyake, 2017). Their model has influenced further research in the field and helped understand the complex nature of EFs (Miyake et al., 2000). The modern conceptualization of EFs is influenced by clinical observations and most scientists agree that specific regions of the brain specialize in particular cognitive functions (Egner, 2017). According to the most popular concept, executive functions refer to processes that direct, configure, and/or modulate the performance in different cognitive domains (Hart, 2015). According to Kim et al. (2018), higher level cognitive abilities result from the concerted action of a multifunctional cognitive system. Executive functions are activated when a person participates in complex tasks that require planning, monitoring, and organizing via adapting to the current situation, and subsequent changes. Core executive functions include processes like selective attention, working memory, inhibition and cognitive flexibility (Diamond, 2013). Selective attention refers to the ability to focus on a specific stimulus or task while filtering out other irrelevant or distracting information (Goldstein, 2021). Cognitive flexibility, also referred as “shifting”, refers to our ability to switch between diverse mental frameworks, tasks, or strategies (Diamond, 2013).

In the context of aphasia, executive functions play a crucial role in language production and comprehension. In language production, people with aphasia (PWA) often struggle with finding the right words, forming grammatically correct sentences, and organizing their thoughts. EFs help in overcoming these difficulties by regulating attention, inhibiting irrelevant information and selecting appropriate words as well as sentence structures. In language comprehension, executive functions help in focusing attention on relevant linguistic cues, inhibiting distractions and integrating information from various sources to comprehend language (Egner, 2017). In the field of monolingual aphasia research, an increasing body of evidence suggests that individuals with aphasia commonly experience cognitive impairments in their executive functions (Marinelli et al., 2017; Murray 2012, 2017; Purdy, 2002; Ramsey et al., 2017; Schumacher et al., 2019; Szöllősi et al., 2015). It is postulated that there is a correlation between non-linguistic

cognitive skills and language capabilities in aphasic individuals due to the shared neural circuits involved. These deficits can greatly influence the traits and consequences of their language abilities (Murray, 2012; Villard & Kiran, 2016). However, previous research has mainly focused on memory in aphasia (Murray, 2017), with limited attention given to the significance of executive function abilities. In case of studies investigating EFs, it has been observed that PWA are capable to recruit extra cognitive resources if the task demands increase and are able to control the automatic responses with high accuracy, albeit more slowly due to potential impairment in information processing. As a result, it is assumed that slowness may influence the information processing of aphasic patients (Szöllösi & Marton, 2016). In the case of naming, Biegler and colleagues (2008) observed that naming is a very difficult task for most of the aphasics due to the impaired inhibition processes. In addition, problems associated with naming seem to be connected to an impaired semantic blocking as well due to the impairment of inhibition processes (Biegler et al., 2008). Other studies investigating executive functions in aphasic patients revealed impaired working memory, cognitive flexibility and inhibition (Murray, 2012; Vallila-Rohter & Kiran, 2013; Lee & Pyun, 2014). Marinelli et al. (2017) investigated the link between language deficit and cognitive impairment in a sample of 184 individuals diagnosed with aphasia. The study found that persons diagnosed with aphasia experienced more pronounced language deficits, which were subsequently associated with more severe cognitive impairment (Marinelli et al., 2017). In the field of aphasia research, substantial attention has been devoted to examining impairments in the working memory (Christensen et al., 2018). Conversely, the body of research exploring cognitive flexibility deficits in individuals with aphasia remains comparatively limited. The ability to shift between cognitive processes, known as cognitive flexibility, relies on the coordinated functioning of various underlying abilities, such as attention, processing speed, working memory and inhibitory control (Diamond, 2013). In the context of aphasia, cognitive flexibility can significantly impact communication and language recovery. Individuals with aphasia may struggle with adapting their language use in different contexts, which can hinder their social interactions and overall quality of life. Most studies in aphasia research employ the following assessment tools to measure potential impairment in executive functions: the classical Stroop task, the flanker task, semantic verbal fluency, the Trail Making Test, the Wisconsin Card Sorting Test (WCST), verbal and spatial n-back task, digit span and the Rey Complex Figure. The executive functions measured by these tools are summarized in Table 2.

Table 2. Commonly employed assessment tools in aphasia research for measuring executive functions

Tasks	Executive functions			Verbal	Non-verbal
	<i>Inhibition</i>	<i>Updating</i>	<i>Switching</i>		
Stroop	✓			✓	
Flanker	✓				✓
Fluency	✓	✓	✓	✓	
TMT			✓		✓
WCST			✓		✓
n-back (verbal)		✓		✓	
n-back (spatial)		✓			✓
digit span		✓		✓	
Rey Complex Figure		✓			✓

1.3.1 Updating in aphasia

Working memory (WM) is defined as a system of limited capacity, responsible for holding and manipulating information while undertaking cognitive tasks (Baddeley, 2003). The connection between working memory and cognitive control in aphasia has been a topic of considerable interest in neuropsychological research. Neuroanatomical data provide evidence of the coexistence of WM and language impairment in aphasia (Gabrieli et al., 1988; Murray et al., 2001; Tompkins et al., 1994; Wright & Shisler, 2005). Studies examining verbal and spatial WM assume the left hemisphere's role in this coexistence (Baldo & Dronkers, 2006). The role of WM in language comprehension, problem-solving, reasoning and decision-making has been widely acknowledged (Novais-Santos et al., 2007). Consequently, PWA may experience difficulties in language comprehension and in other cognitive control functions due to impairments in their working memory capacity (WMC). WM is essential for cognitive control processes to function effectively as impairments in WM may contribute to deficits in other cognitive control processes such as attentional control, response inhibition, task switching and monitoring. Attentional deficit can comprise the ability to allocate cognitive resources efficiently, resulting in reduced comprehension and slower retrieval of linguistic information (Murray, 2012). This can be particularly evident in complex sentence structures, where individual with aphasia may struggle with maintaining the necessary attentional resources to process and comprehend the entire sentence. The deficit in attentional control may be related to WM limitation, as maintaining task-relevant information in mind is crucial for selective attention (Barde et al., 2010). Furthermore, individuals with aphasia frequently show deficits in response inhibition, manifested by difficulties suppressing prepotent or automatic responses (Szöllösi & Marton, 2016). This deficit has also been linked to WM limitations. WMC plays a crucial role in inhibitory control, as it requires the active maintenance and manipulation of task-relevant information while inhibiting automatic responses (Wright & Shisler, 2005). Thus, working memory impairments in aphasia may contribute to deficits in response inhibition. Shifting is another executive function process that is often impaired in individuals with aphasia, and it involves the ability to flexibly shift attention and adjust cognitive strategies in response to changing task demands (Squire, 2009). Research has shown that WMC is closely related to task switching abilities, as it requires the ability to maintain and manipulate multiple task sets in mind (Draheim et al., 2016). Therefore, WM deficits in

aphasia may lead to difficulties in cognitive flexibility. Monitoring is another executive function process that has been found to be impaired in individuals with aphasia, and it involves the continual evaluation and updating of ongoing performance, detecting errors and adjusting behaviour accordingly (Botvinick, et al., 2004). WM plays a critical role in monitoring by maintaining task goals and relevant information in mind while continuously comparing it to ongoing performance (Redick, 2014). Consequently, aphasic patients may show deficits in monitoring due to WM limitations. It is important to note that the specific executive function processes that are affected by working memory impairments may vary across individuals with aphasia, depending on the specific lesion location and the extent of brain damage.

Most studies investigating the working memory of individuals with monolingual aphasia have indicated an impairment when updating (Mayer & Murray, 2012; Murray et al., 2001; Potagas et al., 2011; Wright & Shisler, 2005). However, it is notable that many studies have employed linguistically demanding tasks. To complete these tasks, individuals are required to engage in semantic and/or phonological processing enabling 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 ensure the tasks were simple and fully non-linguistic (Christensen & Wright, 2010; Christensen et al., 2018).

Christensen and Wright (2010) conducted a study examining both linguistic and non-linguistic working memory in a sample of 12 monolingual individuals with aphasia whose language impairments varied as measured by the Aphasia Quotient (AQ) of the Western Aphasia Battery (WAB) with scores ranging from 47.9 to 90.7. The researchers employed the *n*-back task using three distinct categories of stimuli, different in terms of linguistic load. This linguistic load refers to the semantic and phonological variations of the stimuli. The category fruit represented the highest linguistic load, fribbles e.g. novel objects could be classified as semi-linguistic and blocks as non-linguistic stimuli. The Christensen and Wright study (2010) suggested that the working memory performance was significantly improved by verbal encoding, especially in aphasic participants. Their findings indicate that aphasic participants demonstrated a similarity in performance with the control group regarding WM tasks that varied according to linguistic load, though performance of

aphasics was limited. It was also observed that by decreasing the linguistic elements of the task, the performance accuracy of aphasic participants decreased.

In a later study Christensen et al. (2018) investigated WM impairments in aphasia. The study involved 14 individuals with aphasia and compared their performance with 13 control participants. To measure WM impairments, the study employed verbal and spatial *n*-back tasks, the flanker test as well as forward digit and spatial tasks. For the verbal task, the study employed the verbal *n*-back task which included letters. For the spatial task, the study used an *n*-back task with black circles. Christensen et al. (2018) study revealed that aphasic participants demonstrated poorer performance in the verbal tasks compared to the control group. However, in spatial tasks both groups performed similarly, suggesting that aphasics tend to exhibit significant challenges in WM in the context of verbal tasks. The study also indicated that impairments in verbal WM in aphasics could be due to inhibition problems e.g. an inability to suppress irrelevant information, which might also play a role in working memory deficits.

In addition to investigating non-linguistic working memory in individuals with aphasia, recent studies have focused on the efficacy of WM training in aphasia. For example, Zakariás et al. (2018) investigated whether the benefits of computerised WM training would help to improve not only the participants' working memory skills but also auditory comprehension. The training targeted various components of working memory. The study involved three individuals with aphasia in the chronic phase of recovery. The results showed that aphasics demonstrated some improvement regarding at least one measure of auditory comprehension and everyday memory tasks. Moreover, two aphasics exhibited some improvement in measures of working memory and functional communication skills. Zakariás et al. (2018) study revealed that the WM performance could be enhanced by a computer-based training in the chronic stage of recovery in individuals diagnosed with aphasia.

Furthermore, Nikravesht et al. (2021) investigated how WM training affects people with aphasia in memory and language performance. The study involved 13 participants diagnosed with aphasia with moderate and mild symptoms. Their findings revealed that aphasics exhibited notable enhancements in memory tasks. Additionally, the language performance of individuals with aphasia improved as well, suggesting that working

memory training could be beneficial not only to memory but also to language abilities in individuals with aphasia.

1.3.2 Shifting in aphasia

The available research on executive functions suggests that people with post-stroke aphasia often demonstrate deficits in cognitive flexibility (Jaillard et al., 2009; Jokinen et al., 2015; Kiss & Csépe, 2024; Povroznik et al., 2018; Schumacher et al., 2019; Tsiakiri et al., 2024; Turunen, 2017). In aphasia research, the Trail Making Test (TMT) is frequently used to investigate shifting impairment (Tsiakiri et al., 2024). TMT is a commonly employed assessment tool for the evaluation of executive dysfunction and frontal lobe involvement (Demakis, 2004). However, recent advancements in brain imaging research have underscored the significance of other cerebral regions, including the parietal cortex (Varjacic et al., 2018). The executive network is comprised of the frontal lobe, parietal lobe, subcortical structures and cerebellum. These regions are interconnected via white matter pathways. Injury to these structures or their connections can result in a reduction in processing speed and the emergence of executive function issues (Tsiakiri et al., 2024). The TMT-B assesses several cognitive functions, including attention, visual search, hand movement as well as a language component requiring the recognition of numbers and letters. Although a significant proportion of stroke patients are able to complete the simpler TMT-A, a considerable number of patients experience difficulty in finishing the more complex TMT-B (Nishimura et al., 2022). The TMT-B is generally more challenging for post-stroke patients than TMT-A, as it requires the ability to recognise numbers and letters. The analysis of the number of mistakes made in the TMT-B can be beneficial in the case of post-stroke patients. The analysis conducted by Nishimura et al. (2022) of the test scores revealed that the subjects with the lowest scores, or those who were the slowest, primarily had damage in the visual areas of the brain. In contrast, the participants with moderate scores mainly had damage in the language-processing regions of the brain. Finally, it is important to consider some potential limitations of the Trail Making Test when employing it. It should be noted that the TMT results may be influenced by factors such as age, education and cultural background, which could limit their generalisability. The TMT assesses EFs and attention, but neglects memory and social cognition, which are crucial for understanding stroke outcomes. The test is not always reliable and may not detect subtle changes in cognitive function. Furthermore, the TMT results depend on an individual's baseline skills. Testing by paper

and pencil may distort results. Despite its widespread use, it is essential to consider supplementary assessments for a more comprehensive understanding of cognitive function post-stroke (Tsiakiri et al., 2024).

1.3.3 Inhibition in aphasia

The number of studies investigating inhibition impairment in aphasia is rather limited. The existing studies employ the classical Stroop and the Eriksen flanker tasks. In the Stroop Task (Stroop, 1935), the participants are required to read three different tables as quickly as possible. Two of the tables represent the congruent condition, in which participants are required to read names of colours printed in black ink and name different colour patches. Conversely, in the third table, naming the colour of the word is investigated in which words are printed in an inconsistent colour of 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 out loud the word (Scarpina & Tagini, 2017). In the flanker task, 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). The findings of these studies indicate the impairment in fluent and non-fluent types of aphasia in these tasks (Kendrick et al., 2019; Kuzmina & Weekes, 2016; Schumacher et al., 2022).

Schumacher et al. (2022) investigated executive function impairment in individuals with chronic post stroke aphasia (N=32) through various aphasia and cognitive batteries, including the Stroop task. The study showed that individuals with more severe impairments in language tests tended to score lower in the Stroop Language component. The study also revealed that even when considering non-verbal skills, individuals with greater non-verbal impairments scored lower in the Stroop Control component, suggesting that difficulties in terms of attention and controlling responses, which are not directly related to language, also affect performance in the Stroop task. Overall, Schumacher et al. (2022) revealed that both language and non-verbal skills play important roles in how well someone can perform in the Stroop task with more severe impairments leading to lower scores.

Furthermore, Kendrick et al. (2019) focused on the role of verbal load in frontal lesion aphasia. The study employed several cognitive batteries, including the Stroop and flanker

tasks. This study revealed that individuals with aphasia showed general slowness in reaction times and decreased accuracy. No statistically significant differences were found between high and low verbal tasks.

Finally, Kuzmina and Weekes (2016) investigated inhibition and language processing impairments in fluent and non-fluent types of aphasia. In their study, they employed the classical Stroop and flanker tasks, analysing a total of 57 participants with aphasia, divided into three groups: a fluent aphasia group (N=17) and a non-fluent aphasia group (N=19) and a control group (N=21). The findings indicated that the non-fluent aphasia group exhibited more pronounced inhibition impairments compared to their fluent aphasic counterparts. The fluent aphasia group performed similarly to the control group in the flanker test, suggesting that inhibition impairments were more apparent in tasks that include more verbal elements. Kuzmina and Weekes (2016) identified a correlation between the scores in the flanker and Stroop tasks, indicating differing executive control impairments between fluent and non-fluent aphasia types. Additionally, the results revealed significant links between the interference and comprehension scores in the flanker task of individuals with fluent and non-fluent types of aphasia, highlighting the importance of inhibition in language comprehension. Finally, the authors noted that not all individuals with aphasia exhibited inhibition impairments, suggesting that language processing difficulties may not always correlate with cognitive impairments.

1.4 The role of executive functions in bilingual aphasia

It is already known from studies that monolingual aphasics often experience deficits in the executive function system (Purdy 2002; Murray, 2012; Szöllösi 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 symptoms of aphasia as it prevents people with aphasia from compensating for linguistic difficulties (Mooijman et al., 2022). Therefore, EFs are classified as a crucial factor regarding functional communicative abilities and the recovery of linguistic skills (Ramsberger, 2005; Fridriksson et al., 2006; Olsson et al., 2019). Individuals with bilingual aphasia may experience challenges with language choice as well as 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 as

well as the specific demands of each language. Several studies have confirmed impaired EFs in bilingual individuals diagnosed with aphasia, albeit with rather mixed and contradictory results regarding the relationship between language and domain-general cognitive control. Moreover, while most studies have confirmed that bilingual aphasic patients with language control problems in everyday communication exhibit domain-general cognitive control problems, indications of cognitive control advantages are also observed (for a review, see Mooijman et al., 2022).

1.4.1 Inhibition in bilingual aphasia

The comprehensive meta-analysis by Mooijman et al. (2022) examined studies investigating executive control (EC) deficits in bilinguals with aphasia. The analysis included 27 articles investigating deficits in non-linguistic EC in bilingual aphasia. The results revealed that inhibition impairments were the most frequent area of EC research. The Stroop Task was primarily used in these studies to investigate prepotent response inhibition (Miyake et al., 2000; Friedman & Miyake, 2004). The group studies conducted by Penn et al. (2017) and Faroqi-Shah et al. (2018) revealed that the majority of bilingual patients with aphasia 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 task is a commonly used assessment of resistance to distractor interference. Several studies have shown that bilingual individuals with aphasia exhibited impairments in the flanker task compared to the healthy control groups (Dash et al., 2020; Green et al., 2010; Keane & Kiran, 2015; Van der Linden et al., 2018; Verreyt et al., 2013). However, the performance of a significant number of bilingual persons with aphasia was unimpaired in the flanker task (Calabria et al., 2019; Green et al., 2010, 2011). Nevertheless, most studies indicate that the majority of bilingual aphasic patients showed impairments when measured using the Stroop Task and unimpaired inhibition abilities when using the flanker task. These contradictory findings could be due to the differences in the linguistic demands of each task or the type of inhibition such as prepotent response inhibition in the Stroop task and resistance to distractor interference in the flanker task (Mooijman et al., 2022).

Furthermore, it has been found that studies investigating inhibition impairment in bilingual people with aphasia 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, moreover, these impairments may therefore be resolved over time. According to a study conducted by Penn et al. (2017), it was found that inhibition impairments of participants in both the acute and subacute phases persisted. Additionally, studies investigating participants in the chronic phase also showed inhibition deficits, suggesting that these impairments continue to persist (Mooijman et al., 2022).

1.4.2 Updating in bilingual aphasia

Data on the updating component of WM in bilingual aphasics is limited (Penn et al., 2009; Adrover-Roig et al., 2011; Lee et al., 2016; Penn et al., 2017) and of mixed outcome.

The preliminary study of Penn et al. (2009) investigated impairments in updating in bilinguals with aphasia in the chronic stage of recovery. The study involved two bilingual and eight monolingual aphasics with mild and moderate symptoms. The Working Memory Self-Ordered Pointing Test used by the authors did not reveal impairments in the two bilingual patients, whereas impaired updating was demonstrated in the eight monolingual aphasics.

Furthermore, Adrover–Roig et al. (2011) have investigated a 53-year-old right-handed Basque-Spanish bilingual male who had a haemorrhagic incident of stroke. The patient in the chronic stage of his recovery at the time of investigation showed selective impairment, e.g. his L2 was more intelligible than the L1 even after 3 months of speech therapy in both languages. The brain damage concluding in the patient was restricted to the left basal ganglia, resulting in impairments in his L1 to a larger extent. The language assessment tools included the Bilingual Aphasia Test and the Boston Naming Test in both languages. The executive function assessments included the forward and backward digit span tasks, the classical Stroop test and the Trail Making Test (TMT). The results of these executive function assessments revealed impairments in updating, inhibition and shifting.

Lee et al. (2016) described the impairments of a bilingual patient with crossed aphasia, a rare case in dextrals, e.g. a right hemispheric lesion in a right-handed person. The 47-year-old male patient had an extensive haemorrhage in the right basal ganglia. The investigation used the Western Aphasia Battery (WAB) performed in the subacute stage

of recovery and later in the chronic stage following a six-month-long course balanced proficiency in both languages, exhibiting equal abilities in the L1 (Korean) and L2 (Japanese). The WAB was employed in both languages, with the AQ scores for Korean and Japanese as 32.0 and 50.6, respectively. Based on the WAB results, the patient was diagnosed with Broca's aphasia. The fMRI (functional Magnetic Resonance Imaging) study revealed left lateralised activation in both language tasks, especially in the inferior frontal gyrus. The non-linguistic assessments were conducted in the subacute stage using a range of tests, including the digit span task, TMT, Rey Complex Figure Test and Wisconsin Card Sorting Test (WCST). Results of these tests revealed multiple impairments in the subacute stage of recovery, including inhibition, updating and shifting. Lee et al. (2016) revealed that, despite the absence of a follow-up assessment of the executive functions in the chronic stage, repetition of the WAB and the naming test showed no sign of the paradox pattern of bilingual aphasia.

Finally, Penn et al. (2017) investigated the recovery patterns during the acute and subacute stages of recovery in post-stroke participants with bilingual aphasia (N=10). The ten aphasic patients (7 males and 3 females of 27-65 years) with different sites of and types of aphasia were tested over two periods of time within the first 12 weeks following the incident leading to severe symptoms of aphasia. The control group of 19 neurologically intact bilingual individuals (6 males and 13 females) were matched as closely as possible to the aphasic patients in terms of age, level of education and linguistic variety. Penn et al. (2017) study revealed impaired updating tested by a non-linguistic n-back task in individuals with aphasia. It is, however, noteworthy that they showed impairment both in the acute and subacute stages of recovery.

1.4.3 Shifting in bilingual aphasia

The number of studies investigating shifting impairment in bilinguals with aphasia is also limited. Six of these studies identified impaired shifting abilities in 15 participants (over varying periods of post-onset, lesion location as well as types and severity of aphasia) (Kohnert, 2004; Adrover-Roig et al., 2011; Kong et al., 2014; Lee et al., 2016; Marini et al., 2016; Penn et al., 2017). Three studies including four participants (over varying periods of time post-onset, lesion locations as well as types and severity of aphasia) identified unimpaired shifting abilities (Aglioti et al., 1996; Penn et al., 2009; Marien et al., 2017). Similarly to the findings with regard to updating, most of the bilingual aphasics

with impaired switching abilities were in the subacute phase of recovery. Penn et al.'s (2017) study suggested that the shifting ability 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 the WCST can be characterized as a non-linguistic test, as the TMT requires to be sequenced and therefore relies on linguistic knowledge. The shifting ability was also impaired 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 skills and working memory (Sánchez-Cubillo et al., 2009). As a result, it can be concluded that most bilingual individuals with aphasia may experience shifting problems (Mooijman et al., 2022).

1.4.4 Executive functions in terms of verbal fluency in people with 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 the category fluency test), participants are requested to produce as many different words as possible from a given semantic category (e.g. animals, fruits, vegetables) (Bose et al., 2022). In terms of the letters, 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 verbal 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 verbal fluency task, participants are required to produce words beginning with a specific letter/phoneme while suppressing the activation of related semantic concepts (Patra et al., 2020). Studies have shown that such activation can have a detrimental effect (Friesen et al., 2014; Luo et al., 2010).

Research examining the relationship between executive functions and verbal fluency tasks has indicated that successful performance in verbal fluency tasks relies on both lexical and executive abilities (Bittner & Crowe, 2007; Patra et al., 2020; Shao et al., 2014). In case of aphasia, numerous studies have found that people diagnosed with aphasia produce a limited number of answers in verbal fluency tasks (Bose et al., 2017; Kiran et al., 2014), likely due to a combination of lexical deficits and executive control difficulties. While lexical deficits have been proposed as the primary cause, recent research also implicates executive control impairments as an underlying factor (Bose et al., 2017; Bose et al., 2022; Faroqi -Shah et al., 2018; Patra et al., 2020). In bilingual aphasia, the number of studies investigating verbal fluency and executive control processes is rather limited (Carpenter et al., 2020; Faroqi -Shah et al., 2018; Kiran et al., 2014; Patra et al., 2020). This is particularly evident in the context of comparing semantic and letter fluency, however, research has demonstrated that a comparison between the two can provide a more comprehensive insight into the role of executive control processes in verbal fluency tasks (Bose et al., 2022; Friesen et al., 2014; Patra et al., 2020). These studies moved beyond the traditional approach of examining verbal fluency tasks in aphasia, as they included further variables beyond only calculating the number of correct answers. For instance, by calculating the fluency difference score (Bose et al., 2022; Friesen et al., 2014; Patra et al., 2019; Patra et al., 2020), searching within a subcategory (Patra et al., 2019), examining switching from a subcategory to another (Troyer et al., 1997), which all demand higher executive control demands to perform successfully. Furthermore, the literature on verbal fluency has identified mean retrieval latency as an important variable (Friesen et al., 2014), it has linked longer mean retrieval latency with fewer correct responses to greater cross-linguistic interference in healthy bilingual population. The fluency difference score (FDS), which represents the difference between performance on the two conditions, has been proposed as a measure of executive abilities in healthy individuals. Specifically, a smaller difference score as a proportion of the semantic fluency score has been associated with superior executive functioning (Friesen et al., 2014). Studies comparing semantic and letter verbal fluency tasks have revealed significant differences in healthy and clinical population between the two. While most studies found that the letter verbal fluency task places a greater demand on executive functions (Bose et al., 2022; Friesen et al., 2014; Patra et al., 2019; Shao et al., 2014; Thiele et al., 2016; Patra et al., 2020;) a few found the opposite (Gordon et al., 2018; Whiteside et al., 2016), therefore further research is needed to investigate verbal fluency,

especially in the domain of aphasia. In case of semantic fluency task in bilingual aphasic patients, Kiran et al. (2014), found that bilingual patients with aphasia produced fewer correct number of answers and switching than healthy bilinguals while both groups used similar clustering strategies. Furthermore, Kiran et al. (2014) did not find cross-linguistic differences at the group level in individuals with bilingual aphasia (despite parallel impairment), only in healthy bilingual controls. In case of healthy controls, they demonstrated better performance in their dominant language, aligning with the hypothesis that the non-dominant language imposes greater cognitive demands, resulting in reduced verbal output (Kiran et al., 2014).

In the bilingual aphasia literature significant progress has been made in investigating the role of lexical and executive control in verbal fluency along with independent measures of executive functions (Carpenter et al., 2020; Faroqi-Shah et al., 2018; Patra et al., 2020). Faroqi-Shah et al. (2018) investigated the relationship between cognitive control, word retrieval in aphasia. The study included participants with monolingual (N=18) and bilingual aphasia (divided into two subgroups, N=10 in each group) in the chronic phase of recovery as well as matching control groups comprised of neurologically healthy monolingual and bilingual participants of corresponding ages, sex and educational backgrounds. All bilingual participants (Tamil- English) demonstrated a high level of proficiency in bilingualism. The results of the Western Aphasia Battery (WAB) indicated that participants with bilingual aphasia exhibited parallel impairment with regard to their L1 and L2, moreover, both the monolingual and bilingual aphasics exhibited a moderate degree of impairment with different subtypes of fluent and non-fluent aphasia. The study employed the semantic verbal fluency task, object naming and the Stroop task. The results indicated that no correlation between the semantic verbal fluency and the Stroop task was found. However, a strong correlation was observed between object naming and the semantic verbal 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 of people with aphasia for whom word retrieval is no longer possible (Faroqi-Shah et al., 2018).

Carpenter et al. (2020) investigated 13 individuals with bilingual aphasia (Spanish-English) and 22 healthy bilingual controls in verbal semantic fluency task in four conditions: No-Switch in L1, No -Switch in L2, Self-Switch and Forced Switch. The

bilingual individuals with aphasia were in the chronic phase of recovery, with eleven having acquired aphasia from stroke, one from traumatic brain injury, and one from a brain tumour. Carpenter et al. (2020) found that bilingual individuals with aphasia were more vulnerable to the impact of the executive functions demand in verbal fluency tasks in comparison to the healthy control groups. Furthermore, when examining cross-linguistic difference in the letter fluency task, the study indicated that bilinguals with aphasia did not exhibit such difference, unlike healthy bilingual controls. According to Carpenter et al. (2020) this absence of cross-linguistic variation in the aphasia group suggests that heightened executive control demands may impede performance in bilingual individuals with aphasia. Additionally, they found that bilinguals with aphasia experienced greater difficulty in the forced-switched condition, which placed greater demand on the executive control mechanism, while they performed similarly to healthy participants in easier self-switch task (Carpenter et al., 2020).

Patra et al. (2020) investigated the role of executive control processes in verbal semantic and letter fluency as well as independent measures of executive control (Stroop task, Trail Making Test and backward digit span) in eight Bengali-English bilingual individuals with aphasia. All participants were diagnosed with non-fluent aphasia types from severe to mild impairments in both languages as well as were in the chronic phase of recovery. They examined not only the number of correct answers but also the fluency difference score, cluster size, number of switches, within cluster pauses, between cluster-pauses as well as 1st-RT and Sub-RT. The results indicated that bilingual participants with aphasia performed poorly in the verbal fluency measures, where executive control demands were higher (e.g. letter fluency, FDS, number of switches and between cluster-pauses). Furthermore, their findings were reinforced by correlational analysis, which revealed a significant relationship between Stroop ratio and backward digit span as well as verbal fluency variables (e.g. number of correct answers, number of switches and 1st-RT).

1.4.5 Limitations in the existing literature

The investigation of executive function impairments in bilingual aphasia poses a complex challenge in the existing literature. A notable observation from current studies is the lack of homogeneity among the participants, which often includes case studies of stroke patients, individuals with brain tumours and rare cases of aphasia. This variability

complicates the interpretation of findings and raises concerns about the generalisability of results across different contexts.

Furthermore, another significant limitation in these studies is the insufficient attention given to aphasia severity. Many investigations fail to account for the degree of language impairment when assessing executive functions, which can result in misleading conclusions about the relationship between language and non-linguistic cognitive processes. The severity of aphasia may significantly influence both language use and the underlying executive functions, suggesting that a more nuanced approach is required.

Finally, the absence of simple, fully non-linguistic tests to assess executive functions in bilingual individuals with aphasia represents another significant gap in the literature. Current methods often rely on complex tasks that may rely on language skills. The development and implementation of simpler tests designed specifically to evaluate fully non-linguistic executive functions could enhance the clarity and comparability of findings across bilingual aphasia studies.

1.5 The present study

1.5.1 Research aim

The primary objective of this study was to examine the relationship between impairments in language modalities and executive functions in individuals with mono-and bilingual aphasia. To achieve these aims, a range of non-linguistic tests was employed to identify these deficits in executive functions and further investigate these deficits in naming, auditory comprehension and fluency. Additionally, it also aimed to investigate assumed working memory and cognitive flexibility impairments in non-linguistic tests. The investigation focused on whether bilinguals with aphasia perform better in non-linguistic tests than monolingual aphasics. Furthermore, performance differences were examined between aphasic participants and neurologically healthy participants, for both bilinguals and monolinguals. In addition to investigating executive function impairments in linguistic and non-linguistic batteries, the study sought to investigate performance differences between fluent and non-fluent aphasia types, as well as the effect of age and education on performance.

1.5.2 Hypotheses

- (1) The first hypothesis proposed that the impairment of executive functions would negatively affect naming in participants with aphasia, resulting in slower performance, increased response time and decreased accuracy. It was assumed that the longer the time to complete the task was, the more mistakes were made. This was thoroughly investigated in the Boston Naming Test (BNT).
- (2) The second hypothesis was that impaired executive functions would also affect auditory comprehension of grammatical structures and complex sentences, resulting in decreased accuracy in participants with aphasia. To identify the expected impairments, the Token Test and the Test for Reception of Grammar were employed.
- (3) The relationship between word retrieval and executive functions in participants with aphasia as well as in individuals from the healthy reference groups was investigated using verbal tasks including semantic and letter fluency ones. Lower performance was expected in participants with aphasia in both fluency tasks because of a possible impairment in inhibitory control due to aphasia (Patra et al., 2020). In addition, both aphasic and healthy participants were expected to demonstrate lower performance in the letter fluency task as it requires greater recruitment of executive control (Bose et al., 2022).
- (4) Regarding cross-linguistic comparison in the semantic fluency task, it was expected that the bilingual aphasia group would demonstrate similar performance, without significant cross-linguistic differences, in contrast to healthy bilinguals (Kiran et al., 2014; Patra et al., 2020).
- (5) Furthermore, this paper compared performance in terms of semantic verbal fluency with regard to naming in the BNT to investigate the potential relationship between the two. It is known that the performance of aphasics in semantic fluency tasks may show dissociation with naming, here measured by the BNT. It was expected that if an individual performed poorly or successfully in the semantic fluency task, they might not perform similarly in naming.
- (6) It was assumed that impaired cognitive flexibility has a negative effect on performance in non-linguistic shifting tasks. It was anticipated that as response time increases, the number of mistakes will also increase for both aphasia groups in comparison to the reference groups. This was thoroughly investigated in the

Trail Making Test (TMT) as well as in the Number and Letter Sudoku tasks. Furthermore, it was expected that both aphasic and healthy participants would demonstrate lower performance in part B of the TMT and in the Letter Sudoku task, due to the presence of a greater number of linguistic elements.

- (7) The study proposed that participants with aphasia would demonstrate impaired working memory in the visual, as well as in the auditory tasks (Choinski et al., 2020). To identify the expected impairments, the Visual Sequential Memory Test, the Rey-Osterrieth Complex Figure B Test and the Auditory Sequential Memory Test were employed. Furthermore, it was assumed that bilinguals with aphasia will perform better in working memory tests than monolingual aphasics, while significant performance differences were expected between aphasic participants and neurologically healthy participants as matched reference, for both bilinguals and monolinguals.
- (8) Additionally, it was assumed that the severity of aphasia has an impact on the outcomes of executive functions. Specifically, it was expected that the difference in the EFs of individuals with milder forms of aphasia (fluent aphasics) would be greater between the monolingual and bilingual groups than those with more severe symptoms of aphasia (non-fluent aphasics), suggesting that EFs may be more readily accessible in milder forms of aphasia.
- (9) Finally, regarding the impact of age and education on performance, it was hypothesized that older bilinguals would perform better in non-linguistic tasks compared to monolinguals in both the aphasia and healthy groups (Bialystok et al., 2014). In the monolingual groups, it was expected that higher age would correlate with lower scores. In terms of healthy mono-and bilingual participants, higher education was expected to correlate with higher scores. However, in case of both aphasia groups, more education was expected to have a reduced effect (Roberts, et al., 2024).

Table 3 Summary of hypotheses with relevant tests and expected outcomes

Hypotheses	Tasks applied	Expected outcomes
(1) Executive function impairment affects naming	BNT	PWA expected to show increased RT and decreased accuracy compared to healthy participants. Longer task completion time correlates with more mistakes.
(2) Executive function impairment affects auditory comprehension	Token Test and TROG- H	PWA expected to have decreased accuracy when processing complex grammatical structures and sentences.
(3) Relationship between word retrieval and executive functions	Semantic and letter verbal fluency tasks	Lower performance in PWA in both fluency tasks compared to healthy participants. All participants expected to perform worse in letter fluency.
(4) Cross-linguistic comparison in fluency	Semantic verbal fluency tasks in L1 and L2	PWA demonstrate similar performance, in contrast to healthy bilinguals.
(5) Relationship between word retrieval and naming	BNT and semantic fluency task	If an individual performed poorly or successfully in the semantic fluency task, they might not perform similarly in naming.
(6) Cognitive flexibility impacts non-linguistic shifting tasks	TMT, Number and Letter Sudoku	Increased response time correlates with more mistakes in PWA compared to the reference group. All participants expected to perform worse in part B of TMT and Letter Sudoku due to the presence of a greater number of linguistic elements.
(7) WM impairment in visual and verbal domains	Visual and Auditory Sequential Memory Tests, ROCF-B	PWA expected to perform worse than neurologically healthy participants; bilinguals with aphasia expected to perform better than monolingual aphasics.
(8) Severity of aphasia impacts performance	BNT, TT, TROG-H, verbal fluency tasks, VSMT, ASMT, ROCF-B, TMT, Sudoku tasks	PWA with milder forms expected to show better performance compared to PWA with more severe symptoms.
(9) Effect of age and education on performance	BNT, TT, TROG-H, verbal fluency tasks, VSMT, ASMT, ROCF-B, TMT, Sudoku tasks	In bilingual groups, older bilinguals expected to perform better in non-linguistic tasks than monolinguals. In monolingual groups, higher age expected to correlate with lower scores, and higher education with higher scores. For both aphasia groups, more education expected to have a reduced effect.

2 METHODS

2.1 Participants

The study aimed to investigate linguistic and non-linguistic capabilities of individuals with aphasia, comparing monolingual and bilingual populations while also including neurologically healthy participants for comparative purposes. A total of 54 participants were recruited for this study, divided into four groups: monolingual people with aphasia (N=10), bilingual people with aphasia (N=8), monolingual healthy participants (N=18), and bilingual healthy participants (N=18). All participants with aphasia had suffered a cerebrovascular accident. Participants with multiple stroke incidents were excluded. Clinical criteria for aphasic participants included: (1) signs of aphasia as indicated by their performance during the WAB test in both languages, (2) at least 6 months post-onset of their stroke, (3) premorbid right-handedness (4) no sign of apraxia or dysarthria. Concerning bilinguals, all participants were interviewed about their language background using the Hungarian version of the Bilingual Aphasia Test (Paradis, 1989; adapted to Hungarian by Labas-Weber, n.d.) questionnaire (language acquisition history, language of instruction, language usage and dominance) in the presence of the author of this study and speech-language pathologists, which showed that all bilinguals used their languages parallelly both before and after the stroke incident. In case of severe cases of aphasia, family members provided the necessary information about the language background. In case of the monolingual groups, all participants were native Hungarian speakers. Furthermore, all participants provided informed consent, and their confidentiality data anonymization was maintained by assigning unique identification number to each participant. Participants were informed of their right to withdraw from the study at any time without consequences.

