PHONOLOGICAL PROCESSING AS A MARKER OF LATENT COGNITIVE VULNERABILITY: A PRE- AND POST-STROKE CASE STUDY IN A PATIENT WITHOUT APHASIA

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Abstract: This study presents a case of a patient whose phonological processing was assessed before and after an ischemic stroke in the right posterior cerebral artery, without clinical signs of aphasia. Using a standardized assessment tool, a marked decline was observed in tasks involving repetition, blending, and segmentation of sound units, particularly when processing pseudowords, while automated processes such as oral reading and auditory phonological processing remained relatively preserved. The findings indicate that even lesions outside the classical language areas can lead to selective language-cognitive impairments. The study supports the concept of the network-based and bilateral organization of language functions and highlights the potential of phonological tasks as a sensitive tool for early detection of latent cognitive-linguistic vulnerability and increased neurovascular risk.

Keywords: phonological processing; ischemic stroke; subclinical vulnerability; cognitive reserve; right hemisphere lesion; neurovascular risk

ФОНОЛОГИЧНАТА ПРЕРАБОТКА КАТО МАРКЕР ЗА ЛАТЕНТНА КОГНИТИВНА УЯЗВИМОСТ: ПРОСЛЕДЯВАНЕ НА СЛУЧАЙ ПРЕДИ И СЛЕД ИНСУЛТ ПРИ ПАЦИЕНТ БЕЗ АФАЗИЯ

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Резюме: Изследването представя случай на пациент, при който е проследена фонологичната преработка преди и след исхемичен инсулт в дясната задна мозъчна артерия, без наличие на клинична афазия. Чрез прилагане на стандартизиран инструмент за оценка се установява значимо влошаване на уменията за повторение, сливане и сегментиране на звукови единици, особено при работа с псевдодуми,

докато автоматизираните процеси като четене на глас и слухова фонологична обработка остават относително запазени. Резултатите показват, че дори при лезии извън класическите езикови зони могат да настъпят селективни езиково-когнитивни нарушения. Проучването подкрепя концепцията за мрежовата и билатерална организация на езиковите функции и подчертава потенциала на фонологичните задачи като чувствителен инструмент за ранно откриване на латентна когнитивно-езикова уязвимост и повишен невроваскуларен риск.

Ключови думи: фонологична преработка; исхемичен инсулт; субклинична уязвимост; когнитивен резерв; дяснохемисферна лезия; невроваскуларен риск

INTRODUCTION

Phonological processing is a core linguistic mechanism that provides access to the sound structure of language and is directly related to the identification, analysis, manipulation, and temporary storage of sound units (Shtereva, 2012; Nadeau, 2001). It is crucial for various speech activities such as naming, repetition, and reading (Kendall & Nadeau, 2016), and encompasses three interrelated components: phonological awareness, working memory, and long-term phonological representation - which connect auditory perception with language production (Shtereva, 2012).

Disruptions in the phonological system can affect a wide range of language skills - comprehension, reading, and writing (Asenova, 2009; Tsenova, 2012). In most types of aphasia, deficits occur in all three components, with repetition and phonological working memory being the most vulnerable (Kendall & Nadeau, 2016; Robson et al., 2019). Tasks involving pseudowords and syllable manipulation are particularly indicative, as they require abstract processing without reliance on the lexical system (Woollams, 2013). According to Martin and Saffran (1997), phonological processing is closely tied to auditory-verbal short-term memory and does not constitute an autonomous system - when semantic deficits are present, reliance on phonological strategies increases, conversely, phonological deficits lead to reduced repetition abilities. These findings underscore the diagnostic value of phonological tasks in language disorders.

Stroke is one of the leading causes of acquired language impairment. Aphasia, which most often results from lesions in the left hemisphere, is characterized by varying degrees of impairment in speech comprehension, expression, repetition, and naming. However, not all strokes lead to aphasia. When the right hemisphere is affected, language deficits often remain subclinical though they may involve subtle impairments in prosody, discourse organization, pragmatic language use, and, in some cases, phonological processing (Berthier et al., 2010; Van Dun et al., 2015).

