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Investigating performance variations in verbal fluency and executive functions in fluent and non-fluent bilingual aphasia

Summary

The existing literature on bilingual aphasia is limited, especially in investigating verbal semantic and letter fluency. The present study, in which fluency impairment variations of fluent and non-fluent bilingual people with aphasia (bPWA) are studied, is part of a larger-scale research. The study aimed to investigate performance variations in executive functions and verbal fluency among fluent and non-fluent bPWA compared to healthy participants. A total of 26 participants were recruited, including 6 fluent and 2 non-fluent bPWA, as well as 18 bilingual healthy participants (HB). The results indicated significant letter fluency and switching impairment in both aphasia groups, with non-fluent bPWA exhibiting more pronounced deficits. The findings contribute to the understanding of verbal fluency impairments in fluent and non-fluent bPWA and highlight the need for tailored therapeutic interventions and further exploration of cognitive and lexical deficits in bilingual aphasia.

Keywords: bilingual aphasia, semantic and letter fluency, executive functions, multiple case study

1. INTRODUCTION

It is now widely recognised that more than half of the global population is bilingual (Ardila & Ramos, 2007; Grosjean & Li, 2013), which has resulted in a marked rise in the incidence of bilingual aphasia (Ansaldo & Saidi, 2014; Gitterman et al., 2012). 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 (Gitterman et al., 2012) and it can be classified into two types of impairments: parallel and selective (Fabbro, 2001). Parallel impairment occurs when both languages of a bilingual person are affected to a similar extent. Selective impairment, on the other hand, refers to a situation where one language is more affected than the other (Gitterman et al., 2012). In the case of aphasia subtypes, a broadly accepted distinction is made between fluent and non-fluent categories (Chapey, 2008). 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 often incoherent and may contain irrelevant words, especially in severe cases (Hedge, 2024). 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; Hedge, 2024).

Verbal fluency tasks are frequently used to investigate the correlation between executive and language function in healthy adults (Hughes & Bryan, 2002; Patra et al., 2019) and clinical populations (Bittner & Crowe, 2007; Carpenter et al., 2020; Faroqi-Shah et al., 2018; Henry et al., 2004; Wauters et al., 2020). Executive functions are a set of top-down mental processes that are essential for tasks that require concentration and attention. These processes are particularly important when going on procedural automatism or relying on instinct or intuition would be insufficient or impossible (Diamond, 2013). The influential model proposed by Miyake and colleagues (2000) consists of three distinct components of executive functions, such as updating, inhibition and shifting. Miyake and colleagues argued that these components represent core processes underlying executive functions and can be measured separately (Friedman & Miyake, 2017; Friedman et al., 2008; Miyake & Friedman, 2012; Miyake et al., 2000). Verbal fluency tests usually include semantic and letter fluency tasks, where participants are requested to produce as many different words as possible within a fixed period of time, usually under one minute (Bose et al., 2022). In terms of the letter fluency task, 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. 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, 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, 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 (Friese 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, 2020; Shao et al., 2014; Thiele et al., 2016) 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 1sr-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 1 st-RT).

1.1 The present study

The aforementioned studies have significantly advanced our understanding of the relationship between executive functions and verbal fluency performance in bilingual individuals with aphasia. However, these studies primarily examined bilingual aphasia at the group level, including participants with only non-fluent aphasia or those exhibiting different fluency patterns with similar impairment levels. While they conducted individual-level analyses, they neglected to focus on performance differences across fluent and non-fluent aphasia types. Understanding the nuances between fluent and non-fluent aphasia subtypes is essential for developing tailored therapeutic interventions and enhancing our comprehension of the cognitive-linguistic interface in bilingual aphasia. Therefore, the present study aimed to investigate performance variations in executive functions, verbal semantic and letter fluency among fluent and non-fluent bilingual individuals with aphasia, in comparison to healthy bilingual participants.

Verbal fluency performance is typically assessed by the total number of acceptable words generated during the allotted time, as well as the temporal parameters, such as the number of words produced in shorter time segments within the total duration. The aim was to investigate the degree of word retrieval deficits experienced by individuals diagnosed with fluent and non-fluent aphasia. It was anticipated that both bPWA groups would demonstrate lower overall accuracy in semantic and letter fluency tasks relative to the healthy bilingual participants due to the impact of aphasia on word retrieval. Although the degree of this difference was expected to vary between the two aphasia groups. Additionally, both the aphasic and healthy groups were expected to demonstrate poorer performance in the letter fluency task, as it requires greater engagement of executive control processes (Bose et al., 2017, 2022; Carpenter et al., 2020; Patra et al., 2020). Regarding cross-linguistic comparison in the semantic fluency task, it was expected that both aphasia groups would demonstrate similar performance, without significant cross-linguistic differences, in contrast to healthy bilinguals (Kiran et al., 2014; Patra et al., 2020).

The study also examined how the two aphasia groups differed from the healthy bilingual participants in the distribution of responses across the four-time intervals. It was hypothesized that the distribution of correct responses across the four intervals would significantly differ between the two aphasia groups and the healthy bilingual participant, although the degree of this difference was expected to vary between the two aphasia groups. Furthermore, it was investigated whether errors, such as repetitions and responses outside the target category, were more common in the aphasia groups.

Finally, the Trail Making Test was used to examine possible impairments in executive functions. The study hypothesized that both fluent and non-fluent bilingual individuals with aphasia would experience difficulties in the Trail Making Test, particularly in Part B. However, the degree of the difference was expected to vary between the two aphasia groups. Even if the fluent bPWA group exhibited relatively better performance compared to the non-fluent participants, it was anticipated that the fluent bPWA group would still show a greater TMT difference score compared to healthy bilingual individuals, indicating potential deficits in switching abilities.

2. METHODS

2.1 Participants

All participants with bilingual aphasia had suffered a cerebrovascular accident. Clinical criteria for aphasic participants included: (1) signs of aphasia as indicated by their performance during the Western Aphasia Battery (WAB) in both languages (Kertesz, 1982), (2) at least 6 months post-onset of their stroke, (3) premorbid right-handedness. The bilingual aphasia group included 8 participants, with demographic details presented in Table 1. Participants' ages ranged from 44 to 81 years, with a mean age of 63.5 years (SD= 13.02). This group included 3 males and 5 females, educational background measured in years from 11 to 20 years (M= 13.38 years, SD= 3.20). The participants were classified into different educational levels: three participants with secondary education (bPWA1, bPWA3, bPWA7), three with vocational education (bPWA4, bPWA6, bPWA8) and two with higher education (bPWA2, bPWA5). The post-onset days varied from 184 to 8978 days, with a mean of 2641.13 days (SD= 3835.87). Six participants were classified as fluent, and two individuals were classified as non-fluent based on the WAB performances and evaluations of (former) speech-language pathologists. Regarding aphasia types, five participants were classified as anomic (bPWA1, bPWA2, bPWA3, bPWA4, bPWA5), one as conduction (bPWA7) and two as global (bPWA6, bPWA8) based on evaluation of the speech-language pathologists who participated in the assessments. The participants' first language (L1) was either Croatian (CRO) or Hungarian (HU), while their second language (L2) (Hungarian, Slovakian, German) was acquired at varying ages (see Table 1 for details). All participants were interviewed about their language background using the Hungarian version of the Bilingual Aphasia Test (Paradis, 1989; adapted to Hungarian by Lábas-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. Specifically, participants bPWA1, bPWA2 and bPWA3 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, bPWA6, 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 bPWA6 and bPWA8 and Slovakian for bPWA5 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 bPWA4, bPWA5, bPWA6, bPWA7 and bPWA8 in both languages. Parallel impairment was observed in all cases of aphasic participants, as determined by the evaluation of the speech-language pathologists and the WAB results. The Aphasia Quotient (AQ) of the WAB is presented in Table 1 for both languages.