Table 4 includes the comparison of the demographic data between aphasic and healthy participants. The mean age of the monolingual aphasia group was 68.7 years (SD=9.99), while the bilingual aphasia group had a mean age of 63.5 (SD=13.02). The monolingual reference group had a mean age of 67.67 (SD=10.99), while the bilingual reference group had a mean age of 65 (SD=9.80), both highly comparable with the aphasia groups.

Table 4. Demographic and clinical data of mono- and bilingual healthy and aphasic participants

	Monolingual aphasics (N=10)	Bilingual aphasics (N=8)	Monolingual reference group (N=18)	Bilingual reference group (N= 18)
Age				
Mean	68.7	63.5	67.67	65
SD	9.99	13.02	10.99	9.80
Min-Max	49-83	44-81	45-85	46-80
Sex (%)				
Male	60	62.5	44.44	27.78
Female	40	37.5	55.56	72.22
Education in years				
Mean	12.7	13.38	13.28	13.17
SD	3.62	3.20	3.63	5.51
Min-Max	11-22	11-20	8-22	8-30
Post-onset days				
Mean	2174.8	2641.13	-	-
SD	3532.16	3835.87	-	-
Min-Max	181-10717	184-8978	-	-
Lesion site (%)				
Left	90	100	-	-
Right	-	-	-	-
Bilateral	10	-	-	-
Speech (%)				
Fluent	70	75	-	-
Non-fluent	30	25	-	-
Aphasia severity (%)				
Severe	30	25	-	-
Moderate	40	12.5	-	-
Mild	30	62.5	-	-
L1 (%)				
Hungarian		62.50		27.78
Croatian		37.50		72.22
L2 (%)				
Hungarian		37.50		72.22
Croatian		-		16.66
Slovakian		50.00		5.56
German		12.50		5.56
AoA L2 (%)				
0-3		37.50		50.00
3-6		50.00		38.89
over 6		12.50		11.11

In terms of sex distribution, the monolingual aphasia group comprised of 60% males and 40% females. The bilingual aphasia group comprised of 62.5% males and 37.5% females. The monolingual reference group had 44.44% males and 55.56 % females, while the bilingual reference group had 27.78% males and 72.22 % females. In terms of educational attainment, the monolingual aphasia group had an average 12.7 years of education (SD=3.62), the bilingual aphasia group had a mean of 13.38 years (SD=3.20). The monolingual reference group had a mean of 13.28 years (SD=3.63), and the bilingual reference group had a mean of 13.17 years (SD=5.51). The mean number of post-onset-days for the monolingual aphasia group was 2174.8 (SD=3532.16), while the bilingual aphasia group had a mean of 2641.13 days (SD=3835.87). The lesion sites of the aphasic participants were predominantly in the left hemisphere. Among the monolingual aphasics 70% were classified as fluent and 30 % as non-fluent, while in the bilingual aphasia group, 75% were classified as fluent and 25% as non-fluent. Regarding aphasia severity, 30% of monolinguals and 25% of bilinguals had severe symptoms. Moderate symptoms were diagnosed in 40% of monolinguals and 12.5% of bilinguals, while 30% of monolinguals and 62.5 % of bilinguals had mild symptoms. Concerning the linguistic background of bilinguals, the bilingual aphasic participants had their L1 as Croatian (37.50%) or Hungarian (62.50%) and had acquired their L2, Hungarian (37.50%) or Slovakian (50%) or German (12.50%) at varying ages. Similarly to the bilingual aphasia group, the bilingual neurologically healthy participants had their L1 as Croatian (72.22%) or Hungarian (27.78%) and acquired their L2, Hungarian (72.22%) or Croatian (16.66%) or Slovakian (5.56%) or German (5.56%), at varying ages. The monolingual healthy participants served as a reference for the monolingual aphasia group, while the bilingual healthy participants served as a reference for the bilingual aphasia group. The demographic details of the healthy monolingual participants (mHP) are presented in Appendix 3, while data of the healthy bilingual participants (bHP) are included in Appendix 4. Table 5 presents the individual details of the monolingual people with aphasia (mPWA), while Table 6 includes details of the bilingual people with aphasia (bPWA). The aphasia severity ranged from severe to mild in both aphasia groups and participants were diagnosed with different types of aphasia (Broca, anomic, global and conduction). In case of the bPWA group, parallel impairment was observed as determined by the evaluation of the speech - language pathologists and the WAB results. The Aphasia Quotient (AQ) of the WAB is reported for the mPWA group in Table 5, and for the bPWA group in Table 6 for both languages.

Table 5. Individual demographic and clinical data of the monolingual aphasia group

Participants	Age	Sex	Education in years	Post-onset days	Speech	Lesion site	Aphasia type	Aphasia severity	WAB AQ
mPWA1	49	female	11	395	non-fluent	left	Broca	severe	35.1
mPWA2	76	male	11	556	fluent	left	Anomic	moderate	72.9
mPWA3	71	male	11	181	fluent	right and left	Anomic	mild	96.8
mPWA4	63	male	11	183	non-fluent	left	Global	severe	40.3
mPWA5	71	male	11	10717	fluent	left	Anomic	moderate	67
mPWA6	69	female	16	6162	fluent	left	Conduction	moderate	62.2
mPWA7	61	male	11	2363	non-fluent	left	Broca	severe	36.1
mPWA8	83	female	11	278	fluent	left	Anomic	mild	76
mPWA9	64	male	22	730	fluent	left	Anomic	mild	95
mPWA10	80	female	12	183	fluent	left	Anomic	moderate	54

Table 6. Individual demographic and clinical data of the bilingual aphasia group

Participants	Age	Sex	Education in years	Post on set days	Speech	Lesio n site	Aphasia type	Aphasia severity (parallel)	WAB AQ L1	WAB AQ L2	L 1	AoA L1	L2	AoA L2
bPWA1	73	female	12	8580	fluent	left	Anomic	mild	92.2	95.7	CRO	from birth	HU	6
bPWA2	72	female	16	603	fluent	left	Anomic	mild	79.9	83.8	CRO	from birth	HU	6
bPWA3	57	male	12	8978	fluent	left	Anomic	mild	78.6	90.6	CRO	from birth	HU	3
bPWA4	60	male	11	369	fluent	left	Anomic	mild	91.2	82	HU	from birth	DE	30
bPWA5	49	female	20	225	fluent	left	Anomic	mild	95	88.4	HU	from birth	SK	3
bPWA6	72	male	11	201	non-fluent	left	Global	severe	14.9	15.5	HU	from birth	SK	6
bPWA7	44	female	14	1989	fluent	left	Conducti on	moderate	53	50	HU	from birth	SK	3
bPWA8	81	female	11	184	non-fluent	left	Global	severe	9.2	5	HU	from birth	SK	6

In the bilingual aphasia group, participants bPWA 1, bPWA2 and bPWA 3 was born in Hungary and lived in small towns speaking Croatian in a small community. The language of instruction at school was Hungarian and Croatian language was also taught. They acquired Croatian as their L1 and their L2 was Hungarian at the age of six and three. The home language was Croatian; they used Hungarian at school and workplaces. Participants bPWA5, bPWA 6, bPWA7 and bPWA8 were born in Slovakia in small towns still speaking Hungarian. They first acquired Hungarian and Slovakian at the age of 3 and 6. The language of instructions at school was Hungarian for participants bPWA 6 and bPWA 8 and Slovakian for bPWA 5 and bPWA7. The home language was Hungarian, while they used Hungarian and Slovakian at school and work. Participant bPWA4 was born in Hungary and moved to Germany at the age of 30, the language of instruction was Hungarian. He used Hungarian as home language and German at work on a daily basis. Participants bPWA1, bPWA2, bPWA3, received only speech therapy in Hungarian, while bPWA 4, bPWA5, bPWA 6, bPWA 7 and bPWA 8 in both languages.

2.2 Procedures

Participants with aphasia were recruited from a variety of sources. The recruitment process was conducted via three principal channels: (a) institutional, (b) private speech and language therapists as well as (c) individual.

- (a) Institutional recruitment: Some participants were recruited from rehabilitation centres and hospitals, who were approached in collaboration with rehabilitation departments where speech therapists identified suitable candidates based on predefined inclusion criteria.

The individuals bPWA2, mPWA2 and mPWA7 were recruited from the Sopron Erzsébet Teaching Hospital and Rehabilitation Institute in Hungary (Soproni Erzsébet Oktató Kórház és Rehabilitációs Intézet). The hospital provided a speech therapist as well as a bilingual psychologist for the Croatian tests, in addition to a quiet and private room for the assessments. The speech therapist conducted the Hungarian tests with bPWA2, mPWA2 and mPWA7, while the Croatian tests were carried out by the bilingual psychologist with bPWA2. Both the Hungarian and Croatian assessments were conducted in the presence of the author of this study. The hospital director of the Rehabilitation Institute in Sopron gave written permission (reference number: 543-2/2023) for the author of this study to enter the Institution and make use of the speech therapy room to conduct assessments. Participant bPWA5 was recruited from Penta Hospitals, Nemocnica Dunajská Streda in Slovakia. The director of the hospital authorised in writing for the author of this study to enter the Institution and make use of the speech therapy room to conduct assessments. The hospital provided a speech therapist and a suitable room for the assessments. Since the speech therapist was bilingual (L1 Hungarian, L2 Slovakian), all the tests were conducted in the presence of the speech therapist and the author of this study.

- (b) Private Speech Therapists: Additional participants were recruited through private speech therapists. These professionals were contacted to identify individuals who were actively seeking therapy and meet the eligibility requirements of the study. Written informed consent was obtained from both the therapists and participants prior to collecting data. Individuals bPWA6, bPWA7 and bPWA8 were recruited from a private speech therapist in Slovakia, while individuals mPWA8, mPWA9 and mPWA10 were recruited from a private speech therapist in Hungary.

(c) Individual recruitment: A subset of participants was recruited on an individual basis, particularly those who had completed a course of formal speech therapy and were no longer receiving regular treatment. These individuals were approached directly, often through community outreach or support groups for people with aphasia. Data for this group was collected in their homes to ensure a comfortable and familiar environment, thereby facilitating a more effective assessment. The following participants were recruited individually: bPWA1, bPWA3, bPWA4, mPWA1, mPWA3, mPWA4, mPWA5 and mPWA6. All participants provided written informed consent.

Data collection methods included standardised linguistic and non-linguistic assessments as well as a questionnaire tailored to the communication skills and bilingualism of the participants from the Bilingual Aphasia Test. Due to the length of the tests, the examinations took place on several occasions. Every participant was tested individually. All procedures were conducted in accordance with ethical guidelines, ensuring that the participants were fully informed of the study's purpose and their right to withdraw at any time. An empty copy of the informed consent form and the questionnaire from the Bilingual Aphasia Test are included in the Appendix.

2.3 Assessment tools

2.3.1 Linguistic batteries

In this study, language and cognitive functions implementing language batteries such as the Western Aphasia Battery (WAB), the Boston Naming Test (BNT), the Token Test (TT), the Hungarian version of the Test for Reception of Grammar (TROG-H) and verbal fluency tasks were assessed. The WAB, the BNT and semantic fluency were administered in both languages to bilingual participants. The principal objective of applying these batteries in this study was to investigate executive functions in terms of auditory comprehension, fluency and naming. For the measured EFS, please refer to Table 7.

Table 7. Overview of linguistic batteries for measuring executive functions

Tests	Verbality	Measured EFs	Languages	Scoring
Semantic verbal fluency	verbal output	WM, cognitive flexibility, inhibition	L1 and L2	number of correct answers, repetitions, and out-of-category responses
Letter verbal fluency			Hungarian	
Boston Naming Test			L1 and L2	
Token Test	pointing to the correct form/picture	WM, attention control, cognitive flexibility, inhibition	Hungarian	number of correct answers
TROG		WM, inhibition, cognitive flexibility		number of correct answers in each block

The WAB has been extensively employed in both clinical and research settings to evaluate individuals with aphasia (Kertesz, 2020), serving as an assessment tool for identifying the type of aphasia and language abilities. Four main parts were used to examine aphasia severity, namely spontaneous speech, comprehension, repetition and naming. The Aphasia Quotient (AQ) was based on their performance in the four parts of the WAB test (Kertesz, 2006). The scoring system is outlined in Table 8 whereby the maximum available score was 100.

Table 8. Scoring system for the Western Aphasia Battery to identify the severity of aphasia

AQ Score	Severity
0-25	Very severe
26-50	Severe
51-75	Moderate
76+	Mild

In the present study, the deficits in auditory comprehension at the sentence level were measured using the Token Test (TT) (De Renzi & Faglioni, 1978). The following cognitive functions collectively contributed towards the ability of an individual to perform well in the test: working memory, cognitive flexibility, inhibition, problem-solving, attention control, planning and organization. The test was comprised of 20 figures, 10 large and 10 small, consisting of two shapes (squares and circles) in different colours (red, green, yellow, white and black). The participants had to follow the

instructions using the correct figures to complete the commands while concentrating on several factors at the same time. The TT consisted of six blocks with 36 commands; the number of correct answers were examined (0-8 very severe; 9-16 severe; 17-24 moderate; 25-29 mild, above 30 no impairment). The last section contained the most complex commands which could not be repeated. All instructions could only be given once and were worth 1 point each. If the participant could only, complete the task after the instruction was repeated, only 0.5 points were given. If the participant answered wrongly 5 times in the test, the test ended. An empty copy of the TT is included in the Appendix. The following information regarding their educational background was considered when scoring:

+ 1 point for those who have only finished 6th grades

-1 point for those who have completed 9 to 12 years of vocational education or another form

-2 points for those in upper secondary school or other 4-year secondary school systems

-3 points for those at university

The Hungarian version of the TROG test was employed to measure the participants' comprehension of grammatical structures (Lukács et al., 2012). Several EFs were assessed using the test, including working memory, inhibition, cognitive flexibility, attention, problem-solving, planning and organization. In this test, the participants were asked to choose one of four pictures that represented the verbal command. The TROG-H test was added to the current study to collect further information about what grammatical structures were intact and which sections impaired in individuals with aphasia, for instance, nouns, verbs, adjectives, etc. Furthermore, this test could also serve as a basis for assessing comprehension, especially when the participants were unable to take the Token Test. In this case, the TROG-H test was essential in preparing the therapy course as it gathered information about the participant's comprehension at the grammatical level. The results of the test provided the speech therapist with the necessary data to understand the linguistic strengths and weaknesses of each individual. The parts of the TROG-H test are illustrated in Table 9. The highlighted blocks I. and L. were omitted from in the Hungarian version due to the grammatical differences between English and Hungarian. In this study, the number of correct answers (maximum 4) in each block was investigated.

Table 9. Parts of the TROG-H

A.	Noun
B.	Verb
C.	Adjective
D.	Combination of two
E.	Negation
F.	Combination of three
G.	Singular /Plural pronouns
H.	Interchangeable parts in active sentences
I.	Male/ Female pronouns
J.	Singular/ Plural nouns
K.	Comparative/ Superlative
L.	Interchangeable parts in passive sentences
M.	in and on prepositions
N.	Subordinate clause, subject-subject
O.	X, but not Y
P.	above and under
Q.	not only X, but Y also
R.	Subordinate clause, subject- X
S.	Neither X, nor Y
T.	Subordinate clause, X-subject

Furthermore, the Boston Naming Test (Kaplan, Goodglass & Weintraub, 1983) was added to evaluate confrontational picture-naming abilities. The test consisted of 60 black-line drawings ordered based on their level of difficulty (Gitterman et al., 2012). While it primarily assessed language and semantic memory, it also involved certain EFs, for example, inhibition, working memory, cognitive flexibility, attention, planning and organization. The participants, whose accuracy (the number of correct answers out of 60) and response times were measured in seconds, had to access their lexical knowledge to be able to name a word. For an empty copy of the BNT, please refer to Appendix 5.

Finally, the letter and semantic fluency tasks from the Addenbrooke’s Cognitive Examination were employed. In the semantic verbal fluency task, the participants were required to name as many animals as they could in one minute. The semantic verbal fluency tasks were conducted in both languages in the bilingual groups from which the number of correct answers was compared. The letter verbal fluency task was only carried out in Hungarian, in which the participants had to name as many words as they could starting with the letter ‘M’ other than names, cities and countries in one minute. Potential impairment in inhibition, working memory, cognitive flexibility, monitoring, planning and organization was investigated in both aphasia groups. The maximum available score in the fluency tasks was 7, (see Table 10 for details regarding the scoring system).

Furthermore, the fluency results were analysed in detail to investigate possible differences in the timing of responses in the Hungarian version of the semantic and letter verbal fluency tasks. The distribution of responses over 15-second intervals was compared between the aphasic and the reference groups. Additionally, errors such as out-of-category responses, repetitions and the number of correct answers in each interval were also investigated.

Table 10. The scoring system of the letter and semantic fluency tasks

Letter Verbal Fluency	Semantic Verbal 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
1- 3	1- 6	1
0	0	0

2.3.2 *Non-linguistic batteries*

The present study investigated the accuracy, speed, and efficiency of participants in neuropsychological tests designed to assess cognitive flexibility and working memory. Several tests were employed - including the Trail Making Test (TMT), the Rey-Osterrieth Complex Figure B Test (ROCF-B), an Auditory Sequential Memory Test (ASMT), a Visual Sequential Memory Test (VSMT) as well as a Number and Letter Sudoku Test using post-stroke rehabilitation software to evaluate cognitive flexibility and problem-solving skills aimed at achieving goals. Non-linguistic tests were added to minimize the impact of language impairments on the performance of the participants. The assessments only began once the participants had demonstrated a clear understanding of the tasks. Table 11 summarizes the measured executive functions in these batteries.

Table 11. Overview of the non-linguistic batteries for measuring executive functions

Tests	Measured EFs	Scoring
Visual Sequential Memory Test	WM, inhibition	RT in seconds, mistakes percentage
ROCF-B	WM	scores (max 31)
Auditory Sequential Memory Test	WM, cognitive flexibility, inhibition	number of correct answers
Trail Making Test	cognitive flexibility, WM	RT in seconds, number of mistakes
Number and letter Sudoku	cognitive flexibility, WM, inhibition	RT in seconds, mistakes percentage

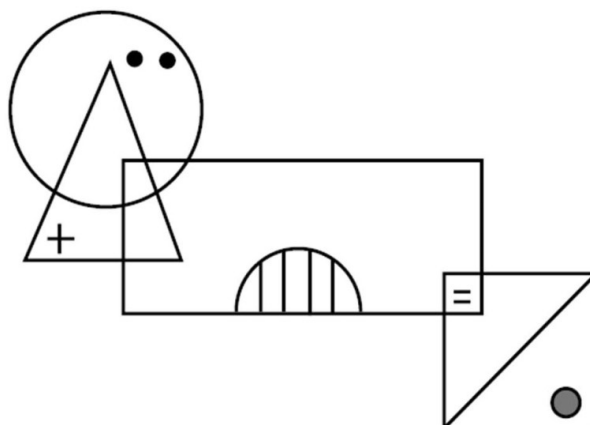
The Trail Making Test (TMT) is a widely used clinical task for the evaluation of cognitive flexibility impairment in participants with aphasia. The test assesses the capacity to shift between sets, requiring the participant to connect an alternating series of numbers and letters. Failure to shift attentional set results in a pattern of perseveration, whereby the individual continues to select based on the previously successful or overlearned set. Performance on the TMT is sensitive to the frontal lobe, particularly to the lateral frontal lobe (Egner, 2017). The Trail Making Test (TMT) consisted of two parts. In Part A, the participants had to draw a line connecting consecutive numbers, while in Part B, they had to join numbers and letters together in an alternating progressive sequence (McMorris, 2016). TMT was employed to measure visual attention, working memory and cognitive flexibility. Time to complete TMT-A and TMT-B is the most used measure of TMT, slowed TMT-B performance compared to TMT-A performance can be a sign of impaired capacity to modify a plan of action and simultaneously maintain two streams of thought (Tsiakiri et al., 2024). In both parts, response time was recorded in seconds, along with the number of errors made in each part. In the case of severe form of

aphasia, the examiner stopped the assessment if the participant was unable to progress, particularly in Part B. In such cases, only the number of errors was documented.

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, visual memory and executive functions by 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, the participants were required to draw the figure from memory (refer to Figure 8). This recalling phase assessed visual memory, organizational strategies and planning, monitoring as well as inhibitory control (Kirkwood et al., 2001). The maximum score achievable was 31. The scoring instructions included the following:

- The number of drawn elements (11 points): a circle, two small points, a triangle, a cross, a rectangle, an arc, a square, a diagonal line, an equal sign, large point, 4 lines.
- The position of elements (8 points): a cross in the triangle, two points in the circle, a large point in the square, an arc in the rectangle, 4 lines inside the arc, the square, the equal sign, the diagonal line in the square.
- Overlaps (8 points): circle-triangle, triangle-rectangle, circle-rectangle, rectangle-square.
- The Proportions between the four principal elements (4 points).

Figure 8. Rey-Osterrieth Complex Figure B Test



In the Auditory Sequential Memory Test, the participants were required to match words to corresponding pictures (see Figure 9). A trial test was conducted to determine if the participants understood and could carry out the task. If successful, a sequence of unrelated words was read aloud and the participants asked to reproduce the sequence by pointing to the corresponding pictures. The test began with a sequence of two words which gradually increased to a maximum of nine. The maximum score achievable was 44. The pictures were sourced from a Hungarian Aphasia Therapy Exercise Book (Szabó & Sándor, 2021). The task measured working memory as well as cognitive flexibility and inhibition.

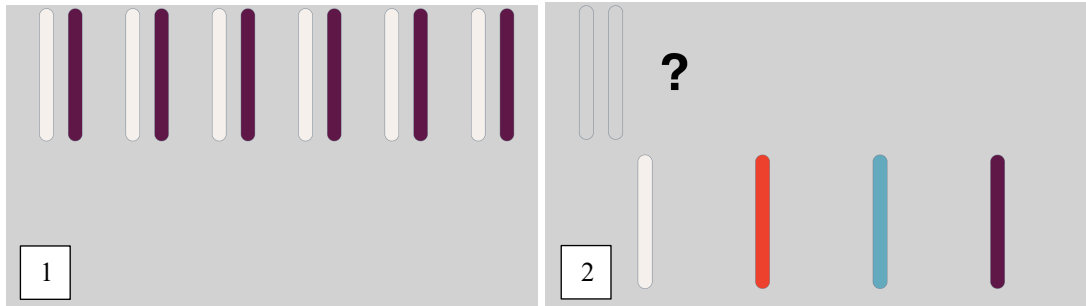
Figure 9. Pictures included in the Auditory Sequential Memory Test



A Visual Sequential Memory Test was applied from a Hungarian rehabilitation software which was made specifically for post-stroke patients (called Afázia App created by Katalin Nádudvari and Ali Baharev, PhD available online at <https://afazia.app/>), involving coloured sticks and requiring the participants to memorise the order of 12 such sticks (Cseh & Hegyi, 1995, pp. 7-27). Each part of the test involved two colours, such as white and purple, but these had to be chosen from four different colours, namely white, red, blue and purple (see Figure 10). The software instantly provided feedback to the participant, indicating whether the selected colour was correct or incorrect. All the participants completed the test on the same tablet to ensure the assessment environment was consistent. Their response times were measured in seconds to investigate differences

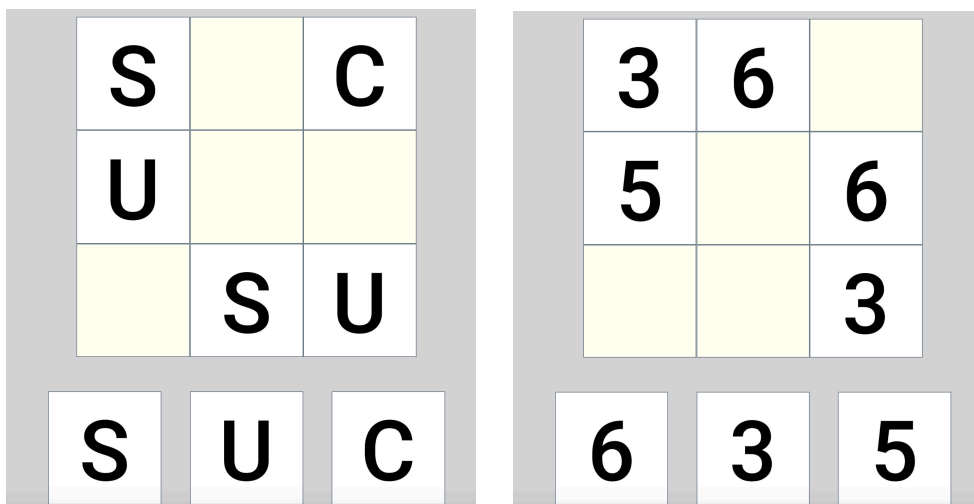
in performance between aphasics and neurologically healthy individuals. The test evaluated working memory and cognitive flexibility.

Figure 10. An example of the Visual Sequential Memory Test



The Number and Letter Sudoku tasks were also used from the Afázia App. In these tasks, each letter / number could appear once in each row and column (see Figure 11). Here, similarly to the Visual Sequential Memory Test, the software instantly provided feedback to the participant, indicating whether the selected letter/number was correct or incorrect. All the participants completed the tasks on the same tablet to ensure the assessment environment was consistent. The response times were measured in seconds assessing working memory, attention, problem-solving as well as cognitive flexibility, planning and organisation.

Figure 11. An example of the Letter and Number Sudoku tasks



2.4 Data analysis

The study used the Kolmogorov-Smirnov (KS) test for two independent groups. The KS test is a non-parametric and distribution-free test that imposes no assumptions regarding the underlying data distribution. Specifically, the two-sample KS test with a one-sided alternative hypothesis for stochastic dominance was employed. Unlike the Mann–Whitney U test, which primarily evaluates differences in central tendencies between two populations, the KS test considers the entire distribution of data (Dodge, 2008). In the case of discrete data, the KS test tends to be conservative, as noted in previous studies (Noether, 1963; Slakter, 1965; Walsh, 1963). The study used the SciPy library’s implementation for analysis (Virtanen et al., 2020), specifically with the `kstest` function.

For the analysis of paired samples, the Wilcoxon signed-rank (WSR) test, a non-parametric method to assess the significance of differences in paired data was employed, which was also performed using a one-sided alternative hypothesis to evaluate stochastic dominance. The calculations were implemented using the `wilcoxon` function from the SciPy Library (Virtanen et al., 2020). This implementation uses permutation tests for samples with ties.

To assess monotonic relationships between two variables, X and Y (e.g., the effect of age on test scores), the Kendall's tau correlation coefficient was employed. This non-parametric measure does not assume specific distributions for X, Y, or their joint distribution (X, Y). The analysis was conducted using the `kendalltau` function from the SciPy library (Virtanen et al., 2020), which accounts for tied ranks through permutation tests.

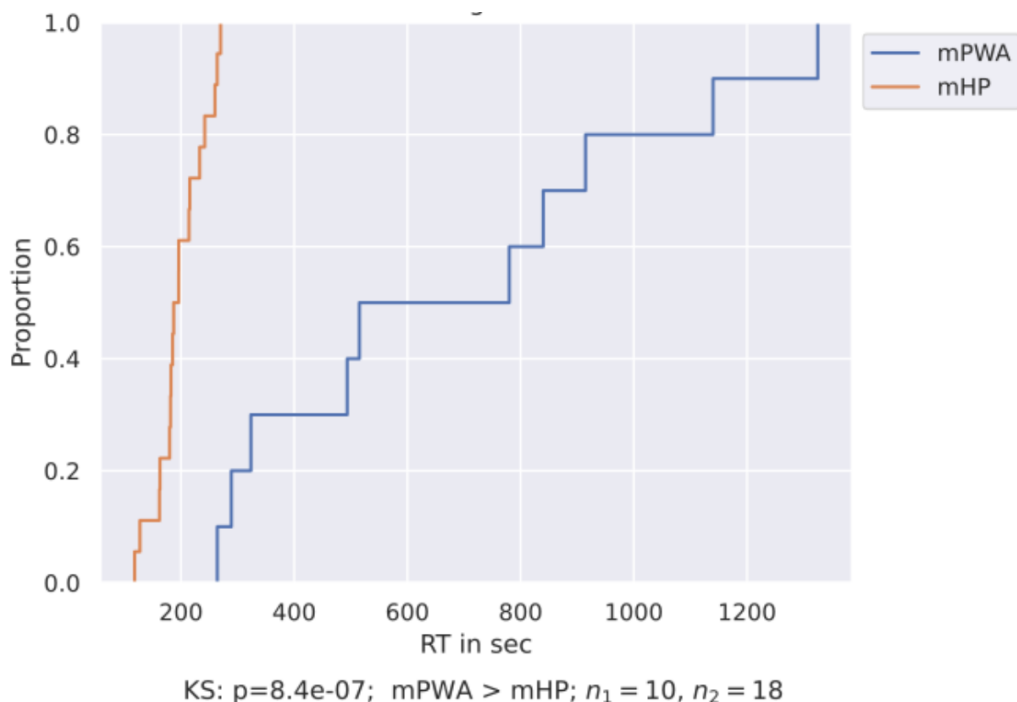
To evaluate linear relationships between two variables, the Pearson’s correlation coefficient was used, as implemented in the SciPy library (Virtanen et al., 2020). However, this statistic is not robust (Wilcox, 2005) and may yield misleading results in the presence of outliers (Devlin et al., 1975; Huber, 2004). Specifically, it lacks both distributional robustness (Vaart, 1998) and outlier resistance (Wilcox,2005). To address these limitations, we required both Kendall’s tau and Pearson’s correlation coefficients to be statistically significant and to share the same sign (positive or negative) before interpreting results.

The empirical cumulative distribution function (ECDF) is a useful statistical tool for visualising the distribution of data points in a dataset. In the present study, the ECDF plots

were used to illustrate the difference in performance between individuals with bilingual and monolingual aphasia as well as between individuals with aphasia and healthy participants.

Figure 12 illustrates an example of an ECDF graph, where the x-axis represents the values of the variable being studied, e.g. response time or test scores. The y-axis represents the cumulative proportion of participants scoring at or below a given score. For instance, a point on the stepped line at 0.6 indicates 60% of the observations fall below this value. The line rises in steps, with each step corresponding to an observation in the dataset. In the example graph two groups are compared: individuals with monolingual aphasia (mPWA) and monolingual healthy participants (mHP) in a task where performance differences in response time between the two groups were compared. It can be seen in the example, that the p-value and $mPWA > mHP$ are added in the figure. The relation sign means that the mPWA group produced greater numerical data compared to the mHP group, meaning that the mPWA group were slower because their RT was higher. It is important to note that, the stepped line of the group with the greater numerical data is constantly situated below the other line. The steepness of the lines can also provide insight into the variability of performance within each group. In our example, a steep stepped line (orange for mHP) indicates less variability, while a flatter stepped line (blue for mPWA) suggests more variability in performance.

Figure 12. An example of an ECDF graph



3 RESULTS

It is important to note that all the findings presented in this study are derived from the comparison conducted between the monolingual and bilingual aphasia groups as well as between the two aphasia groups and the reference groups. The order of analysis follows the same pattern for all the assessment tools, starting with the comparison of the two aphasia groups and continuing with the comparison between aphasia groups and the reference groups.

3.1 Linguistic assessments

This section presents the findings from the Boston Naming Test (BNT), Token Test (TT), verbal semantic and letter fluency tasks and the Test for Reception of Grammar (TROG-H). Table 12 (significant with **bold**) provides a summary of the results of the linguistic tests between mono-and bilingual aphasia groups as well as between aphasics and reference groups. Table 13 (significant with **bold**) includes the results of the statistical analysis with p values between aphasics and reference groups.

Table 12. Summary of linguistic test results comparing monolingual and bilingual aphasics, and aphasics with their healthy counterparts

Comparison	Linguistic tests				
	Token	TROG	Naming	Semantic and letter fluency	
				Total score	Every 15 seconds
mPWA vs. monolingual reference group	Yes, aphasia < reference PWA achieved lower scores.	Yes, aphasia < reference in the following blocks: G,H,J,K,M, N,P,R,S,T	Yes, for RT aphasia > reference. Yes, for number of correct answers aphasia < reference,	Yes, aphasia < reference PWA produced fewer responses.	Yes, PWA produced lower number of correct responses in all 4 intervals. No, for errors and repetitions. Similar distribution of answers.
bpWA vs. bilingual reference group		Yes, for bpWA in blocks G and M	PWA were slower and produced fewer answers.	Yes, for semantic fluency > letter fluency Both PWA and HP produced fewer responses in letter fluency.	
bpWA vs. mPWA		No	No, for RT and number of correct answers.	No, for the number of correct answers, repetitions and errors.	

Yes- significant finding, No- not significant findings.

Table 13. Results from the statistical analysis (KS) of the linguistic tests between mono-and bilingual aphasic and reference groups

	Linguistic batteries					TROG-H Blocks
	BNT-HU		Token	Semantic fluency	Letter fluency	
	number of correct answers	RT in sec.	score	score	score	
mPWA vs. monolingual reference group	KS: D= 0.844, p < .001 aphasia < reference	KS: D= 0.944, p < .001 aphasia > reference	KS: D= 0.800, p < .001 aphasia < reference	KS: D= 0.800, p < .001 aphasia < reference	KS: D= 0.844, p < .001 aphasia < reference	Block A- KS: D=0.000, p=1.000 Block B- KS: D=0.200, p=.523 Block C- KS: D=0.100, p=.835 Block D- KS: D=0.344, p=.175 Block E- KS: D=0.200, p=.523 Block F- KS: D=0.444, p=.058 Block G- KS: D=0.500, p=.027 Block H- KS: D= 0.600, p=.005 Block J- KS: D= 0.700, p=.001 Block K- KS: D=0.500, p=.027 Block M- KS: D= 0.489, p=.031 Block N- KS: D= 0.500, p=.027 Block O- KS: D=0.433, p=.066 Block P- KS: D= 0.467, p=.043 Block Q- KS: D=0.200, p=.523 Block R- KS: D= 0.700, p=.001 Block S- KS: D=0.589, p=.006 Block T- KS: D=0.511, p=.024 aphasia < reference
bPWA vs. bilingual reference group	KS: D=0.694, p= .002 aphasia < reference	KS: D=0.819, p < .001 aphasia > reference	KS: D=0.833, p < .001 aphasia < reference	KS: D= 0.639, p= .006 aphasia < reference	KS: D=0.764, p < .001 aphasia < reference	Block A- KS: D=0.000, p=1.000 Block B- KS: D=0.319, p=.275 Block C- KS: D= 0.375, p=.172 Block D- KS: D=0.250, p=.438 Block E- KS: D=0.375, p=.172 Block F- KS: D=0.375, p=.172 Block G- KS: D=0.500, p=.044 Block H- KS: D=0.319, p=.275 Block J- KS: D=0.125, p=.779 Block K- KS: D=0.444, p=.086 Block M- KS: D=0.583, p=.015 Block N- KS: D=0.458, p=.070 Block O- KS: D= 0.403, p=.124 Block P- KS: D=0.444, p=.086 Block Q- KS: D=0.458, p=.070 Block R- KS: D=0.389, p=.149 Block S- KS: D=0.458, p=.070 Block T- KS: D=0.333, p=.241 aphasia < reference

3.1.1 Naming: increased response time and decreased accuracy in the Boston Naming Test

This section presents the findings from the Boston Naming Test (BNT) that both bilingual and monolingual individuals with aphasia as well as both the bilingual and monolingual reference groups took. The primary aim of this analysis was to compare the performance of these groups in terms of accuracy (measured by the total score in the BNT) and response times (RT) during the naming tasks. The individual scores and mean scores of the group concerning monolingual participants are presented in Table 14, while those of the bilinguals are presented in Table 15.