Functional imaging studies demonstrate that the right hemisphere can be actively involved in language processing, particularly in cases of compensatory reorganization following left-hemisphere damage (Xing et al., 2016; Noonan et al., 2013). These findings are important in the context of the present study, because they suggest that lesions in the right hemisphere, even if they don't directly affect phonological encoding, may still impact attentional control and working memory. These are both essential for efficient phonological processing.

The growing scientific interest in phonological function is also driven by its sensitivity to vascular and neurodegenerative changes. Structural brain alterations such as white matter hyperintensities and medial temporal lobe atrophy are associated with an increased risk of cognitive vulnerability and stroke (Mele et al., 2024). Neuroimaging studies indicate that such findings often co-occur with subtle but clinically significant cognitive and language impairments detectable only through specialized testing (Dimitrova-Kirilova, 2023). "Silent" brain infarcts, although clinically asymptomatic, are linked to brain atrophy and declines in executive functions, attention, memory, and processing speed, with greater periventricular hyperintensity volume showing a stronger relationship with these deficits (Zhang et al., 2021). Atrophy of the thalamus, fronto-insular cortex, and right inferior temporal gyrus also correlates with lower cognitive performance (Zhu et al., 2021). In carotid stenosis, more pronounced atrophy and hyperintensities are observed in the affected hemisphere, along with reductions in global cognition (MMSE, MoCA) and lower scores in tests of mental processing speed, learning, visuospatial abilities, verbal processing, reasoning, and executive functions (Johnston et al., 2004; Martinić-Popović et al., 2009; Mathiesen et al., 2004; Balestrini et al., 2013). Neuroimaging and neuromodulation data indicate that the right posterior inferior frontal gyrus (pIFG) plays a significant role in phonological decision-making, regardless of stimulus modality, and its damage leads to slower reaction times and more errors (Hartwigsen et al., 2010). The meta-analysis by Vigneau et al. (2010) supports these conclusions, showing that the right hemisphere contributes to phonological processing mainly through attention and working memory, with specific unilateral activation observed primarily during sentence and text processing. These findings support the concept of hemispheric asymmetry and highlight that language difficulties can manifest even in the absence of overt aphasia.

In this context, sensitive linguistic tools such as the standardized SAPA test (Kendall et al., 2010) and its Bulgarian adaptation, SOFA – Standardized Assessment of Phonology in Aphasia (СОФА – *Стандартизирана оценка за фонология при афазия*, Bulgarian title) (Marinova & Shtereva, 2023), enable precise domain-specific assessment. Findings from Shtika and Shtereva (2024) show that Subtest 3 of SOFA (repetition, blending, and segmentation of real and pseudowords) accounts for over 79% of the variance in spoken speech in patients with motor and sensory-motor aphasia, making it an exceptionally prognostic indicator.

The present study reports the case of an adult patient whose phonological processing was assessed before and after an ischemic stroke in the territory of the right posterior cerebral artery. Comparing results from the same individual before and after a brain injury provides unique insight into language vulnerability and interhemispheric compensatory plasticity in stroke. The aim is to trace the dynamics of language functioning and to evaluate the potential of the SOFA test as an indicator of latent cognitive vulnerability in the absence of clinical aphasia. The study seeks to answer whether subtle phonological processing impairments can be detected following right-hemisphere stroke, and to determine the prognostic and diagnostic value of this mechanism beyond the framework of traditional aphasia.

METHODOLOGY

Respondent and Study Timeline

This study presents the case of a 70-year-old male, born in Sofia, Bulgaria, with a university degree and over 40 years of professional practice as a neurologist. His native language is Bulgarian. The patient is right-handed, although during adolescence he temporarily used his left hand as dominant due to a surgical intervention. In adulthood, there were no indications of left-handedness or mixed lateralization.

The respondent was included in the study in January 2022 as part of the control group in a doctoral research project on phonological processing in aphasia, which applied the SOFA (Shtika, 2024). The initial assessment revealed no cognitive or language deficits, with results corresponding to preserved functioning in these domains.