Table 1. Aphasic participant details

Participants	Age	Sex	Education in years	Education level	Post on set days	Speech	Lesion site	Aphasia type	Aphasia severity (parallel)	WAB AQ L1	WAB AQ L2	L1	AoA L1	L2	AoA L2
bPWA1	73	female	12	secondary	8580	fluent	left	anomic	mild	92.2	95.7	CRO	from birth	HU	6
bPWA2	72	female	16	higher education	603	fluent	left	anomic	mild	79.9	83.8	CRO	from birth	HU	6
bPWA3	57	male	12	secondary	8978	fluent	left	anomic	mild	78.6	90.6	CRO	from birth	HU	3
bPWA4	60	male	11	vocational	369	fluent	left	anomic	mild	91.2	82	HU	from birth	DE	30
bPWA5	49	female	20	medical school	225	fluent	left	anomic	mild	95	88.4	HU	from birth	SK	3
bPWA6	72	male	11	vocational	201	non-fluent	left	global	severe	14.9	15.5	HU	from birth	SK	6
bPWA7	44	female	14	secondary	1989	fluent	left	conduction	moderate	53	50	HU	from birth	SK	3
bPWA8	81	female	11	vocational	184	non-fluent	left	global	severe	9.2	5	HU	from birth	SK	6
Mean	63.5		13.38		2641.13					64.25	63.88				7.88
SD	13.02		3.20		3835.87					34.84	35.96				9.06
min-max	44-81		11-20		184-8978					9.2-95	5-95.7				3-30

The healthy bilingual group consisted of 18 participants, whose demographic characteristics are presented in Table 2. Participants' ages ranged from 46 to 80 years, with a mean age of 65 years (SD= 9.80). The group involved 13 females and 5 males and had educational attainment ranging from 8 to 30 years (M= 13.17 years, SD= 5.51). Similarly to the bilingual aphasia group, the participants had their first language (L1) as Croatian (CRO) or Hungarian (HU) and had acquired their second language (L2), Hungarian or Croatian or Slovakian (SK) or German (DE), at varying ages. This group served as a reference for the bilingual aphasia group. All participants (bPWA and HB) provided informed consent, and the confidentiality of data was maintained by assigning unique identification number to each participant.

Table 2. Neurologically healthy bilingual participant details

Participants	Age	Sex	Education in years	Education level	L1	AoA L1	L2	AoA L2
HB1	62	female	12	secondary	CRO	from birth	HU	3
HB2	63	female	11	vocational	CRO	from birth	HU	3
HB3	66	female	16	higher education	CRO	from birth	HU	3
HB4	66	female	14	vocational	CRO	from birth	HU	6
HB5	67	female	8	elementary	CRO	from birth	HU	6
HB6	67	female	16	higher education	CRO	from birth	HU	6
HB7	71	female	8	elementary	CRO	from birth	HU	3
HB8	72	male	8	elementary	CRO	from birth	HU	3
HB9	72	male	11	vocational	CRO	from birth	HU	6
HB10	76	female	8	elementary	CRO	from birth	HU	6
HB11	77	female	11	vocational	CRO	from birth	HU	6
HB12	69	male	11	vocational	HU	from birth	DE	30
HB13	50	female	18	higher education	HU	from birth	SK	from birth
HB14	80	female	8	elementary	CRO	from birth	HU	6
HB15	60	female	30	doctorate	HU	from birth	CRO	from birth
HB16	46	female	18	higher education	HU	from birth	CRO	from birth
HB17	47	male	17	higher education	CRO	from birth	HU	3
HB18	59	male	12	secondary	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

2.2 Assessment tools

The letter and semantic fluency tasks were administered from the Hungarian version of the Addenbrooke's Cognitive Examination (Dudás et al., 2002). In the semantic fluency task, the participants were required to name as many animals as they could in one minute. In the letter fluency task, the participants had to name as many words as they could with the letter 'M', except names, cities and countries in one minute. Potential impairments in inhibition, working memory and cognitive flexibility were investigated in people with aphasia. The maximum available score in the fluency tasks was 7 in both tasks. In the case of the semantic fluency task, if the participant generated more than 21 words, they received a score of 7. A score of 6 was given for word count between 17 and 21, while a score of 5 was assigned for generating 14 and 16 words. For further details, please refer to Table 3. In the letter fluency task, participants who generated a word count exceeding 17, they received a score of 7. Participants who generated between 14 and 17 words earned a score of 6. For further details of the scoring system of the letter fluency task, please refer to Table 3. The distribution of responses across 15-second intervals was also compared between both aphasic and healthy participants (only in the Hungarian version). Additionally, it was also investigated whether errors such as out-of-category responses and repetitions were more common in the aphasic groups. The semantic fluency task was assessed in both languages (CRO/SK/DE from the WAB test), while letter fluency was assessed in Hungarian.

Table 3. The scoring system of the letter and semantic fluency tests

Letter fluency	Semantic fluency	Score
> 17	> 21	7
14-17	17-21	6
11-13	14-16	5
8-10	11-13	4
6-7	9-10	3
4-5	7-8	2
1-3	1-6	1
0	0	0

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 in the TMT is sensitive to the frontal lobe, particularly to the lateral frontal lobe (Egner, 2017). It consists of two parts. In part A, the participants had to draw a line (on paper using pen/pencil) connecting consecutive numbers (from 1 to 25), while in part B, they had to join numbers and letters together in an alternating progressive sequence (McMorris, 2016). In both parts, response times were recorded in seconds, along with the number of errors made in each part. In the case of non-fluent forms 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. Although participants unable to complete Part B are often marked as taking 301 seconds in Trail Making Test interpretations, the present study included participants in the fluent aphasia group who successfully performed the task in over 301 seconds. Consequently, for non-fluent participants, the number of mistakes was analysed instead of assigning the 301-second mark. Additionally, for individuals with fluent bilingual aphasia, it was possible to calculate the Trail Making Test difference and ratio scores. The TMT difference (TMTB-TMTA) score has been proposed as the optimal measure of task switching ability (Sánchez-Cubillo et al., 2009), while the TMT ratio (TMT B/TMT A) is suggested to mitigate the influence of perceptual speed to some extent (Lamberty et al., 1994; Salthouse, 2011). TMT was used to measure visual attention, working memory and cognitive flexibility. While the TMT is frequently employed as a non-linguistic assessment, it is important to recognize that its reliance on letter sequencing necessities linguistic competence. Consequently, when interpreting TMT results, the potential influence of aphasia on linguistic abilities should be considered.