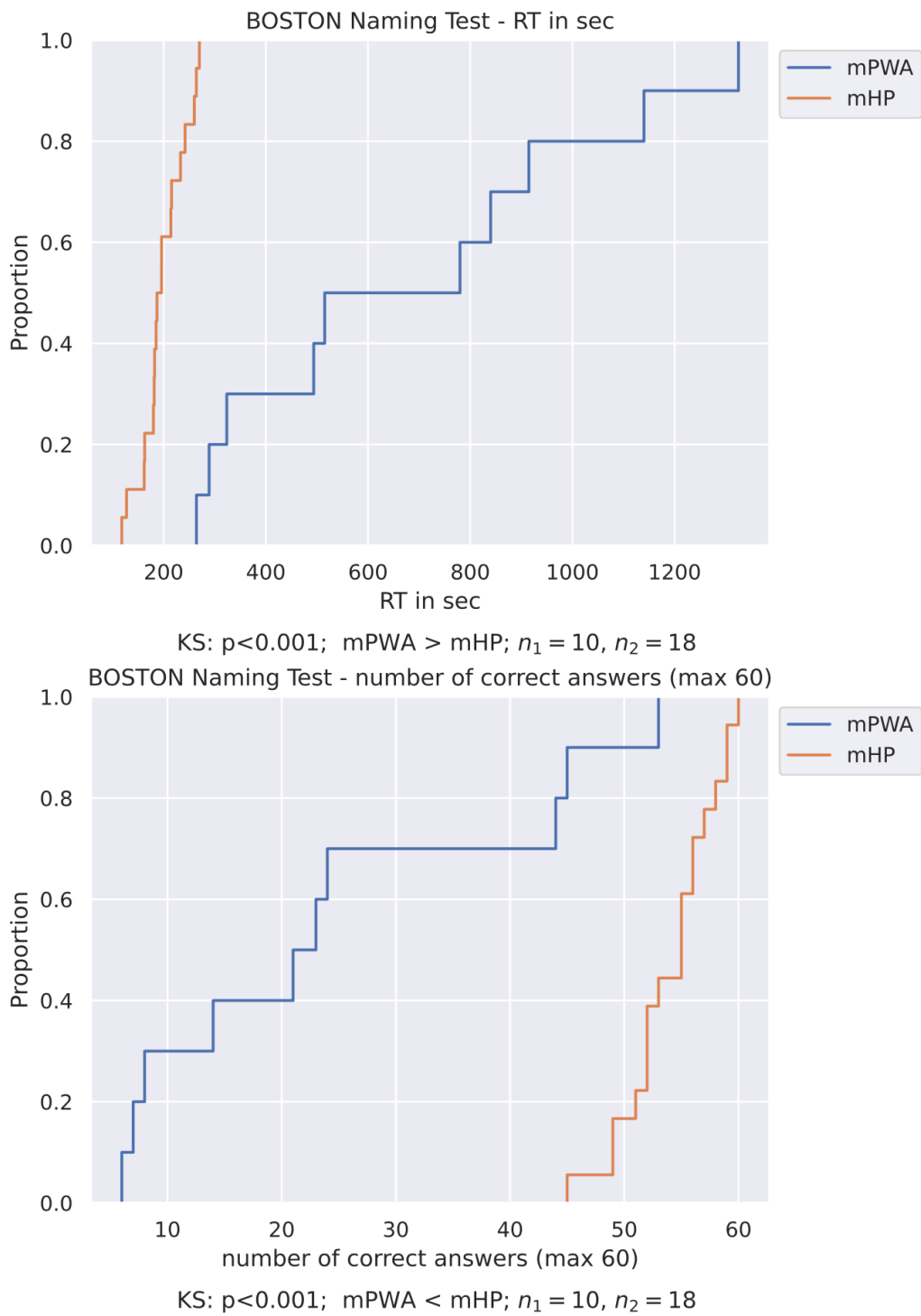
3.1.1.1 Monolingual aphasics vs. bilingual aphasics

The maximum score possible in the BNT was 60 points. The scores achieved by the bPWA participants ranged from 0 to 54 (M=29.38, SD=20.84), while the scores for the monolingual aphasics ranged from 6 to 53 (M= 24.50, SD=17.19). The response times for the bPWA group varied with a range from 148.07 to 850.00 seconds (M=562.52, SD=236.99). Similarly, the response times in the mPWA group also varied, ranging from 264.17 to 1325.00 seconds (M=688.55, SD=370.04). Overall, the analysis of accuracy and response times revealed a trend only between the mPWA and the bPWA groups in the Hungarian version of the BNT (RT- KS: D=0.300, p=.378; scores- KS: D=0.450, p=.124).

3.1.1.2 Monolingual aphasics vs. monolingual reference group

In the BNT the mean score for the group of monolingual aphasics was 24.50 (SD=17.19), which is substantially lower than the mean score of 54.06 (SD=4.02) for the monolingual reference group, indicating a marked impairment in naming ability among participants with aphasia (KS:D=0.844, $p < .001$). The range of scores in the group of aphasics (6-53) further highlights the variability in performance, with some participants scoring extremely low (as low as 6), while others approached the upper limits of the scoring scale. In contrast, the reference group exhibited a more homogeneous level of performance, with scores clustered between 45 and 60. The response times further illustrate the cognitive challenges faced by the group of aphasics. The mean RT for the mPWA group was 688.55 seconds (SD=370.04), which is notably longer than 198.72 seconds (SD=43.47) observed in the monolingual reference group (KS: D=0.944, $p < .001$). The distribution of response times within the group of aphasics, ranging from 264.17 to 1325.00 seconds, further underscores the substantial variability in processing speed among the participants. Notably, some individuals required over 1300 seconds to respond, highlighting the broad spectrum of processing capabilities within the group (refer to Table 14). This is in stark contrast to the reference group, where the maximum recorded response time was 270 seconds. The results indicate a statistically significant difference in naming scores and response times between the aphasia and reference groups (refer to Figure 13). These findings support the hypothesis that cognitive impairments associated with aphasia negatively affect both naming accuracy and processing speed.

Figure 13. Number of correct answers and response times in the Boston Naming Test between the monolingual participants with aphasia (mPWA) and the monolingual reference group (mHP)

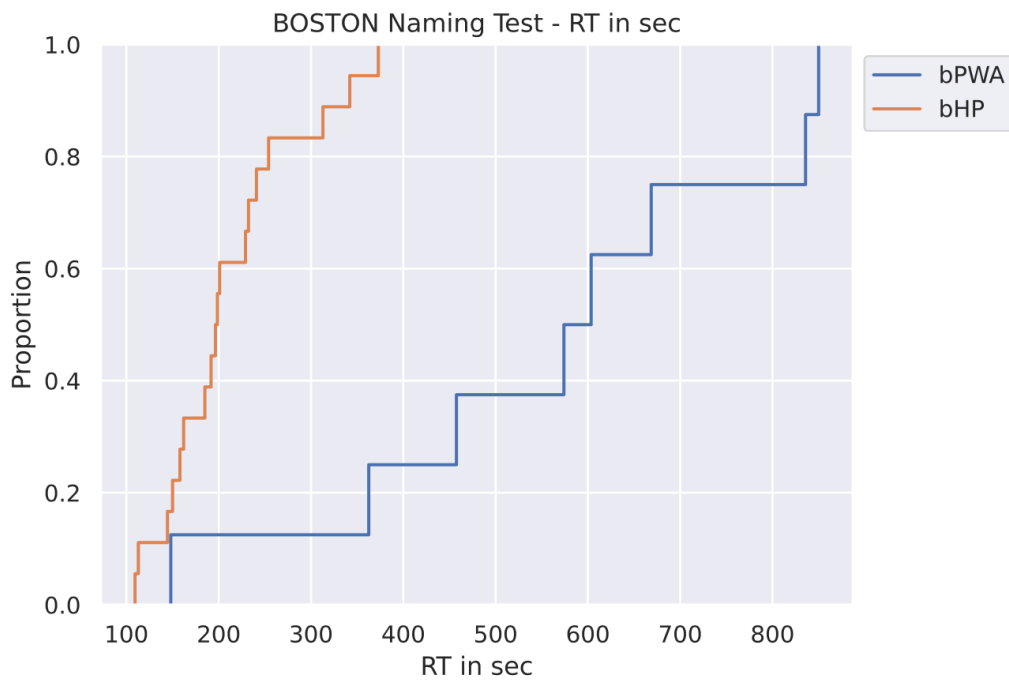


3.1.1.3 Bilingual aphasics vs. bilingual reference group

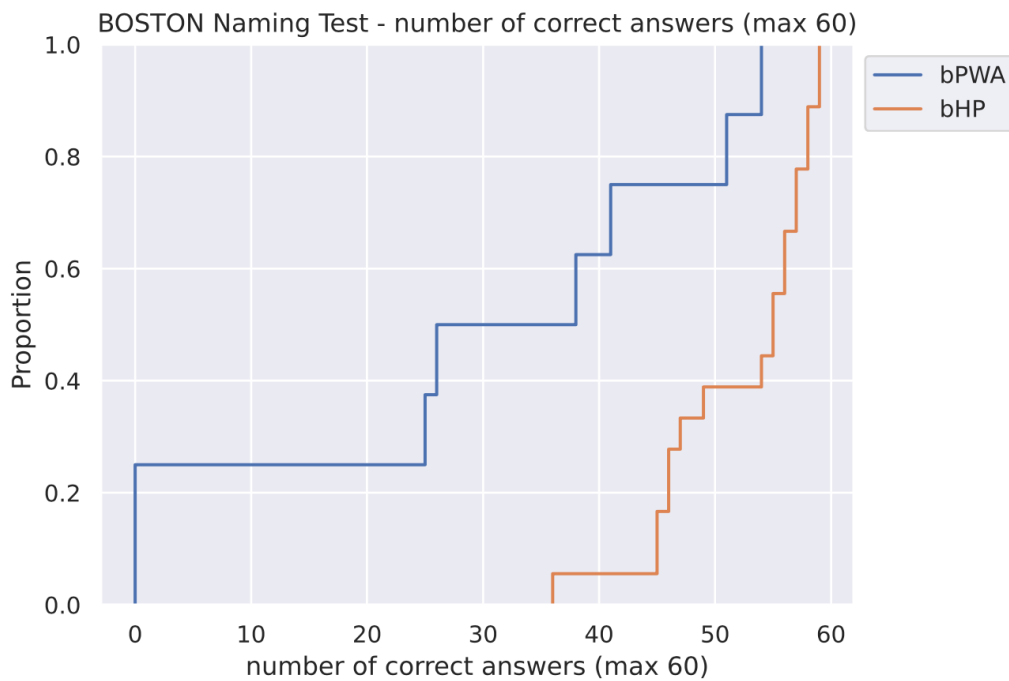
The group of bilingual aphasics exhibited a wide range of scores in the Hungarian Boston Naming Test with minimum and maximum scores of 0 and 54, respectively ($M= 29.38$, $SD=20.84$), indicating a significant degree of impairment in terms of naming ability (refer to Figure 14). The RTs observed in the bPWA group ranged from 148.07 to 850.00 seconds ($M= 562.52$, $SD=236.99$). These findings suggest a considerable degree of variability in both naming ability and processing speed among aphasic participants. The presence of such a substantial level of variability suggests the likelihood of more profound deficits being experienced by some individuals rather than others, possibly due to their subtype of aphasia (fluent or non-fluent) and lesion location. In contrast, the bilingual reference group demonstrated a markedly higher mean score in the BNT ($M= 52.11$, $SD=6.57$), and a range of scores from 36 to 59. The response times for the bHP group ranged from 109.31 to 372.94 seconds ($M= 210.7$, $SD=73.61$). This data indicates that the bilingual reference group performed significantly better than the group of bilingual aphasics regarding both naming accuracy (KS: $D= 0.694$, $p=.002$) and processing speed (KS: $D=0.819$, $p < .001$). Similarly to the monolingual aphasia group, the results suggest that as naming ability decreased, response times increased supporting the hypothesis that impairments in executive functions such as inhibitory control and working memory may contribute to longer response times as well as reduced accuracy in people diagnosed with aphasia.

In the Croatian/Slovakian/German versions of the BNT, the reference group also performed faster ($M=270.71$, $SD=66.98$) and had higher number of correct answers ($M=37.44$, $SD=7.83$) when compared to the bPWA group (score: $M=14.63$, $SD=12.87$; RT: $M=719.89$, $SD=392.52$). Furthermore, the analysis revealed that both the bilingual aphasia and the reference group performed significantly better in the Hungarian versions. In the Hungarian version of the BNT, the bPWA group had a means score of 29.38 ($SD=20.84$), which was significantly better compared to the CRO/SK/DE versions (WSR: $W=34.50$, $p=.016$). The bilingual reference group also performed better in the Hungarian version of the BNT ($M=52.11$, $SD= 6.57$) than in the CRO/SK/DE version (WSR: $W=171.00$, $p < .001$). For individuals scores, refer to Table 15.

Figure 14. Number of correct answers and response time in the Boston Naming Test between the group of bilingual participants with aphasia (bPWA) and the bilingual reference group (bHP)



KS: $p < 0.001$; bPWA > bHP; $n_1 = 8$, $n_2 = 18$



KS: $p = 0.002$; bPWA < bHP; $n_1 = 8$, $n_2 = 18$

Table 14. Results of the linguistic tests in the group of monolingual aphasics and the monolingual reference group

Participants		BNT-HU (max score 60)	BNT- HU RT in sec.	Token (max score 36)	Letter Fluency- HU (max score 7)	Semantic Fluency- HU (max score 7)
Group of monolingual aphasics (N=10)	mPWA1	6	493.72	5	0	0
	mPWA2	14	914.73	18	2	1
	mPWA3	53	264.17	32	2	6
	mPWA4	7	1325.00	0	0	1
	mPWA5	45	323.58	19	2	4
	mPWA6	21	515.21	18	2	3
	mPWA7	8	1140.06	11	0	1
	mPWA8	23	840.00	24	1	2
	mPWA9	44	289.00	31	7	7
	mPWA10	24	780.00	18	1	2
Range of scores (min-max)		6-53	264.17- 1325.00	0-32	0-7	0-7
Mean score		24.50	688.55	17.60	1.70	2.70
SD		17.19	370.04	10.23	2.06	2.31
Monolingual reference group (N=18)	mHP1	52	215.51	33	6	6
	mHP2	49	181.50	31	4	6
	mHP3	55	118.10	32	7	7
	mHP4	51	214.13	30	5	7
	mHP5	55	162.90	33	6	7
	mHP6	58	195.87	35	6	7
	mHP7	55	127.43	33	7	7
	mHP8	49	182.33	35	3	7
	mHP9	52	185.21	30	6	6
	mHP10	57	180.00	33	6	7
	mHP11	45	196.00	31	2	5
	mHP12	60	187.00	33	6	7
	mHP13	56	233.00	33	5	7
	mHP14	59	242.00	33	7	7
	mHP15	52	264.00	33	4	7
	mHP16	53	260.00	31	3	6
	mHP17	59	270.00	31	6	7
	mHP18	56	162.00	33	3	7
Range of scores (min-max)		45-60	118.10- 270.00	30-35	2-7	5-7
Mean score		54.06	198.72	32.39	5.11	6.67
SD		4.02	43.47	1.46	1.57	0.59

Table 15. Results of the linguistic tests in the group of bilingual aphasics and the bilingual reference group

Participants	BNT-HU (max score 60)	BNT- HU RT in sec.	BNT- CRO/ SK/DE (max score 60)	BNT- CRO/SK/ DE RT in sec.	Token (max score 36)	Letter Fluency- HU (max score 7)	Semantic Fluency- HU (max score 7)	Semantic Fluency - CRO/SK/ DE (max score 7)	
Group of bilingual aphasics (N=8)	bPWA1	51	362.58	27	336.96	27	4	6	3
	bPWA2	25	835.81	7	541.96	23	1	4	1
	bPWA3	26	603.52	12	750.40	17	3	1	0
	bPWA4	38	457.54	13	625.60	30	3	1	1
	bPWA5	54	148.07	36	250.19	30	1	7	7
	bPWA6	0	668.60	0	800.00	4	0	0	0
	bPWA7	41	574.00	22	1500.00	17.5	3	5	1
	bPWA8	0	850.00	0	954.00	5	0	0	0
Range of scores (min-max)	0-54	148.07- 850.00	0-36	250.19- 1500.00	4-30	0-4	0-7	0-7	
Mean score	29.38	562.52	14.63	719.89	19.19	1.88	3.00	1.63	
SD	20.84	236.99	12.87	392.52	10.34	1.55	2.38	2.39	
Bilingual reference group (N=18)	bHP1	46	240.88	22	209.68	32	5	6	5
	bHP2	57	196.43	39	227.16	33	4	7	6
	bHP3	56	191.70	43	273.44	31	5	7	6
	bHP4	59	144.48	33	252.14	35	6	7	6
	bHP5	47	232.27	36	286.79	29	5	6	5
	bHP6	58	112.91	41	229.99	33	5	7	6
	bHP7	46	200.99	36	405.92	32	2	6	4
	bHP8	59	198.62	37	272.95	33	2	6	5
	bHP9	45	372.94	39	360.54	28	6	4	4
	bHP10	45	312.91	27	230.06	32	4	7	5
	bHP11	49	254.05	39	263.54	31	4	4	4
	bHP12	55	109.31	25	295.60	32	5	7	5
	bHP13	58	185.00	52	200.00	33	7	7	4
	bHP14	36	342.00	34	348.00	29	4	6	5
	bHP15	56	158.00	38	180.00	32	7	7	6
	bHP16	54	229.00	45	202.00	32	7	7	7
	bHP17	57	162.00	51	242.00	33	6	7	5
	bHP18	55	150.00	37	393.00	35	6	7	4
Range of scores (min-max)	36-59	109.31- 372.94	22-52	180.00- 405.92	28-35	2-7	4-7	4-7	
Mean score	52.11	210.75	37.44	270.71	31.94	5.00	6.39	5.11	
SD	6.57	73.61	7.83	66.98	1.86	1.50	0.98	0.90	

3.1.2 *Impairment in auditory comprehension of grammatical structures and complex sentences*

This section presents the results of the Hungarian version of the Test for Reception of Grammar (TROG-H) and the Token Test (TT). The TROG-H assessment provided valuable insights into intact and impaired grammatical structures in auditory comprehension, when aphasic participants demonstrated extremely poor performance in the TT. The data for participants with aphasia are summarized in Table 16. The table includes individual scores across 18 blocks. The mean scores for each group are also reported to facilitate comparative analyses in Figures 15 and 16. The results of the Token Test are summarised in Tables 14 and 15, which present individual scores, ranges and mean scores.

3.1.2.1 Monolingual aphasics vs. bilingual aphasics

In the TROG-H test, when the performances of the two groups of aphasics were compared (refer to Table 16) the statistical analysis revealed similar level of performance and reached no statistical significance between the monolingual and bilingual participants with aphasia (in each block $p > .100$).

In the Token Test, both aphasia groups exhibited similar performance in auditory comprehension (mPWA: $M= 17.60$, $SD=10.23$; bPWA: $M=19.19$, $SD=10.34$), revealing no statistical significance between the two groups (KS: $D=0.200$, $p=.622$). It was observed that participants in both aphasia groups experienced difficulties in more complex commands, as they might have caused confusion, leading to complete the commands unsuccessfully. Beyond deficits in grammar comprehension, impaired inhibition may also be responsible for poor performance in more complex commands, as completing the commands successfully required simultaneous execution and proper inhibition, such as, selecting the correct form, size and colour all at once.

Table 16. Individual scores from the TROG-H test in the groups of monolingual (mPWA) and bilingual aphasics (bPWA). The TROG-H contained 18 blocks and the maximum available score in each block was 4.

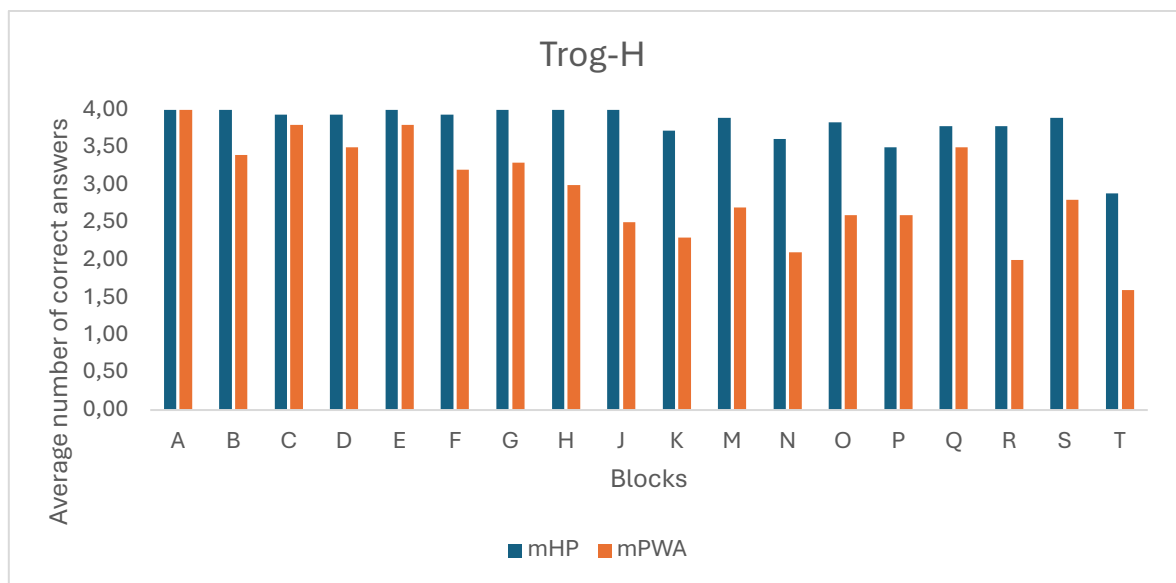
	A	B	C	D	E	F	G	H	J	K	M	N	O	P	Q	R	S	T
mPWA 1	4	4	2	3	3	2	3	2	1	2	1	0	2	2	4	1	3	3
mPWA 2	4	4	4	4	4	4	3	3	2	2	4	1	4	3	4	2	2	2
mPWA 3	4	4	4	4	4	4	4	4	3	4	4	3	4	4	4	3	3	2
mPWA 4	4	1	4	3	3	4	3	3	3	0	3	0	0	0	0	0	0	0
mPWA 5	4	4	4	3	4	4	4	4	3	3	2	4	3	3	4	2	4	2
mPWA 6	4	4	4	4	4	3	2	1	1	4	3	3	4	3	4	2	3	1
mPWA 7	4	4	4	4	4	1	2	2	0	3	1	1	0	2	4	2	2	1
mPWA 8	4	4	4	4	4	3	4	4	4	0	4	4	4	3	4	3	4	1
mPWA 9	4	4	4	4	4	4	4	4	4	4	4	4	3	4	4	4	4	2
mPWA 10	4	1	4	2	4	3	4	3	4	1	1	1	2	2	2	1	3	2
Mean (mPWA)	4.00	3.40	3.80	3.50	3.80	3.20	3.30	3.00	2.50	2.30	2.70	2.10	2.60	2.60	3.40	2.00	2.80	1.60
bPWA 1	4	3	4	4	4	4	4	4	4	3	3	2	4	4	3	4	4	3
bPWA 2	4	4	3	4	4	3	3	3	4	2	1	3	3	1	2	3	3	0
bPWA 3	4	4	4	4	4	4	3	4	4	4	3	2	2	3	4	2	3	1
bPWA 4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2
bPWA 5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3
bPWA 6	4	1	2	1	1	0	0	0	2	1	0	0	0	0	0	0	0	0
bPWA 7	4	4	4	4	3	4	4	4	3	0	3	1	3	0	2	1	2	2
bPWA 8	4	2	1	2	2	1	3	0	4	0	1	0	0	0	0	0	0	0
Mean (bPWA)	4.00	3.25	3.25	3.38	3.25	3.00	3.13	2.88	3.63	2.25	2.38	2.00	2.50	2.00	2.38	2.25	2.50	1.38

3.1.2.2 Monolingual aphasics vs. monolingual reference group

In the TROG-H test, the scores varied between participants with monolingual aphasia, reflecting a range of comprehension abilities (refer to Table 16). The highest scores were consistently observed in blocks A-C and E, where most participants achieved the maximum score of 4. The individual scores of the monolingual reference group were consistently high with many participants achieving the maximum score across various blocks. A comparative analysis of the monolingual aphasia and reference groups was performed using the Kolmogorov-Smirnov test (KS) to identify significant differences in comprehension scores across the various blocks. The results of this analysis indicated significant differences in comprehension between the two groups in the following blocks: G, H, J, K, M, N, P, R, S and T (for p values refer to Table 13). These results suggest that the mPWA group exhibited significantly lower comprehension abilities in these specific

blocks compared to the mHP group. A comparison of the mean scores per block between the mPWA and mHP groups are illustrated in Figure 15. The significant differences observed in specific blocks suggest that certain grammatical structures may be more challenging for individuals with aphasia to process.

Figure 15. Comparison of performance (mean scores) between the group of monolingual aphasics (mPWA) and the monolingual reference group (mHP) in the Hungarian version of the TROG test which consisted of 18 blocks with a maximum available score of 4 in each block



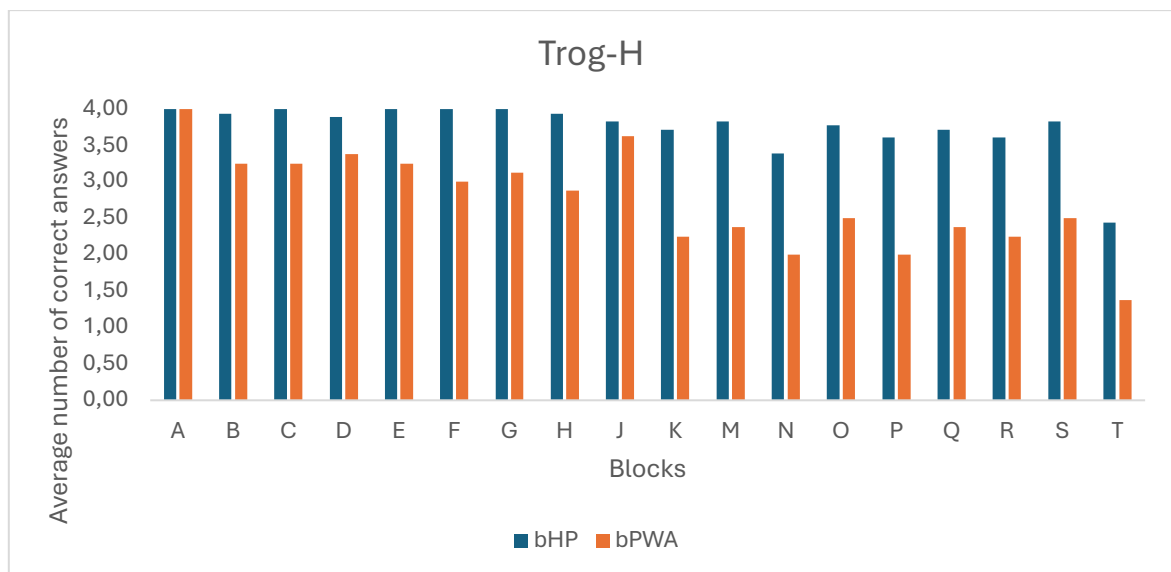
In the Token Test, the individual scores in the aphasia group ranged from a minimum of 0 to a maximum of 32 ($M=17.60$, $SD=10.23$) indicating a wide degree of variability in performance, with some individuals demonstrating relatively high scores while others performed poorly. In contrast, the monolingual reference group scored substantially higher in the TT with scores ranging from 30 to 35 ($M=32.39$, $SD=1.46$). The comparison between the mPWA group and the monolingual reference group revealed a statistically significant difference. The analysis highlighted that the mPWA group performed significantly worse than the mHP group ($KS: D=0.800$, $p < .001$).

3.1.2.3 Bilingual aphasics vs. bilingual reference group

In the TROG-H test, the data from the bilingual reference group (bHP) demonstrated consistently high scores across the majority of the blocks. The mean scores for each block were predominantly the maximum score of 4 or near to it. In contrast, the results from the group of bilingual aphasics presented a markedly different picture. As shown in Figure

16, the mean scores across the blocks were significantly lower than those of the bHP group, particularly in blocks G and M where the mean scores were 3.13 and 2.50, respectively. This discrepancy highlights the challenges faced by individuals with aphasia in comprehending grammatical structures. The statistical analysis indicated significant differences in comprehension between the two groups in blocks G (KS:D=0.500, $p = .044$) and M (KS: D= 0.583, $p = .015$), suggesting that certain grammatical structures may be more difficult for individuals with aphasia to comprehend, potentially due to the nature of their language impairment. Furthermore, the individual scores reveal a spectrum of comprehension abilities within the bPWA group, indicating that while some individuals may retain a degree of grammatical understanding, many struggle (refer to Table 16). This variability highlights the need for tailored interventions that address the specific grammatical challenges faced by bilingual individuals with aphasia.

Figure 16. Comparison of performance (mean scores) between the group of bilingual aphasics (bPWA) and the bilingual reference group (bHP) in the Hungarian version of the TROG test (TROG-H) which consisted of 18 blocks with a maximum available score of 4 in each block



In the TT, performances in the bPWA group also varied with scores ranging from 4 to 30 ($M=19.19$, $SD=10.34$). Similarly to the mPWA group, the bPWA group demonstrated a wide range of abilities with some participants scoring lower than others (refer to Table 15). In contrast, the scores of the bilingual reference group ranged from 28 to 35 ($M=31.94$, $SD=1.86$). The analysis of the bPWA group compared to the bilingual healthy reference group also yielded a significant difference (KS: D= 0.833, $p < .001$).

3.1.3 Impairment in semantic and letter fluency

The semantic and letter fluency tasks were designed to assess the verbal fluency of participants during four 15-second-long periods, allowing for a detailed analysis of their performance over time. The results are summarised in Tables 17-19, illustrating the correct answers provided by each participant in both the semantic and letter fluency tasks alongside the number of mistakes and repetitions made (significant with **bold**). Furthermore, the overall performance was compared based on the scoring system, for individual scores see Tables 14 and 15. The results of the fluency tasks are presented in the following sections: a comparison of performance between the monolingual and bilingual participants with aphasia is provided. Then, a comparison of the monolingual aphasia group with the monolingual reference group is presented. Moreover, a comparison of the bilingual aphasia group with the bilingual reference group is provided. Furthermore, the performance of all groups in the two fluency tasks is compared, as well as the performance in semantic fluency in both languages. Finally, a comparison of performance between the naming abilities in the Boston Naming Test and semantic fluency task is provided.

3.1.3.1 Monolingual aphasics vs. bilingual aphasics

The detailed examination of performance over the four periods provided an insight into the patterns in fluency exhibited by each group (refer to Figure 17). In the semantic fluency task, during the first period (0-15 seconds), both groups of aphasics exhibited the highest percentage of correct answers, namely 44.32% of their total responses for the mPWA group and 43.04% for their bPWA counterparts. During the second period (15-30 seconds), a decline in the percentage of correct responses from both groups was observed, that is, 19.32% for the mPWA group and 22.78% for their bPWA counterparts. In the third period (30-45 seconds), the mPWA group produced the lowest percentage of correct answers, namely 14.57%, compared to 20.25% for their bPWA counterparts. During the final period (45-60 seconds), 21.59% of responses from the mPWA group were correct, compared to 13.92% for their bPWA counterparts, the lowest percentage recorded in this task. In terms of the number of correct answers, repetitions and errors across the 15-second intervals, the analysis did not reach any statistical significance (refer to Table 17).

Figure 17. Distribution of answers (%) in the semantic fluency tasks in aphasic and healthy participants across 15-second intervals

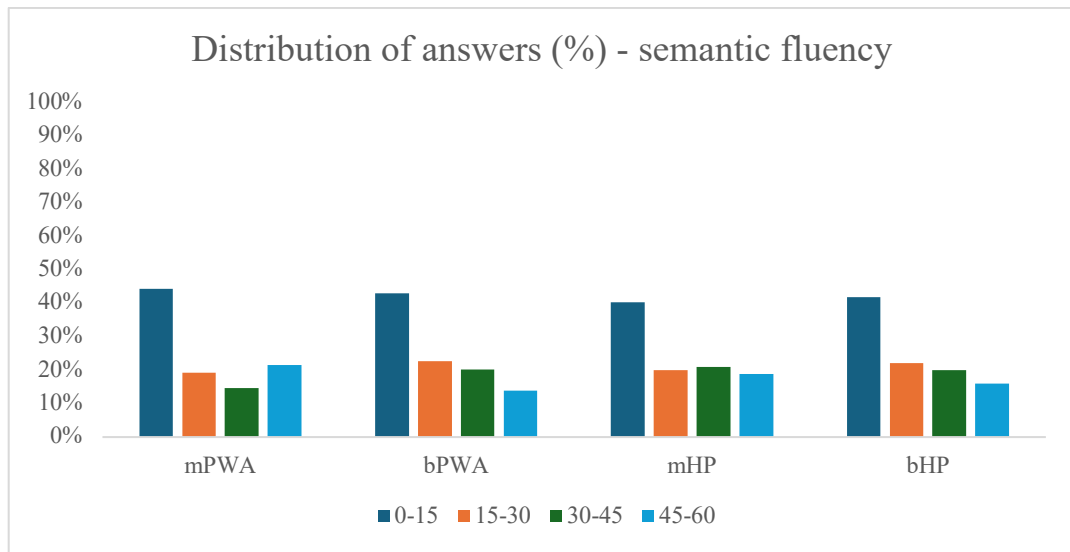
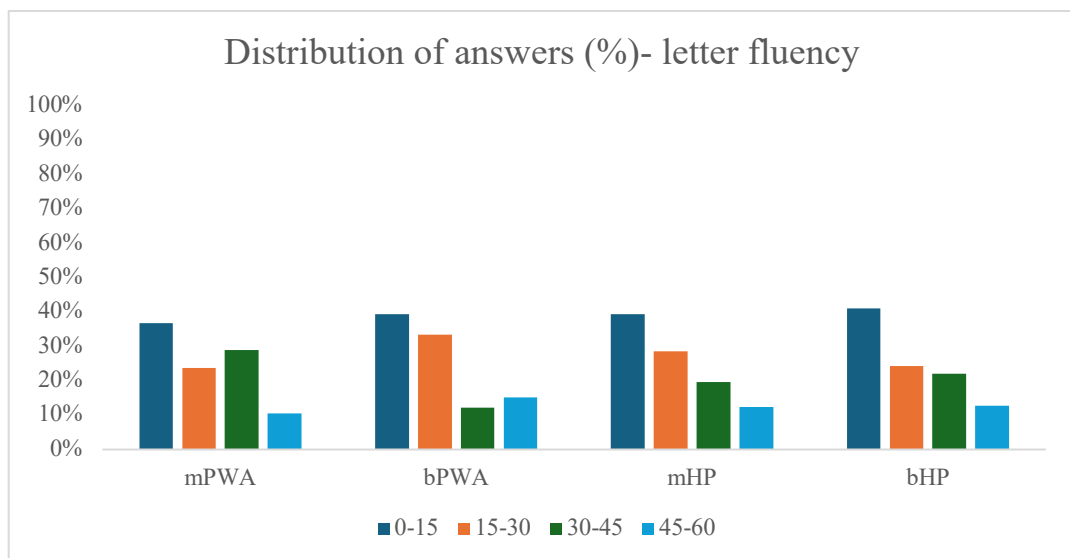


Figure 18. Distribution of answers (%) in the letter fluency tasks in aphasic and healthy participants across 15-second intervals



In the letter fluency task, during the first period, once again the highest percentage of correct answers were recorded, that is, 36.84% for the mPWA group and 39.39% for their bPWA counterparts (refer to Figure 18). In the second period, similarly to in the semantic verbal fluency task, a decline in the percentage of correct responses from both groups was observed with the mPWA and bPWA groups recording 23.68% and 33.33%, respectively. During the third period, the mPWA group produced 28.95%, while the bPWA group

recorded the lowest percentage of correct answers at 12.12% across all four periods. In the final period, the mPWA group demonstrated the lowest percentage of correct responses of 10.53% across all four periods compared to 15.15% from their bPWA counterparts. Similarly to the semantic fluency task, the analysis of the number of correct answers, repetitions and errors across the four intervals reached no statistical significance (refer to Table 17).

In addition to comparing the distribution of answers between the mPWA and bPWA groups, the overall performance in both the semantic verbal and letter fluency tasks was analysed based on scores from the scoring system (see Tables 14 and 15). The analysis of the semantic fluency task in terms of the total number of correct answers revealed no statistical significance between the mPWA ($M= 2.70$, $SD=2.31$) and bPWA ($M= 3.00$, $SD=2.38$) groups (KS: $D= 0.200$, $p > .100$). Similarly to the semantic fluency task, both aphasia groups performed similarly in the letter fluency task (mPWA: $M= 1.70$, $SD=2.06$; bPWA: $M=1.88$, $SD=1.55$; KS: $D=0.400$ $p > .100$). The results indicate that both monolingual and bilingual individuals with aphasia face challenges in fluency tasks with the mean scores reflecting their limited level of performance.

3.1.3.2 Monolingual aphasics vs. monolingual reference group

A further comparison was made between the performance of the monolingual aphasia group and that of the monolingual reference group with regard to the distribution of their answers (refer to Figures 17 -18 and Table 18) and overall performance (refer to Table 15 and Figure 19).

