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Phoneme production ability in stroke patients: A neuropsycholinguistic perspective

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Abstract: This study examines the ability to produce phonemes in stroke patients from a neuropsycholinguistic perspective. The case study involved two stroke survivors who experienced disturbances in the frontal lobe (located in the left hemisphere) and were categorized as having moderate strokes. Data were collected through in-depth interviews, audio recordings, and documentation. The analysis employed an interactive data analysis model, which included stages such as data condensation, data presentation, and conclusion drawing. The results indicated that speech production disorders in stroke patients are closely related to aphasia syndromes, particularly Broca's aphasia, which causes articulation difficulties due to weakened motor control of speech organs. Patients were only able to produce limited sentences, typically consisting of four to six words. In addition to the consonant /r/, which is a phoneme with high complexity in tongue movement, there were also difficulties in pronouncing the consonants /s/, /l/, /t/, and /d/, which require coordination of tongue movement with the palate and teeth. Conversely, vowel phoneme production remained within normal limits. Consistent family support plays a significant role in accelerating speech recovery in patients. These findings contribute to a better understanding of post-stroke phonological disorders and can serve as a foundation for developing effective speech rehabilitation strategies.

Keywords: *Neuropsycholinguistics, Phoneme, Stroke.*

1. Introduction

Stroke is a severe medical disorder that can damage one hemisphere of the brain [1]. It happens when blood flow to the brain is blocked (ischaemic stroke) or a blood vessel breaks (hemorrhagic stroke) [2-4]. The brain has two halves, the left and right, that work together to manage language and cognitive activities [5, 6]. Thus, the location of the brain damage induced by a stroke significantly affects the kind of impairment that occurs.

Strokes in the left hemisphere usually lead to language problems and paralysis on the right side of the body. Aphasia (trouble understanding or making language), dysarthria (trouble articulating because of weak speech muscles), apraxia of speech (trouble planning speech movements), and phonological disorders (trouble pronouncing certain sounds, primarily because of limited tongue movement) are all common disorders [7-9]. Those disorders occur because the left hemisphere is primarily responsible for linguistic processes, including speech production, comprehension, and verbal memory [10-12]. Stroke can also change the rhythm of speech, making it sound flat and unexpressive. These issues not only impair speech skills but also adversely influence the quality of life, social interactions, and mental health of stroke survivors [13, 14]. Strokes in the right hemisphere, on the other hand, might create problems with seeing and understanding space, paralysis on the left side of the body, and not being aware of one's own body (anosognosia) [15, 16].

The interconnection between neurology and linguistics, as in stroke cases, makes neuropsycholinguistics arise as an interdisciplinary domain that examines the correlation between the brain's nervous system and linguistic proficiency. Stroke, especially ischaemic stroke affecting the left

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hemisphere, is recognised to impair speech motor abilities [17]. Thus, it potentially influences phoneme generation. Numerous prior studies have focused on early stroke diagnosis and artificial intelligence-driven speech analysis. Nevertheless, qualitative investigations into phoneme production patterns among stroke survivors within a neuropsycholinguistic framework remain somewhat constrained. Moreover, limited research has particularly investigated articulation challenges in stroke survivors possessing advanced academic backgrounds and language proficiency prior to the event.

This study seeks to elucidate phoneme generation capabilities in stroke patients through a neuropsycholinguistic framework. The primary focus is on problems with consonant articulation and how family support can aid in healing. It is anticipated that the findings of this study will enhance the advancement of neuropsycholinguistic-based speech therapy and augment interdisciplinary understanding that integrates linguistics, neurology, and psychology.

2. Method

This study utilised a case study methodology, a qualitative research technique designed for comprehensive analysis of a phenomenon, individual, group, process, or event within a real-world environment, characterised by distinctly established parameters [18]. This methodology was selected to achieve a comprehensive comprehension of the particular phonological capabilities of stroke patients from a neuropsycholinguistic standpoint. The study subjects, chosen through purposive sampling, included two university lecturers: one from the Indonesian Language and Literature Education Study Program, who experienced a stroke due to frontal lobe (left hemisphere) damage and has been classified as having a moderate stroke since 2011, and the other from the Fine Arts Education Study Program, who suffered a similar stroke in 1992.