2.3 Procedures

Participants with bilingual aphasia were recruited from a variety of sources. The recruitment was conducted via three principal channels: (a) institutional, (b) private speech and language therapists, (c) individual. Aphasia subtypes in both languages were assessed by highly experienced speech-language pathologists.

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, was 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 test, while the Croatian test was carried out by the bilingual psychologist. 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 gave written authorisation to 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 a Hungarian-Slovakian private speech therapist (bPWA6, bPWA7, bPWA8). The speech-language pathologist helped in the process of identifying individuals who were actively seeking therapy and met the eligibility requirements of the study. Written informed consent was obtained from both the therapists and participants prior to collecting data. The speech-language pathologist conducted both the Hungarian and Slovakian assessments in the presence of the author of this study.

c) Individual recruitment: Participant bPWA1 and bPWA3 were recruited on an individual basis, who had completed a course of formal speech therapy and was no longer receiving regular treatment. The individuals were approached directly, through support groups for people with aphasia with the help of a highly experienced speech-therapist who was willing to help the assessments voluntarily. Data for these individuals was collected in their homes to ensure a comfortable and familiar environment, thereby facilitating a more effective assessment. The assessments were conducted in the presence of, a speech -language pathologist, a Croatian Hungarian interpreter and the author of this study. All participants provided written informed consent.

The assessments were performed in several sessions and 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 their participation at any time. The WAB tests were administered in both languages and were administered on two different occasions. All sessions were recorded with digital voice recorder.

2.4 Data analysis

In the present study for statistical analysis, the Kolmogorov-Smirnov (KS) test, a non-parametric and distribution-free test that imposes no assumptions regarding the underlying data distribution, was used. 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 employed the SciPy library's implementation (Virtanen et al., 2020), specifically with the kstest function. The KS test was used to investigate performance differences in verbal fluency and the TMT between fluent bPWA and HB, as well as between non-fluent bPWA and HB groups.

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. In the present study, the Wilcoxon signed-rank test was employed to analyse performance differences between semantic and letter fluency tasks across all groups, as well as to compare differences in semantic fluency task performance between the languages within each group.

3. RESULTS

The findings presented in this study are based on the test results of the fluent and non-fluent bilingual aphasics compared with the bilingual participants' performance in the reference group. The individual scores as well as the mean and standard derivations (SD) for the verbal fluency tests and the Trail Making Test along with the result of the statistical analysis are presented in Appendix A-D. The findings regarding the group differences in verbal fluency are presented first, followed by the detailed results of the Trail Making Test, which was used to examine potential impairments in switching ability.

3.1 Group differences in verbal letter and semantic fluency

In the Hungarian versions of the verbal fluency tasks, differences between fluent bPWA and healthy bilingual participants were found in terms of the scores of total number of correct answers in the letter fluency task (refer to Figure 1) (fluent bPWA: M= 2.5, SD= 1.22; HB: M= 5, SD= 1.50), while the semantic fluency task did not reveal any group differences in the total number of correct answers (fluent bPWA: M= 4, SD= 2.53; HB: M= 6.39, SD= 0.98).

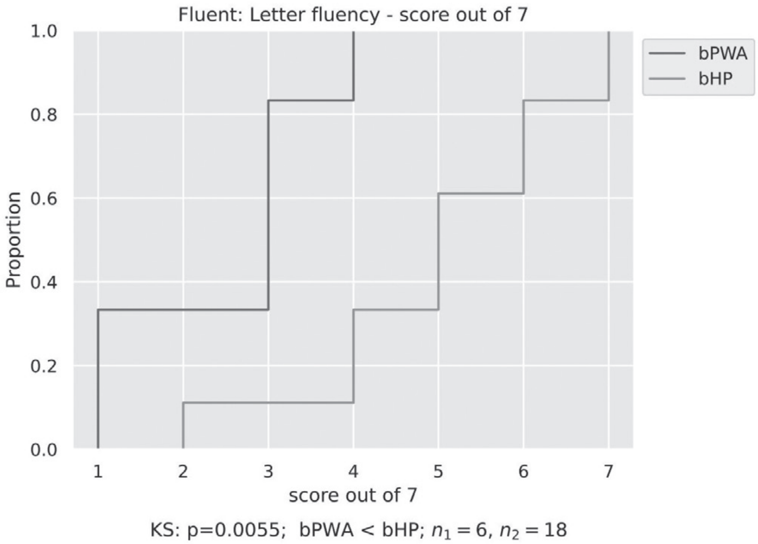

Figure 1. Comparison of the fluency scores in the Hungarian version of the letter fluency task between fluent bilingual aphasics and healthy bilingual participants

Further analysis of answer distribution in the semantic fluency task, across four 15 second intervals, indicated that while overall performance was similar, the distribution of answers during varied between fluent bPWA and HB in the first and second intervals, but not in the subsequent intervals. In the letter fluency task, fluent bPWA demonstrated significantly lower performance compared to HB across all time intervals. The non-fluent participants performed both fluency tasks poorly and the comparison between non-fluent bPWA and HB revealed significant differences in both fluency tasks, as well as in all the four intervals for both semantic and letter fluency tasks. The analysis of repetitions and out-of-category responses did not reveal any significant differences in any group comparison for the semantic and letter fluency tasks, suggesting that while both aphasias groups struggled with overall fluency, their patterns of repetition and category errors were not statistically different from those of healthy bilinguals.

Furthermore, the comparison between semantic and letter fluency tasks within both bPWA groups and the HB group revealed no significant differences within the fluent and non-fluent aphasia groups. However, the HB group exhibited a significant difference, with better performance in the semantic fluency task compared to the letter fluency task (see Figure 2).

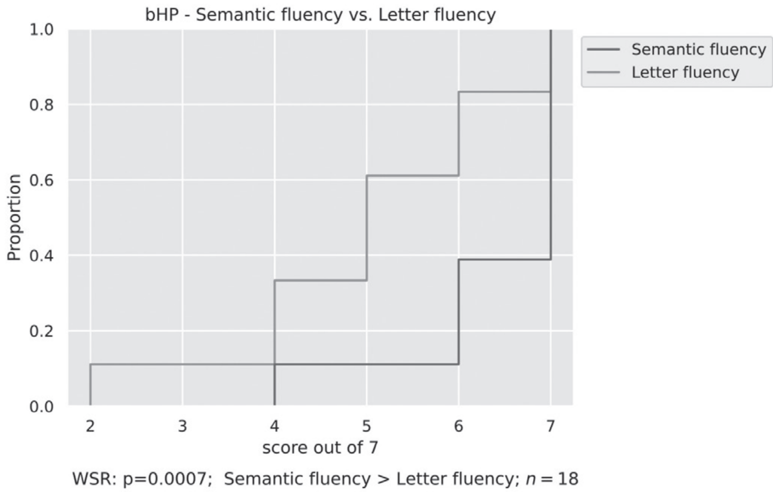

Figure 2. Comparison of semantic and letter fluency tasks in the healthy bilingual reference group

Finally, in the Croatian, Slovakian and German versions of the semantic fluency test, no significant cross linguistic differences were observed in either the fluent or the non-fluent bPWA groups. However, the HB group showed significantly better performance in the Hungarian version of the semantic fluency task.