In January 2024, the patient experienced an ischemic stroke in the territory of the right posterior cerebral artery (RPCA). The diagnosis was confirmed by computed tomography (CT) and magnetic resonance imaging (MRI) conducted at the Military Medical Academy – Sofia. Neuroimaging revealed thrombosis in the RPCA territory and hypodense areas in the right parieto-occipital region, without involvement of left-hemisphere language zones. Clinically, the stroke presented with left-sided hemiparesis (more pronounced in the arm), sensory impairments, and visual deficits. No aphasia was detected—speech remained clear, without dysarthria, with preserved comprehension and language production.

A follow-up MRI in April 2024 at University Multi-profile Hospital "St. Ivan Rilski" – Sofia, compared to the previous scans, revealed chronic post-ischemic encephalomalacia and gliotic changes in the right thalamus, right occipital lobe, and hippocampus, as well as a persistent cavernoma in the right frontal region without evidence of hemorrhage. Bilateral gliotic foci of vascular origin were noted, without progression. No new vascular events, aneurysms, or acute pathologies were detected. The brainstem, cerebellum, and medulla spinalis were structurally intact. These findings were consistent with chronic cerebrovascular lesions and

old ischemic changes. Accompanying medical records indicated pleuropneumonia, hiatal hernia, duodenal ulcer (in remission), anemia, mildly reduced serum albumin, and emphysematous changes. No dementia, neurodegenerative disease, or other conditions were identified that could compromise the validity of the cognitive or language assessment during the follow-up evaluation.

Due to changes in emotional state and a decline in general health, the follow-up SOFA test was conducted in May 2025. The aim was to determine whether, and to what extent, the right-hemisphere lesion, despite being outside classical language zones, affected phonological processing ability.

RESEARCH INSTRUMENTATION

SOFA is designed for precise, domain-specific evaluation of the phonological system through tasks targeting three key aspects: phonological awareness, phonological working memory, and phonological manipulation (Kendall & Nadeau, 2016). The Bulgarian adaptation, carried out by Marinova and Shtereva (2023), was developed in accordance with the structural and linguistic specifics of Bulgarian and approved by the Ethics Committee of Sofia University "St. Kliment Ohridski."

SOFA consists of three subtests, systematically covering different levels and mechanisms of phonological processing:

1. Reading Aloud – includes selected real words, pseudowords, pseudo-homophones, and words with non-standard orthography. Stimuli are selected according to frequency of use, syllable structure, word length, and phoneme–grapheme correspondences to control for lexical frequency and orthographic effects.
2. Auditory Phonological Processing – assesses the ability to recognize rhyming real and pseudowords, make lexical decisions, and discriminate minimal pairs. Tasks are designed to engage both automatic and consciously controlled phonological processes.
3. Repetition, Blending, and Segmentation – includes tasks at the phoneme and syllable levels, with real and pseudowords, and manipulation tasks such as segmenting initial, final, or medial phonemes/syllables to test flexible handling of phonological material.

The linguistic material was constructed based on the structural characteristics of the Bulgarian phonological system described by Tilkov (1983) and Boyadzhiev & Tilkov (1999), as well as the principles of non-linear syllable structure formulated by Stoel-Gammon and Stemberger (1994). Pseudowords were generated using the Wuggy algorithm, ensuring structural and statistical similarity to real words while preserving natural sound patterns and probabilistic models of Bulgarian (Shtereva et al., 2020).

Stimuli and instructions were presented in both audio and visual formats, with standardized delivery for all participants. Scoring criteria were binary:

1 point for a correct and 0 points for an incorrect response. Before the main assessment, training items with feedback were provided; during the test proper, no corrections or additional prompts were allowed. The assessment was conducted individually, in a quiet environment, without time pressure, with an average duration of 25–35 minutes. SOFA allows both quantitative and qualitative analysis of phonological processing and is applicable not only in aphasia but also in other neurological conditions, including stroke without clinically apparent aphasia. The test is non-fatiguing, adaptable to individual pace, and compatible with other diagnostic batteries such as the *Boston Diagnostic Aphasia Examination* (BDAE).

