Phonological Disorder in Speaking Among Stroke Patients: A Neurolinguistics Study

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Abstract

The objective of this research is to identify the types of phonological disorders in Indonesian-speaking stroke patients and to determine the disturbed dominant hemisphere based on the structure of these phonological disorders. The data are obtained from the utterances of stroke patients who experience difficulty in producing speech. Data are collected using the listening method related to language disorders in stroke patients with basic recording techniques, followed by the technique of free listening without speech involvement. Data analysis uses the matching method, with the basic technique being the KES (Key Element Segregation) technique, which involves categorizing phonological disorders such as addition, omission, substitution, or metathesis in vowel and consonant sounds. Additionally, the dominant disturbance in either Broca's or Wernicke's areas, as viewed through the phonological disorders, is identified. The results show that phonological disorders occur more frequently in consonant sounds (54.66%) compared to vowel sounds (45.33%) in stroke patients. Sound omission and substitution are the two most common types of disturbances observed. The analysis also suggests that phonological disorders in most stroke patients are related to disturbances in the dominant hemisphere, particularly in Broca's area, which controls speech sound production. However, there is one case (Patient V) that indicates a disturbance in the language comprehension area, Wernicke's area.

Keywords: broca's area, wernicke's area, phonological disorders, neurolinguistics, stroke.

Abstrak

Penelitian ini bertujuan untuk mengidentifikasi tipe-tipe gangguan fonologis yang terjadi pada penderita stroke dalam berbahasa Indonesia dan menentukan hemisfer dominan yang terganggu berdasarkan susunan gangguan fonologis tersebut. Metode yang digunakan adalah deskriptif kualitatif dengan pendekatan neurolinguistik. Data diambil dari ujaran penderita stroke yang mengalami kesulitan dalam memproduksi ujaran. Teknik pengumpulan data menggunakan metode simak dengan teknik dasar rekam dan dilanjutkan dengan teknik simak bebas libat cakap. Metode dan teknik analisis data menggunakan metode padan, teknik dasarnya adalah teknik pilah unsur penentu (PUP) yaitu dengan memilah-milah gangguan fonologis yang meliputi adisi, omisi, substitusi atau metatesis pada bunyi vokal dan konsonan. Begitu juga dengan memilah-milah hemisfer dominan area Broca atau Wernicke yang terganggu dilihat dari gangguan fonologis yang terjadi. Hasil penelitian menunjukkan bahwa gangguan fonologis lebih sering terjadi pada bunyi konsonan (54,66%) dibandingkan bunyi vokal (45,33%) di antara penderita stroke. Omisi dan substitusi bunyi merupakan dua jenis gangguan yang paling sering terjadi pada ujaran penderita stroke. Analisis juga menunjukkan bahwa gangguan fonologis pada sebagian besar penderita stroke terkait dengan gangguan pada hemisfer dominan, khususnya area Broca, yang mengendalikan produksi bunyi ujaran. Namun, terdapat satu kasus yang menunjukkan gangguan pada area pemahaman bahasa, yaitu area Wernicke pada penderita stroke V.

Kata Kunci: *area broca, area wernicke, gangguan fonologis, neurolinguistik, stroke.*

1. Introduction

Phonological aspects of speaking performance are deeply rooted in the brain's neurological functions. Brain regions such as Broca's area and Wernicke's area play pivotal roles in the production and comprehension of speech sounds, directly influencing phonological processes. Damage to these regions, as commonly observed in stroke patients, can severely impair the ability to produce and understand language sounds, resulting in various phonological disorders. Language disorders refer to the inability or difficulty in verbal or written communication, caused by various factors including brain injury, illness, or other neurological conditions. A common type of language disorder is phonological disorder, which occurs when individuals experience challenges in producing or understanding the sounds used to form words (LaPointe, 2005; Murdoch, 2010). Phonological disorders can be described as difficulties in the use and comprehension of linguistic sounds, stemming from disruptions in an individual's phonological system. According to the American Speech-Language-Hearing Association (ASHA) (2020), phonological disorders refer to difficulties in organizing and using phonemes within a language. Rvachew (2007) emphasizes that phonological disorders represent a complex aspect of language disorders, affecting an individual's ability to accurately produce and comprehend linguistic sounds. This phenomenon is not limited to adults but also occurs in children, with causes ranging from genetic to environmental factors that impact the proper use of language sounds (Ingram, 2002). In the context of language use, phonological disorders are particularly concerning among stroke patients, as their effects often extend to multiple facets of daily life. Stroke survivors frequently experience phonological impairments due to damage in brain regions involved in sound processing and phoneme production.