3.2 Group differences in the Trail Making Test

The analysis revealed statistically significant difference in RT between fluent bPWA and HB in both TMT-A and TMT-B demonstrating that fluent bPWA needed significantly longer time to complete the task than HB (refer to Figures 3-4). Regarding the non-fluent participants, the study only analysed the RT in TMT-A due to the fact the non-fluent bPWA were unable to solve part B. As a result, the number of mistakes were also analysed in both parts. The analysis revealed significantly longer RTs in the TMT-A for the non-fluent bPWA group compared to the HB group (refer to Figure 5). In terms of error analysis, in Part A, only the non-fluent bPWA group performed significantly worse compared to the HB group, while the fluent bPWA group did not show significant differences, suggesting that despite their significantly slower performance, their accuracy remained intact. In contrast, in Part B, both the fluent and non-fluent bPWAs made significantly more errors than the HB group. The TMT ratio and difference were calculated for the fluent bPWA, as the necessary RT data was missing for the non-fluent bPWA group. The TMT ratio scores showed no statistically significant difference between fluent bPWA and healthy controls (fluent bPWA: M= 2.73, SD= 1.11; HB: M= 2.63, SD= 1.02), suggesting that both groups experienced the expected pattern of longer times on TMT-B compared to TMT-A. In contrast, the TMT difference scores revealed a significant difference, with fluent bPWA exhibiting notably higher scores than the reference group (fluent bPWA: M= 149.17, SD= 83.92; HB: M= 74.50, SD= 66.34) suggesting impairment in switching abilities.

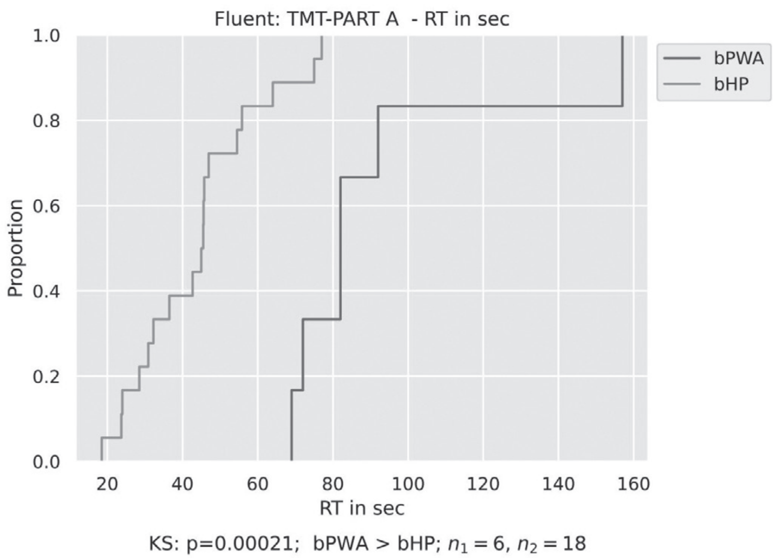

Figure 3. Comparison of RT in the TMT-A between fluent bilingual aphasics and healthy bilingual participants

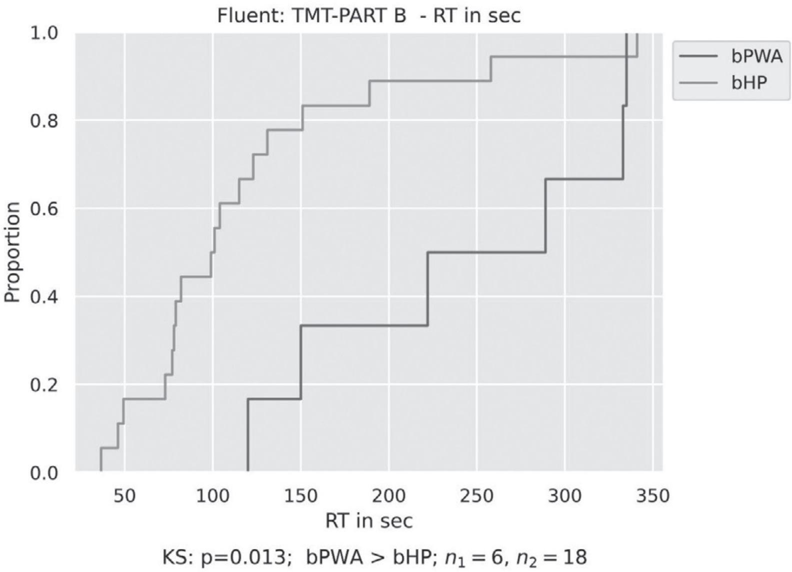

Figure 4. Comparison of RT in TMT-B between fluent bilingual aphasics and healthy bilinguals

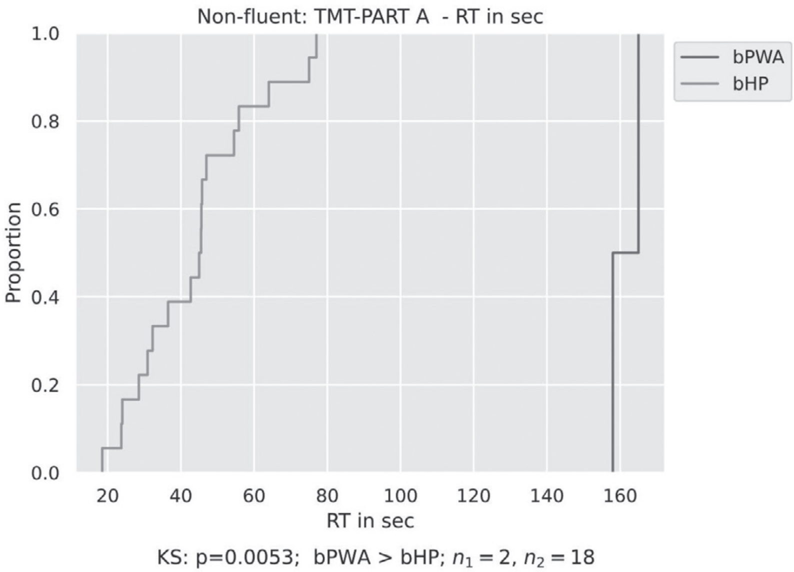

Figure 5. Comparison of RT in TMT-A between non-fluent bilingual aphasics and healthy bilinguals

4. DISCUSSION

The present study sought to elucidate the performance variations in executive functions, verbal semantic fluency, and letter fluency among bilingual people with aphasia (bPWA), specifically comparing fluent and non-fluent aphasia groups with healthy bilingual participant. The results indicate significant performance deficits in both aphasia groups compared to healthy controls, particularly in tasks requiring greater executive control, such as letter fluency.