Three primary methods were used to collect data: in-depth interviews, audio recordings, and written records. Interviews were conducted to gather information about the subjects' experiences with communication difficulties, emotions, perceptions, and linguistic conditions following a stroke, employing a semi-structured interview guide created using the Google Forms platform. Audio recordings were utilised to capture the subjects' verbal performance, especially with the pronunciation of specific damaged phonics. Documentation corroborated the research findings by examining medical histories, speech treatment documents, and pertinent observational data.

The data were analysed using interactive data analysis model, in three main steps: data condensation, which means sorting and simplifying the data based on the research focus by looking for meaningful patterns, themes, and relationships; data presentation, which means putting the data into a structured narrative and thematic format; and drawing conclusions and checking them against the main findings to get a complete picture of the phenomenon of impaired phonology in stroke patients (Miles et al., 2014).

3. Findings and Discussion

The study's findings reveal that the speech output of two informants who suffered a stroke exhibited signs of aphasia resulting from lesions in the frontal and temporoparietal regions of the left hemisphere of the brain. This is further supported by restricted verbal capabilities, including the removal and substitution of phonemes, along with challenges in constructing whole speech patterns. Stroke victims have significant difficulty making phonemes because damage to the left side of the brain limits their capacity to do so. The left hemisphere is in charge of language tasks like grammar, pronunciation, naming, and logical-analytical processing [19, 20]. Consequently, damage to this region frequently results in aphasia disorders, notably Broca's aphasia, which is marked by the inability to speak fluently, although language comprehension remains intact [21, 22]. Stroke patients with nonfluent aphasia usually have speech problems because the left frontal lobe, specifically Broca's region, is damaged [23, 24]. Broca's region is in charge of planning and carrying out the motor motions needed for speech, such as coordinating the muscles of the tongue, lips, jaw, and larynx [25, 26]. Thus, when a stroke injures this part of the brain, people have trouble making precise muscular signals to make speech sounds. As a

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result, communication is minimal; it is jerky, choppy, and often sounds like "telegraphic" style, with only main words (such as nouns and verbs) and no complete sentences [27-29].

From a linguistic point of view, poor phoneme production can be seen in several types of articulation problems, especially with dental-alveolar and labial consonants, which need precise tongue and lip movements. Phonemes can be replaced, left out, or added, which is how mistakes happen. For instance, people who have this condition often make their speech more telegraphic or can only say 4 to 6 words at a time [30]. An examination of two stroke patients indicated that impairment to the left hemisphere markedly affected phoneme generation, especially consonants, necessitating intricate motor control. The phoneme /r/ was the sound that both interviewees had the most trouble saying, which shows that post-stroke damage to the neuromotor system makes it very hard to say consonants that require tongue vibration and intricate motor control. Additionally, deficits were identified in the articulation of the consonants /s/, /l/, /t/, and /d/, necessitating the coordination of tongue movement with the palate and teeth. Patients frequently replace or remove these consonants in their speech, particularly in initial and medial locations within words. In other words, left hemisphere injury has the biggest effect on consonants that need exact motions of the tongue and lips.

Table 1.
Phonemes that are Impaired and the Forms of Articulation Difficulties Experienced.

Phonemes	Place of Articulation	Manner of articulation	Difficulty
/r/	Alveolar	Rapid tongue vibration on the hard palate (trill/tap)	The most difficult. Requires fine motor and rhythmic control. Often replaced by /l/, /d/, or omitted.
/s/	Alveolar	Blowing air between the tongue and teeth	Inability to precisely control the airflow. Replaced by /t/ or missing in words.
/l/	Alveolar lateral	The tip of the tongue touches the alveoli, and air comes out from the sides of the tongue.	Lateral coordination is impaired. The phoneme /l/ sounds blurred or resembles /d/.
/t/ dan **/d/**	Dental-alveolar	Alveolar tongue pop (voiceless /t/, voiced /d/)	The tip of the tongue has difficulty reaching the point of articulation. Substitutions or omissions occur, especially at the beginning of words.