ETHICAL CONSIDERATIONS

The study was conducted in accordance with the principles of the Declaration of Helsinki for ethical conduct in medical research involving human participants. The patient's initial participation in the control group in 2022 was part of a doctoral project approved by the Ethics Committee of Sofia University "St. Kliment Ohridski," following the signing of informed consent.

After the cerebrovascular event and in light of the scientific significance of the case, the respondent was invited to participate again. The follow-up evaluation was performed after providing full information on the study's objectives, methods, potential benefits, and voluntary nature. The patient signed a new informed consent form, confirming his willingness to participate in the present research.

RESULTS

SOFA Test Performance

The participant was assessed with the SOFA test at two time points—approximately two years prior to an ischemic stroke in the territory of the right posterior cerebral artery, and one year after the event. The results are presented in Table 1 and illustrated in Figure 1. The total score decreased from 168/190 points (88.42%) pre-stroke to 140/190 points (73.68%) post-stroke, representing a reduction of nearly 15 percentage points.

Subtest-level analysis revealed varying degrees of decline. Subtest 1 (Reading) showed a minimal decrease—from 64/65 points (98.46%) to 63/65 points (96.92%)—suggesting preserved automated visual–phonological decoding. Subtest 2 (Auditory Phonological Processing) indicated a moderate decline—from 49/55 points (89.09%) to 45/55 points (81.82%)—with more pronounced difficulties in minimal pair discrimination and lexical decision tasks, likely related to reduced efficiency in auditory–phonemic analysis. Subtest 3 (Repetition, Blending, Segmentation) was the most affected, with scores dropping from 55/70 points (78.57%) to 32/70 points (45.71%)—a difference of 32.86 percentage points—particularly in pseudoword tasks, which require intensive phonological working memory engagement and manipulation of sound units.

The pre-stroke profile indicated high performance across all language domains, with a slightly lower score in Subtest 3, potentially reflecting early signs of reduced phonological capacity or latent vascular vulnerability. Post-stroke, a marked deterioration in phonological manipulation was observed, while automated and lexically supported processes remained relatively preserved.

Table 1. SOFA Test Results – Pre- and Post-Stroke

Subtest	**Max. Score**	**Pre-Stroke (points)**	**Pre-Stroke (%)**	**Post-Stroke (points)**	**Post-Stroke (%)**
Subtest 1: Reading	65	64	98.46%	63	96.92%
Subtest 2: Auditory Phonological Processing	55	49	89.09%	45	81.82%
Subtest 3: Repetition, Blending, Segmentation	70	55	78.57%	32	45.71%
Total SOFA Score	190	**168**	**88.42%**	**140**	**73.68%**