Stroke-induced speech disorders significantly affect communication abilities, manifesting in conditions such as apraxia of speech, dysarthria, and aphasia (Rahmadani, 2018). While existing studies have explored the effects of stroke on language processing and neural mechanisms, there remains a need for deeper understanding of its impact on speech abilities and brain functions. Johan and Susanto (2018) assert that the complexities and variations of language impairments in stroke patients are considerable. Stroke survivors may encounter diverse linguistic challenges, ranging from difficulties in comprehending words and sentences, to struggles with articulating appropriate words and phrases, as well as challenges in reading and writing. Furthermore, stroke can adversely affect cognitive functions such as reasoning, memory, and concentration. Among these impairments, phonological disorders frequently attributed to stroke are particularly significant and are characterized as disruptions in linguistic function arising from brain dysfunction.

Blumstein (1995) highlight two principal brain regions are implicated in stroke-related language impairments: Broca's area and Wernicke's area. Located in the left hemisphere, Broca's area governs language production, while Wernicke's area is crucial for language comprehension. When a stroke impacts one or both of these regions, it can result in multifaceted language impairments, including difficulties in producing coherent speech or understanding spoken language (Saur et al., 2008). These disorders stem from damage to various brain regions responsible for language processing, particularly the left hemisphere. The severity and nature of the speech impairments depend on the location and extent of the brain injury (Hillis, 2007).

A notable manifestation of stroke-related linguistic impairments is the disruption in the production and recognition of speech sounds. Stroke survivors often struggle to produce and differentiate specific linguistic sounds, particularly in the articulation of speech phonemes (Johan & Susanto, 2018). For example, when attempting to say the word bola, a patient may omit the voiced bilabial consonant [b], rendering the word as ola. This omission, or consonant sound elision, is attributed to damage in brain areas involved in processing speech sounds. Consequently, stroke patients may face challenges in recognizing and producing specific linguistic sounds. Another example involves difficulties in distinguishing phonetically similar sounds, such as the voiceless bilabial [p] versus the voiced bilabial [b], or the voiceless labiodental [f] versus the voiced labiodental [v]. These challenges can significantly impair everyday conversational understanding, rendering communication arduous for stroke patients.

This study focuses on investigating the production of vowel and consonant sounds in Indonesian-speaking stroke patients with language impairments, while examining the neurological basis of such impairments in the dominant cerebral hemisphere. The primary objectives are to identify the types of phonological errors exhibited by stroke patients, analyze disruptions in the dominant hemisphere's phonological mechanisms, and contribute to a deeper understanding of the neurolinguistic dimensions of stroke-related language impairments.

Previous researches such as Johan & Susanto (2018); Ramadani (2018); and Nabila (2019) have provided foundational insights into language disorders in stroke patients, yet several gaps remain that warrant further investigation. This study aims to supplement and expand existing knowledge with a specific focus on phonological impairments in stroke patients. Prior studies have not thoroughly examined phonological disorders, particularly in the production of vowel and consonant sounds. Moreover, few studies have explored the relationship between brain hemisphere damage and phonological disturbances in stroke patients. This research seeks to address these gaps by analyzing phonological language impairments, with particular attention to the production of vowels and consonants, and exploring the hemispheric damage associated with the observed phonological deficits. Distinct from previous studies, this research employs Blumstein's (1994) theoretical framework on sound changes and utilizes the theory of lateralization to identify the affected brain regions.