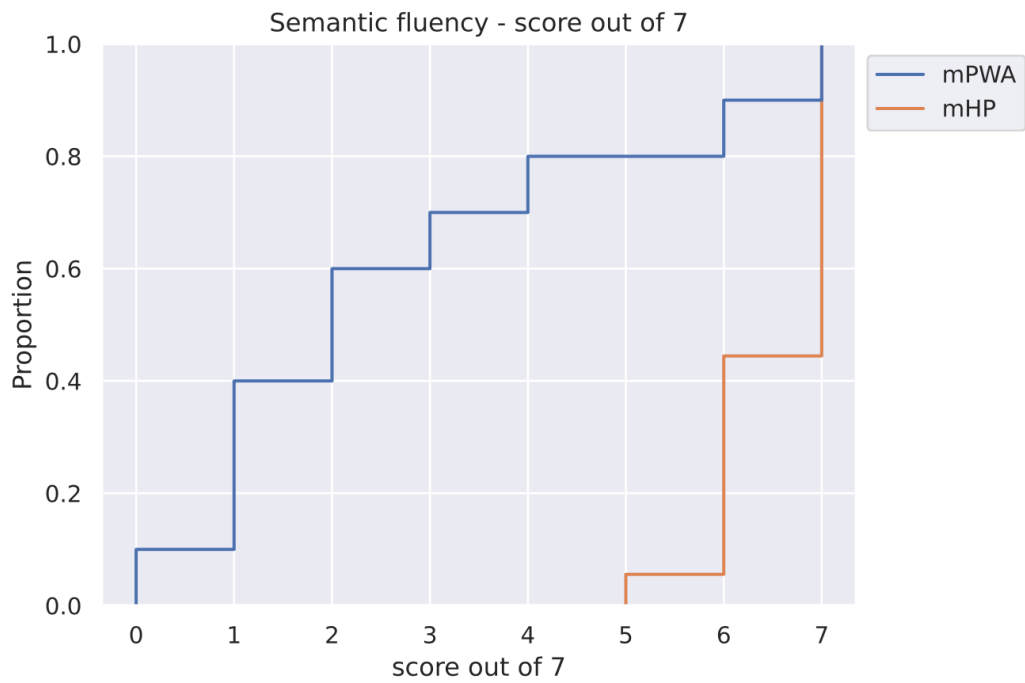
In the semantic fluency task, during the first period (0-15 seconds), both groups produced the highest percentage of correct answers, namely 44.32% and 40.23% for the mPWA and mHP groups, respectively. In the second period (15-30 seconds), a decline in the percentage of correct answers from both groups was observed with the mPWA and mHP groups producing 19.32% and 20%, respectively. During the third period (30-45 seconds), the mPWA group demonstrated the lowest number of correct answers with a percentage of 14.57 % while the mHP group achieved 20.91%. In the final period (45-60 seconds), 21.59% of answers from the mPWA group were correct compared to 18.86% by the mHP group, which was the lowest percentage by this group. The breakdown of scores across each period shows that the mHP participants consistently scored higher than

their mPWA counterparts across all periods. The statistical analysis using the KS test indicated a significant difference in terms of the number of correct answers in all four periods (KS: $D=0.800$, $p < .001$), confirming that the mHP participants performed better in the semantic verbal fluency task compared to the mPWA individuals. However, error rates and repetitions were similar (refer to Table 18).

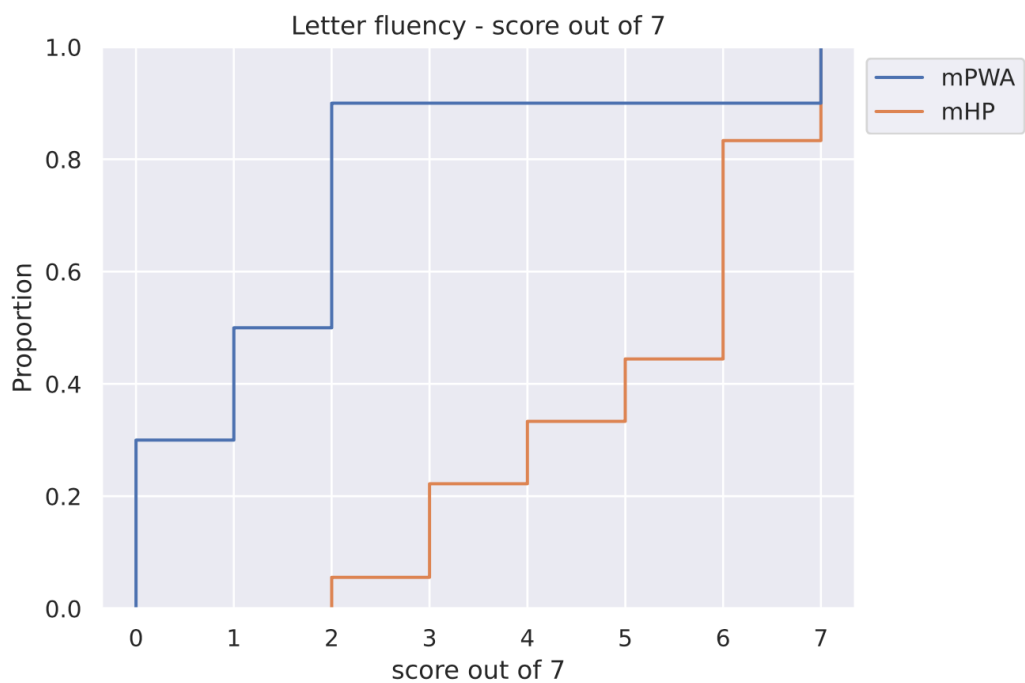
In the letter fluency task, the first period once again demonstrated the highest percentage of correct answers with the mPWA group producing 36.84% compared to 39.32% for their mHP counterparts. During the second period, similarly to the semantic fluency task, a decline in the percentage of correct responses from both groups was observed, namely 23.68% and 28.63% for the mPWA and mHP groups, respectively. In the third period, the mPWA group produced 28.95%, while the mHP group 19.66%. During the final period, both groups demonstrated the lowest percentage of correct responses across all four periods, that is, 10.53% and 12.39% for the mPWA and mHP groups, respectively. The statistical analysis of the number of correct answers revealed significant differences between the mPWA and mHP groups in all the four intervals (first- KS: $D=0.700$, $p < .001$; second- KS: $D=0.900$, $p < .001$; third and fourth- KS: $D=0.844$, $p < .001$). Similarly to the semantic verbal fluency task, similar performance was observed in error rates (KS: $D=0.200$, $p > .100$) and repetitions (KS: $D=0.144$, $p > .100$).

The analysis of the overall performances revealed a significant difference between the mPWA and mHP groups in both the semantic and letter verbal fluency task (refer to Figure 19). The mHP group performed better in both tasks. The results of the fluency tasks demonstrate a clear disparity in performance between the two groups. The mean scores indicate that the mPWA group struggled considerably in both the semantic and letter fluency tasks with mean scores of 2.70 and 1.70, respectively. In contrast, the mHP group demonstrated significantly higher mean scores of 6.67 and 5.11 in the semantic verbal and letter fluency tasks, respectively. The results highlight the difference between neurologically healthy brain and the impacts of aphasia on individuals in verbal fluency.

Figure 19. Results of the total number of correct answers in semantic and letter fluency tasks between monolingual aphasics (mPWA) and monolingual reference group (mHP)



KS: $p < 0.001$; mPWA < mHP; $n_1 = 10$, $n_2 = 18$



KS: $p < 0.001$; mPWA < mHP; $n_1 = 10$, $n_2 = 18$

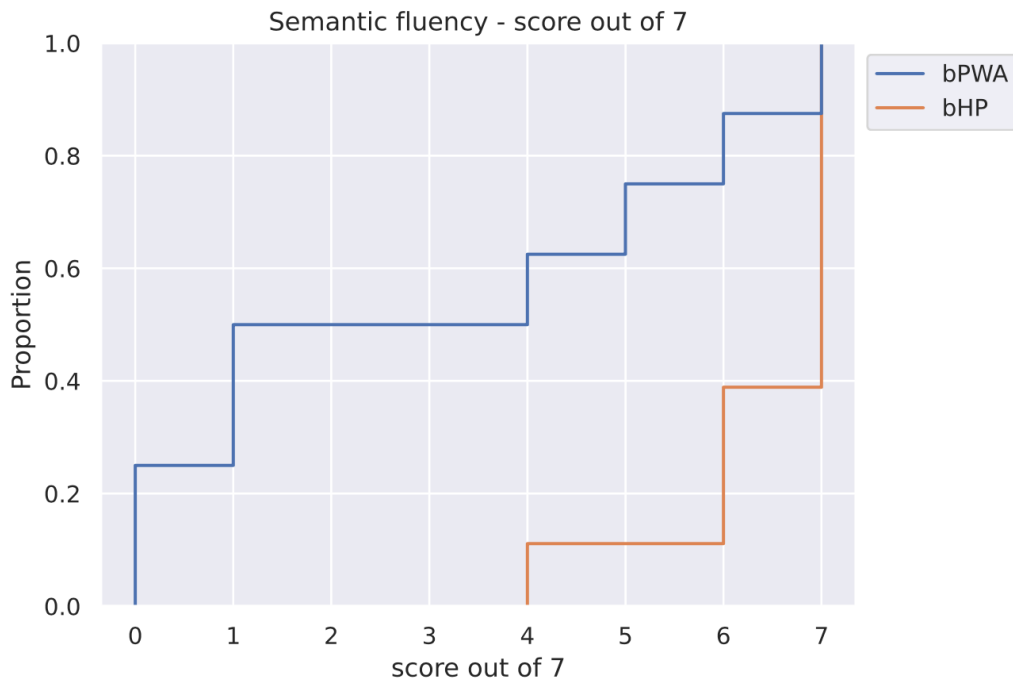
3.1.3.3 Bilingual aphasics vs. bilingual reference group

A further comparison was made between the performances of the bilingual aphasia group and the bilingual reference group with regard to the distribution of answers (refer to Figures 17-18 and Tables 19) and overall performance (see Table 15 and Figure 20).

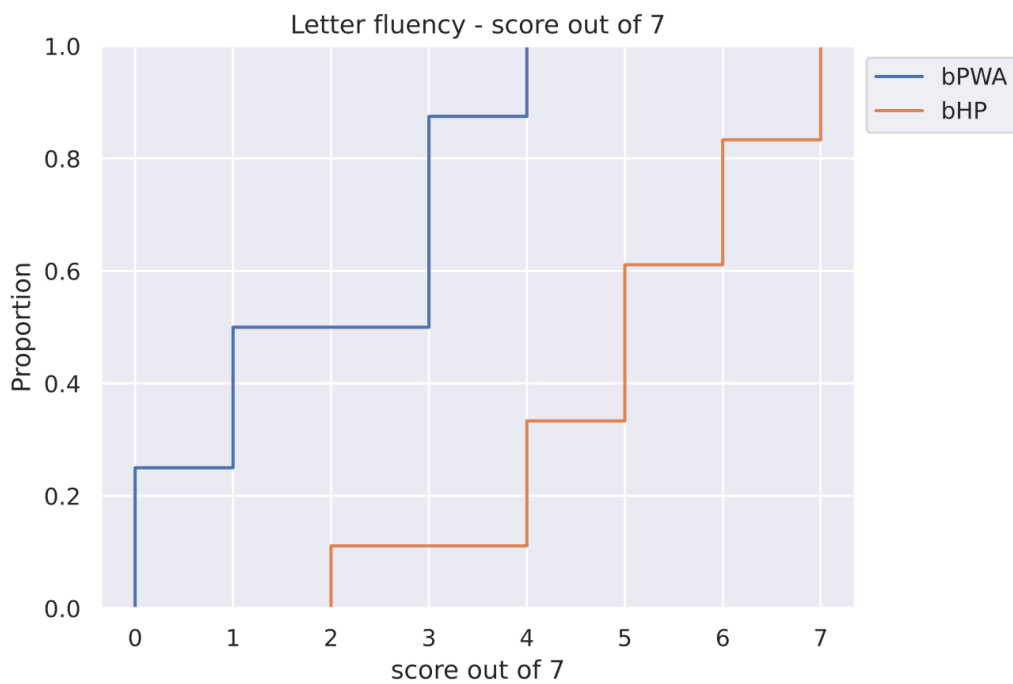
In the semantic fluency task, during the first period (0-15 seconds), both groups produced the highest percentage of correct answers, namely 43.04% and 41.78% for the bPWA and bHP groups, respectively. In the second period (15-30 seconds), a decline in the percentage of correct responses from both groups was observed, that is, 22.78% and 22.15% for the bPWA and bHP groups, respectively. During the third period (30-45 seconds), the bPWA group achieved 20.25% compared to 20.09% by the bHP group. In the final period (45-60 seconds), both groups recorded the lowest percentage of correct responses, namely 13.92% and 15.98% for the bPWA and bHP groups, respectively. The statistical analysis of the number of correct answers across 15-second intervals revealed significant differences between the bPWA and bHP groups in all the four intervals (first - KS:D=0.889, $p < .001$; second - KS:D=0.722, $p < .001$; third and fourth- KS:D=0.639, $p=.006$). However, the error rates (KS: D=0.208, $p > .100$) and repetitions (KS: D= 0.250, $p > .100$) were similar.

In the letter fluency task, during the first period, once again, the highest percentages of correct answers were recorded, namely 39.39% and 40.97% for the bPWA and bHP groups, respectively. In the second period, similarly to during the semantic fluency task, a decline in the percentage of correct responses from both groups was observed, that is, 33.33% and 24.23% for the bPWA and bHP groups, respectively. During the third period, the bPWA group recorded the lowest percentage of correct answers across all four periods, namely 12.12%, compared to 22.03% for their bHP counterparts. In the final period, the bHP group demonstrated the lowest percentage of correct responses across all four periods, that is, 12.78%. compared to 15.15% for the bPWA group. The statistical analysis of the number of correct answers across 15-second intervals revealed significant differences between the bPWA and bHP groups in all four intervals (first- KS: D= 0.611, $p=.009$; second- KS: D=0.639. $p=.006$; third- KS: D=0.667, $p= .003$; fourth: KS: D=0.764, $p < .001$). However, once again the error rates (KS: D=0.139, $p > .100$) and repetitions (KS: D= 0.069, $p > .100$) showed similar performance.

Figure 20. Results of the total number of correct answers in semantic and letter fluency tasks between bilingual aphasics (bPWA) and bilingual reference group (bHP)



KS: $p=0.006$; bPWA < bHP; $n_1 = 8$, $n_2 = 18$



KS: $p<0.001$; bPWA < bHP; $n_1 = 8$, $n_2 = 18$

The analysis of the overall performances revealed a significant difference between the bPWA and bHP groups in both the semantic and letter verbal fluency task (refer to Figure 20). The bHP group performed better in both tasks. The results from the fluency tasks demonstrate a clear disparity in performance between the aphasia and reference groups. The mean scores indicate that the bPWA group struggled considerably in both the semantic and letter fluency tasks with mean scores of 3 and 1.88, respectively. In contrast, the bHP group recorded significantly higher mean scores of 6.39 and 5 in the semantic and letter fluency tasks.

3.1.3.4 Semantic fluency in both languages

In the Hungarian version of the semantic fluency task, the bPWA group had a mean score of 3.00 (SD=2.38), while in the CRO/SK/DE version had a mean score of 1.63 (SD=2.39). However, the analyses revealed no statistical significance between the two versions (WSR: $W=31.00$, $p=.063$). For individuals scores, please refer to Table 15. In contrast the bHP group performed significantly better in the Hungarian version ($M=6.39$, $SD=0.98$) than in the CRO/SK/DE version ($M=5.11$, $SD=0.90$; WSR: $W=168.00$, $p<.001$). The results support our hypothesis: aphasic participants were expected to perform similarly in both tasks, whereas healthy bilingual individuals were predicted to exhibit significant performance differences.

Table 17. Comparison of the number of correct answers during each 15-second-long period in the semantic verbal and letter fluency tasks between the mPWA and bPWA participants

	Semantic fluency					
	0-15 sec.	15-30 sec.	30-45 sec.	45-60 sec.	mistakes	repetition
mPWA 1	0	0	0	0	0	0
mPWA 2	3	2	1	0	0	0
mPWA 3	9	3	3	3	0	0
mPWA 4	1	1	0	0	0	1
mPWA 5	4	3	0	4	1	4
mPWA 6	5	0	1	3	2	2
mPWA 7	1	0	1	0	0	0
mPWA 8	2	0	1	4	1	0
mPWA 9	10	6	4	5	0	4
mPWA 10	4	2	2	0	1	3
scores mPWA	39	17	13	19	5	14
bPWA 1	7	6	3	2	1	0
bPWA 2	5	4	4	0	2	0
bPWA 3	3	0	0	2	1	3
bPWA 4	6	0	0	0	0	5
bPWA 5	7	6	6	4	0	0
bPWA 6	0	0	0	0	0	0
bPWA 7	6	2	3	3	0	1
bPWA 8	0	0	0	0	0	0
scores bPWA	34	18	16	11	4	9
p value (mPWA vs. bPWA)	KS: D=0.325, p > .100	KS: D= 0.300, p > .100		KS: D= 0.025, p > .100	KS: D=0.150, p > .100	
	Letter fluency					
	0-15 sec.	15-30 sec.	30-45 sec.	45-60 sec.	mistakes	repetition
mPWA 1	0	0	0	0	0	0
mPWA 2	2	1	1	0	0	0
mPWA 3	1	2	2	0	0	0
mPWA 4	0	0	0	0	0	0
mPWA 5	1	1	2	0	0	1
mPWA 6	3	0	1	0	2	4
mPWA 7	0	0	0	0	0	0
mPWA 8	1	0	0	0	0	0
mPWA 9	6	4	4	4	0	1
mPWA 10	0	1	1	0	2	0
scores mPWA	14	9	11	4	4	6
bPWA 1	4	3	1	1	0	1
bPWA 2	2	0	0	1	0	0
bPWA 3	0	2	3	1	2	1
bPWA 4	3	4	0	0	2	2
bPWA 5	1	1	0	0	0	0
bPWA 6	0	0	0	0	0	0
bPWA 7	3	1	0	2	0	0
bPWA 8	0	0	0	0	0	0
scores bPWA	13	11	4	5	4	4
p value (mPWA vs. bPWA)	KS: D=0.200, p > .100	KS: D=0.275, p > .100	KS: D=0.175, p > .100	KS: D=0.400, p > .100	KS: D=0.050, p > .100	KS: D= 0.100, p > .100

Table 18. Comparison of the number of correct answers during 15-second-long period in the semantic verbal and letter fluency tasks between the neurologically healthy monolingual group (mHP) and the monolingual aphasia group (mPWA)

	Semantic fluency					
	0-15 sec.	15-30 sec.	30-45 sec.	45-60 sec.	mistakes	repetition
mHP1	6	5	6	4	0	1
mHP2	9	5	4	3	0	3
mHP3	9	2	9	4	0	0
mHP4	10	5	3	2	0	0
mHP5	12	2	7	4	0	1
mHP6	19	3	5	6	0	2
mHP7	11	6	6	3	0	0
mHP8	11	3	3	7	0	1
mHP9	10	3	2	3	0	1
mHP10	7	4	10	4	1	0
mHP11	7	3	5	1	0	0
mHP12	11	11	10	9	0	0
mHP13	9	8	3	3	0	1
mHP14	9	6	3	9	0	0
mHP15	8	5	4	4	0	0
mHP16	8	3	5	3	0	0
mHP17	14	9	4	10	0	0
mHP18	7	5	3	4	0	2
scores	177	88	92	83	1	12
p value (mHP vs. mPWA)	KS: D=0.800, p < .001 aphasia < reference				KS: D=0.344, p > .100	KS: D=0.244, p > .100
	Letter fluency					
	0-15 sec.	15-30 sec.	30-45 sec.	45-60 sec.	mistakes	repetition
mHP1	4	5	3	3	1	0
mHP2	3	2	3	1	0	0
mHP3	3	6	5	5	1	1
mHP4	6	3	2	0	0	4
mHP5	7	5	2	2	0	0
mHP6	5	5	2	2	0	5
mHP7	8	6	2	2	0	2
mHP8	3	3	1	0	0	0
mHP9	6	2	4	3	0	0
mHP10	7	3	3	3	0	1
mHP11	2	2	1	0	1	1
mHP12	6	3	5	3	1	0
mHP13	6	6	0	0	0	0
mHP14	6	6	3	4	0	1
mHP15	3	4	3	0	0	0
mHP16	4	2	1	0	0	0
mHP17	11	2	4	0	0	2
mHP18	2	2	2	1	0	0
scores	92	67	46	29	4	17
p value (mHP vs. mPWA)	KS: D=0.700, p < .001 aphasia < reference	KS: D= 0.900, p < .001 aphasia < reference	KS: D= 0.844, p < .001 aphasia < reference		KS:D=0.200, p > .100	KS: D=0.144, p > .100

Table 19. Comparison of the number of correct answers during 15-second-long period in the semantic verbal and letter fluency tasks between the neurologically healthy bilingual group (bHP) and the bilingual aphasia group (bPWA)

	Semantic fluency					
	0-15 sec.	15-30 sec.	30-45 sec.	45-60 sec.	mistakes	repetition
bHP1	8	3	4	2	0	0
bHP2	10	8	8	3	0	0
bHP3	13	4	7	2	2	0
bHP4	16	6	6	6	0	0
bHP5	10	4	1	3	1	0
bHP6	11	7	9	7	0	0
bHP7	10	3	5	1	2	0
bHP8	9	5	4	2	0	0
bHP9	7	2	0	4	0	2
bHP10	9	7	2	5	0	0
bHP11	8	2	2	1	0	1
bHP12	12	10	7	7	0	1
bHP13	14	11	7	10	0	0
bHP14	8	3	5	2	0	0
bHP15	10	4	4	4	0	0
bHP16	7	8	7	5	0	2
bHP17	12	5	5	3	0	1
bHP18	9	5	5	3	0	1
scores	183	97	88	70	5	8
p value (bHP vs. bPWA)	KS: D=0.889, p < .001 aphasia < reference	KS: D= 0.722, p < .001 aphasia < reference	KS: D= 0.639, p= .006 aphasia < reference		KS: D= 0.208, p > .100	KS: D=0.250, p > .100
	Letter fluency					
	0-15 sec.	15-30 sec.	30-45 sec.	45-60 sec.	mistakes	repetition
bHP1	7	3	2	0	0	0
bHP2	6	1	1	1	0	1
bHP3	5	3	3	0	0	0
bHP4	7	3	4	1	0	0
bHP5	7	2	2	1	0	1
bHP6	2	6	4	1	1	1
bHP7	3	0	1	0	3	2
bHP8	3	0	1	1	0	0
bHP9	8	3	1	2	1	3
bHP10	4	1	1	2	3	0
bHP11	3	3	2	1	1	1
bHP12	5	2	4	2	0	0
bHP13	8	7	4	4	0	1
bHP14	3	2	0	3	1	0
bHP15	7	5	6	3	0	0
bHP16	6	7	5	1	0	1
bHP17	5	3	3	5	0	0
bHP18	4	4	6	1	0	0
scores	93	55	50	29	10	11
p value (bHP vs. bPWA)	KS: D=0.611, p= .009 aphasia < reference	KS: D= 0.639, p= .006 aphasia < reference	KS: D=0.667, p= .003 aphasia < reference	KS: D=0.764, p < .001 aphasia < reference	KS: D=0.139, p > .100	KS: D=0.069, p > .100

3.1.3.5 Semantic fluency vs. Letter fluency

Performance in the semantic and letter fluency tasks was also compared, revealing statistically significant differences between the two tasks in both the aphasic and the reference groups. As no significant differences were observed between the monolingual and bilingual participants in the analysis, the aphasic and reference groups were expanded to include both monolingual and bilingual individuals. The analysis of the combined aphasic group (mPWA+bPWA) revealed a significant difference between the two tasks, indicating that the participants with aphasia performed better in the semantic fluency task in comparison with the letter fluency task (refer to Figure 21). Similar results were observed in the combined reference group (mHP+bHP), indicating that the participants in the reference group performed significantly better in the semantic fluency task compared to in the letter fluency task (refer to Figure 22). These findings support our hypothesis, that both aphasic and healthy participants perform better in the semantic fluency task in comparison with the letter fluency task. As letter fluency tasks generally requires greater recruitment of executive control for both groups.

Figure 21 Comparison of semantic and letter fluency tasks in the aphasia groups

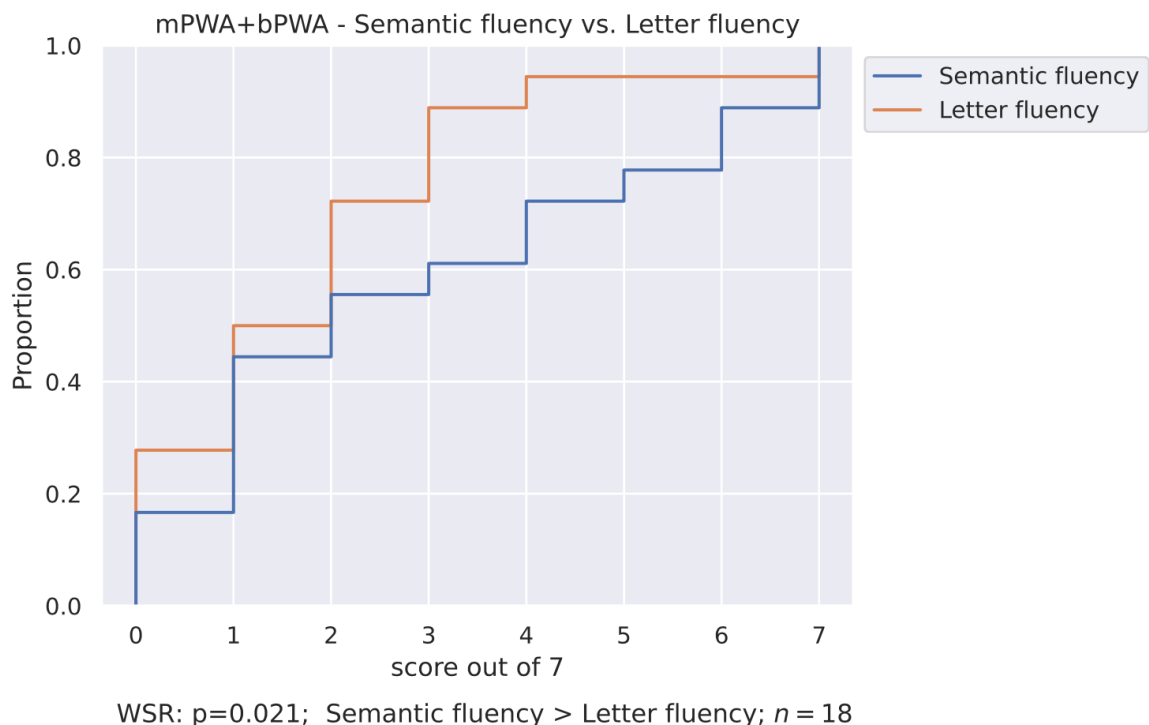
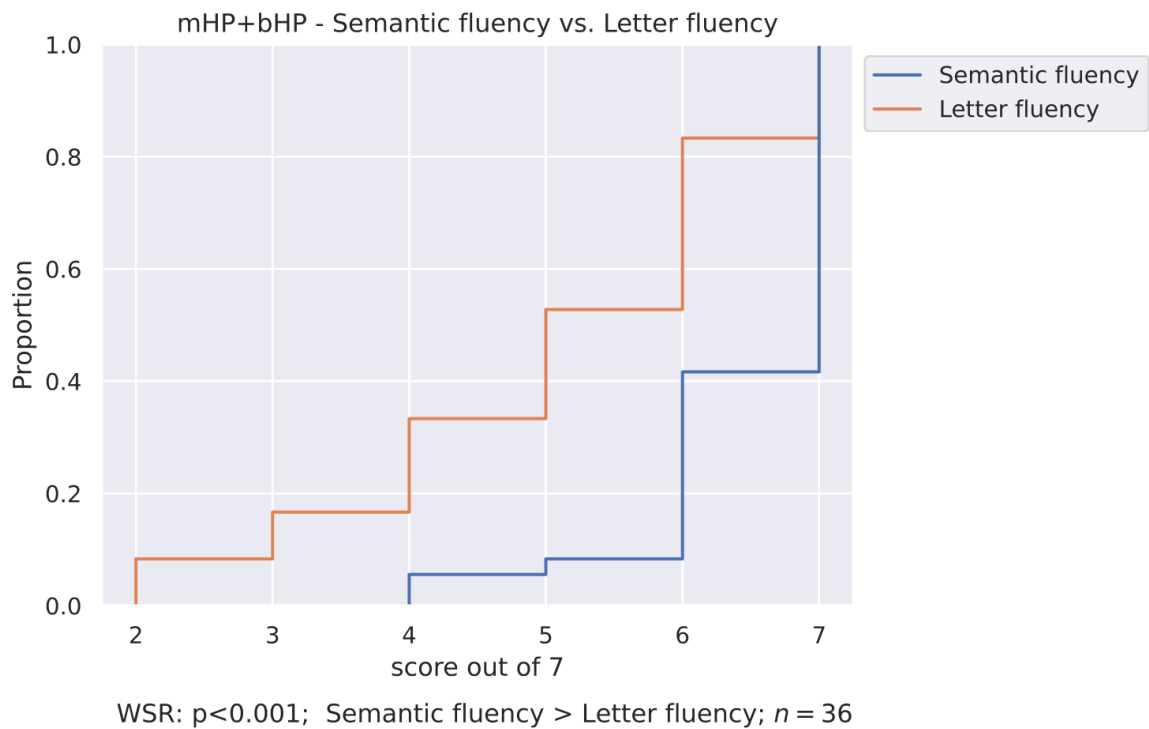


Figure 22. Comparison of semantic and letter fluency tasks in the reference groups



3.1.3.6 Relationship between naming and fluency

This section presents the findings from the analysis of semantic fluency and naming performance among mono- and bilingual participants, specifically focusing on the z-scores derived from the assessments. It was expected that if a participant performed poorly or successfully in the semantic fluency, they might not perform similarly in naming.

In the monolingual reference group, some participants (mHP1, mHP 2, mHP 4, mHP9, mHP11, mHP15 and mHP16) performed below average in both naming and fluency (for details, refer to Table 20). From all these participants, mHP11 performed extremely below average in both fluency and naming, as indicated by z-scores of -2.47 and -2.32, respectively. In contrast, participants mHP 3, mHP5, mHP 6, mHP10, mHP 12, mHP13, mHP 14 and mHP17 scored above average in both tasks. Moreover, participant mHP 8 scored above average in fluency ($z = 0.83$) and below average in naming ($z = -1.29$), while mHP18 scored above average in naming ($z = 0.50$) and below in fluency ($z = -0.83$). These results suggest that while most mHP participants performed similarly across tasks, others did not, reinforcing the hypothesis of dissociation.

Table 20. Comparing naming and semantic fluency in the monolingual aphasia and reference group with z- scores

Participant	Semantic fluency-HU z-score	BNT -HU z-score
mPWA 1	-1.23	-1.14
mPWA 2	-0.78	-0.64
mPWA 3	1.51	1.75
mPWA 4	-0.78	-1.07
mPWA 5	0.59	1.23
mPWA 6	0.14	-0.22
mPWA 7	-0.78	-1.01
mPWA 8	-0.32	-0.09
mPWA 9	1.96	1.20
mPWA 10	-0.32	-0.03
mHP1	-0.83	-0.53
mHP2	-0.83	-1.29
mHP3	0.83	0.24
mHP4	-0.83	-0.78
mHP5	0.83	0.24
mHP6	0.83	1.01
mHP7	0.83	0.24
mHP8	0.83	-1.29
mHP9	-0.83	-0.53
mHP10	0.83	0.75
mHP11	-2.47	-2.32
mHP12	0.83	1.52
mHP13	0.83	0.50
mHP14	0.83	1.27
mHP15	-0.83	-0.53
mHP16	-0.83	-0.27
mHP17	0.83	1.27
mHP18	-0.83	0.50

In the monolingual aphasia group, participants mPWA 1, mPWA 2, mPWA 4, mPWA 7, mPWA8 and mPWA 10 performed below average in both naming and fluency, while participants mPWA 3, mPWA5 and mPWA 9 displayed above-average performance in both fluency and naming (see Table 20). While participant mPWA 6 scored above average in fluency ($z= 0.14$), and below average in naming ($z= -0.22$). Overall, most mPWA participants performed similarly in naming and fluency, except mPWA6.

Table 21. Comparing naming and semantic fluency in the bilingual aphasia and reference group with z- scores

Participant	Semantic fluency- HU z-score	BNT -HU z-score	Semantic fluency CRO/SK/DE z-score	BNT- CRO/SK/DE z-score
bPWA 1	1.13	1.11	0.62	1.03
bPWA 2	0.38	-0.22	-0.28	-0.63
bPWA 3	-0.76	-0.17	-0.73	-0.22
bPWA 4	-0.76	0.44	-0.28	-0.14
bPWA 5	1.51	1.26	2.41	1.78
bPWA 6	-1.13	-1.51	-0.73	-1.22
bPWA 7	0.76	0.60	-0.28	0.61
bPWA 8	-1.13	-1.51	-0.73	-1.22
bHP1	-0.41	-0.96	-0.13	-2.03
bHP2	0.64	0.77	1.02	0.20
bHP3	0.64	0.61	1.02	0.73
bHP4	0.64	1.08	1.02	-0.58
bHP5	-0.41	-0.80	-0.13	-0.19
bHP6	0.64	0.92	1.02	0.47
bHP7	-0.41	-0.96	-1.27	-0.19
bHP8	-0.41	1.08	-0.13	-0.06
bHP9	-2.51	-1.11	-1.27	0.20
bHP10	0.64	-1.11	-0.13	-1.37
bHP11	-2.51	-0.49	-1.27	0.20
bHP12	0.64	0.45	-0.13	-1.64
bHP13	0.64	0.92	-1.27	1.91
bHP14	-0.41	-2.52	-0.13	-0.45
bHP15	0.64	0.61	1.02	0.07
bHP16	0.64	0.30	2.16	0.99
bHP17	0.64	0.77	-0.13	1.78
bHP18	0.64	0.45	-1.27	-0.06

In the Hungarian versions of the fluency and the Boston Naming Test, most neurologically healthy bilingual participants performed above average in both tasks (bHP 2, bHP3, bHP4, bHP6, bHP12, bHP15, bHP16, bHP17, bHP18). While others (bHP1, bHP5, bHP7, bHP9, bHP11, bHP14) scored below average in both tasks (for details, see Table 21). From these participants, bHP9 ($z = -2.51$) and bHP11 ($z = -2.51$) scored below average in fluency, while their performance in naming was also below average, though to a lesser extent (bHP9: $z = -1.11$; bHP11: $z = -0.49$). Moreover, participant bHP14 scored below average in naming ($z = -2.52$) and in fluency ($z = -0.41$), though to a lesser degree. Interestingly, participant bHP8 performed above average in naming ($z = 1.08$) and below average in fluency ($z = -0.41$). In contrast, participant bHP10 scored above average in fluency ($z = 0.64$) and below average in naming ($z = -1.11$). Similarly to the mHP group, the results suggest that while most bHP participants performed similarly across tasks, others did not, reinforcing the hypothesis of dissociation. In the Croatian /Slovakian/ German versions of the fluency and naming tasks, most participants in the bHP group

scored below average in both tasks (bHP1, bHP5, bHP7, bHP8, bHP10, bHP12, bHP18), for z- scores please refer to Table 21. Participant bHP 1 scored below average in naming ($z = -2.03$), and in fluency as well though to a lesser extent ($z = -0.13$). Participants bHP2, bHP3, bHP6, bHP15 and bHP16 scored above average in both naming and fluency. Participants bHP9, bHP11, bHP13 and bHP17 scored below average in fluency, while scored above average in naming (see Table 21). In contrast bHP4 performed below average in naming ($z = -0.58$), while performed above average in fluency ($z = 1.02$).

In the Hungarian version, aphasic participants bPWA1, bPWA5, and bPWA7 scored above the average in both naming and fluency, while bPWA3, bPWA6 and bPWA8 scored below the average in both tasks. Participant bPWA 2 performed above average in fluency ($z = 0.38$), while performed below average in naming ($z = -0.22$). In contrast, bPWA 4 scored above average in naming ($z = 0.44$), and below in fluency ($z = -0.76$). In the Croatian/Slovakian/ German versions, bPWA1 and bPWA 5 scored above average in both fluency and naming. Participants bPWA2, bPWA3, bPWA4, bPWA 6 and bPWA 8 scored below average in both tasks. Only participant bPWA 7 scored below average in fluency ($z = -0.28$), while scored above average in naming ($z = 0.61$). Overall, the results suggest that most bilingual aphasic participants performed similarly in naming and fluency tasks in both languages, except bPWA2, bPWA4 and bPWA7.

3.2 Non-linguistic assessments

This section presents the findings from the Trail Making Test, the Number and Letter Sudoku tasks as well as the auditory and visual working memory tasks. Table 22 (significant with **bold**) provides a summary of the results of the non-linguistic tests between mono- and bilingual aphasia groups as well as between aphasics and reference groups. Table 23 (significant with **bold**) includes the results of the statistical analysis with p values between aphasics and reference groups in non-linguistic tests.