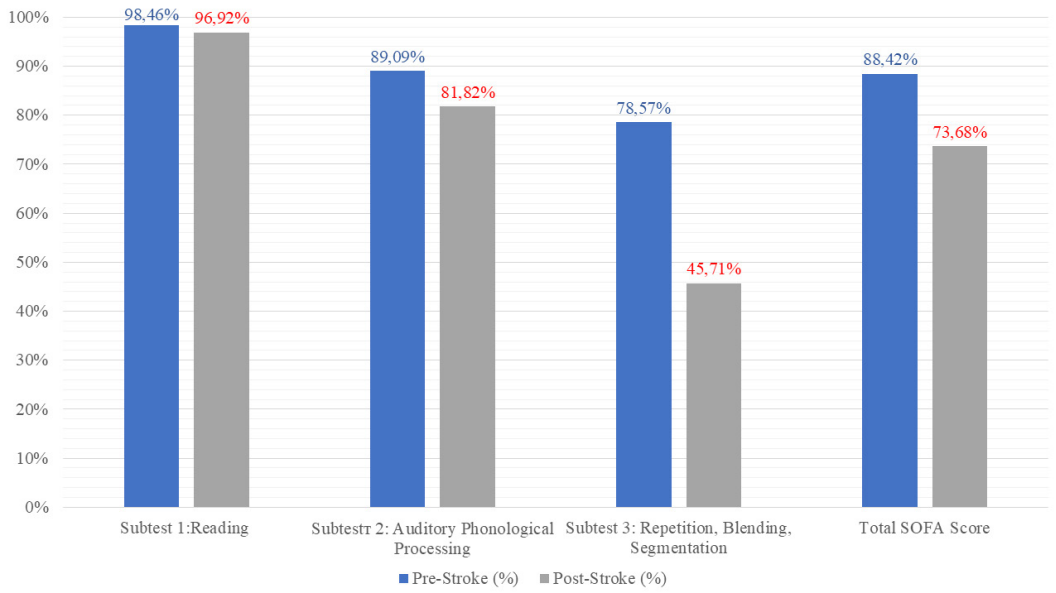

Fig. 1. Percentage scores on the SOFA test – pre- and post-stroke

The patient was assessed as part of a doctoral research project (Shtika, 2024) involving the SOFA test, which enabled direct comparison of his pre-stroke performance with that of a control group of 29 healthy participants, as shown in Table 2. Analysis of the three main subtests revealed that the patient's pre-stroke performance was close to the control group's mean scores, both in raw points and in percentages. This comparison provides a reliable baseline for evaluating

post-stroke changes, as it offers an individual pre-event profile against normative data from a comparable sample.

Before the stroke, the patient demonstrated excellent results in Subtest 1 (98.46%) and Subtest 2 (90.91%), comparable to or exceeding the control group's average scores. However, in Subtest 3, his score was lower—72.86% compared to the control group mean of 83.40%—indicating the presence of selective difficulties in phonological processing even prior to the cerebrovascular event.

Table 2. Comparison of mean raw and percentage SOFA scores (Subtests 1, 2, and 3) between the patient (pre-stroke) and the control group

Group	Subtest 1 – Total (65 pt	%	Subtest 2 – Total (55 pts)	%	Subtest 3 – Total (70 pts)	%	Total SOFA–Total (190 pts)	%
Control Group	62.69	96.45	48.93	88.97	58.38	83.40	170.103	89.53
Patient pre-stroke	64	98.46	50	90.91	51	72.86	168	88.42

BEHAVIOURAL AND MOTIVATIONAL ASPECTS DURING TESTING

When interpreting the results, it is important to consider the researcher's observations regarding the participant's behavioural engagement during the two testing sessions.

During the initial assessment (January 2022), the participant demonstrated high motivation, sustained concentration, and a clear willingness to complete the tasks. However, he reported that the audio recordings were difficult to perceive, which led him to adopt a compensatory strategy of overtly repeating each stimulus aloud. This approach likely supported his performance, particularly in tasks involving auditory-phonological processing.

In contrast, during the follow-up assessment in May 2025, the participant exhibited an opposite behavioral profile—heexpressed low interest, mild physical discomfort, and fatigue, though without a marked desire to terminate participation. He did not report any difficulty perceiving the audio recordings and did not employ the earlier compensatory strategy, despite the presence of identical tasks.

DISCUSSION

This case study highlights phonological processing as a sensitive indicator of cognitive and linguistic vulnerability, even in post-stroke patients without aphasia. The findings demonstrate a substantial decline in performance on Subtest 3 of the SOFA test following an ischemic stroke in the territory of the right posterior cerebral artery (RPCA), despite the absence of lesions in the classical left-hemispheric language areas.

The patient's total score decreased from 168 points (88.42%) pre-stroke to 140 points (73.68%) post-stroke, with the most pronounced reduction observed in Subtest 3 (repetition, blending, segmentation)—from 78.57% to 45.71%. Tasks involving pseudowords were particularly affected; these require intensive cognitive processing, manipulation of sound units, and access to abstract phonological representations. According to Kendall & Nadeau (2016), such tasks are among the most sensitive to impairments in phonological encoding and working memory, and they are frequently severely disrupted in individuals with aphasia. In the present case, this pattern emerges despite the absence of aphasia, underscoring the high diagnostic sensitivity of this subtest.

Notably, these linguistic difficulties arose following a right-hemispheric stroke—a lesion site traditionally regarded as non-language dominant. However, multiple studies (Berthier et al., 2010; Van Dun et al., 2015; Yuan et al., 2025; Hartwigsen et al., 2010) indicate that the right hemisphere can play a compensatory or supportive role in language processing, particularly in the presence of bilateral or reorganised neural networks. In this context, the presented case adds to the growing evidence in support of a dynamic, network-based model of language organisation, in which both hemispheres contribute to maintaining linguistic functions.