Table 1 shows that phonemes with articulation points in the front of the oral cavity, particularly dental-alveolar and alveolar, are the most vulnerable groups to impairment in patients with left frontal lobe stroke. This occurs because these phonemes require fine synchronization between tongue movement, airflow, and oral muscle tension, which is heavily influenced by the neuromotor system. For example, the sound /r/ requires rapid tongue vibration against the palate, making it very difficult to produce if muscle control is impaired.

Unlike consonants, vowels such as /a/, /i/, /u/, /e/, and /o/ tend to be relatively well produced. This is because vowel articulation does not require as fine motor coordination as alveolar consonants [31, 32]. Vowels are produced by changes in the shape of the oral cavity and the general position of the tongue without requiring direct contact between the organs of articulation [33, 34]. Thus, even though overall word production is impaired, patients can still pronounce vowels clearly, allowing some parts of speech to be recognized.

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Table 2.
Comparison of Difficulties in Consonant and Vocal Phoneme Production for Left Frontal Lobe Stroke Patients.

Aspects of Phoneme Production	Consonant Phonemes	Vowel Phonemes
Motor Coordination Level	High (requires precise movements of the tongue, lips, and teeth)	Low to moderate (only requires tongue position and oral cavity shape)
Specific Point of Articulation Involvement	Yes (e.g., alveolar, dental, bilabial)	No (no direct contact between organs)
Sensitivity to Broca's Area Lesions	High (impaired detailed motor skills)	Low (can still be controlled by other areas or simple motor pathways)
Complexity of Articulatory Movements	Complex (e.g., trills, pops, fricatives)	Simple (opening and changing the position of the cavity)
Speech Output	Discontinuous, may be interrupted or lost	Generally stable and audible

Table 2 shows that vowel production is generally neuromotorically simpler than consonant production. Vowel phonemes do not require rapid movements, high air pressure, or complex coordination between the speech organs. For example, to pronounce the vowel /a/, a person only needs to open the mouth and adjust the general position of the tongue without having to touch the tongue to a specific point. In contrast, to pronounce /r/ or /s/, the tongue must move with a specific speed, direction, and pressure, which are greatly affected by damage to motor areas of the brain such as Broca's area. As a result, even though patients with left frontal lobe strokes experience severe impairment of consonant articulation, they can still pronounce vowels quite well, so that their speech, although choppy, still contains recognizable sound elements. From that finding, this study confirms the relationship between articulation complexity and the likelihood of post-stroke disorders, as shown in Figure 1.

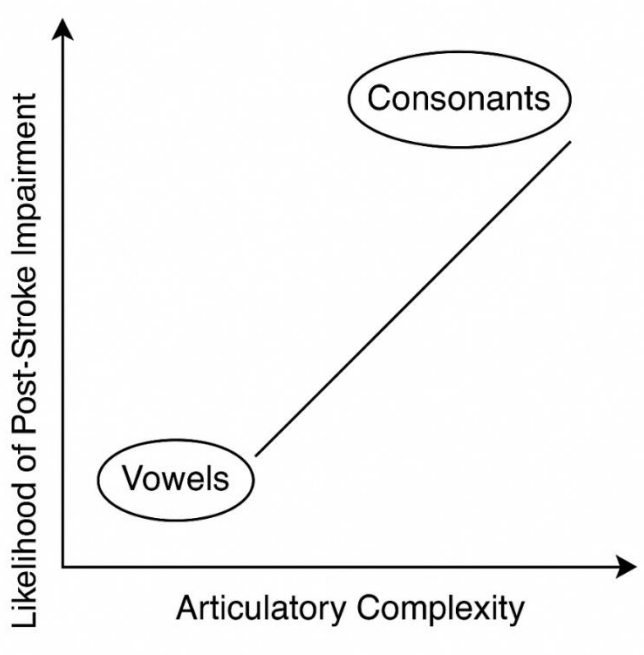

Figure 1.
Relationship between Articulation Complexity and the Likelihood of Post-Stroke Disorders.