The research hypothesizes that stroke-induced damage to Broca's area, Wernicke's area, or the Arcuate Fasciculus significantly contributes to phonological errors, such as substitutions, additions, omissions, and metathesis. The study aims to deepen the understanding of the neurolinguistic dimensions of stroke-related language impairments by examining these phonological disturbances and their correlation with specific brain regions. By integrating Blumstein's (1994) Theory of Sound Change and the Theory of Lateralization, this research seeks to elucidate how damage to critical brain areas disrupts phonological processing. Ultimately, this study aspires to contribute valuable insights into targeted therapeutic interventions for improving speech performance in stroke patients.

Stroke patients often experience phonological impairments as a direct consequence of damage to brain areas involved in the production and comprehension of speech sounds. These disorders may manifest as substitutions, additions, omissions, and metathesis of sounds, leading to difficulties in both speech production and comprehension. According to Jones et al. (2019), phonological disturbances in stroke patients can result from damage to key brain regions such

as Broca's area and Wernicke's area, which play pivotal roles in language production and comprehension.

Blumstein (1994) identifies several types of phonological disorders that can be observed, including:

a. Substitution: This occurs when an individual replaces one sound with another in their speech. For example, substituting the sound /k/ with /t/, so that "kucing" is pronounced as "tucing."
b. Addition: Addition occurs when an individual inserts an extra sound into a word. For instance, inserting the sound /s/ between two syllables, causing "rumah" to be pronounced as "rusuma."
c. Omission: Omission refers to the deletion of a sound from a word. An example is the removal of the sound /l/, leading to the pronunciation of "beli" as "bei."
d. Metathesis: Metathesis involves an irregular reordering of sounds in speech. An example is the misordering of sounds, such as the irregular sound pattern in the word "tempat," which is pronounced as "tepmat."

These phonological disruptions, often observed in stroke patients, highlight the complex interplay between brain function and language processing.
The theories explored in this research provide a comprehensive framework for understanding phonological disorders in stroke patients. This research critically reviews existing literature to establish a foundational understanding and identify gaps in the current body of knowledge. The study is anchored in two interconnected and correlated theoretical frameworks: Blumstein's Theory and the concept of Lateralization.

Blumstein's (1994) Theory of phonological disorder outlines several phonological impairments commonly observed in stroke patients, including substitutions (replacing one sound with another), additions (inserting extra sounds), omissions (deleting sounds), and metathesis (reordering sounds). These disorders can lead to significant challenges in speech production and comprehension. For instance, stroke patients with damage to Broca's area may struggle with the production of organized speech, while damage to Wernicke's area can result in fluent but semantically incoherent speech. The research aims to analyze these phonological disruptions in stroke patients, using observation and documentation of their speech patterns.

The Theory of Lateralization further informs the study by focusing on the role of the left hemisphere of the brain, particularly Broca's and Wernicke's areas, in language processing. Broca's area is crucial for speech production, while Wernicke's area is involved in language comprehension. The theory posits that damage to these areas leads to specific types of language impairments: damage to Broca's area results in difficulties in speech production, while damage to Wernicke's area affects language comprehension. The Arcuate Fasciculus connects these areas, and damage to this pathway can disrupt the coordination between speech production and comprehension.

By integrating Blumstein's theory of phonological disorder and the theory of lateralization, this research aims to provide a nuanced understanding of how specific brain damage correlates with phonological disturbances in stroke patients, shedding light on the connection between impaired speech production and the affected brain regions in the left hemisphere.

2. Method

This study adopts a qualitative research approach. Specifically, it employs a qualitative research design, with the overarching aim of narratively explaining the language disorders observed in stroke patients, particularly focusing on phonological impairments in speech. The research targets the verbal expressions of stroke patients who experience difficulties in language production, making their speech patterns the central object of analysis. Stroke patients were selected randomly, and their speech abilities were evaluated by analyzing their verbal outputs by addressing their sensitivity, maintaining eye contact, and giving patients enough time to express themselves without rushing or interrupting. This study is fundamentally qualitative in nature, aiming to provide a detailed and descriptive account of the phonological disruptions encountered by stroke patients in their speech production.

