

Doctoral (PhD) Dissertation Booklet

**The impact of working memory on the recovery from
aphasia**



Written by: Annamária Kiss

Supervisor: Prof. Dr. Valéria Csépe

Multilingualism Doctoral School

University of Pannonia, Veszprém

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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 (Marinelli et al., 2017; Murray 2012, 2017; Olsson et al., 2019; Purdy, 2002; Ramsey et al., 2017; Schumacher et al., 2019). 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). Despite their significant influence on each other, the role of executive functions has not been extensively studied in the existing aphasia literature. In the field of monolingual aphasia research, substantial attention has been devoted to examining impairments in the working memory (Christensen & Wright, 2010; Christensen et al., 2018; Mayer & Murray, 2012; Nikraves et al., 2021; Potagas et al., 2011; Wright & Shisler, 2005; Zakariás et al., 2018). Conversely, the body of research exploring cognitive flexibility deficits in individuals with aphasia remains comparatively limited (Povroznik et al., 2018; Schumacher et al., 2019; Tsiakiri et al., 2024; Turunen, 2017), as well as in case of examining impairments in inhibition (Kendrick et al. 2019; Kuzmina & Weekes, 2016; Schumacher et al., 2022). Additionally, the current data available in the literature regarding bilingual aphasia is also limited, especially on working memory and cognitive flexibility (Adrover-Roig et al., 2011; Kong et al., 2014; Lee et al., 2016; Marini et al., 2016; Penn et al., 2009, 2017). As a result, there is a significant gap in the relevant literature on the characteristics of cognitive flexibility and working memory in bilingual individuals diagnosed with aphasia. This dissertation seeks to bridge this gap by providing data acquired by testing executive functions in mono- and bilingual individuals with aphasia.

Furthermore, studies investigating the role of executive functions in verbal fluency 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).

Beyond investigating executive function impairments in bilingual aphasia, researchers have started to grow an interest in exploring the potential bilingual advantage in bilingual aphasia regarding non-linguistic executive functions, however, the number of studies in this area is still limited and the results remain inconclusive. These studies often adopt a comparative approach, examining the performance of mono- and bilingual people with aphasia with varying subtypes of aphasia and phases of recovery. The current literature 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).

Purpose of the Research

The primary objective of this dissertation 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. The hypotheses of the dissertation are summarized in Table 1.

Table 1. Summary of hypotheses with relevant tests and expected outcomes

Hypotheses	Tasks applied	Expected outcomes
(1) Executive function impairment affects naming	Boston Naming Test (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 (TT) 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	Trail Making Test (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, Rey Complex Figure -B (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, Visual and Auditory Sequential Memory Tests, 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, Visual and Auditory Sequential Memory Tests, 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.

Methods

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, mean age:68.7 yrs), bilingual people with aphasia (N=8, mean age: 63.5 yrs), monolingual healthy participants

(N=18, mean age: 67.67 yrs), and bilingual healthy participants (N=18, mean age: 65 yrs). 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), which showed that all bilinguals used their languages parallelly both before and after the stroke incident. In case of the monolingual groups, all participants were native Hungarian speakers. 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. 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). 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 (0-3: 37.50%; 3-6: 50%; over 6: 12.50%). 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 (0-3: 50%; 3-6: 38.89%; over 6: 11.11%)

Procedures

Participants with aphasia were recruited from a variety of sources. The recruitment process was conducted via three principal channels: institutional, private speech and language therapists as well as individual. Some participants were recruited from rehabilitation centres and hospitals (Sopron Erzsébet Teaching Hospital and Rehabilitation Institute in Hungary; 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. Furthermore, participants were recruited through private speech therapists in Hungary and Slovakia. 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. Written informed consent was obtained from both the therapists and participants prior to collecting data. 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.

Assessment tools

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.

The BNT was added to evaluate confrontational picture-naming abilities (Kaplan et al., 1983). 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 executive functions, 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.

The TT was added to assess deficits in auditory comprehension at the sentence level. 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 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 TROG-H was employed to measure the participants' comprehension of grammatical structures (Lukács et al., 2012). In this test, the participants were asked to choose one of four pictures that represented the verbal command. Several executive functions were assessed using the test, including working memory, inhibition, cognitive flexibility, attention, problem-solving, planning and organization.

Fluency tasks: 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.

Furthermore, 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.

TMT consists of two parts. In Part A, the participants must draw a line connecting consecutive numbers, while in Part B, they must join numbers and letters together in an alternating progressive sequence (McMorris, 2016). 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.