Post-stroke linguistic proficiency was markedly affected by the speech therapy, social background, and familial support [35-37]. The treatment consisted of intonation therapy, behavioural therapy, and

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auditory exercises aimed at enhancing linguistic awareness and articulation [38]. Even though the rehabilitation procedure did not fully restore the patient's language skills to their original level, their excitement and regular therapy significantly improved their speaking skills.

These findings corroborate neuropsycholinguistic research indicating that language production arises from a complex interplay of the neurological system, articulatory organs, and cognitive language systems. Aphasia syndromes that occur due to post-stroke brain injury illustrate a direct correlation between neurological structures (including the motor cortex, Broca's area, and the white matter) and linguistic processes such as articulation, morphology, and syntax. Consequently, these findings emphasise the significance of an interdisciplinary approach in the treatment of stroke patients, primarily through the collaboration of neurologists, linguists, and psychologists to achieve optimal language recovery.

The results of this study demonstrate that phonemic production in stroke survivors is directly influenced by injury to the left hemisphere of the brain, specifically to Broca's region and the motor network facilitating articulation. This is in line with classical neurolinguistic theory, which says that the left hemisphere is in charge of important language tasks like speech planning, articulation, and syntax [19, 20]. Problems with the consonants /r/, plosives, and nasals show that the brain and speech organs do not work well together, especially when it comes to managing the small motions needed to say complicated phonemes.

Moreover, results indicating difficulties in pronouncing the consonants /s/, /l/, /t/, and /d/ corroborate evidence that the coordination among the tongue, palate, and teeth is similarly compromised. These phonemes necessitate precise control of tongue movements; thus, disruption to the fine motor pathways in the brain post-stroke results in phonetic and phonological problems in patients. On the other hand, the fact that the capacity to make vowel sounds is still mostly intact suggests that the pathways that control vowel sounds are less likely to be damaged by problems with the neuromotor system, or that making vowel sounds does not rely as much on complicated motions [33, 34].

Clinically, this underscores the significance of neuropsycholinguistic-based speech treatment that addresses not just articulation but also language motor planning and phonological awareness, especially for consonants necessitating exact coordination. These findings augment the existing literature regarding the correlation between the locus of brain lesions and the resultant language impairments, thus establishing a foundation for the formulation of a more focused rehabilitation strategy for patients with nonfluent aphasia secondary to stroke.

4. Conclusion

This study demonstrates that a stroke impacting the left hemisphere of the brain, particularly the frontal lobe region linked to speech motor function, profoundly influences phoneme production, especially for consonants that require great articulatory precision. The consonants /r/, /s/, /l/, /t/, and /d/ had the most noticeable problems with phoneme formation. These sounds need the tongue, palate, and teeth to work together in a highly complex way. Errors in producing these consonants were usually substitutions, omissions, or additions. This shows that the person had trouble planning and making fine motor motions. Conversely, the generation of vowel phonemes such as /a/, /i/, /u/, /e/, and /o/ remained within normal parameters. This indicates that more straightforward vowel generation processes, which do not rely on a precise point of articulation, have considerable resilience to the neurological effects of stroke. Consequently, these results indicate that articulatory complexity is closely related to the extent of phonological impairment following a stroke.

The practical consequences of these results underscore the necessity of formulating speech treatment that emphasises articulatory coordination training, especially for complex consonants, within a language rehabilitation program for stroke patients. This therapy could involve intonation training, oral motor exercises, and a neurolinguistic-based multimodal approach to help with full speech recovery. This study also offers a conceptual enhancement for the creation of a more tailored and context-specific individual linguistic rehabilitation intervention model.

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This study has various limitations, including the small number of individuals, which limits the generalizability of the results, and the lack of direct brain imaging data to confirm the site of neurological lesions. Moreover, the study concentrated exclusively on phonemic elements, neglecting other linguistic dimensions, including morphology and syntax. Consequently, subsequent research should incorporate a larger participant pool, employ neuroimaging data to enhance clinical outcomes, and broaden the study's focus to include more linguistic elements influenced by stroke. Creating phonemic evaluation tools based on neurolinguistics and measuring the efficiency of therapeutic interventions for complex consonants are also significant goals for more effective and targeted language rehabilitation.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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