Table 22. Summary of non-linguistic test results comparing monolingual and bilingual aphasics, and aphasics with their healthy counterparts

Comparison	Non-linguistic tests						
	WM			Cognitive flexibility and shifting			
	VSMT	ASMT	ROCF-B	Number Sudoku	Letter Sudoku	TMT A	TMT B
mPWA vs. monolingual reference group	Yes, for mean RT aphasia > reference PWA had longer RT. No, for mistakes	Yes, aphasia < reference PWA achieved lower scores.	No	No, for RT and mistakes percentage.	No, for RT and mistakes percentage.	Yes, for RT. aphasia > reference PWA had longer RT. No, for errors.	Yes, for RT and errors. aphasia > reference
bPWA vs. bilingual reference group	Yes, for mean RT and mistakes percentage. aphasia > reference	No		Yes, for RT aphasia > reference bPWA had longer RT. No, for mistakes pct.		Yes, for RT. aphasia > reference. No, for errors.	
bPWA vs. mPWA	No, for RT and mistakes percentage.	No		No, for RT and mistakes percentage.		No, for RT and number of mistakes.	

Yes- significant finding, No- not significant findings.

Table 23. Results from the statistical analysis (KS) of the non-linguistic tests between mono- and bilingual aphasic and reference groups

Participants	ASMT score	Non-linguistic batteries				ROCF-B score	TMT A RT	TMT B RT	VSMT mean RT
		Number Sudoku mean RT	Number Sudoku mistakes pct.	Letter Sudoku mean RT	Letter Sudoku mistakes pct.				
mPWA vs. monolingual reference group	KS: D=0.489, p= .031 aphasia < reference	KS: D=0.444, p > .100	KS: D=0.278, p > .100	KS: D=0.278, p > .100	KS: D=0.389, p > .100	KS: D=0.411, p= .084	KS: D=0.733, p < .001 aphasia > reference	KS: D=0.689, p= .001 aphasia > reference	KS: D=0.489, p= .031 aphasia > reference
bPWA vs. bilingual reference group	KS: D=0.417, p > .100	KS: D=0.635, p= .010 aphasia > reference	KS: D=0.286, p > .100	KS: D=0.349, p > .100	KS: D=0.206, p > .100	KS: D=0.375, p > .100	KS: D=0.889, p < .001 aphasia > reference	KS: D=0.667, p= .013 aphasia > reference	KS: D=0.500, p= .044 aphasia > reference

3.2.1 Cognitive flexibility impairment in the TMT and Number & Letter Sudoku

The results are summarised in terms of the mistakes percentage and mean response times (RT) in seconds for the Number and Letter Sudoku tasks as well as completion times and number of mistakes for the Trail Making Test (TMT) Parts A and B. Due to the severity of aphasia, some participants (specifically bPWA6 and mPWA4), were unable or unwilling to complete the Sudoku tasks. As a result, the Letter and Number Sudoku tasks were completed by a total of 7 bPWA and 9 mPWA subjects, respectively. With regard to the TMT, all the participants were willing to complete the tasks, however, the performance of bPWA6 and bPWA8 in TMT Part B was so effortful that an analysis of the number of mistakes was conducted instead. The individual scores are presented in a clear and concise manner in Tables 24 and 25.

3.2.1.1 Monolingual aphasics vs. bilingual aphasics

In the Number Sudoku task, a closer examination of the individual RTs revealed a range of performance within both groups, with the bPWA group exhibiting a wider range (2.72 to 24.27 sec) compared to the mPWA group (4.16 to 23.18 sec). In the Number Sudoku task, the bPWA group (M=9.58, SD=6.85) performed slightly faster in comparison with the mPWA group (M=10.53, SD=7.42), however, without reaching any statistical significance (KS: D= 0.413, p > .100). In terms of mistakes percentage, the mPWA group

made less mistakes ($M=3.60$, $SD=4.47$) compared to the bPWA group ($M=8.46$, $SD=13.19$), but without any statistical significance (KS: $D=0.286$, $p > .100$).

In the Letter Sudoku task, the RTs for the bPWA group ranged from 4.03 to 21.29 sec compared to 4.86 to 12.84 sec for the mPWA group. The findings suggest that while the performance in both groups varied, the mean RT in the bPWA group ($M= 10.37$, $SD=5.48$) was on average longer compared to the mPWA group ($M=8.54$, $SD=2.91$). However, it did not reach any statistical significance (KS: $D= 0.381$, $p > .100$). In terms of mistakes percentage, the bPWA group made less errors ($M= 5.89$, $SD=7.18$) compared to the mPWA group ($M= 11.52$, $SD=13.64$), though with no statistical significance (KS: $D=0. 302$, $p > .100$).

In TMT Part A, the bPWA group exhibited a mean RT of 109.63 sec ($SD= 42.35$) compared to 117.73 sec ($SD= 50.37$) for the mPWA group (KS: $D= 0.275$, $p > .100$). The RT in the bPWA group ranged from 69 to 165 sec compared to 54.29 to 217 sec for the mPWA group. In terms of the number of mistakes in Part A, the mPWA group made less mistakes (mPWA: $M=1.8$, $SD=4.66$; bPWA: $M=6$, $SD=10.52$), however, it did not reach any statistical significance (KS: $D=0.275$, $p > .100$).

In Part B, the bPWA group exhibited a mean RT of 241.50 sec ($SD=92.61$) compared to 258.10 sec ($SD=148.86$) for the mPWA group (KS: $D=0.200$, $p > .100$). The RTs of the bPWA group ranged from 120 to 333 sec, while those of the mPWA group varied from 79 to 614 sec. In addition, an analysis was conducted on the number of mistakes made, with a particular focus on Part B, where the performance of those with severe aphasia was particularly poor (refer to Tables 24 and 25). It was not possible to measure the completion time of these tasks as the participants were unable to complete them, even with the assistance of the examiner. In Part B the bPWA group made less errors ($M= 9$, $SD= 8.98$) compared to the mPWA group ($M=10$, $SD=8.76$), though without any statistical significance (KS: $D=0.300$, $p > .100$).

Overall, in the Number Sudoku task, the bPWA group was faster, but made more errors, while the mPWA group were slower, but made less errors. In contrast, in the Letter Sudoku task, the mPWA group was faster, but made more errors, while the bPWA group were slower, but made less errors. In case of the TMT, the bPWA were faster in Part A, but made more errors, while the mPWA group were slower but made less errors. In Part

B, the bPWA group were faster and made less errors. Although without reaching any statistical significance.

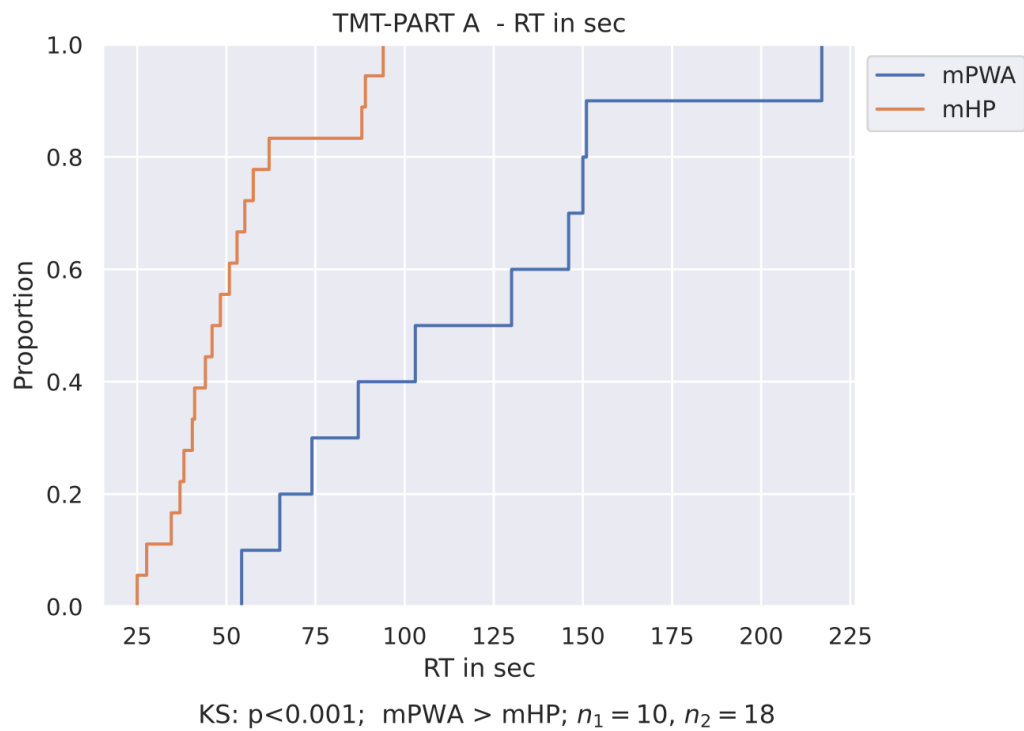
3.2.1.2 Monolingual aphasics vs. monolingual reference group

The mean response time for the group of monolingual aphasics in the Number Sudoku task was 10.53 sec (SD=7.42), with a range from 4.16 to 23.18 sec. The mean response time of the monolingual reference group was 5.04 sec (SD=1.38), with a range from 2.25 to 7.46 sec. This indicates that the group of monolingual aphasics took longer to complete the Number Sudoku task compared to their reference group, though without any statistical significance (KS: $D=0.444$, $p > .100$). In terms of mistakes percentage, the mPWA group made more mistakes (M=3.60, SD=4.47) than the reference group (M=1.38, SD=3.47), with no statistical significance (KS: $D= 0.278$, $p > .100$).

In the Letter Sudoku task, the mean response time of the group of monolingual aphasics was 8.54 sec (SD=2.91) compared to 7.38 sec (SD=2.64) for the monolingual reference group. The mean RT for the group of monolingual aphasics ranged from 4.86 to 12.84 sec compared to from 3.60 to 13.01 sec for the monolingual reference group. In terms of mistakes percentage, the mPWA group made more mistakes (M=11.52, SD=13.64) than the monolingual reference group (M=4.78, SD= 6.57). Once again, the group of monolingual aphasics performed worse than the monolingual reference group. However, the results of the Letter Sudoku task revealed a trend only as it did not reach statistical significance with respect to the response time (KS: $D=0.278$, $p > .100$) and mistake percentage (KS: $D=0.389$, $p > .100$).

In TMT Part A, the mean response time of the group of monolingual aphasics was 117.73 sec (SD=50.37), while that of the monolingual reference group was 51.77 sec (SD=20.26). The RTs for the group of monolingual aphasics ranged from 54.29 to 217.00 seconds in contrast to 25.00 to 94.00 seconds for the reference group. The mPWA group was significantly slower than the monolingual reference group in Part A (refer to Figure 23). In terms of the number of mistakes, the mPWA group (M= 1.8, SD= 4.66) made more mistakes than the mHP group (M=0.17, SD=0.51), though without any statistical significance (KS: $D= 0.289$, $p > .100$).

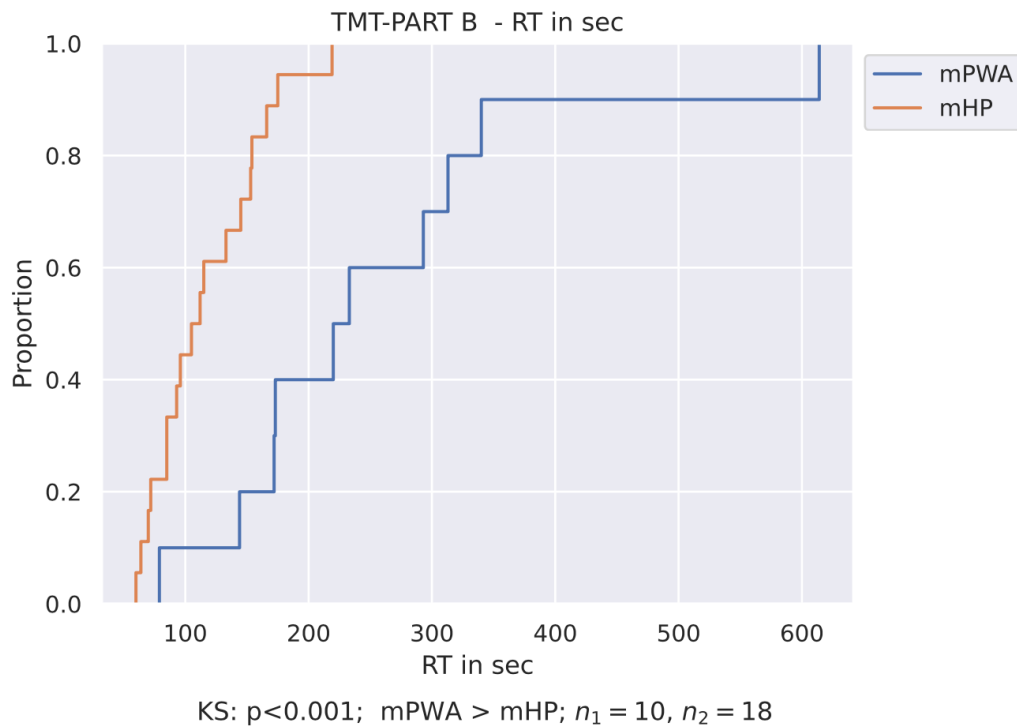
Figure 23. Comparison of response time in TMT Part A between monolingual aphasics (mPWA) and reference group (mHP)



In TMT Part B, the mean RT of the group of monolingual aphasics was 258.10 seconds (SD=148.86), significantly higher than 116.78 seconds (SD=44.33) for the monolingual reference group (KS: $D=0.689$, $p=.001$). Moreover, the group of monolingual aphasics made more mistakes ($M=10$, $SD=8.76$) compared to the monolingual reference group ($M=1$, $SD=1.61$). These results indicate that the group of monolingual aphasics not only took longer to complete the tasks (refer to Figure 24) but also made significantly more errors than their reference group (KS: $D= 0.789$, $p < .001$).

Overall, the mPWA group performed worse in the Sudoku tasks, but not significantly. While in the TMT, the mPWA group were significantly slower in both parts, however, made only significantly more mistakes in Part B than the monolingual reference group.

Figure 24. Comparison of response time in TMT Part B between monolingual aphasics (mPWA) and reference group (mHP)



3.2.1.3 Bilingual aphasics vs. bilingual reference group

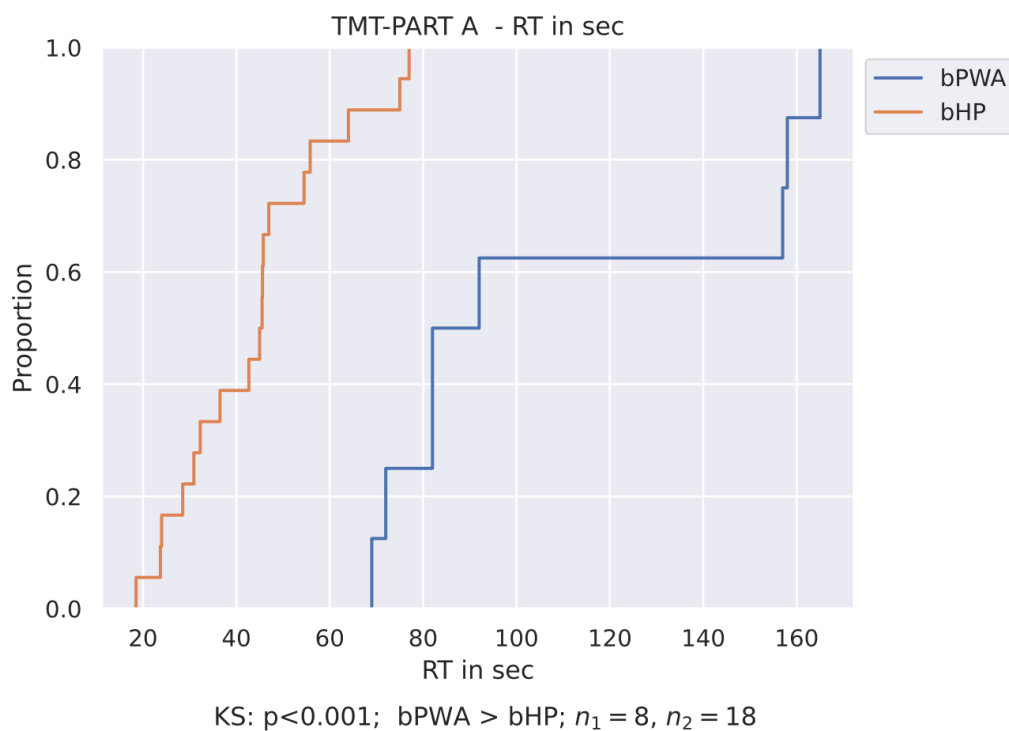
In the Number Sudoku task, the bPWA group ($M=9.58$, $SD=6.85$) performed significantly slower compared to the bilingual reference group ($M=5.46$, $SD=1.58$; KS: $D= 0.635$, $p=.010$). In the bPWA group, the range of scores varied from 2.72 to 24.27 sec. In the bilingual reference group, the scores ranged from 3.05 to 8.92 sec. In terms of mistakes percentage, the bPWA group ($M=8.46$, $SD=13.19$) made more mistakes than the reference group ($M=3.59$, $SD=5.43$), though with no statistical significance (KS: $D= 0.286$, $p > .100$).

In the Letter Sudoku tasks, the the bPWA group ($M=10.37$, $SD=5.48$) was slower compared to the bilingual reference group ($M=7.46$, $SD=2.66$), though without any statistical significance (KS: $D=0.349$, $p > .100$). Similarly to the Number Sudoku task, the bPWA participants ($M=5.89$, $SD=7.18$) made more mistakes than the bilingual reference group ($M=3.06$, $SD=4.32$) in the Letter Sudoku task, however, without any statistical significance (KS: $D=0.206$, $p > .100$).

In TMT Part A, the group of bilingual aphasics achieved a mean response time of 109.63 seconds ($SD= 42.35$) compared to 44.01 seconds ($SD=16.78$) for the bilingual

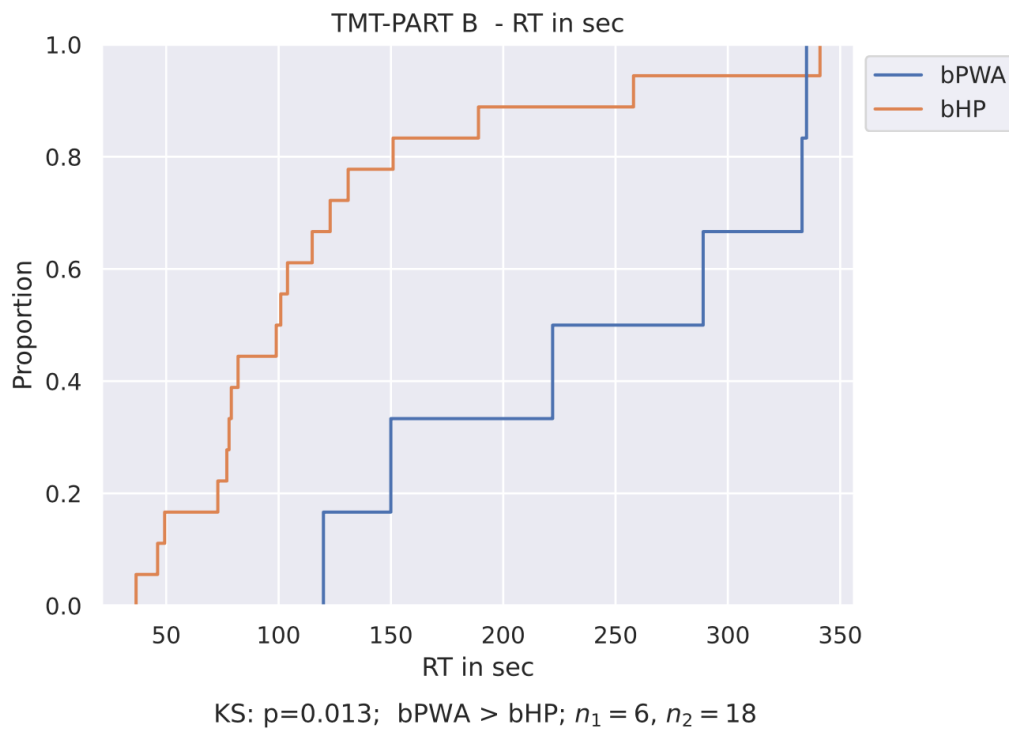
reference group (refer to Figure 25). The mean RT for the group of bilingual aphasics ranged from 69.00 to 165.00 sec in contrast to 18.52 to 77.00 sec for the bilingual reference group. The bPWA group were significantly slower than the bilingual reference group (KS: $D=0.889$, $p < .001$). In terms of the number of mistakes in Part A, the bPWA group made more mistakes ($M= 6$, $SD= 10.52$) than their healthy counterparts ($M=0.06$, $SD=0.24$), though with no statistical significance (KS: $D= 0.375$, $p > .100$).

Figure 25. Comparison of response time in TMT Part A between bilingual aphasics (bPWA) and reference group (bHP)



The results from TMT Part B mirrored this trend with the group of bilingual aphasics obtaining a mean RT of 241.50 sec ($SD=92.61$) compared to 118.51 sec ($SD=77.12$) for the bilingual reference group (see Figure 26). In terms of the number of mistakes in Part B, the group of bilingual aphasics made more errors ($M= 9$, $SD= 8.98$) in contrast to the mistakes for the bilingual reference group ($M=0.39$, $SD=0.85$). The statistical analysis revealed a significant difference between the performances of the bilingual aphasic and the bilingual reference groups in terms of both completion times (KS: $D=0.667$, $p=.013$) as well as error rates (KS: $D=0.778$, $p < .001$) in TMT Part B.

Figure 26. Comparison of response time in TMT Part B between bilingual aphasics (bPWA) and reference group (bHP)



Overall, these findings indicate a difference in performance, suggesting that the group of bilingual aphasics required more time to complete the Sudoku tasks in comparison to the bilingual reference group which was found to be statistically significant in the context of the Number Sudoku task with respect to response times. On the other hand, the difference in terms of response times and error rates during the Letter Sudoku task showed trends only and not statistical significance. In the TMT, the bPWA group was significantly slower in both Parts A and B. Additionally, the bPWA group made more mistakes than their healthy counterparts in both Parts A and B, however, the difference was only significant in Part B.

3.2.1.4 Letter vs. Number sudoku

In addition to comparing performance of individuals with aphasia and the reference groups in the context of the Sudoku tasks, the study set out to identify any significant disparities in task performance between the Letter and Number Sudoku tasks, with particular emphasis on error rates. Therefore, a Wilcoxon signed-rank test (WSR) was performed to analyse the percentage of mistakes made by aphasic and neurologically healthy participants in both Sudoku tasks.

In terms of mistake percentage, the analysis revealed that the combined (mPWA+bPWA) group performed worse in the Letter Sudoku task (M= 9.06, SD=11.32) compared to the Number Sudoku task (M=5.72, SD=9.30), however, without reaching any statistical significance (WSR: W=90.50, $p > .100$).

In contrast, the performance of the combined (mHP+bHP) reference group was markedly different when comparing the two Sudoku tasks. The analysis revealed a significant difference in mistakes percentage between the Letter Sudoku (M=3.92 , SD=5.55) and Number Sudoku (M=2.48, SD=4.63) tasks (WSR: W= 427.50, $p=.049$), indicating that neurologically healthy participants made more mistakes in the Letter Sudoku task compared to the Number Sudoku task (refer to Figure 27). This substantial difference in mistakes percentage suggests that the additional complexity introduced by letters in the Letter Sudoku task may pose a greater cognitive load for neurologically healthy participants.

Figure 27. Letter vs. Number Sudoku in healthy mono-and bilingual reference groups

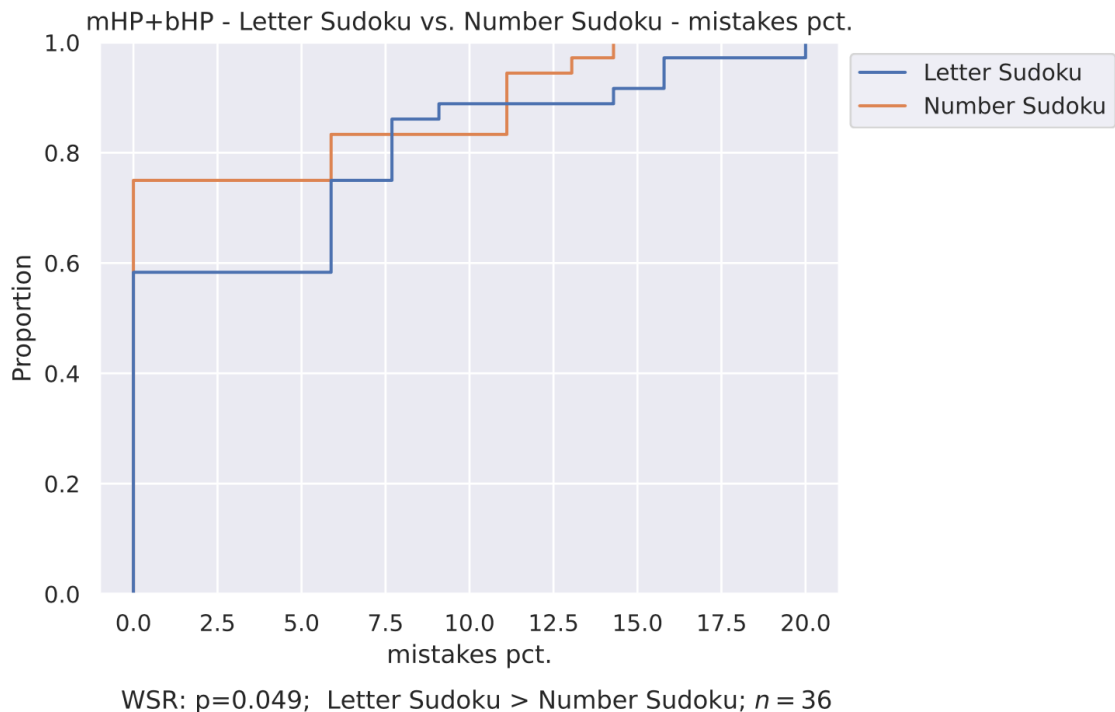


Table 24. Results from the TMT and Number & Letter Sudoku tasks for bilingual aphasics and neurologically healthy individuals

Participants		Number Sudoku (mean RT in sec.)	Letter Sudoku (mean RT in sec.)	Number Sudoku mistakes pct.	Letter Sudoku mistakes pct.	TMT – Part A (RT in sec.)	TMT – Part B (RT in sec.)	TMT – Part A (number of mistakes max 25)	TMT – Part B (number of mistakes max 25)
Group of bilingual aphasics (N=8)	bPWA1	9.94	11.68	0	0	157	335	0	6
	bPWA2	6.45	10.77	5.88	7.69	72	289	0	4
	bPWA3	8.27	6.38	0	0	69	150	0	2
	bPWA4	7.44	9.41	20.00	0	82	222	0	4
	bPWA5	2.72	4.03	0	5.88	92	120	0	1
	bPWA6	-	-	-	-	165	-	23	23
	bPWA7	8.00	9.06	0	7.69	82	333	2	9
	bPWA8	24.27	21.29	33.33	20.00	158	-	23	23
Range of scores (min-max)		2.72-24.27	4.03-21.29	0-33.33	0-20.00	69-165	120-335	0-23	1-23
Mean score		9.58	10.37	8.46	5.89	109.63	241.50	6	9
SD		6.85	5.48	13.19	7.18	42.35	92.61	10.52	8.98
Bilingual reference group (N=18)	bHP1	5.6	8.16	0	0	45.77	99.00	0	0
	bHP2	6.17	9.31	0	7.69	30.90	73.00	0	0
	bHP3	4.83	5.91	5.88	0	64.00	101.00	0	0
	bHP4	4.64	6.41	0	0	24.00	79.00	0	0
	bHP5	4.71	9.2	0	7.69	32.27	131.00	0	1
	bHP6	6.57	9.26	0	5.88	44.98	77.00	0	0
	bHP7	6.88	10.01	0	0	75.00	341.00	0	0
	bHP8	5.04	7.76	0	0	42.68	123.00	0	0
	bHP9	8.92	9.44	11.11	14.29	55.81	258.00	0	2
	bHP10	5.54	11.35	11.11	5.88	54.50	189.00	0	0
	bHP11	8.89	10.82	0	0	36.50	115.00	0	0
	bHP12	4.24	8.31	0	0	46.95	104.00	0	0
	bHP13	3.06	3.73	0	0	18.52	46.20	0	0
	bHP14	5.8	8.92	14.29	7.69	77.00	151.00	0	3
	bHP15	4.99	5.11	11.11	5.88	45.51	82.00	0	0
	bHP16	4.57	3.80	11.11	0	45.60	78.00	1	1
	bHP17	3.92	3.78	0	0	28.51	36.61	0	0
	bHP18	3.87	2.93	0	0	23.73	49.34	0	0
Range of scores (min-max)		3.05-8.92	2.93-11.35	0-14.29	0-14.29	18.52-77.00	36.61-341.00	0-1	0-3
Mean score		5.46	7.46	3.59	3.06	44.01	118.51	0.06	0.39
SD		1.58	2.66	5.43	4.32	16.78	77.12	0.24	0.85

Table 25. Results from the TMT and Number & Letter Sudoku tasks for monolingual aphasics and neurologically healthy individuals

Participants	Number Sudoku (mean RT in sec.)	Letter Sudoku (mean RT in sec.)	Number Sudoku mistakes pct.	Letter Sudoku mistakes pct.	TMT – Part A (RT in sec.)	TMT – Part B (RT in sec.)	TMT – Part A (number of mistakes max 25)	TMT – Part B (number of mistakes max 25)	
Group of monolingual aphasics (N=10)	mPWA1	5.62	7.89	0	20.00	65	173	1	8
	mPWA2	23.18	11.99	0	11.11	151	614	1	4
	mPWA3	9.2	12.84	0	0	150	293	0	6
	mPWA4	-	-	-	-	146	233	15	23
	mPWA5	5.00	5.95	11.11	14.29	87	220	0	5
	mPWA6	5.55	8.22	0	0	74	172	0	5
	mPWA7	21.68	8.33	0	42.86	217	340	0	21
	mPWA8	14.28	11.27	7.69	0	103	313	1	5
	mPWA9	4.16	4.86	7.69	7.69	54.29	79	0	0
	mPWA10	6.1	5.55	5.88	7.69	130	144	0	23
Range of scores (min-max)	4.16-23.18	4.86-12.84	0-11.11	0-42.86	54.29-217	79-614	0-15	0-23	
Mean score	10.53	8.54	3.60	11.52	117.73	258.10	1.8	10	
SD	7.42	2.91	4.47	13.64	50.37	148.86	4.66	8.76	
Monolingual reference group (N=18)	mHP1	7.17	10.87	0	0	55.18	166.00	0	3
	mHP2	5.27	9.32	0	0	48.33	96.00	0	0
	mHP3	4.12	6.12	5.88	5.88	44.13	70.00	0	1
	mHP4	6.55	13.01	0	0	53.00	115.00	0	0
	mHP5	4.32	8.16	0	0	57.55	72.00	0	0
	mHP6	5.32	8.56	0	9.09	41.11	105.00	0	0
	mHP7	4.91	8.49	0	0	38.10	93.00	0	0
	mHP8	6.45	10.08	0	5.88	50.86	112.00	0	0
	mHP9	3.79	6.54	0	0	62.00	153.00	0	0
	mHP10	2.25	3.6	0	0	34.56	60.00	0	1
	mHP11	4.03	6.94	0	5.88	46.00	145.00	0	5
	mHP12	6.1	10.26	0	7.69	89.00	154.00	0	3
	mHP13	4.04	5.66	0	15.79	27.66	85.00	0	0
	mHP14	6.19	6.06	0	0	25.00	64.00	0	0
	mHP15	7.46	5.99	0	0	88.00	175.00	1	1
	mHP16	4.45	4.20	13.04	20.00	94.00	219.00	2	4
	mHP17	3.67	5.23	0	0	40.46	133.00	0	0
	mHP18	4.64	3.70	5.88	15.79	37.00	85.00	0	0
Range of scores (min-max)	2.25-7.46	3.60-13.01	0-13.04	0-20	25.00-94.00	60.00-219.00	0-2	0-5	
Mean score	5.04	7.38	1.38	4.78	51.77	116.78	0.17	1	
SD	1.38	2.64	3.47	6.57	20.26	44.33	0.51	1.61	

3.2.2 *Auditory and visual working memory impairment*

This section presents the results of the study investigating working memory impairments in participants with aphasia, specifically focusing on both the visual and verbal domains. The results are organised according to the three tests employed: the Visual Sequential Memory Test (VSMT), the Rey-Osterrieth Complex Figure B Test (ROCF-B) and the Auditory Sequential Memory Test (ASMT). The results are discussed in terms of response times (RT), percentages of mistakes, and overall performance scores, highlighting the implications of cognitive load for bilingual individuals compared to their monolingual counterparts. The individual scores of the bilingual and monolingual groups are displayed in Tables 26 and 27. The summary of the results is presented in Table 22, while the statistical analysis with p values in Table 23 (significant with **bold**).

3.2.2.1 Monolingual aphasics vs. bilingual aphasics

Results from the Visual Sequential Memory Test performed by the bilingual aphasic participants indicated a mean response time (RT) of 2.58 seconds (sec), with a standard deviation (SD) of 1.60. The average percent of mistakes made by this group was 10.99%, with an SD of 13.77. The range of mistakes varied from 0 to 40%, indicating a high degree of variance in performance among the participants. Individual levels of performance varied considerably, for instance, bPWA8 recorded the highest mean RT of 5.74 sec and 40 % of the answers were wrong, while bPWA5 demonstrated the most efficient level of performance with a mean RT of 1.18 sec and no mistakes. This suggests that increased response times may correlate with a higher incidence of mistakes within the aphasia group. In contrast, the mean RT of the monolingual aphasia group was 2.67 sec (SD = 1.44) in the VSMT, with an average percentage of mistakes made of 11.06% (SD = 13.77). The response times ranged from 1.20 to 5.22 sec, exhibiting a performance of lower variability as compared to the bilingual aphasia group. The percentage of mistakes made for the monolingual aphasia group varied from 0 to 45.45%, once again highlighting the variability of performance. For example, the RTs and percentages of mistakes made for mPWA4 and mPWA7 were high, while the RTs for mPWA3 and mPWA9 were low with no mistakes made. This indicates that, like in the bilingual aphasia group, there is a potential relationship between increased response times and the numbers of mistakes made. In conclusion, although the mean RT for the bilingual aphasia group was lower than for the monolingual aphasia group, the differences revealed a trend only as it did not

reach statistical significance (KS: $D=0.200$, $p > .100$) and the same was valid for the percentage of mistakes (KS: $D=0.150$, $p > .100$). As it was hypothesised, the response time increased, the number of mistakes rose, showing a positive correlation between response time and percentage of mistakes made for both aphasia groups.

Results of the ROCF-B further elucidated the differences in cognitive processes assumed and found in the tasks described above. The performance of the bilingual aphasia group in the ROCF-B test yielded a mean score of 19 (SD = 13.04), with scores ranging from 0 to 30, indicating a moderate level of impairment in visual memory as assessed by this test. While bPWA1 achieved a score of 26, bPWA6 and bPWA 8 with more severe aphasia symptoms scored the lowest, that is 0. The monolingual aphasia group produced a mean score of 19.90 (SD = 7.80) in the ROCF-B with scores ranging from 7 to 31. The bilingual individuals with aphasia scored lower on average than their monolingual aphasic counterparts, with no statistical difference (KS: $D=0.425$, $p > .100$).

The results from the Auditory Sequential Memory Test produced a mean score of 26.75 (SD = 17.48) for the bilingual aphasic participants, with scores ranging from 0 to 44, indicating a substantial level of impairment in verbal working memory. The monolingual aphasic participants achieved a mean score of 30 (SD = 11.88) in the ASMT, with scores ranging from 14 to 44. The analysis revealed that the monolingual aphasia group performed better than the bilingual aphasia group in the Verbal Working Memory Test, a trend again and not statistical significance (KS: $D=0.250$, $p > .100$).