The data on the vowel and consonant sound disorders in stroke patients with language impairments were collected from spoken utterances asked in Indonesian from patients exhibiting phonological disturbances. Stroke patients often present phonological issues, including alterations or abnormalities in the articulation of Indonesian speech sounds. The data for this research was obtained from the speech of stroke patients, which was subsequently analyzed using a neurolinguistic approach to better understand the mechanisms behind phonological disorders in these individuals. This approach also investigates the role of the brain regions involved in language processing and the brain activity associated with speech disturbances in Indonesian.

The research employs the listening method, to collect data on language impairments in stroke patients. The listening method, involving observation, is deemed most suitable for studying this phenomenon. The researcher utilizes various data collection techniques, including conversation, recording, and note-taking. The primary technique employed is the recording method, where the researcher records the patients' speech to assess their linguistic abilities. This is followed by the advanced technique of Uninvolved Conversation Observation Technique (Simak Bebas Libat Cakap), where the researcher listens passively without engaging in the conversation. Additionally, conversations between stroke patients and their doctors are recorded for further analysis. Following the recording process, the note-taking technique is applied, where the researcher replays the patients' speech and documents any disruptions, including instances of substitution, omission, addition, and metathesis.

For data analysis, the study uses the articulatory comparing method, which examines how speech organs (such as the lips, tongue, and teeth) interact to produce speech sounds. This method aims to understand the relationship between the movement and position of these speech organs and the phonetic or phonemic sounds produced. As per Sudaryanto (2015), the primary technique used in this method is the basic technique being the PUP (Key Element Segregation) technique, which separates linguistic elements, particularly vowel and consonant sounds, to facilitate phonological analysis. The researcher also applies the Hubung Banding Menyamakan (HBS) technique, comparing the patients' utterances to those of normal speakers. The analysis is then conducted using Blumstein's (1994) theory of sound change to address the first research question, while the theory of lateralization is applied to assess which brain hemisphere is affected by the phonological impairments.

3. Results and Discussion

The results of this study indicate that phonological disorders occurred in all ten stroke patients, with a total of 75 disruptions. These disruptions were further divided into 45.33% related to vowel sounds and 54.66% related to consonant sounds. Below is a detailed breakdown of the phonological distorder observed in each patient:

Table 1. Results of Phonological Disorders in Stroke Patients

Stroke Patients	Phonological Distorder								Percentage
	Omission		Substitution		Addition		Metathesis		
	V	K	V	K	V	K	V	K	
Stroke Patients 1		2	3	2					9,33%
Stroke Patients 2	6	6	1						17,33%
Stroke Patients 3	1	2	2					3	10,66%
Stroke Patients 4	2	3	1			1			9,33%
Stroke Patients 5	-	-	-	-	-	-	-	-	-
Stroke Patients 6	1	4	2			1			10,66%
Stroke Patients 7	3	5	1						12%
Stroke Patients 8	3	4							9,33%
Stroke Patients 9	2	2	2	2		1			12%
Stroke Patients 10	1	1	3					2	9,33%
Percentage	25,33 %	38,66 %	20%	5,33%	0	4%	0	6,66%	

The findings of this study indicate that phonological disorders are more prevalent in consonant sounds than in vowel sounds among stroke patients. This result suggests that speech production impairments in stroke patients are generally more severe for consonants, which are

more complex to articulate than vowel sounds. Stroke patient V is an exception, as no phonological disturbances were observed in their speech.

Interpretation of Results

Based on the data analysis, the results can be interpreted in terms of the types of phonological disturbances observed, which include substitution, omission, addition, and metathesis. This analysis reveals how each type of disruption affects the production of speech sounds in individuals who have experienced a stroke.