The findings from the semantic and letter verbal fluency tasks elucidate significant differences in verbal fluency capabilities between the participants with fluent and non-fluent bilingual aphasia and healthy bilingual participants. The structured assessment over four 15-second intervals provided a nuanced understanding of how fluency performance fluctuates over time, revealing not only the overall proficiency of each group but also the challenges faced by the aphasia groups in maintaining consistent output. In both fluency tasks, both fluent and non-fluent participants with aphasia generated fewer responses compared to healthy participants which is in concurrence with aphasia literature which has shown that individuals with aphasia tend to have difficulties in lexical retrieval and production (Bose et al., 2017, 2022; Faroqi-Shah et al., 2018; Kiran et al., 2014; Patra et al., 2020). While the semantic fluency task did not reveal significant differences between the fluent bPWA and healthy bilingual participants, although a trend towards lower performance was noted. The non-fluent bPWA group, on the other hand, performed significantly worse across both fluency tasks. This stark contrast highlights the profound impact of non-fluent aphasia on verbal output. The anticipated poorer performance in letter fluency compared to semantic fluency was confirmed, as both bPWA groups and the HB group exhibited lower scores in the letter fluency task, reinforcing the notion that letter fluency tasks demand greater executive control engagement (Bose et al., 2022; Carpenter et al., 2020; Patra et al., 2020). The findings demonstrate that both fluent and non-fluent bPWA exhibited significantly lower performance in letter fluency tasks compared to healthy bilingual participants. This aligns with prior research emphasizing the executive demands of letter fluency, which necessitates not only lexical retrieval but also cognitive flexibility and inhibition (Bose et al., 2017; Carpenter et al., 2020). The anticipated differences in performance between the two aphasia groups were confirmed, with the non-fluent bPWA exhibiting more pronounced deficits in both semantic and letter fluency tasks. The analysis of response distribution across time intervals in the semantic fluency task revealed that the distribution of responses varied significantly in the initial intervals between fluent participants and the reference group. In the letter fluency task, the fluent aphasia group performed poorly compared to the reference group in all the four intervals. The non-fluent aphasia group demonstrated a consistent inability to produce correct responses across all time intervals, indicating a more pervasive deficit in word retrieval in both fluency tasks. The examination of errors, including repetitions and out-of-category responses, yielded no significant differences between the aphasia groups and healthy bilingual participants. The lack of significant differences in error rates and repetitions between bilingual aphasics and the reference group 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.

When comparing the performance of bilingual aphasics with the bilingual reference group in the Trail Making Test, the findings underscored the impact of aphasia on cognitive performance. The results indicated that both fluent and non-fluent bPWA groups demonstrated significant impairments in TMT performance compared to healthy bilingual participants, particularly in Part B of the test. The fluent bilingual aphasia group exhibited significantly longer response times in both parts and higher error rate in part B, while similar error rate was observed in part A compared to their neurologically healthy counterparts. In contrast, the non-fluent participants demonstrated significant difficulties in both parts of the TMT in terms of RT and error rate. 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; Mariën et al., 2017; Penn et al., 2009; Povroznik et al., 2018; Schumacher et al., 2019; Tsiakiri et al., 2024; Turunen, 2017). Even though fluent participants produced correct performance in the TMT-A, they needed significantly longer time to produce the correct performance compared to healthy counterparts. Furthermore, both aphasic and healthy participants experienced the expected pattern of longer times on TMT-B compared to TMT-A. In contrast, the TMT difference scores revealed a significant difference, with fluent bPWA exhibiting notably higher scores than the reference group, suggesting impairment in switching abilities.

5. CONCLUSION

In conclusion, the findings revealed significant performance deficits in both aphasia groups when contrasted with healthy participants, particularly in tasks that necessitate higher levels of executive control, such as letter fluency. The results from the semantic and letter fluency tasks illustrate marked differences in verbal fluency capabilities between the fluent and non-fluent bilingual aphasia groups and their healthy counterparts. The structured assessment conducted over four 15-second intervals provided a detailed understanding of fluency performance over time, highlighting not only the overall performance of each group but also the specific challenges faced by the aphasia groups in maintaining consistent verbal output. The results of the Trail Making Test showed switching impairments in both aphasia groups. This study offers valuable insights into the impairment of verbal semantic and letter fluency in bilingual individuals with aphasia, both fluent and non-fluent. However, it is crucial to recognize the limitations of the research. For example, the relatively small sample size restricts the ability to generalize the findings and apply them more broadly. Future research should aim to investigate the underlying mechanisms that contribute towards the observed differences in verbal fluency impairments. Furthermore, expanding the sample size and including a broader range of cognitive assessments could provide a more comprehensive understanding of the challenges in verbal fluency and executive functions faced by individuals with bilingual aphasia.

REFERENCES

Aglioti, S., Beltramello, A., Girardi, F., & Fabbro, F. (1996). Neurolinguistic and follow-up study of an unusual pattern of recovery from bilingual subcortical aphasia. *Brain*, *119*(5), 1551–1564. https://doi.org/10.1093/brain/119.5.1551

Ansaldo, A. I., & Saidi, L. G. (2014). Aphasia therapy in the age of globalization: Cross-linguistic therapy effects in bilingual aphasia. *Behavioural Neurology*, *2014*, 603085. https://doi.org/10.1155/2014/603085

Ardila, A., & Ramos, E. (2007). *Speech and language disorders in bilinguals.* Nova Science Publishers.

Bittner, R. M., & Crowe, S. F. (2007). The relationship between working memory, processing speed, verbal comprehension and FAS performance following Traumatic Brain Injury. *Brain Injury*, *21*(7), 709–719. https://doi.org/10.1080/02699050701468917

Bose, A., Patra, A., Antoniou, G. E., Stickland, R. C., & Belke, E. (2022). Verbal fluency difficulties in aphasia: A combination of lexical and executive control deficits. *International Journal of Language & Communication Disorders*, *57*(3), 593–614. https://doi.org/10.1111/1460-6984.12710

Bose, A., Wood, R., & Kiran, S. (2017). Semantic fluency in aphasia: Clustering and switching in the course of 1 minute: Semantic fluency in aphasia. *International Journal of Language & Communication Disorders*, *52*(3), 334–345. https://doi.org/10.1111/1460-6984.12276

Carpenter, E., Rao, L., Peñaloza, C., & Kiran, S. (2020). Verbal fluency as a measure of lexical access and cognitive control in bilingual persons with aphasia. *Aphasiology*, *34*(11), 1341–1362. https://doi.org/10.1080/02687038.2020.1759774

Chapey, R. (2008). *Language Intervention Strategies in Aphasia and Related Neurogenic Communication Disorders*, Chapter 33, 879–962. Lippincott Williams & Wilkins.