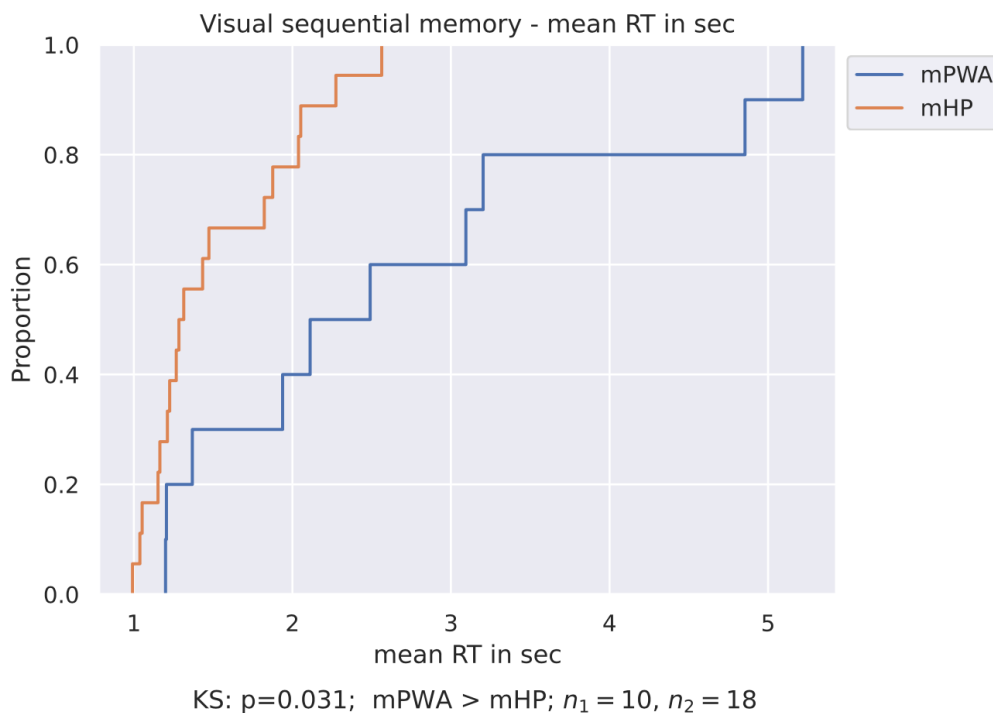
Overall, the mPWA group performed slightly better in the auditory WM task and in the Rey complex task, while bPWA performed slightly better in the visual WM task, however, none of them reached any statistical significance.

3.2.2.2 Monolingual aphasics vs. monolingual reference group

The mean response time (RT) for the Visual Sequential Memory Test was significantly longer in the monolingual aphasia group in comparison with the monolingual reference group (refer to Figure 28). While the monolingual aphasia group exhibited a mean RT of 2.67 sec (SD = 1.44), the monolingual reference group performed the task with a mean RT of 1.51 sec (SD = 0.48). This difference indicates a notable impairment in visual sequential memory among individuals with aphasia (KS: $D=0.489$, $p = .031$). The range of RT scores for the monolingual aphasia group spanned from 1.20 to 5.22 sec, whereas

the reference group's RT scores ranged from 0.99 to 2.56 sec. In addition, we also assessed the percentage of mistakes made during the Visual Sequential Memory Test. The mPWA group made more mistakes ($M= 11.06$, $SD= 13.77$) than the monolingual reference group ($M=3.45$, $SD = 5.21$), though without any statistical significance ($KS:D=0.433$, $p=.066$).

Figure 28. Comparison of the results from the Visual Sequential Memory Test recorded by the monolingual aphasics (mPWA) and monolingual reference group (mHP)

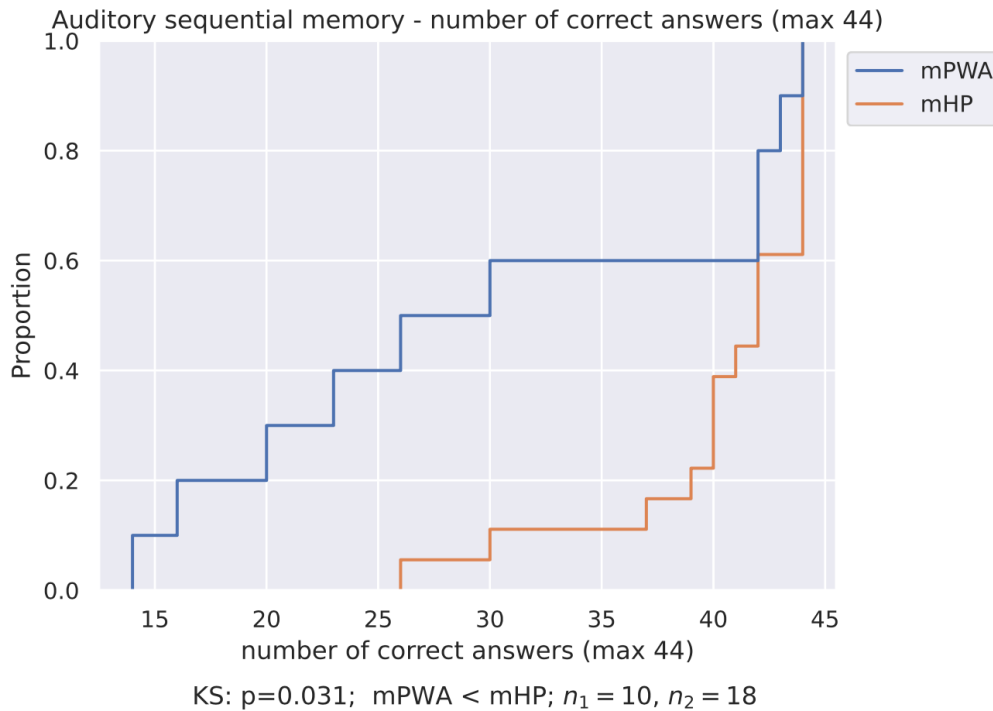


In the ROCF-B test, the monolingual aphasia group had a mean score of 19.90 ($SD = 7.80$) out of a maximum score of 31, while the monolingual reference group achieved a mean score of 26.06 ($SD = 5.22$). In the mPWA group the scores ranged from 0 to 30, while in the monolingual reference group from 15-31. Overall, the monolingual aphasia group performed poorly in comparison with the monolingual reference group, though showing a trend only ($KS: D=0.41$, $p=.084$).

In the Auditory Sequential Memory Test, the monolingual aphasia group performed significantly poorly compared to the monolingual reference group (see Figure 29). The monolingual aphasia group exhibited a mean score of 30 ($SD = 11.88$) out of a maximum score of 44, while the reference group produced a mean score of 40.39 ($SD = 5.02$), suggesting that individuals with aphasia experience impairments in auditory sequential memory as well. The scores recorded by the monolingual aphasia group ranged from 14

to 44, demonstrating variability in performance, with some individuals achieving scores close to the maximum, while others scored considerably lower. In contrast, the scores from the monolingual reference group ranged from 26 to 44, indicating the consistently better level of performance of these participants.

Figure 29. Comparison of the results from the Auditory Sequential Memory Test between the monolingual aphasics (mPWA) and monolingual reference group (mHP)



In conclusion, the mPWA group exhibited significantly slower performance in the VSMT task compared to their healthy counterparts. Although the aphasic participants made more errors, it did not reach statistical significance. In contrast, the mPWA group demonstrated significantly poorer performance in the auditory WM test when compared to the monolingual reference group. Finally, in the Rey Complex task, the mPWA group performed also poorly, though without any statistical significance.

3.2.2.3 Bilingual aphasics vs. bilingual reference group

The response time (RT) results of the Visual Sequential Memory Test indicated a considerable degree of variability within the bilingual aphasia group. The mean RT for the bPWA group was 2.58 seconds (SD = 1.60), with a range from 1.18 to 5.74 seconds. In contrast, the bilingual reference group demonstrated a significantly lower mean RT of 1.34 seconds (SD = 0.33) with scores ranging from 1.01 to 2.04 seconds (KS:D=0.500,

$p=.044$). In addition, the percentage of mistakes committed by the bilingual aphasia group had a mean error rate of 10.99% (SD = 13.77) with a range from 0 to 40%. Conversely, the bilingual reference group exhibited a mean error rate of only 1.87% (SD = 2.46), with scores ranging from 0 to 7.69% (KS:D=0.514, $p= .036$). The higher error rates in the bilingual aphasia group suggest a well-expressed impairment of the visual working memory and reveals a double deficit in terms of response time and accuracy. This finding aligns with our hypothesis that participants with aphasia underperform in visual memory tasks. As it is shown in Figure 30 and 31, a statistically significant difference was found between the two groups both in response time and percentage of mistakes.

Figure 30. Comparison of the mean response time from the Visual Sequential Memory Test recorded by the bilingual aphasics (bPWA) and bilingual reference group (bHP)

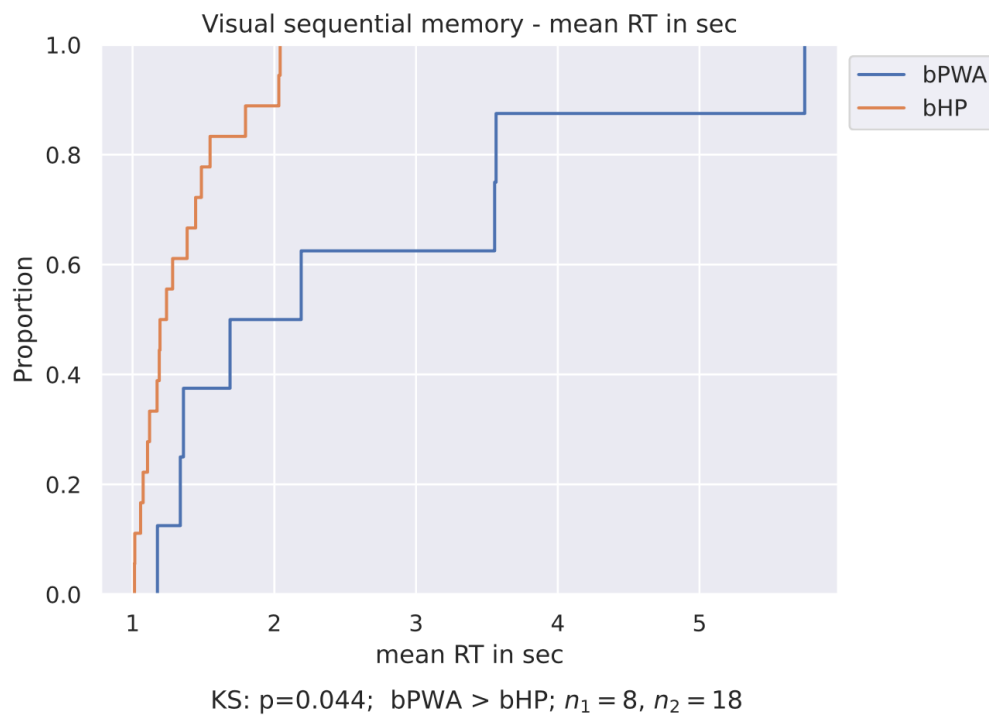
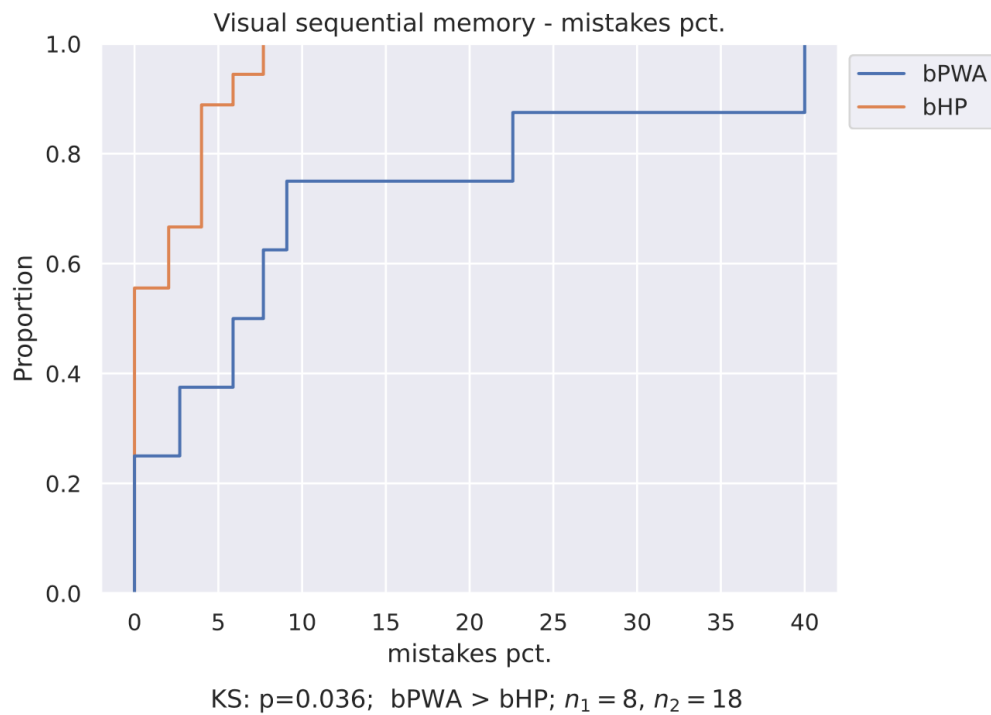


Figure 31. Comparison of the mistakes percentage from the Visual Sequential Memory Test recorded by the bilingual aphasics (bPWA) and bilingual reference group (bHP)



In the ROCF-B test, the bilingual aphasia group achieved a mean score of 19 (SD = 13.04), with scores ranging from 0 to 30. In contrast, the bilingual reference group had a mean score of 25.89 (SD = 4.44), with scores ranging from 15 to 31 (refer to Table 26 for individual scores). Overall, the bPWA group performed poorly in the Rey Complex task in comparison with the bilingual reference group, however, no statistical significance between the two groups was found (KS: $D=0.375$, $p > .100$).

To assess verbal working memory, we employed the Auditory Sequential Memory Test. The bilingual aphasia group had a mean score of 26.75 (SD = 17.48), with scores ranging from 0 to 44. In comparison, the bilingual reference group achieved a higher mean score of 39.56 (SD = 4.53), with scores ranging from 29 to 44. The findings suggest a potential deficit in auditory working memory among the bilingual individuals with aphasia, although with trends only. (KS: $D=0.417$, $p > .100$).

Table 26. Results of the auditory and visual working memory tasks in the group of bilingual aphasics and the bilingual reference group

Participants		Visual sequential memory test (mean RT in sec.)	Visual sequential memory (mistakes pct.)	ROCF-B (max score 31)	Auditory sequential memory test (max score 44)
Group of bilingual aphasics (N=8)	bPWA1	3.56	9.09	26	35
	bPWA2	1.34	2.70	30	36
	bPWA3	1.69	5.88	12	18
	bPWA4	2.19	7.69	27	44
	bPWA5	1.18	0	30	43
	bPWA6	3.55	22.58	0	0
	bPWA7	1.36	0	27	35
	bPWA8	5.74	40.00	0	3
	Range of scores (min-max)		1.18-5.74	0-40	0-30
Mean score		2.58	10.99	19	26.75
SD		1.60	13.77	13.04	17.48
Bilingual reference group (N=18)	bHP1	1.19	0	21	42
	bHP2	1.11	2.04	31	44
	bHP3	1.24	0	21	44
	bHP4	1.12	0	31	44
	bHP5	1.28	4.00	26	35
	bHP6	1.44	2.04	31	42
	bHP7	1.55	5.88	15	29
	bHP8	1.19	4.00	31	35
	bHP9	2.03	4.00	26	36
	bHP10	1.38	7.69	25	38
	bHP11	1.8	0	27	34
	bHP12	1.49	4.00	23	42
	bHP13	1.02	0	31	44
	bHP14	2.04	0	22	35
	bHP15	1.06	0	26	42
	bHP16	1.17	0	24	42
	bHP17	1.07	0	29	44
	bHP18	1.01	0	26	40
Range of scores (min-max)		1.01-2.04	0-7.69	15-31	29-44
Mean score		1.34	1.87	25.89	39.56
SD		0.33	2.46	4.44	4.53

Table 27. Results of the auditory and visual working memory tasks in the group of monolingual aphasics and the monolingual reference group

Participants	Visual sequential memory test (mean RT in sec.)	Visual sequential memory test (mistakes pct.)	ROCF-B (max score 31)	Auditory sequential memory test (max score 44)	
Group of monolingual aphasics (N=10)	mPWA1	2.11	7.69	22	42
	mPWA2	3.2	7.69	11	30
	mPWA3	1.94	0	24	42
	mPWA4	4.85	45.45	13	23
	mPWA5	1.37	0	31	43
	mPWA6	1.21	4.35	24	20
	mPWA7	5.22	20.00	21	16
	mPWA8	3.09	14.29	17	26
	mPWA9	1.20	0	29	44
	mPWA10	2.49	11.11	7	14
Range of scores (min-max)	1.20-5.22	0-45.45	7-31	14-44	
Mean score	2.67	11.06	19.90	30	
SD	1.44	13.77	7.80	11.88	
Monolingual reference group (N=18)	mHP1	1.27	0	31	44
	mHP2	1.05	0	30	44
	mHP3	1.21	0	15	44
	mHP4	2.27	4.00	30	37
	mHP5	1.23	2.04	31	44
	mHP6	1.31	0	28	39
	mHP7	1.15	0	24	40
	mHP8	2.04	6.25	22	30
	mHP9	1.47	0	31	44
	mHP10	1.16	0	29	44
	mHP11	1.82	17.24	23	42
	mHP12	2.05	5.26	22	41
	mHP13	1.04	0	27	44
	mHP14	1.28	5.26	25	40
	mHP15	2.56	7.69	31	42
	mHP16	1.88	14.29	15	26
	mHP17	0.99	0	31	42
	mHP18	1.43	0	24	40
Range of scores (min-max)	0.99-2.56	0-17.24	15-31	26-44	
Mean score	1.51	3.45	26.06	40.39	
SD	0.48	5.21	5.22	5.02	

3.3 Comparison between fluent and non-fluent aphasics in linguistic tests

This section presents the findings from the comparative analysis of linguistic performance between the fluent and non-fluent aphasics as assessed through a series of linguistic batteries. As the study revealed no statistically significant differences between the monolingual and bilingual participants with aphasia, the fluent and non-fluent groups were not divided into monolingual or bilingual groups.

Table 28. Summary of the linguistic test results comparing fluent and non-fluent aphasics

Comparison	Linguistic tests				
	Token	TROG	Naming	Semantic and letter fluency	
				Total score	Every 15 seconds
fluent PWA vs. reference	Yes, aphasia < reference PWA had lower scores.	Yes, in blocks M, R, S, T aphasia < reference	Yes, for RT aphasia > reference. Yes, for number of correct answers, aphasia < reference. PWA had longer RT and showed decreased accuracy.	Yes, aphasia < reference, PWA had fewer exemplars in both semantic and letter conditions.	Yes, PWA produced lower number of correct responses in all 4 intervals in both tasks. Yes, for the number of mistakes and no for repetitions in the semantic fluency. No, for repetitions and errors in the letter fluency.
non-fluent PWA vs. reference		Yes, for all blocks except block A aphasia < reference			Yes, PWA had lower number of correct responses in all 4 intervals in both tasks. No, for repetitions and errors in both tasks.
fluent vs. non-fluent PWA	Yes, fluent > non-fluent Non-fluent had lower scores.	Yes, in blocks D, E, F, G, H, M, N, O, P, R, S fluent > non-fluent	Yes, for number of correct answers. fluent > non-fluent No, for RT.	Yes, fluent > non-fluent. Non-fluent PWA produced fewer correct responses in both tasks.	Yes, non-fluent PWA produced lower number of correct responses in all 4 intervals in both tasks. No, for repetitions and errors.

Yes- significant finding, No- not significant findings.

The participants were comprised of 13 fluent and 5 non-fluent aphasics, compared against each other. Additionally, both aphasia groups were compared against a reference cohort of 36 healthy monolingual and bilingual individuals (for details see Table 32). The Kolmogorov-Smirnov (KS) test was employed in the analysis to determine any statistical significance by focusing on various linguistic measures, including the Boston Naming Test (BNT), Token Test, semantic and letter fluency tasks as well as the Test for Reception of Grammar (TROG-H). The summary of the results is presented in Table 28, while Table 29 includes the results of the statistical analysis with p values (significant with **bold**).

Table 29. Results of the statistical analysis of linguistic tests comparing fluent and non-fluent aphasics

	Linguistic batteries					TROG blocks
	BNT score	BNT RT in sec.	Token score	Semantic fluency score	Letter fluency score	
fluent aphasics (N=13) vs. reference group (N=36)	KS: D=0.665, p < .001	KS: D=0.812, p < .001	KS: D=0.707, p < .001	KS: D=0.609, p < .001	KS: D=0.679, p < .001	Blocks A-K and N-Q: p > .100 Block M- KS: D= 0.400, p= .034 Block R- KS: D= 0.442, p= .017 Block S- KS: D=0.400, p= .034 Block T- KS: D=0.402, p=.033
	aphasia < reference	aphasia > reference	aphasia < reference	aphasia < reference	aphasia < reference	aphasia < reference
non-fluent aphasics (N= 5) vs. reference group (N=36)	KS: D=1.000, p < .001	KS: D=1.000, p < .001	KS: D=1.000, p < .001	KS: D=1.000, p < .001	KS: D=1.000, p < .001	Block A: p > 0.10 Block B- KS:D=0.600, p= .026 Block C- KS:D=0.600, p= .026 Block D-KS:D=0.717, p= .005 Block E- KS:D=0.800, p= .001 Block F- KS:D=0.800, p= .001 Block G- KS: D= 1.000, p < .001 Block H- KS: D=0.972, p < .001 Block J- KS:D=0.717, p= .005 Block K- KS:D=0.772, p= .002 Block M-KS: D=0.861, p < .001 Block N- KS: D=1.000, p < .001 Block O- KS: D=1.000, p < .001 Block P-KS:D=0.889, p < .001 Block Q- KS:D=0.600, p= .026 Block R- KS:D=0.944, p < .001 Block S-KS:D=0.861, p < .001 Block T-KS:D=0.606, p= .025
	aphasia < reference	aphasia > reference	aphasia < reference	aphasia < reference	aphasia < reference	aphasia < reference
fluent aphasics (N=13) vs. non- fluent aphasics (N=5)	KS: D=1.000, p < .001	KS D=0.523, p=.105	KS: D=1.000, p < .001	KS: D=0.769, p=.008	KS: D=1.000, p < .001	Blocks A-C; J-K; Q; T: p > 0.100 Block D- KS: D=0.646, p=.030 Block E- KS: D=0.723, p=.012 Block F: KS: D=0.800, p=.004 Block G- KS:D=0.692, p=.020 Block H- KS: D=0.723, p=.012 Block M- KS: D=0.646, p=.030 Block N- KS: D=0.800, p=.004 Block O- KS: D=0.846, p=.002 Block P- KS: D=0.769, p=.008 Block R- KS: D=0.646, p=.030 Block S- KS: D= 646, p=.030
	fluent > non- fluent		fluent > non-fluent	fluent > non-fluent	fluent > non-fluent	fluent > non-fluent

3.3.1 Boston Naming Test

The results of the BNT revealed a statistically significant difference in performance between the fluent and non-fluent aphasic groups, as well as between both aphasia groups and the reference group (see Table 29). In case of the number of correct answers, the non-fluent aphasia group (M=4.20, SD=3.90) performed significantly poorly in comparison with the fluent aphasia group (M=35.31, SD=13.69; KS: D=1.000, $p < .001$) in the BNT. In contrast, when both aphasia groups were compared to the healthy reference group, aphasic participants were significantly slower and demonstrated poor performance in naming. Namely, the analysis of correct responses indicated that fluent aphasics (M=35.31, SD=13.69) performed significantly worse than the reference group (M=53.08, SD=5.46; KS: D=0.665, $p < .001$). This finding corroborates the hypothesis that fluent aphasia is associated with notable deficits in object naming. Moreover, non-fluent aphasics (M=4.20, SD=3.90) exhibited an even more marked impairment in object naming ability, when compared to the reference group (M=53.08, SD=5.46; KS: D=1.000, $p < .001$). This suggests that non-fluent aphasics struggle with naming tasks more than their fluent counterparts, highlighting the severity of their language deficits.

In addition to accuracy, response times were also analysed. The non-fluent aphasia group was slower (M=895.48, SD=338.85) compared to the fluent aphasia group (M=531.40, SD=251.36), though without reaching any statistical significance (KS: D=0.523, $p=.105$). Furthermore, the analysis revealed that both fluent and non-fluent aphasics recorded longer response times compared to the reference group. Specifically, fluent aphasics (M=531.40, SD=251.36), were significantly slower relative to their counterparts from the reference group (M=204.74, SD=59.90; KS: D=0.812, $p < .001$), suggesting that even though fluent aphasics may respond correctly, their ability to do so is notably slower in comparison to the reference group. Moreover, non-fluent aphasics demonstrated an even greater increase in response times (see Tables 29 and 32) further emphasising how much non-fluent aphasics struggle to identify and articulate the names of objects. The results indicate that both groups of aphasics not only struggled with accuracy but also recorded considerably longer response times, which may be indicative of underlying impairment in executive functions.

3.3.2 *Token Test*

In the Token Test, the non-fluent aphasia group (M=5.00, SD=3.94) performed significantly poorly in comparison with the fluent aphasia group (M=23.42, SD=5.88; KS: D=1.000, $p < .001$). In addition to that, both aphasia group (fluent: KS: D= 0.707, $p < .001$; non-fluent: KS: D= 1.000, $p < .001$) performed significantly poorly when they were compared to the reference group (M=32.17, SD=1.66). The stark difference highlights the profound deficits in auditory comprehension at the sentence level experienced by non-fluent participants. The results suggest that non-fluent aphasia is associated with significant disruptions in the cognitive processes underlying language, which may affect both the understanding of verbal instructions and the ability to respond appropriately.

3.3.3 *TROG-H*

The analysis of the group of fluent aphasics revealed statistically significant differences in performance across several blocks when compared to the reference group indicating that the difference in performance of the group of fluent aphasics was statistically significant in blocks M and R, S and T. Furthermore, the performance of the group of non-fluent aphasics was significantly different in blocks B-H, J-K, M- T when compared to the reference group. Although , the groups of fluent and non-fluent aphasics performed worse in comparison to the reference group, the participants exhibiting non-fluent aphasia struggled more than those with fluent aphasia in blocks D, E, F, G, H, M, N, O, P, R and S (for p values see Table 29, for mean scores refer to Table 32).

3.3.4 *Semantic and letter fluency*

Table 28 presents a summary of the verbal semantic and letter fluency tasks, detailing the total number of correct answers and performance across 15-second intervals.

In case of the semantic fluency task, the non-fluent aphasics (M=0.40, SD=0.55) performed significantly poorly in comparison with the fluent aphasia group (M= 3.77, SD=2.28; KS: D=0.769, $p=.008$). This finding is in line with the expectation that non-fluent aphasia is associated with more severe language impairments, further underscoring the impact of aphasia on semantic fluency. Additionally, when the fluent aphasia group was compared to the reference group (M=6.44, SD= 0.81), the results indicated a

statistically significant difference between them (KS: $D=0.609$, $p < .001$). Similarly to the fluent aphasia group, the non-fluent aphasia group also demonstrated significantly poor performance in comparison with the reference group (KS: $D=1.000$, $p < .001$). These results suggest that both fluent and non-fluent aphasic participants performed significantly worse than the reference group in the semantic fluency task, thereby supporting the hypothesis that individuals with aphasia experience lexical retrieval impairments.

Moreover, the analysis for the number of correct answers across 15-second intervals in the semantic fluency task revealed that non-fluent aphasics performed significantly poorly in all the four intervals in comparison with the fluent aphasia group (first: KS: $D=1.000$, $p < .001$; second: KS: $D=0.923$, $p=.001$; third and fourth: KS: $D=1.000$, $p < .001$). Similar results were observed when both fluent and non-fluent aphasia groups were compared to the reference group. In case of the comparison between fluent aphasics and the reference group, the analysis revealed statistically significant difference in all the four intervals between the two groups (first: KS: $D=0.679$, $p < .001$; second: KS: $D=0.665$, $p < .001$; third: KS: $D=0.637$, $p < .001$; fourth: KS: $D=0.652$, $p < .001$). When the non-fluent aphasia group was compared to the reference group, the aphasia group demonstrated poor performance in all the four intervals in the semantic fluency task (all intervals: KS: $D=1.000$, $p < .001$). Furthermore, the error analysis indicated statistically significant difference only between fluent aphasics ($M=0.69$, $SD=0.75$) and the reference group ($M=0.17$, $SD=0.51$; KS: $D=0.427$, $p=.021$). When non-fluent aphasics ($M=0$, $SD=0$) were compared to the reference group (KS: $D=0.111$, $p > .100$) and to the fluent aphasia group (KS: $D=0.538$, $p=.088$), the analysis revealed trends only. Finally, the analysis of repetitions revealed no statistical significance across any of the comparisons, including those between fluent ($M=1.69$, $SD=1.89$) and non-fluent aphasia groups ($M=0.45$, $SD=0.56$; KS: $D=0.462$, $p > .100$), as well as between both aphasia groups and the reference group ($M=0.56$, $SD=0.81$; fluent: KS: $D=0.357$, $p=.067$; non-fluent: KS: $D=0.189$, $p > .100$).

In terms of the total number of correct answers in the letter fluency task, the non-fluent aphasia group ($M=0$, $SD=0$) demonstrated significantly lower performance (KS: $D=1.000$, $p < .001$) compared to both the fluent aphasia group ($M=2.46$, $SD=1.66$) and

the reference group ($M=5.06$, $SD=1.51$). Similar result was observed when the fluent aphasia group was compared to the reference group (KS: $D=0.679$, $p < .001$).

Furthermore, the analysis across 15 second intervals in the letter fluency task revealed that non-fluent aphasics had significantly lower number of correct responses in all the four intervals when compared to the fluent aphasia group (first: KS: $D=0.846$, $p=.002$; second-fourth: KS: $D=1.000$, $p < .001$). When comparing fluent PWA to the reference group, the results indicated that fluent PWA produced a significantly lower number of correct responses in all the four intervals (first: KS: $D=0.541$, $p = .002$; second and third: KS: $D=0.658$, $p < .001$; fourth: KS: $D=0.686$, $p < .001$). Similarly, the comparison between non-fluent PWA and the reference group revealed significantly poor performance of aphasics in all the four intervals of the verbal letter fluency task (all intervals: KS $D=1.000$, $p < .001$).

The error analysis between fluent ($M=0.62$, $SD=0.96$) and non-fluent aphasics ($M=0$, $SD=0$) revealed no statistical significance (KS: $D=0.308$, $p > .100$). Moreover, in case of the number of errors made between the aphasia groups and the reference group ($M=0.39$, $SD=0.77$), the findings indicated comparable performance (fluent: KS: $D=0.252$, $p > .100$; non-fluent: KS: $D=0.278$, $p > .100$). Similar results were observed when the number of repetitions were analysed between fluent ($M=0.77$, $SD=1.17$) and non-fluent ($M=0$, $SD=0$) aphasia groups (KS: $D=0.462$, $p > .100$), as well as between the aphasia groups and the reference group ($M=0.78$, $SD=1.20$) (fluent: KS: $D=0.965$, $p > .100$; non-fluent: KS: $D=0.444$, $p > .100$).

3.4 Comparison between fluent and non-fluent aphasics in non-linguistic tests

This section presents the findings of the investigation into the performance of fluent and non-fluent aphasics in various non-linguistic tasks, employing the Kolmogorov-Smirnov (KS) test to determine the degree of statistical significance, and focusing on various non-linguistic measures, particularly the Auditory Sequential Memory, Visual Sequential Memory, Number and Letter Sudoku, Rey-Osterrieth Complex Figure B and the Trail Making Test. The results of the statistical analysis are summarized in Tables 30-32.

Table 30. Summary of non-linguistic test results comparing fluent and non-fluent aphasics

Comparison	Non-linguistic tests						
	WM			Cognitive flexibility and shifting			
	VSMT	ASMT	ROCF-B	Number Sudoku	Letter Sudoku	TMT A	TMT B
fluent PWA vs. reference	No for RT and mistakes percentage	Yes, aphasia < reference	No	Yes, for RT aphasia > reference, PWA had longer RT. No, for mistakes percentage.	No, for RT and mistakes percentage.	Yes, for RT aphasia > reference PWA longer RT. No, for errors.	Yes, for RT aphasia > reference PWA longer RT. Yes, for errors aphasia > reference
non-fluent PWA vs. reference	Yes, for RT and mistakes percentage. aphasia > reference PWA had longer RT and made more errors.	PWA had lower scores	Yes, aphasia < reference PWA had lower scores.	No, for RT and mistakes percentage.	Yes, for mistakes percentage, aphasia > reference No, for RT	Yes, for RT and errors. aphasia > reference PWA had longer RT and made more mistakes.	Yes, for RT aphasia > reference PWA longer. Yes, for errors aphasia > reference
fluent vs. non-fluent PWA	Yes, for RT and mistakes percentage. fluent < non-fluent	No	Yes, fluent > non-fluent Non-fluent PWA had lower scores.	No, for RT and mistakes percentage.	No, for RT. Yes, for mistakes percentage. fluent < non-fluent	No, for RT and number of mistakes.	Yes, for number of mistakes. fluent < non-fluent No, for RT.

Yes- significant finding, No- not significant findings.

Table 31. Results of the statistical analysis of non- linguistic tests comparing fluent and non-fluent aphasics

	Non-linguistic batteries								
	ASMT	Number Sudoku		Letter Sudoku		ROCF-B	TMT A	TMT B	VSMT
	score	mean RT	mistakes pct.	mean RT.	mistakes pct.	score	RT	RT	mean RT
fluent aphasics (N=13) vs. reference group (N=36)	KS: D=0.393, p= .039 aphasia < reference	KS: D=0.455, p= .013 aphasia > reference	KS: D=0.212, p > .100	KS: D=0.274, p > .100	KS: D=0.212, p > .100	KS: D=0.231, p > .100	KS: D=0.784, p < .001 aphasia > reference	KS: D=0.568, p= .001 aphasia > reference	KS: D=0.353, p= .071
non-fluent aphasics (N= 5) vs. reference group (N=36)	KS: D=0.800, p= .001 aphasia < reference	KS: D=0.667, p = .052	KS: D=0.333, p > .100	KS: D=0.500, p > .100	KS: D=0.972, p < .001 aphasia > reference	KS: D=0.778, p= .002 aphasia < reference	KS: D=0.861, p < .001 aphasia > reference	KS: D=0.861, p= .006 aphasia > reference	KS: D=0.944, p < .001 aphasia > reference
fluent aphasics (N=13) vs. non-fluent aphasics (N=5)	KS: D=0.569, p=.068	KS: D=0.590, p > .100	KS: D=0.333, p > .100	KS: D=0.385, p > .100	KS: D=1.000, p=.002 fluent < non-fluent	KS: D=0.692, p=.020 fluent > non-fluent	KS: D=0.600, p=.050	KS: D=0.385, p > .100	KS: D=0.723, p=.012 fluent < non-fluent

3.4.1 Cognitive flexibility impairment in TMT and Letter & Number Sudoku

In the Number Sudoku task, the analysis of mean RT revealed only significant difference in performance between the fluent PWA and the reference group (KS: D= 0.455, p= .013). While the non-fluent aphasics (M=17.19, SD=10.10) were slower than their fluent counterparts (M=8.49, SD=5.29) and the reference group (M=5.25, SD=1.48), the results indicated no statistical significance (refer to Table 31). Furthermore, the analysis of mistakes percentage in the Number Sudoku task found no statistical significance in the following comparisons: group of fluent aphasics (M=4.48, SD=6.12) vs. the reference group (M=2.48, SD=4.63) (KS: D=0.212, p > .100), group of non-fluent aphasics (M=11.11, SD=19.24) vs. the reference group (KS: D=0.333, p > .100) and fluent PWA vs. non-fluent PWA(KS: D=0.333, p > .100).

In the Letter Sudoku task, the analysis of mean RT indicated no statistical significance across any of the comparisons (see Tables 30 and 31). In contrast, the analysis of mistakes percentage found significant difference between non-fluent PWA ($M=27.62$, $SD=13.19$) and fluent PWA ($M=4.77$, $SD=5.02$; KS: $D= 1.000$, $p= .002$), as well as between non-fluent PWA and the reference group ($M=3.92$, $SD=5.55$; KS: $D=0.972$, $p < .001$).

In Part A of the Trail Making Test, the fluent aphasia group ($M=100.25$, $SD=34.94$) performed significantly more slowly compared to the reference group ($M=47.89$, $SD=18.75$; KS: $D=0.784$, $p < .001$). Furthermore, the group of non-fluent aphasics were even slower ($M=150.20$, $SD=54.81$) when compared to the fluent aphasia group, though showed trends only (KS: $D= 0.600$, $p =.050$). While the comparison between non-fluent PWA and the reference group revealed significant difference between the two (KS: $D= 0.861$, $p < .001$).

In terms of the number of mistakes made in Part A, the analysis identified no statistical significance in the following comparisons: fluent PWA vs. non- fluent PWA (KS: $D=0.600$, $p= .050$) and fluent PWA vs. reference (KS: $D= 0.147$, $p > .100$). In contrast the comparison between non-fluent PWA ($M=12.40$, $SD=11.35$) and the reference group ($M=0.11$, $SD=0.40$) identified significant difference between the two (KS: $D= 0.717$, $p=.005$).

In Part B of the Trail Making Test, three participants with non-fluent aphasia were analysed instead of 5 as two participants with very severe symptoms of aphasia were unable to solve Part B. Similarly to Part A, both the fluent ($M=252.62$, $SD=138.15$) and non-fluent ($M=248.67$, $SD=84.60$) aphasia groups performed significantly more slowly compared to the reference group ($M=117.64$, $SD=62.00$) (for p values see Table 31). In terms of RT, non-fluent and fluent PWA exhibited similar level of performance in Part B, however, the decreased number of participants in the non-fluent group may have influenced the results.