The analysis shows that omission and substitution of sounds are the two most common types of disturbances in the speech of stroke patients. Omission, referring to the inability of the patient to fully articulate certain sounds, particularly occurs with consonants, with a significant number of instances of disruption. This suggests difficulty in producing the necessary consonantal sounds required for word formation. Substitution, on the other hand, occurs when the patient replaces certain sounds with others that are easier for them to produce. In this context, the most frequent disturbances involve vowel sounds, where substitution is observed, highlighting the challenges stroke patients face in producing specific and complex vowel sounds.

Both phenomena provide important insights into the phonological disorders experienced by stroke patients. The omission and substitution of sounds in speech indicate impairments in the motor control and coordination necessary for producing speech sounds. This understanding offers a deeper insight into the disturbances that occur within the dominant hemisphere of the brain, which is responsible for language processing and motor speech coordination.

Discussion

The phonological disorder of vowel sounds observed in stroke patients revealed an interesting pattern. Among the ten patients studied, nine of them (stroke patients 1, 2, 3, 4, 6, 7, 8, 9, and 10) experienced phonological disturbances in vowel sounds. However, it is important to note that one patient (stroke patient 5) did not exhibit any phonological disturbances in either vowel or consonant sounds. This phenomenon suggests the involvement of the phonological system in language processing in individuals affected by stroke. The observed disturbances in vowel sound production and/or perception in these patients indicate a disruption in the phonological processing, likely related to the involvement of the Broca's area in the dominant hemisphere of the brain.

Vowel Sounds

In the context of phonological disorders involving vowel sounds in stroke patients, one of the most common disturbances observed is omission. Omission refers to the inability of the patient to articulate certain vowel sounds, leading to their absence in speech production. This can occur due to damage in brain areas responsible for sound production, such as Broca's area, which governs the motor control needed for speech articulation. According to the data, stroke patients most frequently experience omission of vowel sounds, accounting for 55.88% of the identified phonological disturbances. Among these, the omission is most prominent in the vowel [a], a front, low, unrounded vowel.

This omission occurs because the stroke patients experience damage in brain areas controlling the muscles required to produce sounds. Observing the articulatory position, all nine

stroke patients showed significant difficulty in producing front vowels, with 70.5% of cases indicating disruptions. This damage affects their ability to coordinate the necessary motor movements for producing specific vowels. As a result, patients are unable to produce these sounds accurately, causing them to be omitted or unheard during speech production.

In the analysis of phonological disturbances in consonant sounds among the ten stroke patients, it was found that the number of patients with consonant sound disturbances was identical to the number of those with vowel sound disturbances. Specifically, nine patients (stroke patients 1, 2, 3, 4, 6, 7, 8, 9, and 10) exhibited phonological disturbances in consonant sounds, which aligns with the disturbances observed in vowel sounds. However, one patient, stroke patient number 5, did not show any phonological disturbances in consonants or vowels. This will be discussed further in the section detailing disturbances related to the affected hemisphere (dominant area of the brain).

Consonant Sounds

In terms of consonant sound disorders, the most frequent phonological disturbance identified was also omission. A total of 70.7% of cases exhibited omissions in consonant sounds. Omission, in this case, refers to the failure of patients to articulate certain consonants that should be present in words. Of these omissions, the consonants most frequently omitted were [k] (velar, stop, voiceless), [l] (alveolar, lateral, voiced), and [s] (alveolar, fricative, voiceless), with omission rates of 17.24%, 13.7%, and 13.7%, respectively. These consonants had the highest frequency of disturbance compared to other consonants.

In addition to [k], [l], and [s], omissions were also observed in other consonants, including [t] (10.3%), and [b], [m], [d], [n], and [r] (6.89% each), while [j], [c], and [y] each showed a 3.44% omission rate. Despite these disturbances, the omissions of [k], [l], and [s] remained the most prominent. This finding indicates that these particular sounds are the most susceptible to phonological omission in stroke patients in this study.