Clough, S., & Gordon, J. K. (2020). Fluent or nonfluent? Part A. Underlying contributors to categorical classifications of fluency in aphasia. *Aphasiology*, *34*(5), 515–539. https://doi.org/10.1080/0 2687038.2020.1727709

Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, *64*, 135–168. https://doi.org/10.1146/annurev-psych-113011-143750

Dodge, Y. (2008). Kolmogorov-Smirnov Test. In *The Concise Encyclopedia of Statistics* (pp. 283–287). Springer New York. https://doi.org/10.1007/978-0-387-32833-1_214

Dudás, R., Stachó, L., Kothencz, G., & Janka, Z. (2002). The Hungarian version of ACE, 6/11/2002-Hungarian translation based on: Mathuranath, P. S., Nestor, P. J., Berrios, G. E., Rakowitz, W., Hodges, J. R. (2000). A brief cognitive test battery to differentiate Alzheimer's disease and frontotemporal dementia. *Neurology*, *55*, 1613–1620.

Egner, T. (2017). *The Wiley Handbook of Cognitive Control*. John Wiley & Sons Ltd.

Fabbro, F. (2001). The bilingual brain: Cerebral representation of languages. *Brain and Language*, *79*, 211–222. https://doi.org/10.1006/brln.2001.2481

Faroqi-Shah, Y., Sampson, M., Pranger, M., & Baughman, S. (2018). Cognitive control, word retrieval and bilingual aphasia: Is there a relationship? *Journal of Neurolinguistics*, *45*, 95–109. https://doi.org/10.1016/j.jneuroling.2016.07.001

Friedman, N. P., & Miyake, A. (2017). Unity and diversity of executive functions: Individual differences as a window on cognitive structure. *Cortex*, *86*, 186–204. https://doi.org/10.1016/j.cortex.2016.04.023

Friedman, N. P., Miyake, A., Young, S. E., DeFries, J. C., Corley, R. P., & Hewitt, J. K. (2008). Individual differences in executive functions are almost entirely genetic in origin. *Journal of Experimental Psychology. General*, *137*(2), 201–225. https://doi.org/10.1037/0096-3445.137.2.201

Friesen, D. C., Luo, L., Luk, G., & Bialystok, E. (2014). Proficiency and control in verbal fluency performance across the lifespan for monolinguals and bilinguals. *Language, Cognition and Neuroscience*, *30*(3), 238–250. https://doi.org/10.1080/23273798.2014.918630

Gitterman, M. R., Goral, M., & Obler, L. K. (Eds.). (2012). *Aspects of Multilingual Aphasia*. Multilingual Matters.

Gordon, J. K., Young, M., & Garcia, C. (2018). Why do older adults have difficulty with semantic fluency?. *Neuropsychology, Development, and Cognition. Section B, Aging, Neuropsychology and Cognition*, *25*(6), 803–828. https://doi.org/10.1080/13825585.2017.1374328

Grosjean, F., & Li, P. (2013). *The Psycholinguistics of Bilingualism*. Wiley-Blackwell.

Hedge, M. N. (2024). *A coursebook on aphasia and other neurogenic language disorders.* Plural Publishing.

Henry, J. D., Crawford, J. R., & Phillips, L. H. (2004). Verbal fluency performance in dementia of the Alzheimer's type: A meta-analysis. *Neuropsychologia*, *42*(9), 1212–1222. https://doi.org/10.1016/j.neuropsychologia.2004.02.001

Hughes, D. L., & Bryan, J. (2002). Adult age differences in strategy use during verbal fluency performance. *Journal of Clinical and Experimental Neuropsychology*, *24*(5), 642–654. https://doi.org/10.1076/jcen.24.5.642.1002

Jaillard, A., Naegele, B., Trabucco-Miguel, S., LeBas, J. F., & Hommel, M. (2009). Hidden dysfunctioning in subacute stroke. *Stroke*, *40*(7), 2473–2479. https://doi.org/10.1161/strokeaha.108.541144

Jokinen, H., Melkas, S., Ylikoski, R., Pohjasvaara, T., Kaste, M., Erkinjuntti, T., & Hietanen, M. (2015). Post-stroke cognitive impairment is common even after successful clinical recovery. *European Journal of Neurology*, *22*(9), 1288–1294. https://doi.org/10.1111/ene.12743

Kertesz, A. (1982). *Western Aphasia Battery* (1st ed.). The Psychological Corporation.

Kiran, S., Balachandran, I., & Lucas, J. (2014). The nature of lexical-semantic access in bilingual aphasia. *Behavioural Neurology*, *2014*, 389565. https://doi.org/10.1155/2014/389565

Lábas-Weber, M. (n.d.). Bilingual Aphasia Test (Hungarian version). (6, May 2025). Retrieved from: https://www.mcgill.ca/linguistics/files/linguistics/hungarian_bat.pdf

Lamberty, G., Putnam, S., Chatel, D., Bieliauskas, L., & Adams, K. (1994). Derived Trail Making Test indices: A preliminary report. *Neuropsychiatry Neuropsychol. Behav. Neurol.*, *7*, 230–234.

Luo, L., Luk, G., & Bialystok, E. (2010). Effect of language proficiency and executive control on verbal fluency performance in bilinguals. *Cognition*, *114*(1), 29–41. https://doi.org/10.1016/j.cognition.2009.08.014

Mariën, P., van Dun, K., Van Dormael, J., Vandenborre, D., Keulen, S., Manto, M., Verhoeven, J., & Abutalebi, J. (2017). Cerebellar induced differential polyglot aphasia: A neurolinguistic and fmri study. *Brain and Language*, *175*, 18–28. https://doi.org/10.1016/j.bandl.2017.09.001

McMorris, T. (2016). Chapter 1-History of Research into the Acute Exercise–Cognition Interaction: A Cognitive Psychology Approach. In the *Exercise-Cognition Interaction*. Academic Press. https://doi.org/10.1016/B978-0-12-800778-5.00001-3

Miyake, A., & Friedman, N. P. (2012). The nature and organization of individual differences in executive functions: Four general conclusions. *Current Directions in Psychological Science*, *21*(1), 8–14. https://doi.org/10.1177/0963721411429458

Miyake, A., Friedmann, N. P., Emmerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex “Frontal lobe” tasks. A latent variable analysis. *Cognitive Psychology*, *41*, 49–100. https://doi.org/10.1006/cogp.1999.0734

Noether, G. E. (1963). Note on the Kolmogorov statistic in the discrete case. *Metrika*, *7*(1), 115–116. https://doi.org/10.1007/bf02613966

Paradis, M. (1989). *The Bilingual Aphasia Test*. Lawrence Erlbaum Associates.