In case of the number of mistakes made in Part B, the results indicated significant differences between fluent and non-fluent aphasics, as well as between both aphasia groups and the reference group. The non-fluent PWA ($M=19.60$, $SD=6.54$) made significantly more mistakes than their fluent counterparts ($M=5.69$, $SD=5.69$; KS: $D=0.778$, $p < .001$). Similar results were observed when the non-fluent group was

compared to the reference group (M=0.69, SD=1.31; KS: D=1.000, $p < .001$), as well as when the fluent group was compared to the reference group (KS: D= 0.714, $p < .001$).

3.4.2 Auditory and visual working memory impairment

In the Visual Sequential Memory Test, the non-fluent PWA (M= 4.29, SD= 1.46) were significantly slower when compared to the fluent aphasia group (M= 1.99, SD= 0.85; KS: D= 0.723, $p = .012$), as well as to the reference group (M= 1.43, SD= 0.41 ; KS: D=0.944, $p < .001$). In contrast, the analysis revealed similar performance between the fluent PWA and the reference group (KS: D= 0.353, $p = .071$).

In terms of mistakes percentage in the VSMT, the non-fluent aphasia group (M= 27.15, SD= 15.41) made significantly more mistakes than their fluent counterparts (M= 4.83, SD= 4.88; KS: D=0.800, $p = .004$) and the reference group (M= 2.66, SD= 4.09; KS: D= 0.889, $p < .001$). While the analysis found no statistical significance between fluent aphasics and the reference group (KS: D= 0.316, $p > .100$).

In the Rey-Osterrieth Complex Figure B Test, no statistical significance was identified by comparing the group of fluent aphasics (M=22.69, SD=8.15) with the reference group (M=25.97, SD=4.78; KS: D= 0.231, $p > .100$). In contrast, the group of non-fluent aphasics (M=11.20, SD=10.80) performed worse than the reference group (KS: D= 0.778, $p = .002$) and the fluent aphasia group (KS:D= 0.692, $p = .020$). The results indicate that the non-fluent aphasics struggled considerably in tasks requiring visual-spatial processing and working memory, further supporting the notion that cognitive impairments associated with non-fluent aphasia may not only influence linguistic challenges. The findings support our assumption that individuals with more severe aphasia symptoms would have greater impairment in non-linguistic working memory tasks.

In the Auditory Sequential Memory Test, both groups of fluent and non-fluent aphasics performed significantly worse compared to the neurologically healthy reference group (refer to Tables 31-32), suggesting that both fluent and non-fluent aphasics experience deficits in auditory sequential memory. In contrast, the analysis revealed no statistical significance between fluent PWA and non-fluent PWA (KS: D= 0.569, $p = .068$).

Table 32. Results of the linguistic and non-linguistic tests with mean scores and SD comparing both fluent and non-fluent PWA and the combined reference group

Tests	Fluent PWA (N=13)	Non-fluent PWA (N=5)	mHP+bHP group (N=36)
BNT RT	M=531.40, SD=251.36	M=895.48, SD=338.85	M=204.74, SD=59.90
BNT score (max 60)	M=35.31, SD=13.69	M=4.20, SD=3.90	M=53.08, SD=5.46
Token score (max 36)	M=23.42, SD=5.88	M=5.00, SD=3.94	M=32.17, SD=1.66
Semantic fluency score (max 7)	M=3.77, SD=2.28	M=0.40, SD=0.55	M=6.44, SD=0.81
Letter fluency score (max 7)	M=2.46, SD=1.66	M=0, SD=0.00	M=5.06, SD=1.51
TROG-Block A	M=4.00, SD=0.00	M=4.00, SD=0.00	M= 4.00, SD=0.00
TROG-Block B	M=3.69, SD=0.85	M=2.40, SD=1.52	M=3.97, SD=0.17
TROG- Block C	M=3.92, SD=0.28	M=2.60, SD=1.34	M=3.97, SD=0.17
TROG- Block D	M=3.77, SD=0.60	M=2.60, SD=1.14	M=3.92, SD= 0.28
TROG- Block E	M=3.92, SD=0.28	M=2.60, SD=1.14	M= 4.00, SD=0.00
TROG- Block F	M=3.69, SD=0.48	M=1.60, SD=1.52	M= 3.97, SD=0.17
TROG-Block G	M=3.62, SD=0.65	M=2.20, SD=1.30	M=4.00, SD=0.00
TROG- Block H	M=3.54, SD=0.88	M=1.40, SD=1.34	M=3.97, SD=0.17
TROG-Block J	M=3.38, SD=0.96	M=2.00, SD=1.58	M=3.92, SD=0.28
TROG-Block K	M=2.69, SD=1.55	M=1.20, SD=1.30	M=3.72, SD=0.51
TROG-Block M	M=3.08, SD=1.12	M=1.20, SD=1.10	M=3.86, SD=0.35
TROG-Block N	M=2.77, SD=1.24	M=0.20, SD=0.45	M=3.50, SD=0.70
TROG-Block O	M=3.38, SD=0.77	M=0.40, SD=0.89	M= 3.81, SD=0.40
TROG-Block P	M=2.92, SD=1.26	M=0.80, SD=1.10	M= 3.56, SD=0.88
TROG-Block Q	M=3.46, SD0.88	M=1.60, SD=2.19	M= 3.75, SD=0.60
TROG-Block R	M=2.69, SD=1.11	M=0.60, SD=0.89	M= 3.69, SD=0.58
TROG-Block S	M=3.31, SD=0.75	M=1.00, SD=1.41	M= 3.86, SD=0.35
TROG-Block T	M=1.77, SD=0.83	M=0.80, SD=1.30	M=2.67, SD=1.33
ASMT score (max 44)	M=33.08, SD=10.62	M=16.80, SD=16.93	M= 33.08, SD=10.62
Number Sudoku RT	M=8.49, SD=5.29	M=17.19, SD=10.10	M=5.25, SD=1.48
Number Sudoku mistakes pct.	M=4.48, SD=6.12	M=11.11, SD=19.24	M=2.48, SD=4.63
Letter Sudoku RT	M= 8.62, SD=2.99	M=12.50, SD=7.61	M= 7.42, SD=2.61
Letter Sudoku mistakes pct.	M=4.77, SD=5.02	M=27.62, SD=13.19	M= 3.92, SD=5.55
ROCF-B score (max 31)	M=22.69, SD=8.15	M=11.20, SD=10.80	M=25.97, SD=4.78
TMT A RT	M=100.25, SD=34.94	M=150.20, SD=54.81	M= 47.89, SD=18.75
TMT A mistakes	M=0.31, SD=0.63	M=12.40, SD=11.35	M=0.11, SD=0.40
TMT B RT	M=252.62, SD=138.15	M=248.67, SD=84.60	M=117.64, SD=62.00
TMT B mistakes	M=5.69, SD=5.69	M=19.60, SD=6.54	M=0.69, SD=1.31
VSMT RT	M=1.99, SD=0.85	M=4.29, SD=1.46	M=1.43, SD=0.41
VMST mistakes pct.	M=4.83, SD=4.88	M=27.15, SD=15.41	M=2.66, SD=4.09

3.5 Effects of age and education level on performance

This section presents the results of the statistical analyses conducted to explore the effects of age and education level on linguistic and non-linguistic batteries. The analyses employed the Kendall's tau and Pearson's R correlation coefficients to assess the strength and significance of these relationships. Tables 34 and 35 summarize the results of the effects of age and education on performance, while the results of the statistical analysis with p values are presented in Tables 36-38 (significant with **bold**).

In the context of the present study, a comparison was made between education level and age across all groups (see Table 33). The results obtained from the monolingual reference group (refer to Figure 32) as well as the mono- and bilingual aphasia group were consistent with the expected outcomes, demonstrating no significant correlation between the two variables. However, the analysis conducted on the bilingual reference group revealed a significant negative correlation between education level and age (see Figure 33). This finding is particularly concerning as it complicates the interpretation of the significant results observed in linguistic and non-linguistic tasks since it is not clear whether these results are attributable to the education level, age or a combination of both factors. Therefore, the interpretation of the results, especially those from the bilingual reference group, must be considered with caution.

Table 33. Comparison of the correlation between age and education level in mono- and bilingual aphasia and reference groups

	Education level vs age	
	Pearson's R	Kendall's t
mHP	-0.307 p= .116	- 0.387 p = .102
bHP	-0.60 p= .012	-0.61 p < .001
bPWA+mPWA	-0.38 p=.106	-0.42 p=.172

Figure 32. Correlation between education level and age in the monolingual reference group

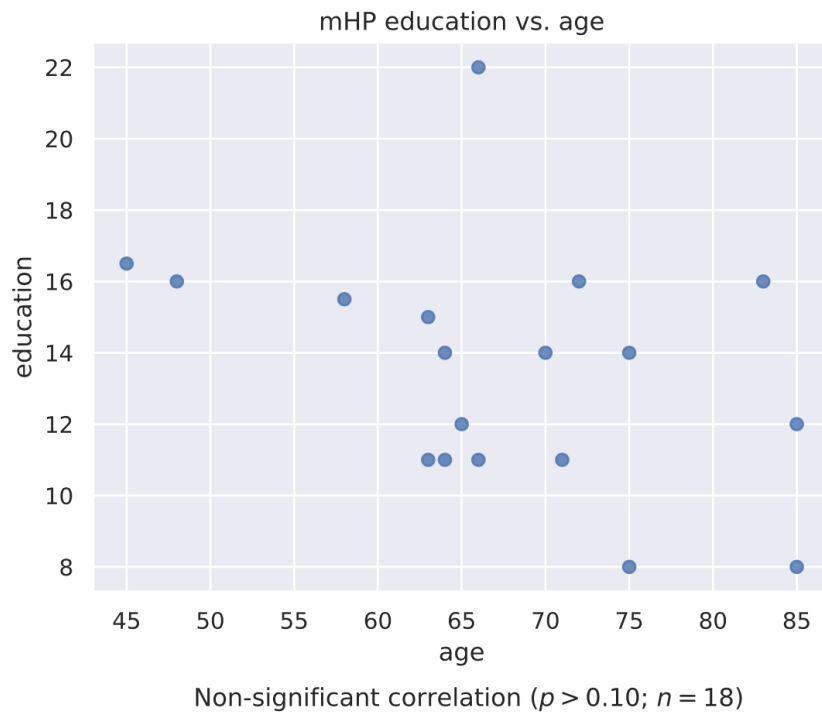


Figure 33. Correlation between education level and age in the bilingual reference group

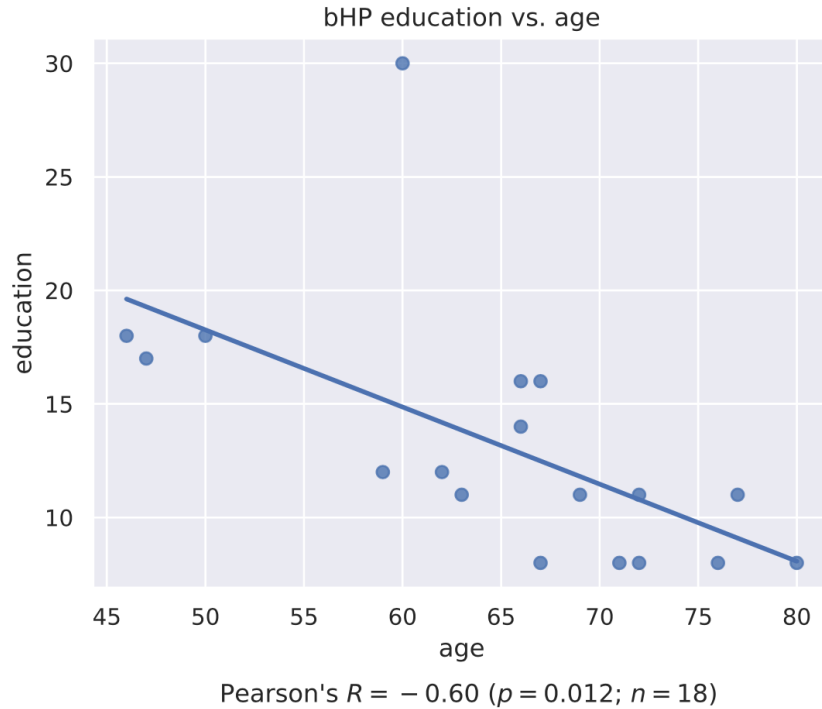


Table 34. Summary of the results investigating the effects of education on performance

Participants	Effect of education on performance						
	Linguistic tests		Non-linguistic tests				
	Naming	Verbal fluency	Sudoku Tasks	TMT	ASMT	VSMT	ROCF-B
Monolingual healthy participants	Yes, for the number of correct answers (+) No, for RT	No, for scores in both tasks	Yes, for RT in letter sudoku (-) No, for mistakes	No, for RT and mistakes in both parts.	No	No, for RT Yes, for mistakes pct (-)	No
Bilingual healthy participants	Yes, for the number of correct answers (+) No, for RT	Yes, for scores in letter fluency (+)	Yes, for RT in letter sudoku (-) No, for mistakes	Yes, for RT in TMT-B (-) No, for errors	Yes, for the number of correct answers (+)	Yes, for both RT and mistakes pct (-)	No
Monolingual aphasics	No, for RT and scores.	No, for scores in both tasks.	No, for RT and mistakes.	Yes, for RT in TMT B (-)	No	No	No
Bilingual aphasics	No, for RT and scores.	Yes, for semantic fluency score (+)	No, for RT and mistakes.	No	No	Yes, for RT and mistakes pct (-)	Yes, for scores (+)

Yes- significant finding, No- not significant findings.

Table 35. Summary of the results investigating the effects of age on performance

Participants	Effect of age on performance						
	Linguistic tests		Non-linguistic tests				
	Naming	Verbal fluency	Sudoku Tasks	TMT	ASMT	VSTM	ROCF-B
Monolingual healthy participants	No	Yes, for semantic fluency (-)	No	Yes, for RT in part B (+)	No	No	No
Bilingual healthy participants	No	Yes, for both fluency tasks (-)	Yes, for RT in both tasks (+)	Yes, for RT in both parts (+)	Yes, for the number of correct answers (-)	Yes, for RT and mistakes pct (+)	No
Monolingual aphasics	No	No	No	No	No	No	No
Bilingual aphasics	No	No	Yes, for RT in letter sudoku (+)	No	No	Yes, for RT and mistakes pct. (+)	No

Yes- significant finding, No- not significant findings.

3.5.1 *In naming and verbal fluency*

In the Boston Naming Test for the monolingual reference group (mHP), the analysis revealed a positive correlation between age and response time and a negative correlation between age and BNT scores (refer to Table 36). Although the results indicate that these correlations were statistically insignificant, the negative trend in BNT scores suggests that as age increases, naming ability may decline, albeit not conclusively within this sample. For the mHP group, education showed a negative correlation with response time and a positive correlation with BNT scores. The Pearson's correlations mirrored these results, indicating no significant relationship between education and response time but a strong positive correlation between education and BNT scores ($r = 0.61, p = .005$). In the fluency tasks, a significant negative correlation was found between age and semantic fluency scores in the monolingual reference group ($t = -0.56, p = .004; r = -0.59, p = .007$). This suggests that as age increases, the semantic fluency scores tend to decrease. Conversely, the correlation between age and letter fluency scores showed trends only. The correlation with education in both fluency tasks was positive but did not reach statistical significance (see Table 36).

For the bilingual reference group (bHP), age also demonstrated a positive correlation with response time and a negative correlation with BNT scores. Furthermore, the relationship between education and performance in the bHP group was more pronounced. A negative correlation was found between education and response time. Furthermore, a significant positive correlation was observed between education and BNT scores ($t = 0.38, p = .042; r = 0.50, p = .009$). In the fluency tasks, a significant negative correlation was found between age and both the semantic and letter fluency scores in the bilingual reference group. For semantic fluency, Kendall's t was -0.52 ($p = .007$) and Pearson's R was -0.52 ($p = .014$), indicating that older bilingual participants exhibited lower semantic fluency scores. This finding complements the results from the monolingual reference group. For letter fluency, the results were even more pronounced, with Kendall's $t = -0.59$ ($p < .001$) and Pearson's $R = -0.68$ ($p < .001$). The correlation between education and both semantic and letter fluency scores in the bilingual reference group revealed a significant positive relationship (see Table 36).

The combined analysis of monolingual and bilingual participants with aphasia revealed a positive correlation between age and response time and a negative correlation

between age and BNT scores. While these correlations were not statistically significant, they suggest a trend where older participants with aphasia may exhibit slower response times and poorer naming abilities. Education levels in the combined aphasia group exhibited a more substantial impact on performance. A negative correlation was found between education and response time, though without statistical significance. Additionally, a positive correlation was observed between education and BNT scores, indicating that greater educational attainment might correlate improved performance in the naming task. In the fluency tasks, the analysis of age revealed negative correlations, though without statistical significance. In contrast, the relationship between education and semantic fluency scores was significant in the combined group of monolingual and bilingual participants with aphasia. Kendall's τ was 0.57 ($p = .002$) and Pearson's R was 0.68 ($p = .002$), indicating a strong positive correlation. For letter fluency, the correlation with education showed trends only (refer to Table 36).

Beyond the analysis of the combined aphasia group, the study also provides individual analysis for the mono-and bilingual aphasia subgroups. In the monolingual aphasia group, the analyses revealed positive correlations between age and response time, as well as between age and BNT scores. While, in the bilingual aphasia group, the analysis revealed a positive correlation between age and response time and a negative correlation between age and BNT scores, however, without reaching any statistical significance (see Table 36). In the semantic and letter fluency tasks, the analysis of age and education revealed a positive correlation in the monolingual aphasia group. Furthermore, the analysis revealed a negative correlation between age and both fluency task scores among bilingual aphasics. In contrast, the relationship between education and semantic fluency scores was significant ($t = 0.68$, $p = .027$; $r = 0.76$, $p = .032$) in bilingual aphasics. In case of the letter fluency task, the analysis revealed trends only between education and scores in the bPWA group (refer to Table 36).

Table 36. Correlation between age and education level in language tests

Participants	Correlation	BNT		Fluency scores	
		RT	Score	semantic	letter
mHP age	Kendall's t	0.20 p=.283	-0.336 p=.065	-0.56 p=.004	-0.32 p=.088
	Pearson's R	0.28 p=.266	-0.43 p=.071	-0.59 p=.007	-0.41 p=.087
mHP education	Kendall's t	-0.05 p=.823	0.49 p=.006	0.34 p=.098	0.30 p=.121
	Pearson's R	-0.10 p=.692	0.61 p=.005	0.35 p=.149	0.24 p=.356
bHP age	Kendall's t	0.30 p=.092	-0.32 p=.075	-0.52 p=.007	-0.59 p < .001
	Pearson's R	0.44 p=.056	-0.56 p=.011	-0.52 p=.014	-0.68 p<.001
bHP education	Kendall's t	-0.36 p=.048	0.38 p=.042	0.48 p=.017	0.73 p < .001
	Pearson's R	-0.41 p=.057	0.50 p=.009	0.38 p=.061	0.71 p < .001
mPWA+bPWA age	Kendall's t	0.23 p=.185	-0.15 p=.428	-0.06 p=.744	-0.14 p=.472
	Pearson's R	0.27 p=.263	-0.22 p=.377	-0.19 p=.446	-0.12 p=.611
mPWA+bPWA education	Kendall's t	-0.32 p=.090	0.38 p=.045	0.57 p=.002	0.38 p=.056
	Pearson's R	-0.45 p=.037	0.44 p=.069	0.68 p=.002	0.52 p=.063
mPWA age	Kendall's t	0.00 p=1.000	0.40 p=.130	0.24 p=.415	0.18 p=.535
	Pearson's R	0.05 p=.902	0.33 p=.354	0.17 p=.647	0.09 p=.822
mPWA education	Kendall's t	-0.30 p=.347	0.24 p=.452	0.48 p=.117	0.48 p=.116
	Pearson's R	-0.43 p=.208	0.35 p=.393	0.64 p=.083	0.88 p=.057
bPWA age	Kendall's t	0.36 p=.275	-0.47 p=.134	-0.37 p=.266	-0.28 p=.449
	Pearson's R	0.56 p=.151	-0.63 p=.093	-0.46 p=.244	-0.40 p=.332
bPWA education	Kendall's t	-0.31 p=.377	0.47 p=.126	0.68 p=.027	0.09 p=.836
	Pearson's R	-0.47 p=.252	0.54 p=.122	0.76 p=.032	-0.16 p=.732

3.5.2 In Sudoku tasks and TMT

For the monolingual healthy participants (mHP), the analysis of the correlation between age and performance in the Letter Sudoku task (both response time and mistakes percentage) revealed no significant relationships. Using Kendall's tau, the correlation for age with response time was found to be 0.03 ($p = .892$). Similarly, the correlation for age

with mistakes percentage was 0.02 ($p = .942$). Using Pearson's correlation coefficient, the findings mirrored those of Kendall's tau, with a correlation of 0.10 for response time ($p = .689$) and 0.04 for mistakes percentage ($p = .889$). In case of Number Sudoku tasks, again no significant correlation was found neither in response time nor in percentage of mistakes (refer to Table 37). The analysis of education levels among monolingual healthy participants showed a significant negative correlation with response time, as indicated by Kendall's tau of -0.51 ($p = .004$). This suggests that higher educational attainment is associated with faster response times in the Letter Sudoku task. The Pearson's correlation coefficient corroborated this finding, with a value of -0.61 ($p = .006$). However, the correlation between education and mistakes percentage was not significant (for p values see Table 37). Regarding education correlation in the Number Sudoku task, the results for RT and mistakes percentage indicated no significant correlation. The correlations between age and TMT A and B response time, as well as the number of mistakes made, were analysed. The results indicated a moderate positive correlation between age and TMT A response time, with Kendall's tau yielding a value of 0.33 ($p = .067$) and Pearson's R yielding a value of 0.47 ($p = .049$). In terms of mistakes made during the TMT A, a similar trend was observed, with Kendall's tau indicating a correlation of 0.39 ($p = .066$) and Pearson's R showing a correlation of 0.44 ($p = .066$). Furthermore, age demonstrated a statistically significant positive correlation with TMT B response time (Kendall's $t = 0.45$, $p = .011$; Pearson's $R = 0.63$, $p = .004$). This suggests that older individuals in the monolingual reference group tended to take longer to complete the TMT B task. Conversely, age did not show a significant correlation with the number of mistakes made, indicating that while older participants were slower, they did not necessarily make more errors. Education levels among monolingual healthy participants did not demonstrate significant correlations with either TMT A response time or the number of mistakes. Similar results were observed in TMT B, indicating a potential negative relationship that did not reach significance (refer to Table 37 for details).

For the bilingual reference group (bHP), the correlation between age and performance in the Letter Sudoku task were significant, as evidenced by a Kendall's tau of 0.58 ($p < .001$) and a Pearson's R of 0.83 ($p < .001$). The relationship between age and mistakes percentage reached no statistical significance, with a Kendall's tau of 0.29 ($p = .143$) and a Pearson's R of 0.36 ($p = .124$). In case of Number Sudoku tasks, significant correlation was found in response time ($t = 0.49$, $p = .005$; $r = 0.61$, $p = .004$) and trends only in

percentage of mistakes ($t = 0.15$, $p = .4623$; $r = 0.17$, $p = .515$). The analysis of education levels among bilingual healthy participants also yielded significant results in the Letter Sudoku task. The Kendall's tau for education and response time was -0.53 ($p = .001$), indicating a significant negative correlation. The Pearson's R further confirmed this relationship with a value of -0.62 ($p = .006$). In terms of mistakes percentage, the correlation with education was not statistically significant. In the Number Sudoku task, the correlation between education and RT in the bilingual reference group suggested a negative relationship, but it did not reach statistical significance (see Table 37). For the percentage of mistakes, the results indicated no significant correlation. Furthermore, age was found to have a significant positive correlation with TMT A response time, with Kendall's tau at 0.40 ($p = .025$) and Pearson's R at 0.55 ($p = .015$). However, the correlation between age and the number of mistakes made during the TMT A reached no statistical significance. In the bilingual reference group, age also exhibited a significant positive correlation with TMT B reaction time (Kendall's $t = 0.63$, $p < .001$; Pearson's $R = 0.58$, $p = .003$). However, the correlation between age and the number of mistakes made was not significant. Regarding educational background for the bilingual reference group, a negative correlation between education and TMT A response time as well as number of mistakes reached no statistical significance. When examining the impact of education on TMT B performance, a significant negative correlation was found between education and response time (Kendall's $t = -0.59$, $p = .001$; Pearson's $R = -0.48$, $p = .006$). However, the correlation with the number of mistakes made was insignificant (refer to Table 37).

When considering both monolingual and bilingual aphasia groups together, the positive correlation between age and response time in the Number Sudoku task was not significant. The percentage of mistakes in the Number Sudoku task also showed no significant negative correlation with age (see Table 37). In contrast, in the Letter Sudoku task, a significant negative correlation was found between education and response time in the combined aphasia group (bPWA + mPWA), with a Kendall's tau of -0.41 ($p = .049$) and Pearson's R of -0.46 ($p = .029$). In terms of mistakes percentage, the negative correlation with education was not significant in the Letter Sudoku task. In contrast, in the Number Sudoku task, the correlation between education and RT in the aphasia group was significant, with a Kendall's tau of -0.51 ($p = .010$) and a Pearson's R of -0.51 ($p = .001$). For the percentage of mistakes made in the Number Sudoku task, the results indicated no significant negative correlation. The analysis for participants with aphasia,

both monolingual and bilingual, revealed that the correlation between age and TMT A response time was moderate. In the combined analysis of mono- and bilingual aphasia group, age did not reveal a significant correlation in TMT Part B with either response time or the number of mistakes (see Table 37). Additionally, a significant negative correlation was observed between education and TMT A response time, with Kendall's tau at -0.42 ($p = .025$) and Pearson's R at -0.52 ($p = .010$). For the number of mistakes made in part A, Kendall's tau was -0.39 ($p = .057$), and Pearson's R was -0.28 ($p = .097$). Education demonstrated a significant negative correlation with TMT B performance in the aphasia group. Specifically, Kendall's tau revealed a significant negative correlation with both response time (Kendall's $t = -0.43$, $p = .034$) and the number of mistakes (Kendall's $t = -0.41$, $p = .034$). Pearson's R further corroborated these findings, with significant negative correlations for both RT ($r = -0.48$, $p = .021$) and mistakes ($r = -0.47$, $p = .006$).

The analysis in the monolingual aphasia group revealed positive correlation between age and RT in both Sudoku tasks, though with no statistical significance. In terms of mistakes percentage in the Letter Sudoku task, the analysis showed negative correlation with age. While in the Number Sudoku task, the analysis revealed a positive correlation with mistakes percentage, though showing trends only (for details, see Table 37). Regarding the effect of education on performance in Sudoku tasks, the analysis revealed negative correlations in RT in both tasks among monolingual aphasics. In case of bilingual aphasics, the analysis revealed positive correlations between age and performance in the Sudoku tasks, however, it reached statistical significance in case of RT in the Letter Sudoku task ($t=0.81$, $p=.011$; $r= 0.80.$, $p=.031$). Moreover, the analysis showed negative correlations between education and RT in both Sudoku tasks among bilingual aphasics, though without statistical significance experienced (refer to Table 37).

Table 37. Correlation between age and education level in cognitive flexibility tasks

Participants	Correlation	Letter Sudoku		Number Sudoku		TMT A		TMT-B	
		RT	mistakes pct.	RT	mistakes pct.	RT	number of mistakes	RT	number of mistakes
mHP age	Kendall's t	0.03 p=.892	0.02 p=.942	0.01 p=.976	0.30 p=.153	0.33 p=.067	0.39 p=.066	0.45 p=.011	0.31 p=.106
	Pearson's R	0.10 p=.689	0.04 p=.889	0.19 p=.467	0.37 p=.121	0.47 p=.049	0.44 p=.066	0.63 p=.004	0.47 p=.047
mHP education	Kendall's t	-0.51 p=.004	0.07 p=.749	-0.24 p=.198	0.27 p=.210	-0.32 p=.075	-0.06 p=.859	-0.29 p=.115	-0.05 p=.817
	Pearson's R	-0.61 p=.006	0.24 p=.320	-0.23 p=.367	0.22 p=.315	-0.30 p=.224	-0.08 p=.800	-0.32 p=.189	-0.26 p=.284
bHP age	Kendall's t	0.59 p<.001	0.29 p=.143	0.49 p=.005	0.15 p=.462	0.40 p=.025	0.10 p=.519	0.63 p<.001	0.18 p=.398
	Pearson's R	0.83 p<.001	0.36 p=.124	0.61 p=.004	0.17 p=.515	0.55 p=.015	0.18 p=.302	0.58 p=.003	0.30 p=.215
bHP education	Kendall's t	-0.53 p=.001	-0.23 p=.265	-0.31 p=.097	0.05 p=.832	-0.29 p=.107	0.13 p=.389	-0.59 p=.001	-0.20 p=.360
	Pearson's R	-0.62 p=.006	-0.10 p=.751	-0.30 p=.186	0.20 p=.446	-0.25 p=.309	0.04 p=.735	-0.48 p=.006	-0.25 p=.275
mPWA +bPWA age	Kendall's t	0.36 p=.062	-0.02 p=.955	0.36 p=.068	0.34 p=.103	0.33 p=.063	0.13 p=.539	0.24 p=.233	0.21 p=.274
	Pearson's R	0.49 p=.038	-0.12 p=.655	0.42 p=.097	0.39 p=.110	0.38 p=.115	0.25 p=.328	0.30 p=.252	0.26 p=.300
mPWA +bPWA education	Kendall's t	-0.41 p=.049	-0.20 p=.358	-0.51 p=.010	-0.15 p=.514	-0.42 p=.025	-0.39 p=.057	-0.43 p=.034	-0.41 p=.034
	Pearson's R	-0.46 p=.029	-0.20 p=.481	-0.51 p=.001	-0.18 p=.572	-0.52 p=.010	-0.28 p=.097	-0.48 p=.021	-0.47 p=.006
mPWA age	Kendall's t	0.14 p=.683	-0.45 p=.135	0.25 p=.412	0.34 p=.299	0.13 p=.659	-0.03 p=.951	0.13 p=.655	-0.14 p=.651
	Pearson's R	0.27 p=.480	-0.55 p=.175	0.19 p=.638	0.39 p=.293	0.13 p=.736	-0.20 p=.535	0.31 p=.387	-0.08 p=.805
mPWA education	Kendall's t	-0.55 p=.080	-0.31 p=.381	-0.55 p=.082	0.17 p=.673	-0.49 p=.106	-0.47 p=.337	-0.67 p=.011	-0.22 p=.474
	Pearson's R	-0.51 p=.133	-0.25 p=.539	-0.44 p=.030	0.22 p=.602	-0.55 p=.043	-0.20 p=.337	-0.52 p=.013	-0.43 p=.123
bPWA age	Kendall's t	0.81 p=.011	0.05 p=.997	0.43 p=.239	0.51 p=.194	0.40 p=.218	0.23 p=.580	0.47 p=.272	0.52 p=.105
	Pearson's R	0.80 p=.031	0.39 p=.406	0.69 p=.084	0.60 p=.193	0.69 p=.083	0.59 p=.187	0.35 p=.494	0.59 p=.126
bPWA education	Kendall's t	-0.45 p=.229	0.11 p=.776	-0.65 p=.063	-0.47 p=.208	-0.35 p=.309	-0.45 p=.280	-0.28 p=.585	-0.52 p=.100
	Pearson's R	-0.57 p=.111	0.02 p=.798	-0.61 p=.014	-0.50 p=.150	-0.45 p=.279	-0.46 p=.137	-0.37 p=.481	-0.53 p=.070

3.5.3 *In Working Memory tasks*

The analysis of the relationship between age and Auditory Sequential Memory Test scores for monolingual healthy participants revealed negative correlation, without statistical significance (see Table 38). Furthermore, the analysis revealed a weak positive correlation between age and response time as well as a moderate positive correlation between age and the percentage of mistakes in the Visual Sequential Memory Test. The results suggested no significant correlation between age and ROCF-B scores in monolingual healthy participants. Moreover, the analysis of the relationship between education levels and Auditory Sequential Memory Test scores showed positive correlations, while a moderate negative correlation was found between education level and VSMT response time (for details see Table 38). Furthermore, there was a significant negative correlation between education and VSMT mistakes, as evidenced by Kendall's tau of -0.40 ($p = .045$) and Pearson's R of -0.47 ($p = .048$), indicating that participants with higher educational attainment made fewer mistakes in the Visual Sequential Memory Test. In contrast, education level showed no significant relationship with the ROCF-B scores.

For the bilingual reference group, the analysis of age in the Auditory Sequential Memory Test showed a strong negative correlation, with a Kendall's tau of -0.50 ($p=.005$) and a Pearson's R of -0.64 ($p=.002$). In the bilingual reference group, age demonstrated a strong positive correlation with Visual Sequential Memory Test response time, with Kendall's tau of 0.70 ($p< .001$) and Pearson's R of 0.72 ($p< .001$). A moderate positive correlation was found between age and the percentage of VSMT mistakes, with Kendall's tau of 0.49 ($p= .009$) and Pearson's R of 0.49 ($p= .029$). The analysis indicated a lack of significant correlation between age and ROCF-B scores, similarly to the monolingual reference group. The education level in the bilingual reference group was positively correlated with ASMT scores, demonstrated by a Kendall's tau of 0.58 ($p=.001$) and a Pearson's R of 0.59 ($p=.001$). Education level in the bilingual healthy participants showed a significant negative correlation with both Visual Sequential Memory Test response time and mistakes. The Kendall's tau for education and response time was -0.46 ($p= .010$), while Pearson's R was -0.46 ($p= .018$). Additionally, education negatively correlated with Visual Sequential Memory Test mistakes, with Kendall's tau of -0.60 ($p= .001$) and Pearson's R of -0.55 ($p= .002$), indicating that bilingual participants with higher education

levels made fewer mistakes. In the ROCF-B, education levels also did not demonstrate a significant relationship (refer to Table 38).

Table 38. Correlation between age and education level in visual and auditory working memory tests

Participants	Correlation	ASMT score	VSMT		ROCF-B score
			RT	mistakes pct.	
mHP age	Kendall's t	-0.08 p=.692	0.17 p=.349	0.27 p=.165	0.03 p=.909
	Pearson's R	-0.30 p=.220	0.36 p=.145	0.54 p=.019	-0.19 p=.456
mHP education	Kendall's t	0.18 p=.353	-0.32 p=.081	-0.40 p=.045	-0.04 p=.831
	Pearson's R	0.24 p=.342	-0.39 p=.105	-0.47 p=.048	-0.12 p=.621
bHP age	Kendall's t	-0.50 p=.005	0.70 p<.001	0.49 p=.009	-0.12 p=.522
	Pearson's R	-0.64 p=.002	0.72 p<.001	0.49 p=.029	-0.24 p=.329
bHP education	Kendall's t	0.58 p=.001	-0.46 p=.010	-0.60 p=.001	0.17 p=.377
	Pearson's R	0.59 p=.001	-0.46 p=.018	-0.55 p=.002	0.21 p=.411
mPWA +bPWA age	Kendall's t	-0.29 p=.108	0.34 p=.058	0.33 p=.072	-0.29 p=.115
	Pearson's R	-0.42 p=.073	0.37 p=.122	0.30 p=.222	-0.46 p=.054
mPWA+bPWA education	Kendall's t	0.22 p=.268	-0.62 p<.001	-0.49 p=.008	0.38 p=.047
	Pearson's R	0.36 p=.115	-0.55 p<.001	-0.44 p=.003	0.49 p=.009
mPWA age	Kendall's t	-0.11 p=.724	0.04 p=.914	0.02 p=.926	-0.20 p=.470
	Pearson's R	-0.32 p=.372	-0.09 p=.796	-0.14 p=.651	-0.38 p=.271
mPWA education	Kendall's t	-0.06 p=.875	-0.55 p=.059	-0.32 p=.278	0.15 p=.654
	Pearson's R	0.23 p=.584	-0.50 p=.026	-0.35 p=.155	0.42 p=.224
bPWA age	Kendall's t	-0.33 p=.333	0.71 p=.014	0.76 p=.010	-0.42 p=.212
	Pearson's R	-0.57 p=.148	0.80 p=.018	0.76 p=.010	-0.54 p=.163
bPWA education	Kendall's t	0.51 p=.112	-0.77 p=.010	-0.75 p=.014	0.73 p=.017
	Pearson's R	0.55 p=.080	-0.62 p=.008	-0.58 p=.006	0.61 p=.018

When considering both mono- and bilingual aphasics together, the correlation analysis indicated a negative correlation between age and Auditory Sequential Memory Test scores, without any statistical significance. A moderate positive correlation was found between age and Visual Sequential Memory Test response time and mistakes percentage.

In the ROCF-B test, the results showed a negative correlation with age. The analysis of education levels among the mono- and bilingual aphasia groups in the Auditory Sequential Memory Test resulted in a positive correlation (for details see Table 38). There was a strong negative correlation between education level and Visual Sequential Memory Test response time, with Kendall's tau of -0.62 ($p < .001$) and Pearson's R of -0.55 ($p < .001$). Additionally, education negatively correlated with VSMT mistakes, as shown by Kendall's tau of -0.49 ($p = .008$) and Pearson's R of -0.44 ($p = .003$). In the ROCF-B test, the Kendall's tau was 0.38 ($p = .047$), and the Pearson's R was 0.49 ($p = .009$), indicating a significant positive correlation between education level and ROCF-B scores.