The comparison between the two time points demonstrates that the SOFA test is sensitive to subtle changes in the language system that are not apparent in the gross clinical picture. This supports the view that phonological processing can serve as a reliable marker of both current language status and potential cognitive risk. Findings from Lee et al. (2014), Schellhorn et al. (2021), and Delano-Wood et al. (2008) emphasise the relationship between pre-stroke cognitive deviations, white matter hyperintensities, and an increased risk of cerebrovascular events. In this regard, the post-stroke deterioration in Subtest 3 performance in an otherwise aphasia-free patient may be interpreted as evidence of vulnerability in network coordination following ischemic injury.

Hypothetically, if confirmed in larger samples, poor performance on Subtest 3 of the SOFA—even in the presence of otherwise preserved language production—could be used as an early marker of cognitive vulnerability and a potential predictor of cerebrovascular risk, especially in older patients or those with additional risk factors. This observation aligns with previous reports describing pre-stroke cognitive dysfunction as a predictor of future cerebrovascular events (Gottesman & Hillis, 2010; Debette & Markus, 2010).

FINDINGS

The results of this single-case study demonstrate that the SOFA test, which measures phonological processing, serves as a sensitive indicator of language deficits even in patients without aphasia following ischemic stroke. The most pronounced decline was observed in Subtest 3 (repetition, blending, and segmentation),

which demands a high degree of cognitive engagement and manipulation of sound units, particularly with pseudowords. The findings indicate that even lesions located in the right hemisphere, outside the classical left-hemispheric language zones, can lead to language–cognitive impairments, supporting the concept of a bilaterally distributed and network-based language system.

Comparison of pre- and post-stroke performance suggests that phonological processing can function not only as a reflection of language ability but also as a potential marker of neurovascular vulnerability and limited compensatory capacity. These results underscore the need to integrate domain-specific tools, such as the SOFA test, into clinical speech–language pathology practice—both for diagnostic and follow-up purposes and for the early identification of patients at elevated risk of cognitive and language deficits as a consequence of vascular events.

LIMITATIONS

This study has several limitations that should be taken into account when interpreting the findings:

1. Case-study design – The data presented refer to a single participant, and therefore, generalization to a broader population should be made with caution. Replication with a larger sample is required.
2. Prior familiarity with the test – Although the patient did not recall the specific items from the initial assessment, familiarity with the structure and format of the tasks during the second testing session may have partially influenced performance (familiarity effect), despite the observed decrease in motivational engagement.
3. Subjective factors during assessment – Researcher observations indicate differences in motivation and behavioural engagement between the two assessments. During the initial testing, the participant demonstrated an active coping strategy (repeating stimuli aloud), whereas in the follow-up session, motivation was lower and no compensatory techniques were employed. This raises questions about the influence of motivational and contextual factors on cognitive performance.
4. Pharmacological support – Following the stroke, the patient took medications that stimulated cognitive function, such as citicoline and simazine. This is an important consideration in interpreting performance. However, the absence of a control group receiving similar medication limits the ability to differentiate between the contributions of neuroplasticity and pharmacological effects.

Despite these limitations, the present study offers a valuable example of an in-depth individual analysis, illustrating the potential of phonological processing as an indicator of neurovascular vulnerability, as well as the sensitivity of these processes to vascular incidents.

CONCLUSION

This case presents a rare example of tracking language-cognitive functioning in a patient without clinical aphasia but with confirmed cerebrovascular damage. Administering the SOFA test before and after a right posterior cerebral artery stroke allowed for an accurate evaluation of changes in phonological processing and revealed a latent vulnerability that would not have been detected through general cognitive tests. Notably, there was a marked deterioration in tasks requiring manipulation of sound units, which highlights therole of right-hemispheric structures and the bilateral organization of language processes.

This study emphasizes the importance of applying early, sensitive, and domain-specific speech and language assessments not only when aphasia is suspected, but also in the context of prevention and monitoring of individuals at neurovascular risk.

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