From an articulatory perspective, the nine stroke patients demonstrated specific difficulty in producing consonant sounds articulated at the alveolar ridge, as reflected by 51.2% of the identified disturbances. This suggests that patients had particular challenges with the articulation of consonants in this location, further indicating potential motor control issues at the level of the oral cavity.

Affected Hemisphere

The data analysis revealed an interesting pattern in the phonological disturbances observed in the ten stroke patients. For patients 1-4 and 6-10, the disturbances in their phonological structures generally indicated damage to the dominant hemisphere, particularly in Broca's area of the brain. This area plays a crucial role in controlling the production of speech sounds. Damage to Broca's area can lead to difficulties in producing the sounds needed to form words correctly. This is reflected in the presence of phonological disturbances such as omission, substitution, addition, and metathesis observed in these patients. However, there was an exception in Patient 5, who experienced damage in the Wernicke's area, responsible for language comprehension. Damage to Wernicke's area results in difficulties understanding spoken or written language. This indicates that while the production of speech sounds was affected, the

primary communication difficulty in this patient stemmed from the impairment in language comprehension, rather than the production of specific sounds.

In summary, this study provides valuable insights into the types and patterns of phonological disorders in stroke patients, highlighting the differential impact of damage to specific brain areas Broca's area and Wernicke's area on speech production and language comprehension.

The primary result of this study highlights that omission is the most prevalent phonological disturbance in stroke patients, affecting both vowel and consonant sounds. The analysis of the affected cerebral hemisphere further supports the role of brain regions in phonological disorders. For patients 1-4 and 6-10, phonological disturbances indicated damage to Broca's area in the dominant hemisphere, directly impacting speech production, conversely, Patient 5 exhibited damage to Wernicke's area. The findings were subjected to thorough analysis, confirming that the identified phonological disturbances are consistent with the neurological roles of Broca's and Wernicke's areas. This distinction between production and comprehension deficits underpins the study's hypothesis that specific brain regions correlate with distinct phonological errors.

4. Conclusion

This study conclusively demonstrates that stroke-induced damage to specific brain regions, particularly Broca's area, leads to significant phonological disorders in patients. This finding directly addresses the research hypothesis, confirming that disruptions in neural mechanisms governing speech production result in observable impairments in both vowel and consonant articulation.

The data reveal that consonant production was more severely impacted (54.66%) than vowel production (45.33%), emphasizing the greater articulatory complexity involved in forming consonant sounds. The most common phonological errors identified were omissions and substitutions, supporting the hypothesis that damage to motor speech regions disrupts the coordination necessary for precise articulation. Notably, the frequent omission of vowels [a] (front, low, unrounded) and [i] (front, high, unrounded), along with consonants [k] (velar, stop, voiceless), [l] (alveolar, lateral, voiced), and [s] (alveolar, fricative, voiceless), highlights specific vulnerabilities in speech sound production following a stroke.

The articulatory analysis further substantiates these findings, showing that 70.5% of vowel sound errors were concentrated in front vowels, while 51.2% of consonant errors occurred at the alveolar ridge. This pattern suggests that stroke patients face significant motor challenges in producing sounds that require refined tongue placement and movement, aligning with the theoretical understanding of Broca's area's role in motor speech control.

An important distinction was observed in subject 5, who exhibited damage to Wernicke's area rather than Broca's area. Unlike other patients who struggled with speech production, subject 5 experienced deficits in language comprehension. This contrast underscores the distinct functions of Broca's and Wernicke's areas, reinforcing the neurological basis for differentiating speech production and comprehension disorders.

This study not only confirms the initial hypothesis but also provides critical insights into how stroke-related brain damage manifests in specific phonological impairments. The results highlight the necessity for rehabilitation programs to develop targeted therapies that address

these speech production deficits. Such tailored interventions could significantly improve communication outcomes for stroke survivors, emphasizing the broader clinical implications of these findings.

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