In the monolingual aphasia group, the analysis revealed negative correlation between age and all WM tasks, though without reaching any statistical significance (refer to Table 38). In terms of education, the mPWA group showed negative correlations with RT and mistakes percentage in the Visual Sequential Memory Test. In contrast, the analysis indicated positive correlation between education and performance in the Rey Complex task. Again, without reaching any statistical significance. Whereas, in the bilingual aphasia group, the analysis revealed significant negative correlation between education and performance in the Visual Sequential Memory Test (RT: $t = -0.77$, $p = .010$; $r = -0.62$, $p = .008$ and mistakes pct: $t = -0.75$, $p = .014$; $r = -0.58$, $p = .006$). In the Rey Complex task, the analysis indicated significant positive correlation with education in the bPWA group ($t = 0.73$, $p = .017$; $r = 0.61$, $p = .018$). Moreover, the results revealed a positive correlation between education and performance in the ASMT, though with no statistical significance. When investigating the effect of age on performance in the VSMT, the results showed significant positive correlation in both RT and mistakes percentage in the bPWA group (RT: $t = 0.71$, $p = .014$; $r = 0.80$, $p = .018$ and mistakes pct: $t = 0.76$, $p = .010$; $r = 0.76$, $p = .010$). Whereas the results indicated negative correlations between age and performances in the ASMT and the Rey Complex task, though with no statistical significance (refer to Table 38).

4 DISCUSSION

The primary objective of this dissertation was to examine the potential of executive function impairments in participants with mono-and bilingual aphasia using linguistic and non-linguistic tests. By comparing the performance of monolingual and bilingual aphasics in both the linguistic and non-linguistic tests, as well as their performance relative to the reference groups, several key differences were investigated. In addition, the study sought to investigate potential bilingual advantage in aphasia. Furthermore, performance differences were investigated between fluent and non-fluent aphasia types, as well as the effects of age and education level on performance.

This study contributes to the growing body of literature on the cognitive performance of bilingual and monolingual individuals, particularly in the context of aphasia. The comparison of bilingual and monolingual individuals with aphasia in linguistic tests revealed some trends only. For instance, in the Boston Naming Test, bilingual participants were faster and reached higher number of correct answers. Similar results were observed in the Token Test, as bilingual aphasics performed slightly better than monolinguals. Overall, both aphasia groups performed similarly in linguistic tasks.

In contrast, as it was expected, the analysis revealed significant differences in linguistic tests when aphasics were compared with neurologically healthy individuals. Based on the language test results, it was observed that all participants with aphasia experienced challenges in information processing, which could impact their ability to recall and manipulate information. The findings of the Hungarian version of the Test for Reception of Grammar (TROG-H) provided significant insights into the comprehension abilities of individuals with aphasia. By comparing the monolingual aphasia group with the monolingual reference group significant differences in comprehension abilities were revealed across multiple blocks of the TROG -H test. The monolingual aphasia group produced notably lower scores in blocks G, H, J, K, M, N, P, R, S and T, indicating that specific grammatical structures may pose challenges for individuals with aphasia. This pattern of results is in line with previous research suggesting that individuals with aphasia often struggle with particular grammatical structures, which may be more complex or require higher levels of syntactic processing (Szöllösi et al., 2015). Similar results were found in the analysis of the group of bilingual aphasics compared to the bilingual

reference group, which revealed significant differences in comprehension abilities, particularly in blocks G and M.

Additionally, the findings from the Token Test provide valuable insights into the performance of individuals with aphasia in auditory comprehension at the sentence level. The analyses revealed consistent patterns of poorer performance in both the mono- and bilingual aphasia groups when compared to their respective healthy reference groups. These findings suggest that both monolingual and bilingual aphasics face significant challenges in language processing, as evidenced by their lower mean scores in the Token Test. The variability in performance observed within both groups of aphasics is noteworthy as it highlights the heterogeneous nature of aphasia. Some individuals from the aphasia groups achieved scores as high as 32 while others scored as low as 0, suggesting that factors such as the type and severity of aphasia as well as individual cognitive profiles may play a role in determining performance outcomes. The overall results of the Token and the TROG-H tests suggest that individuals with aphasia may experience difficulties with complex tasks, which could be related to deficits in executive functions. In other words, it was found that both mono- and bilingual participants with aphasia experienced more difficulty processing and comprehending longer sentences due to impairment in auditory working memory. This finding is consistent with previous research conducted by Basagni et al. (2022).

Furthermore, a special attention was paid to the Boston Naming Test to investigate its correlation with potential impairments in executive functions. It was assumed that deficits in inhibitory control and working memory would lead to longer response times and decreased accuracy. The results obtained from both the mono- and bilingual aphasia groups provided support for this hypothesis, as longer response times were found to be associated with higher number of mistakes. The performance of the group of monolingual aphasics revealed a significantly lower number of correct answers than that of the monolingual reference group. The stark contrast between these groups highlights the profound impact of aphasia on naming. The variability in scores within the group of monolingual aphasics, with some participants scoring as low as 6, indicates how wide the level of severity and cognitive capabilities are. The longer mean response time in the Boston Naming Test further illustrates the processing difficulties experienced by aphasics, reinforcing the notion that aphasia not only affects linguistic output but also

significantly impairs cognitive processing speed. Similar results were observed when examining the group of bilingual aphasics in relation to the bilingual reference group. The correlation between decreased naming ability and increased response times observed in both the group of monolingual aphasics and the bilingual one suggests that executive functions, such as inhibitory control and working memory, may play a crucial role in the performance of individuals with aphasia.

When investigating semantic and letter fluency impairments in aphasics compared to the reference groups, the analysis revealed significant disparities in performance across both semantic and letter fluency tasks. This aligns with the existing aphasia literature, which has shown that individuals with aphasia tend to have difficulties in lexical retrieval and production (Bose et al., 2017; Bose et al., 2022; Faroqi-Shah et al., 2018; Kiran et al., 2014; Patra et al., 2020). Furthermore, the reference groups consistently outperformed the aphasia groups across all intervals, with a statistically significant difference in scores. These findings underscore the profound impact of aphasia on language processing capabilities, as evidenced by the significantly lower mean scores in both fluency tasks for the aphasia groups. A closer examination of the performance of participants across the four 15-second intervals provided a valuable insight into the fluency patterns exhibited by each group. All groups exhibited the highest number of responses in the first interval. The decline in performance observed in the subsequent intervals were similar in percentage of answers in all groups. The lack of significant differences in error rates and repetitions between aphasics and the reference groups further highlights that the primary challenge for participants with aphasia lies in the quantity of correct responses rather than the quality, suggesting a more profound disruption in the fluency of language production. Furthermore, performance in the semantic and letter fluency tasks was also compared, revealing significant differences between the two tasks in both the aphasic and reference groups. All participants performed significantly better in the semantic fluency task. These findings support the assumption, that both aphasic and healthy participants perform better in the semantic fluency task in comparison with the letter fluency task due to greater recruitment of executive control. These findings are consistent with previous research conducted by Bose et al. (2022) and Patra et al. (2020). Additionally, a comparison was made between the Hungarian version and Croatian/Slovakian/ German versions of the Boston Naming test and the semantic fluency test. Both the bilingual aphasia and the bilingual reference group performed significantly better in the Hungarian version of the

Boston Naming Test. In case of the semantic fluency task, as it was expected the bilingual reference group performed significantly better in the Hungarian version. While the bilingual aphasia group performed better in the Hungarian version of the semantic fluency task, the analysis revealed no statistical significance, this finding is consistent with previous research (Kiran et al., 2014; Patra et al., 2020). Furthermore, the study also examined the relationship between performance in semantic fluency and naming tasks. It was expected that if a participant performed poorly or successfully in the semantic fluency, they might not perform similarly in naming. In the mono- and bilingual reference groups, most participants performed similarly in both tasks, however, others did not (mHP8, mHP18, bHP9, bHP11, bHP13, bHP17, bHP4) reinforcing the hypothesis of dissociation. In case of the mono- and bilingual aphasia groups, most participants performed similarly in both tasks, only two participants with aphasia (bPWA2, bPWA4, bPW7, mPWA6) showed different performance in naming and fluency.

The variability in individual scores within both aphasia groups in the languages tests indicates that while some individuals may retain a degree of auditory comprehension of grammatical structures and complex sentences, as well as naming and verbal fluency, many struggled significantly. Therefore, the study investigated performance differences in linguistic tests between fluent and non-fluent participants with aphasia. The comparative analysis of linguistic performance between the fluent and non-fluent aphasics revealed significant differences across multiple domains of language. Fluent aphasics, while impaired, produced and comprehended language better compared to their non-fluent counterparts indicating that non-fluent aphasics experience profound deficits across all linguistic measures (naming, verbal fluency, auditory comprehension of grammatical structures and complex sentences) which suggests a more severe manifestation of aphasia. The comparison between fluent and non-fluent aphasics revealed similar performance in terms of response time in the Boston Naming Test, while fluent aphasics reached significantly higher scores in naming than their non-fluent counterparts. The interaction between the severity of aphasia and executive function performance underscores the complexity of linguistic impairments in aphasia. The performance of fluent aphasics varied, whereas non-fluent aphasics displayed a more uniform pattern of deficits, indicating that the severity of aphasia may play a crucial role in determining the accessibility of executive functions. Moreover, the study also compared performance between fluent aphasics and the combined reference group, as

well as between the non-fluent aphasics and the combined reference group. Both aphasia groups performed significantly poorly in the linguistic tests, when compared to the combined reference group.

Beyond linguistic deficits, the dissertation also aimed to investigate executive function impairment in aphasia, with a specific focus on differences between bilingual and monolingual people diagnosed with aphasia by using tests for the visual and auditory working memory. The findings from the Visual Sequential Memory Test, the Rey Complex Figure Test and the Auditory Sequential Memory Test provided critical insights into the cognitive load and performance discrepancies experienced by these aphasia groups. Statistical analyses of results in the investigated monolingual and bilingual aphasia groups did not reveal any significant differences, neither in the visual and nor in the auditory working memory tests. Results of the Visual Sequential Memory Test confirmed significant performance variability both in the mono- and bilingual aphasia groups shown by the wide range of response times and error rates. The mean response time of the two aphasia groups showed trends only and not statistical significance, suggesting similarities in cognitive load when engaged in visual memory tasks. The variability of performance observed in the aphasia groups, including participants who demonstrated markedly higher response times and error rates, indicates that individual differences might play a crucial role in the cognitive performance of these patients. Both the mono- and bilingual aphasia groups demonstrated impairments in visual memory as shown by the Rey Complex Figure B (ROCF-B) test. Again, the bilingual aphasia group achieved lower mean scores than the monolingual aphasia group on trend and not significance level. Moreover, the Auditory Sequential Memory Test revealed a substantial level of impairment in verbal working memory both in the mono- and bilingual aphasia groups, with bilinguals scoring lower than monolinguals. Again, trend and no statistical significance. Overall, the absence of significant differences in non-linguistic assessments between monolingual and bilingual individuals with aphasia indicates no bilingual advantage in this domain, contrasting with some prior research (Penn et al., 2009; Dash et al., 2020). This discrepancy may stem from variations in task selection (Paap, 2023), however, the present study employed simpler non-linguistic tasks, in contrast to most studies in bilingual aphasia which heavily rely on linguistic assessments (Mooijman et al., 2022).

As expected, the aphasia and reference groups showed statistically significant differences both in the visual and auditory working memory tests. The findings on significant impairments in Visual Sequential Memory among individuals with aphasia are consistent with the existing literature highlighting the complexity of cognitive deficits associated with aphasia, particularly in memory tasks (Mooijman et al., 2022). However, there were several tasks, like for example the ROCF-B test, where the performance difference between of aphasics as compared to healthy participants showed trends only and not statistical significance. Therefore, it was further investigated in terms of aphasia severity. The results of the ROCF-B test revealed significant impairment in non-fluent participants with aphasia, whereas fluent aphasics showed trends only. The results from the Auditory Sequential Memory Test (ASMT) further emphasises the role of auditory working memory deficits in language performance experienced by individuals with aphasia. The significant differences in mean scores in the ASMT in the monolingual aphasia group in comparison with the monolingual reference groups highlight the impact of aphasia on cognitive functions, particularly in tasks requiring retention and manipulation of verbal information. These results are in agreement with available literature on aphasia, drawing attention to the importance of highlighting the main difficulties of aphasic patients in auditory memory tasks (Chosinki et al., 2020).

Furthermore, the results of this study provide a comprehensive insight into the cognitive performance of bilingual and monolingual individuals with a particular focus on cognitive flexibility impairment in aphasia. The findings of the Trail Making Test (TMT) as well as the Number and Letter Sudoku tasks revealed differences in response times and error rates across various cognitive tasks. The comparison between monolingual and bilingual individuals with aphasia in the Number and Letter Sudoku tasks revealed, that the bilingual participants with aphasia performed faster. Similarly to the working memory test results, this difference showed trends only as it did not reach statistical significance. The results from the Trail Making Test further illustrate the cognitive challenges faced by individuals with aphasia. While the bilingual aphasia group performed better in both parts of the TMT, the differences were not statistically significant. These statistically insignificant results highlight the need to be cautious when interpreting them, as variations between individuals and the influence of the severity of aphasia may strongly influence task performance.

When comparing the performance of monolingual and bilingual aphasics with their respective reference groups in the TMT and Sudoku tasks, the findings underscored the impact of aphasia on cognitive performance. Both the mono- and bilingual aphasia groups exhibited significantly longer response times and higher error rates compared to their neurologically healthy counterparts. This outcome is consistent with the literature, which indicates that individuals with aphasia face considerable challenges in cognitive tasks, reflecting the underlying language processing difficulties associated with the condition (Aglioti et al., 1996; Jaillard et al., 2009; Jokinen et al., 2015; Marien et al., 2017; Povroznik et al., 2018; Schumacher et al., 2019; Tsiakiri et al., 2024; Turunen, 2017). The statistical significance of the differences in response times and error rates between the aphasia groups and their reference groups highlights the cognitive deficits experienced by individuals with aphasia. The significant differences in response times and error rates during both parts of the TMT indicate that individuals with aphasia experience a significant impairment in cognitive flexibility.

Moreover, the study aimed to discern any significant disparities in performance between the Number and Letter Sudoku tasks. The results indicated that while the aphasia groups (both monolingual and bilingual) did not exhibit statistically significant differences in performance between the two tasks, the neurologically healthy reference groups demonstrated a marked difference. The analysis revealed a significant difference in response times, with the Letter Sudoku task taking considerably longer to complete than the Number Sudoku task. Additionally, the error rate analysis indicated that neurologically healthy participants made more mistakes in the Letter Sudoku task compared to the Number Sudoku task. These findings suggest that the additional cognitive load associated with the Letter Sudoku task, which involves linguistic processing, may pose greater challenges.

Similarly to the linguistic tests, the study compared performance differences between fluent and non-fluent aphasics in non-linguistic tests too. The results revealed a complex interplay between fluency and cognitive performance in non-linguistic tasks among individuals with aphasia. Both fluent and non-fluent aphasics demonstrated significant impairments in various cognitive domains compared to a neurologically healthy reference group. Notably, while fluent aphasics exhibited some deficits, non-fluent aphasics consistently performed more poorly across multiple non-linguistic assessments. For

instance, the analysis revealed no statistical significance between fluent aphasics and the reference group in terms of the Visual Sequential Memory Test and the Rey Complex task. In contrast, the non-fluent aphasia group performed significantly poorly in those tasks when compared to the combined reference group. Additionally, both the fluent and non-fluent aphasia groups performed significantly poorly in the Auditory Sequential Memory Test when compared to the combined healthy reference group. Furthermore, the comparison between fluent and non-fluent aphasics revealed significant differences between the two groups in the Visual Sequential Memory Test and in the Rey Complex task. In these tasks, the fluent aphasia group performed significantly better than their non-fluent counterparts, whereas in the Auditory Sequential Memory Test the analysis revealed trends only.

Furthermore, the significant differences in performance observed in Trail Making Tests and Sudoku tasks further underscore the cognitive challenges faced by non-fluent aphasics, particularly in terms of visual-spatial processing and executive functions. The findings from the Sudoku tasks revealed that there was a significant difference in mean response times between the fluent aphasic group and the reference group, suggesting that even fluent aphasics experience notable impairments in cognitive processing speed. However, the absence of significant differences in the percentage of mistakes made indicates that while response times are affected, the accuracy of task performance may remain relatively intact for the fluent aphasia group. Additionally, a comparison of the group of non-fluent aphasics with the reference group in terms of the mean RT and percentage of mistakes made did not yield any meaningful results due to an insufficient number of participants. In the Trail Making Test, both fluent and non-fluent aphasics performed poorly compared to the reference group. When fluent aphasics were compared to non-fluent aphasics in the Number Sudoku task, the analysis revealed trends only. In contrast, non-fluent aphasics performed significantly poorly in the Letter Sudoku tasks, though with similar processing speed. In Part A of the Trail Making Test, fluent and non-fluent aphasics performed similarly, however, fluent aphasics performed significantly better in Part B.

Additionally, the study investigated the effects of age and education level on performance in both linguistic and non-linguistic tests in the aphasia and reference groups. However, it is important to note that the results of the correlation between age

and education level must be treated with caution due to the small sample size and the significant differences found between age and education level in the bilingual reference group. For healthy participants, both monolingual and bilingual, education was consistently positively correlated with Boston Naming Test scores and negatively correlated with response times. Age, while showing some negative trends in naming performance, did not yield statistically significant correlations in the healthy participants. In participants with aphasia, the trends were similar, with education again showing a weak positive relationship with naming performance. Furthermore, age did not exhibit strong correlations in the aphasia groups either, although the observed trends suggest that older individuals may experience greater challenges in naming tasks in the bilingual aphasia group. The analysis of fluency tasks revealed significant age-related deterioration in semantic fluency for both the monolingual and bilingual reference groups. The strong negative correlations observed in these groups indicate that older adults may struggle to generate words within a semantic category as they age. The participants with mono- and bilingual aphasia did not yield significant correlations between age and fluency scores, possibly reflecting the complex interplay between language impairment and cognitive ageing in individuals with aphasia. However, the education level demonstrated a strong positive correlation with semantic fluency scores in the bilingual aphasia group.

The analysis of performance during Sudoku tasks revealed differing patterns across the various groups of participants. For the monolingual reference group, no significant correlations were found between age and performance. Conversely, the bilingual reference group exhibited significant positive correlations between age and performance in both the Letter and Number Sudoku tasks in terms of processing speed. In the groups of monolingual aphasics, the results mirrored those of the monolingual reference group with no significant correlations between age and performance. Whereas the analysis found significant positive correlation between age and performance in the Letter Sudoku task in terms of processing speed among bilingual individuals with aphasia. In the Letter Sudoku task, education level demonstrated significant negative correlation with response times among healthy bilingual and monolingual participants. Similar results were observed in both the Letter and Number Sudoku tasks in the aphasia groups, though with no statistical significance. The Trail Making Test results indicated significant positive correlations between age and response times for both the mono- and bilingual reference groups, suggesting that older adults may experience slower processing speeds when

completing this task. In the groups of aphasics, while age did not reveal significant correlations with performance in the Trail Making Test, education level demonstrated significant negative correlations with response times in Part B in the monolingual aphasia group.

Finally, the working memory tasks yielded mixed results regarding the influence of age and education level on performance. In the monolingual reference group, no significant correlations were found between age and working memory scores. In contrast, the bilingual reference group exhibited strong negative correlations in the Auditory Sequential Memory Test and strong positive correlations in the Visual Sequential Memory Test. Furthermore, the analysis revealed strong negative correlations between education and performance in the Visual Sequential Memory test in both the mono- and bilingual reference group. Similarly to the monolingual reference group, the monolingual aphasia group exhibited weak negative correlations between age and working memory tasks. In contrast, the bilingual aphasia group had a strong positive correlation between age and performance in the Visual Sequential Memory Test. In terms of education, the analysis revealed a strong negative correlation between education and performance in the Visual Sequential Memory Test and a strong positive correlation in the Rey Complex task among bilingual aphasics. Overall, the bilingual aphasia group performed similarly in non-linguistic tests in terms of the effect of age on performance, when compared to the monolingual aphasia group. Older participants tended to have reduced performance in both aphasia groups. Similar results were observed between healthy mono- and bilingual participants.

5 CONCLUSION

In conclusion, this dissertation offers valuable insights into the potential impairment of executive functions in individuals with mono- and bilingual aphasia. By employing a range of linguistic and non-linguistic tests, the study has highlighted several critical findings regarding the differences between monolingual and bilingual aphasics, the impact of fluency types, and the role of age and education level in cognitive performance. The results of this study put emphasis on the complex interplay between executive functions and language skills in individuals with mono- and bilingual aphasia, moreover, may contribute towards a deeper understanding of the effects of aphasia on language function and processing speed.

Based on the linguistic test results, the study revealed significant impairments in participants with aphasia in naming, verbal fluency as well as auditory comprehension of grammatical structures and complex sentences. The results of the linguistic tests supported the hypothesis that impairments in executive functions may contribute to longer response time and decreased accuracy.

Based on the non-linguistic test results, both bilingual and monolingual individuals with aphasia demonstrated impairments in the visual and auditory working memory as well as in cognitive flexibility. These results underscore the importance of considering individual differences in cognitive processing when assessing and treating individuals with aphasia. By adopting a complex approach that accounts for the specific challenges faced by bilingual individuals, clinicians can enhance therapeutic outcomes and support individuals in their recovery. Further research is needed to explore the intricacies of working memory in bilingual populations affected by aphasia, ultimately contributing to a more comprehensive understanding of cognitive functions in this context.

The comparison of fluent and non-fluent aphasics revealed that non-fluent aphasics demonstrated significant impairments in linguistic and non-linguistic tests. While fluent aphasics exhibited some deficits, non-fluent aphasics consistently performed more poorly across multiple assessments, suggesting that the cognitive impairments associated with non-fluent aphasia are particularly pronounced.

Finally, the results of this study may have important implications for clinical practice and the assessment of individuals with aphasia. The observed variability in performance between the bilingual and monolingual individuals with aphasia highlights the necessity for tailored assessment and intervention strategies that consider the unique linguistic and cognitive profiles of each individual. Clinicians should be aware of the potential variability within populations of aphasics, possibly necessitating a more nuanced approach when planning treatment. Especially in case of bilingual patients as assessment of both languages is often neglected. Furthermore, this dissertation includes several linguistic and cognitive assessments which would be beneficial for speech therapist to employ. It is highly recommended that speech therapist employ both linguistic and cognitive assessments to develop tailored therapy for post-stroke patients. Additionally, the regular implementation of these cognitive tasks in therapy is expected to enhance overall language skills as well as auditory comprehension, mirroring findings from other studies that demonstrate positive effects of executive function training on language skills (Bontemps et al., 2024; Choinski et al., 2023; Nikravesht et al., 2021; Zakariás et al., 2018). Incorporating tasks that assess inhibition, shifting and working memory into therapy may help facilitate language recovery and improve overall communication outcomes for both bilingual and monolingual individuals with aphasia in all phases of recovery.

LIMITATIONS OF THE STUDY AND FUTURE RESEARCH

While this study provides valuable insights into executive function impairments in bilingual and monolingual individuals with aphasia, the results, further assumptions and suggestions are not without limitations. One of the reasons is the relatively small sample size preventing generalization and broader use of the findings. Additionally, the lack of statistically significant differences between the mono-and bilingual aphasia groups reflects the need for further research with larger samples to explore the trends found more comprehensively. Future research should aim to investigate the underlying mechanisms that contribute towards the observed differences in cognitive processing speeds. Variables include language proficiency, age of acquisition and the nature of the language impairment. Future studies should consider longitudinal designs to assess changes in working memory performance over time, particularly in response to targeted interventions. Furthermore, research exploring the neural correlates of executive functions in bilingual individuals with aphasia may provide deeper insights into the cognitive processes involved. A proper design of behavioural tasks may be supported by a better understanding of the underlying mechanisms in individuals with aphasia tribute to developing more effective therapeutic approaches that cater to the unique and special needs of bilingual individuals with aphasia.

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APPENDICES

Appendix 1: Consent form

TÁJÉKOZTATÓ

Rehabilitációs Intézmény:

Vizsgálatvezető neve:

A tájékoztatást végző személy neve és beosztása

Jelen tájékoztató célja a kutatás tárgyának bemutatása. **Kérjük, mielőtt döntene a részvételről figyelmesen olvassa el a részletes tájékoztatót.**

Jelen kutatás célja a munkamemória megismerése kétnyelvű és egynyelvű post-stroke afáziás személyek esetében. A kutatásban szereplő feladatokat játékos jellegű memória tesztekkel, illetve számítógépes szoftver segítségével végezzük. A tesztek eredményei, nem diagnosztika jellegűek. A tesztfelvételek a logopédiai foglalkozások keretében zajlanak, az Ön igényeihez igazodva. A vizsgálatok **anonim** módon történnek, minden résztvevő egy kód elnevezést kap, melyből nem következtethető ki a résztvevő személyazonossága és személyes adatai. Személyes adataihoz (nem, kor, iskolai végzettség, CT eredménye) kizárólag a kutatást vezető személy és a kutatást vezető témavezetője férnek hozzá. A vizsgálatban **nem kötelező** a részvétel, ez kizárólag önkéntes alapon zajlik. A tesztfelvételeket bármikor megszakíthatja. Döntése semmilyen módon nem befolyásolja az adott intézményben a logopédiai terápiát és/vagy egyéb ellátást.

Amennyiben megtisztel bennünket részvételével, kérjük írja alá a Tájékoztatót és az Etikai Nyilatkozatot, melyeket Ön is készhez kap egy-egy példányban.

....., 20.....

.....
kutatásban résztvevő aláírása

.....
tájékoztató személy aláírása

.....
kutatásvezető aláírása

Etikai nyilatkozat

Nevem: _____
(nyomtatott betűkkel)

Lakcím: _____

Hozzájárulok, hogy a “The impact of working memory on the recovery from aphasia” című doktori disszertációt (Pannon Egyetem, Többynnyelvűségi Nyelvtudományi Doktori Iskola) kutatásához a felvételsorozatban (magnetofon, videó, számítógép stb.) rögzített hangzó anyagomat nyelvészeti elemzésekre felhasználják. A mellékelt betegtájékoztatót elolvastam és megértettem, illetve készhez kaptam. Aláírásommal beleegyezem a kutatásban való részvételhez, melyet bármikor visszavonhatok. Részvételem teljes mértékben önkéntes és befolyástól mentes. Tudomásul veszem, hogy a kutatásban a nevem nem szerepel, azonosíthatóságomat nem teszik lehetővé; a felvételekhez csak az arra jogosult kutató férhet hozzá. Aláírásommal igazolom, hogy az egészségügyi dokumentumaimat önként rendelkezésre bocsájtom a kutatás céljának elérése érdekében.

.....
(aláírás)

Hozzájárulok, hogy a felvett (rögzített) hangzó anyagomat részleteiben, a névtelenség biztosítása mellett a kutatási eredmények közlésekor (tudományos előadás, publikáció, ill. oktatási segédanyag részeként) felhasználják.

IGEN – NEM

.....
(aláírás)

Dátum:

.....
tájékoztató személy aláírása

.....
kutatásvezető aláírása

Appendix 2: Questionary about language experience and proficiency from the Bilingual Aphasia Test

APHASIA VIZSGÁLAT MAGYARUL KÉT-, VAGY TÖBBNYELVŰEK SZÁMÁRA

A KÉTNyelvűség EsetTörténete

Az alábbi kérdéseket a megadott formában kell feltenni a vizsgált személynek. Ha a beteg nem képes megadni a kért információkat, akkor valaki más (például egy családtag) is szolgálhat felvilágosítással.

Alany:

Dátum:

Legmagasabb iskolai végzettség:

L1:

L2:

AoA L1:

AoA L2:

1. Mikor született?
2. Hol született?
3. Gyermekkorában milyen nyelvet beszélt leginkább otthon?
4. Beszélt gyermekkorában egyéb más nyelvet is otthon?
5. Milyen más nyelvet (nyelveket) beszélt még otthon gyermekkorában?
6. Mi volt az édesapja anyanyelve?
7. Beszélt az édesapja más nyelvet is ezenkívül?
8. Milyen nyelven beszélt leginkább önhöz az édesapja?
9. Beszélt az édesapja más nyelven is ezenkívül otthon?
10. Mi volt az édesanyja anyanyelve?
11. Beszélt az édesanyja más nyelvet is ezenkívül?
12. Milyen nyelven beszélt leginkább önhöz az édesanyja?

13. Beszélt ezenkívül más nyelven is otthon az édesanyja?
14. Milyen nyelven beszélt leginkább Ön otthon a barátaival/ rokonokkal?
15. Hány évig járt iskolába?
16. Amikor elkezdett iskolába járni, milyen nyelvű iskolába járt?
17. Ebben az időben folyt más nyelven is a tanítás?
18. Milyen más nyelven folyt még a tanítás?
19. Milyen nyelvet beszélt a tanulók többsége ebben az iskolában?
20. Járt ezután olyan iskolába, ahol más nyelven folyt a tanítás?
21. Miután befejezte a tanulmányait, mi volt a foglalkozása?
22. A betegsége előtt milyen nyelveken tudott beszélni?
23. A betegsége előtt milyen gyakran és hol használta a magyar nyelvet?
24. A betegsége előtt milyen gyakran és hol használta a másik nyelvet?

Appendix 3: Individual demographic data of the monolingual healthy participants

Demographic data of the healthy monolingual participants

Participants	Age	Sex	Education in years
mHP1	70	female	14
mHP2	71	male	11
mHP3	72	female	16
mHP4	75	female	8
mHP5	66	male	11
mHP6	64	female	11
mHP7	63	female	15
mHP8	63	male	11
mHP9	65	female	12
mHP10	45	female	16.5
mHP11	85	male	8
mHP12	64	male	14
mHP13	48	female	16
mHP14	58	male	15.5
mHP15	75	male	14
mHP16	85	female	8
mHP17	83	female	16
mHP18	66	male	22
Mean	67.67		13.28
SD	10.99		3.63
min -max	45-85		8-22

Appendix 4: Individual demographic data of the healthy bilingual participants

Demographic data of the healthy bilingual participants							
Participants	Age	Sex	Education in years	L1	AoA L1	L2	AoA L2
bHP1	62	female	12	CRO	from birth	HU	3
bHP2	63	female	11	CRO	from birth	HU	3
bHP3	66	female	16	CRO	from birth	HU	3
bHP4	66	female	14	CRO	from birth	HU	6
bHP5	67	female	8	CRO	from birth	HU	6
bHP6	67	female	16	CRO	from birth	HU	6
bHP7	71	female	8	CRO	from birth	HU	3
bHP8	72	male	8	CRO	from birth	HU	3
bHP9	72	male	11	CRO	from birth	HU	6
bHP10	76	female	8	CRO	from birth	HU	6
bHP11	77	female	11	CRO	from birth	HU	6
bHP12	69	male	11	HU	from birth	DE	30
bHP13	50	female	18	HU	from birth	SK	from birth
bHP14	80	female	8	CRO	from birth	HU	6
bHP15	60	female	30	HU	from birth	CRO	from birth
bHP16	46	female	18	HU	from birth	CRO	from birth
bHP17	47	male	17	CRO	from birth	HU	3
bHP18	59	male	12	HU	from birth	CRO	23
Mean	65		13.17				6.28
SD	9.80		5.51				7.77
min-max	46-80		8-30				0-30

Appendix 5: Test materials- The Boston Naming Test (Hungarian version)

BOSTON NAMING TEST

Név.....

Dátum.....

Hely.....

Életkor:.....

	kép	helyes	SzC.	laten.	FC.
1.	ágy (egy bútor)				
2.	fa (erdőben nő)				
3.	ceruza (írásra használjuk)				
4.	ház (épületfajta)				
5.	síp (jeleznek vele)				
6.	olló (vágnak vele)				
7.	fésű (a hajunkhoz használjuk)				
8.	virág (kertben nő)				
9.	fűrész (asztalos használja)				
10.	fogkefe (a szánkhoz használjuk)				
11.	helikopter (légi utazásra használjuk)				
12.	seprű (takarításhoz használjuk)				
13.	kagyló (tengeri állat)				
14.	gomba (ennivaló)				
15.	függöny (ablakra teszik)				
16.	tolószék (kórházban található)				
17.	teve (állat)				
18.	maszk (ruházat része)				
19.	perec (ennivaló)				
20.	pad (ülni lehet rajta)				

21.	ütő (sportoláshoz használják)				
22.	csiga (állat)				
23.	tűzhányó (egy hegyfajta)				
24.	tengericsikó (tengeri állat)				
25.	hinta (gyerekek játszanak vele)				
26.	kajak (vízben használják)				
27.	földgömb (egy térképajta)				
28.	koszorú (temetőben van ilyen)				
29.	hód (állatfajta)				
30.	szájharmonika (hangszer)				
31.	orrszarvú (állatfajta)				
32.	makk (fáról esik le)				
33.	bástya (a vár része)				
34.	gólyaláb (magasabbá tesz)				
35.	dominó (játék)				
36.	kaktusz (növény)				
37.	mozgólépcső (felmegyünk rajta)				
38.	hárfa (hangszer)				
39.	függőágy (fekszünk rajta)				
40.	kopogtató (az ajtón van)				
41.	pelikán (egy madár)				
42.	sztetoszkóp (az orvosok használják)				
43.	piramis (Egyiptomban található)				

44.	száj kosár(kutyákra teszik)				
45.	sárkány (mesebeli állat)				
46.	tölcsér (ezen keresztül öntenek)				
47.	harmonika (hangszer)				
48.	dézsza (mosnak benne)				
49.	ananász (trópusi gyümölcs)				
50.	körző (rajzolniak vele)				
51.	retesz (az ajtón van)				
52.	állvány (fényképezők használják)				
53.	jogar (a kormányzás jelképe)				
54.	cukorfogó (evőeszközfajta)				
55.	szfinx (Egyiptomban található)				
56.	járom (földműveléskor állatokra teszik)				
57.	lugas (kertben található)				
58.	paletta (festők használják)				
59.	szögmérő (geometriában használjuk)				
60.	akvárium (halakat tartunk benne)				

Appendix 6: Test materials- Token Test in Hungarian
Token teszt rövidített változat

Név:..... Dátum:.....

I. Rész: Mind a 20 figura látható.

- 1.Érintsen meg egy kört!
- 2.Érintsen meg egy négyzetet!
3. Érintsen meg egy sárga figurát!
4. Érintsen meg egy piros figurát!
5. Érintsen meg egy fekete figurát!
6. Érintsen meg egy zöld figurát!
7. Érintsen meg egy fehér figurát!

II. Rész: Csak a nagy figurák láthatók.

- 8.Érintse meg a sárga négyzetet!
- 9.Érintse meg a fekete kört!
- 10.Érintse meg a zöld kört!
- 11.Érintse meg a fehér négyzetet!

III. Rész: Mind a 20 figura látható

- 12.Érintse meg a kis fehér kört!
- 13.Érintse meg a nagy sárga négyzetet!
- 14.Érintse meg a nagy zöld négyzetet!
- 15.Érintse meg a kis fekete kört!

IV. Rész: csak a nagy figurák láthatók.

- 16.Érintse meg a piros kört és a zöld négyzetet!
- 17.Érintse meg a sárga négyzetet és a fekete négyzetet!
- 18.Érintse meg a fehér négyzetet és a zöld kört!
- 19.Érintse meg a fehér kört és a piros kört!

V. Rész: Mind a 20 figura látható.

- 20.Érintse meg a nagy fehér kört és a kis zöld négyzetet!
- 21.Érintse meg a kis fekete kört és a nagy sárga négyzetet!
- 22.Érintse meg a nagy zöld négyzetet és a nagy piros négyzetet!
- 23.Érintse meg a nagy fehér négyzetet és a kis zöld kört!

VI. Rész: Csak a nagy figurák láthatók.

- 24.Tegye a piros kört a zöld négyzetre!
- 25.Érintse meg a fekete kört a piros négyzettel!
- 26.Érintse meg a fekete kört és a piros négyzetet!
- 27.Érintse meg a fekete kört vagy a piros négyzetet!
- 28.Vegye el a zöld négyzetet a sárga négyzet mellől!
- 29.Ha van itt egy kék kör, érintse meg vele a piros négyzetet!
- 30.Tegye a zöld négyzetet a piros kör mellé!
- 31.Érintse meg lassan a négyzeteket és gyorsan a köröket!
- 32.Tegye a piros kört a sárga négyzet és a zöld négyzet közé!
- 33.Érintse meg az összes kört, kivéve a zöld kört!
- 34.Érintse meg a piros kört, ne a fehér négyzetet!
- 35.A fehér négyzet helyett, érintse meg a sárga kört!
36. A fekete kör érintése után, érintse meg a sárga kört!