Patra, A., Bose, A., & Marinis, T. (2019). Performance difference in verbal fluency in bilingual and monolingual speakers. *Bilingualism: Language and Cognition*, *23*(1), 204–218. https://doi.org/10.1017/s1366728918001098

Patra, A., Bose, A., & Marinis, T. (2020). Lexical and cognitive underpinnings of verbal fluency: Evidence from Bengali-English bilingual aphasia. *Behavioral Sciences*, *10*(10), 155. https://doi.org/10.3390/bs10100155

Penn, C., Frankel, T., Watermeyer, J., & Russell, N. (2009). Executive function and conversational strategies in bilingual aphasia. *Aphasiology*, *24*(2), 288–308. https://doi.org/10.1080/02687030902958399

Povroznik, J. M., Ozga, J. E., Haar, C. V., & Engler-Chiurazzi, E. B. (2018). Executive (dys)function after stroke: Special considerations for behavioral pharmacology. *Behavioural Pharmacology*, *29*(7), 638–653. https://doi.org/10.1097/fbp.0000000000000432

Salthouse, T. A. (2011). What cognitive abilities are involved in trail-making performance?. *Intelligence*, *39*(4), 222–232. https://doi.org/10.1016/j.intell.2011.03.001

Sánchez-Cubillo, I., Periáñez, J. A., Adrover-Roig, D., Rodríguez-Sánchez, J. M., Ríos-Lago, M., Tirapu, J., & Barceló, F. (2009). Construct validity of the trail-making test: Role of Task-switching, working memory, inhibition/interference control, and visuomotor abilities. *Journal of the International Neuropsychological Society*, *15*(3), 438–450. https://doi.org/10.1017/s1355617709090626

Schumacher, R., Halai, A. D., & Lambon Ralph, M. A. (2019). Assessing and mapping language, attention and executive multidimensional deficits in stroke aphasia. *Brain*, *142*(10), 3202–3216. https://doi.org/10.1093/brain/awz258

Shao, Z., Janse, E., Visser, K., & Meyer, A. S. (2014). What do verbal fluency tasks measure? Predictors of verbal fluency performance in older adults. *Frontiers in Psychology*, *5*. https://doi.org/10.3389/fpsyg.2014.00772

Slakter, M. J. (1965). A comparison of the Pearson Chi-Square and Kolmogorov Goodness-of-Fit Tests with respect to validity. *Journal of the American Statistical Association*, *60*(311), 854–858. https://doi.org/10.1080/01621459.1965.10480833

Thiele, K., Quinting, J. M., & Stenneken, P. (2016). New ways to analyze word generation performance in brain injury: A systematic review and meta-analysis of additional performance measures. *Journal of Clinical and Experimental Neuropsychology*, *38*(7), 764–781. https://doi.org/10.1080/13803395.2016.1163327

Troyer, A. K., Moscovitch, M., & Winocur, G. (1997). Clustering and switching as two components of verbal fluency: Evidence from younger and older healthy adults. *Neuropsychology*, *11*(1), 138–146. https://doi.org/10.1037//0894-4105.11.1.138

Tsiakiri, A., Christidi, F., Tsiptsios, D., Vlotinou, P., Kitmeridou, S., Bebeletsi, P., Kokkotis, C., Serdari, A., Tsamakis, K., Aggelousis, N., & Vadikolias, K. (2024). Processing speed and attentional shift/mental flexibility in patients with stroke: A comprehensive review on the trail making test in stroke studies. *Neurology International*, *16*(1), 210–225. https://doi.org/10.3390/neurolint16010014

Turunen, K. E. A., Laari, S. P. K., Kauranen, T. V., Uimonen, J., Mustanoja, S., Tatlisumak, T., & Poutiainen, E. (2017). Domain-specific cognitive recovery after first-ever stroke: A 2-year follow-up. *Journal of the International Neuropsychological Society*, *24*(2), 117–127. https://doi.org/10.1017/s1355617717000728

Virtanen, P., Gommers, R., Oliphant, T. E. *et al. (2020).* SciPy 1.0: Fundamental algorithms for scientific computing in Python. *Nature Methods*, *17*(3), 261–272. https://doi.org/10.1038/s41592-019-0686-2

Walsh, J. E. (1963). Bounded probability properties of Kolmogorov-Smirnov and similar statistics for discrete data. *Annals of the Institute of Statistical Mathematics*, *15*(1), 153–158. https://doi.org/10.1007/bf02865912

Wauters, L., Marquardt, T., & Muñoz, M. L. (2020). Verbal fluency in three Spanish-English bilingual speakers with TBI. *Journal of Communication Disorders*, *84*, 105971. https://doi.org/10.1016/j.jcomdis.2019.105971

Whiteside, D. M., Kealey, T., Semla, M., Luu, H., Rice, L., Basso, M. R., & Roper, B. (2016). Verbal fluency: Language or executive function measure?. *Applied Neuropsychology. Adult*, *23*(1), 29–34. https://doi.org/10.1080/23279095.2015.1004574

Appendices

Appendix A. Comparison of the number of correct answers during each 15-second-long period in the Hungarian version of the semantic verbal and letter fluency tasks in bilingual aphasic participants

			Semantic verbal fluency				
	0-15 sec	15-30 sec	30-45 sec	45-60 sec	mistakes	repetition	max score
bPWA 1	7	6	3	2	1	0	6
bPWA 2	5	4	4	0	2	0	4
bPWA 3	3	0	0	2	1	3	1
bPWA 4	6	0	0	0	0	5	1
bPWA 5	7	6	6	4	0	0	7
bPWA 6	0	0	0	0	0	0	0
bPWA 7	6	2	3	3	0	1	5
bPWA 8	0	0	0	0	0	0	0
			Letter fluency				
	0-15 sec	15-30 sec	30-45 sec	45-60 sec	mistakes	repetition	max score
bPWA 1	4	3	1	1	0	1	4
bPWA 2	2	0	0	1	0	0	1
bPWA 3	0	2	3	1	2	1	3
bPWA 4	3	4	0	0	2	2	3
bPWA 5	1	1	0	0	0	0	1
bPWA 6	0	0	0	0	0	0	0
bPWA 7	3	1	0	2	0	0	3
bPWA 8	0	0	0	0	0	0	0

Appendix B. Comparison of the number of correct answers during each 15-second-long period in the Hungarian version of the semantic verbal and letter fluency tasks in healthy bilingual participants