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. This recalling phase assessed visual memory, organizational strategies and planning, monitoring as well as inhibitory control (Kirkwood et al., 2001).

In the ASMT, the participants were required to match words to corresponding pictures. 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 VSMT 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.

The Sudoku tasks were also used from the Afázia App. In these tasks, each letter / number could appear once in each row and column. The response times were measured in seconds assessing working memory, attention, problem-solving as well as cognitive flexibility, planning and organisation.

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. 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.

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. Additionally, to evaluate linear relationships between two variables, the Pearson's correlation coefficient was used, as implemented in the SciPy library (Virtanen et al., 2020).

Results

Linguistic assessments

In the linguistic assessments, monolingual persons with aphasia (mPWA) and bilingual persons with aphasia (bPWA) performed similarly. When both aphasia groups were compared to the reference groups, the results revealed significant impairment in naming, auditory comprehension and verbal fluency in aphasic participants. The comparison between fluent and non-fluent aphasics revealed significant differences in all linguistic tasks (for details, see Table 2).

Table 2. 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, for semantic fluency > letter fluency	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.	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.	
fluent vs. non-fluent aphasics	Yes, fluent > non-fluent	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 produced fewer correct responses in both tasks.	Yes, fluent > non-fluent. No, for repetitions and errors.

Yes- significant finding, No- not significant findings.

Non-linguistic assessments

In the on-linguistic assessment, the analysis revealed similar performance between mPWA and bPWA in all tasks, while found significant differences between aphasics and healthy participants. The mPWA group performed significantly poorly in the Visual and Auditory Sequential Memory tests and in both parts of the TMT. The bPWA group demonstrated poor performance in the Visual Sequential Memory Test, Number Sudoku and in both parts of the TMT when compared to the reference group. The comparison between fluent and non-fluent aphasics revealed statistically significant differences in the Visual Sequential Memory Test, Rey Complex Figure- B, and in TMT B (see Table 3).

Table 3. 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.	Yes, for RT and errors. aphasia > reference
bPWA vs. mPWA	No, for RT and mistakes percentage.	No		No, for RT and mistakes percentage.		No, for RT and number of mistakes.	
fluent vs. non-fluent aphasics	Yes, for RT and mistakes pct. fluent < non-fluent	No	Yes, fluent > non-fluent	No, for RT and mistakes pct.	Yes, for mistakes percentage. fluent < non-fluent No, for RT.	No, for RT and number of mistakes.	Yes, for number of mistakes. fluent < non-fluent

Yes- significant finding, No- not significant findings.

Effects of age and education on performance

The study found significant positive correlations between education and performance in naming, auditory working memory for both the mono-and bilingual reference groups. In the aphasia group, education positively correlated with verbal semantic fluency and the Rey Complex Figure-B. Conversely, strong negative correlations were found between education and performance in Letter Sudoku task and Visual Sequential Memory Test for both reference groups. The bilingual reference group also showed strong negative correlations between education and performance in the TMT-B and the Visual Sequential Memory Test. For the monolingual aphasia group, the results revealed significant negative correlations between education and response time in TMT- B. In the bilingual aphasia group, education positively correlated with performance in the Rey Complex task, but negatively correlated with performance in the Visual Sequential Memory Test.

Regarding the effect of age on performance, the results indicated strong negative correlations between age and performance in verbal fluency tasks for both reference groups. Furthermore, strong positive correlations were observed between age and performance in Sudoku Tasks, TMT, and Visual Sequential Memory Test in the bilingual reference group. In the monolingual aphasia group, the analysis found no statistically significant correlations between age and performance in linguistic and non-linguistic tasks. In contrast, the results indicated strong positive correlations with age in the Letter Sudoku task and in the Visual Sequential Memory Test for the bilingual aphasics.

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.

In linguistic test, the analysis revealed significant differences 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. 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 correlation between decreased naming ability and increased response times observed in mono- and the bilingual aphasia groups 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. 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.

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, reinforcing the hypothesis of dissociation. Similar results were observed in the aphasia groups, as most participants performed similarly in both tasks, while four participants with aphasia 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. 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). 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. Moreover, 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. 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).

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. 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).

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. Both fluent and non-fluent aphasics demonstrated significant impairments in various cognitive domains compared to a neurologically healthy reference group. Moreover, 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. 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. 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 the Trail Making Test, both fluent and non-fluent aphasics performed poorly compared to the reference group. 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, 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.

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.

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.

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