	0-15 sec	15-30 sec	30-45 sec	45-60 sec	mistakes	repetition	max score
Semantic fluency							
HB 1	8	3	4	2	0	0	6
HB 2	10	8	8	3	0	0	7
HB 3	13	4	7	2	2	0	7
HB 4	16	6	6	6	0	0	7
HB 5	10	4	1	3	1	0	6
HB 6	11	7	9	7	0	0	7
HB 7	10	3	5	1	2	0	6
HB 8	9	5	4	2	0	0	6
HB 9	7	2	0	4	0	2	4
HB 10	9	7	2	5	0	0	7
HB 11	8	2	2	1	0	1	4
HB 12	12	10	7	7	0	1	7
HB 13	14	11	7	10	0	0	7
HB 14	8	3	5	2	0	0	6
HB 15	10	4	4	4	0	0	7
HB 16	7	8	7	5	0	2	7
HB 17	12	5	5	3	0	1	7
HB 18	9	5	5	3	0	1	7
Letter fluency							
	0-15 sec	15-30 sec	30-45 sec	45-60 sec	mistakes	repetition	max score
HB 1	7	3	2	0	0	0	5
HB 2	6	1	1	1	0	1	4
HB 3	5	3	3	0	0	0	5
HB 4	7	3	4	1	0	0	6
HB 5	7	2	2	1	0	1	5
HB 6	2	6	4	1	1	1	5
HB 7	3	0	1	0	3	2	2
HB 8	3	0	1	1	0	0	2
HB 9	8	3	1	2	1	3	6

Letter fluency

	0-15 sec	15-30 sec	30-45 sec	45-60 sec	mistakes	repetition	max score
HB 10	4	1	1	2	3	0	4
HB 11	3	3	2	1	1	1	4
HB 12	5	2	4	2	0	0	5
HB 13	8	7	4	4	0	1	7
HB 14	3	2	0	3	1	0	4
HB 15	7	5	6	3	0	0	7
HB 16	6	7	5	1	0	1	7
HB 17	5	3	3	5	0	0	6
HB 18	4	4	6	1	0	0	6

Appendix C. Individual scores in the Trail Making Test for aphasic participants

		TMT-A RT in sec	TMT-A number of mistakes	TMT-B Rt in sec	TMT-B number of mistakes	TMT ratio	TMT difference
Fluent bPWA	bPWA1	157	0	335	6	2.13	178
	bPWA2	72	0	289	4	4.01	217
	bPWA3	69	0	150	2	2.17	81
	bPWA4	82	0	222	4	2.71	140
	bPWA5	92	0	120	1	1.30	28
	bPWA7	82	2	333	9	4.06	251
	Mean	92.33	0.33	241.5	4.33	2.73	149.17
	SD	32.72	0.82	92.61	2.88	1.11	83.92
	Range of scores (min-max)	69-157	0-2	120-335	1-9	1.3-4.06	28-251
Non-fluent bPWA	bPWA6	165	23	no data	23	no data	
	bPWA8	158	23		23		
	Mean	161.5	23		23		
	SD	4.95	0		0		
	Range of scores (min-max)	158-165	23		23		
HB mean		44.04	0.06	118.51	0.39	2.63	74.50
HB SD		16.78	0.24	77.12	0.85	1.02	66.34
Range of scores (min-max)		18.52-77	0-1	36.61-341	0-3	1.28-4.62	8.1-266

Appendix D. Results of the semantic fluency tasks in both languages (significant in bold)

		Semantic fluency (HU) total number of answers	Letter fluency (HU) total number of answers	Semantic fluency (CRO/SK/DE) total number of answers
Fluent	bPWA1	18	9	9
	bPWA2	13	3	6
	bPWA3	5	6	0
	bPWA4	6	7	2
	bPWA5	23	2	23
	bPWA7	14	6	6
	Mean	13.17	5.5	7.67
	SD	6.91	2.59	8.16
Non-fluent	bPWA6	0	0	0
	bPWA8	0	0	0
	Mean	0	0	0
	SD	0	0	0
HB	Mean	24.33	12.61	15.39
	SD	8.34	5.14	3.27

	Semantic versus letter fluency (HU) Total number of correct answers	Semantic fluency (HU) versus (CRO/SK/DE) Total number of correct answers
fluent bPWA (N= 6)	W= 16, p > *.100*	W= 19.5, p= .062
non-fluent bPWA (N= 2)	W= 1.5, p > *.100*	W= 1.5, p > *.100*
HB (N= 18)	**W= 154, p= .001 semantic fluency > letter fluency**	**W= 168, p= .001 HU > CRO/SK/DE**

Appendix E. Results of the statistical analysis in verbal fluency tests, as well as in TMT in both aphasia groups compared to the bilingual reference group (significant in bold)

	Fluent bPWA (N= 6) versus HB (N= 18)	Non-fluent bPWA (N= 2) versus HB (N= 18)
Semantic fluency: total number of correct answers (HU)	KS: D= 0.556, p= .051	**KS: D= 1.000, p= .005 bPWA < HB**
Letter fluency: total number of correct answers (HU)	**KS: D= 0.722, p= .005 bPWA < HB**	**KS: D= 1.000, p= .005 bPWA < HB**
Semantic fluency (HU): 0-15 sec	**KS: D= 0.889, p < .001 bPWA < HB**	**KS: D= 1.000, p= .005 bPWA < HB**
Semantic fluency (HU): 15-30 sec	**KS: D= 0.722, p= .005 bPWA < HB**	**KS: D= 1.000, p= .005 bPWA < HB**
Semantic fluency (HU): 30-45 sec	KS: D= 0.556, p= .051	**KS: D= 1.000, p= .005 bPWA < HB**
Semantic fluency (HU): 45-60 sec	KS: D= 0.556, p= .051	**KS: D= 1.000, p= .005 bPWA < HB**
Semantic fluency (HU): repetitions	KS: D= 0.333, p > *.100*	KS: D= 0.333, p > *.100*
Semantic fluency (HU): answers out of category	KS: D= 0.333, p > *.100*	KS: D= 0.167, p > *.100*
Letter fluency (HU): 0-15 sec	**KS: D= 0.611, p= .027 bPWA < HB**	**KS: D= 1.000, p= .005 bPWA < HB**
Letter fluency (HU): 15-30 sec	**KS: D= 0.611, p= .027 bPWA < HB**	**KS: D= 1.000, p= .005 bPWA < HB**
Letter fluency (HU): 30-45 sec	**KS: D= 0.667, p= .013 bPWA < HB**	**KS: D= 1.000, p= .005 bPWA < HB**
Letter fluency (HU): 45-60 sec	**KS: D= 0.722, p= .005 bPWA < HB**	**KS: D= 1.000, p= .005 bPWA < HB**
Letter fluency (HU): repetitions	KS: D= 0.056, p > *.100*	KS: D= 0.444, p > *.100*
Letter fluency (HU): answers out of category	KS: D= 0.222, p > *.100*	KS: D= 0.333, p > *.100*
TMT-A RT in sec	**KS: D= 0.889, p= < .001 bPWA > HB**	**KS: D= 1.000, p= .005 bPWA > HB**
TMT-A number of mistakes	KS: D= 0.167, p= .756	**KS: D= 1.000, p= .005 bPWA > HB**
TM-B RT in sec	**KS: D= 0.667, p= .013 bPWA > HB**	no data
TMT-B number of mistakes	**KS: D= 0.778, p= .002 bPWA > HB**	**KS: D= 1.000, p= .005 bPWA > HB**