GREAT JOURNS

Journal of Linguistics

Vol.1 No.2, September 2026

Neuroanatomical Correlates of Language Processing in Acquired Aphasia: A Lesion–Symptom Mapping Study of 40 Adults in the Kenyan Rift Valley

Mercyrose J. Jesang[1,*], **Benard Kodak**[2], **Kenneth Odhiambo**[3], **Beatrice Owiti**[4]

[1] PhD Candidate, Department of Linguistics, Maasai Mara University, Narok, Kenya

[2] Professor and Dean, School of Arts, Humanities, Social Sciences and Creative Industries, Maasai Mara University, Narok, Kenya

[3] Senior Lecturer, Maasai Mara University, Narok, Kenya

[4] Senior Lecturer, Meru University of Science and Technology, Meru, Kenya

**Corresponding author: Mercyrose J. Jesang, Maasai Mara University*



Great Journs
ISSN: 2328-4870
Vol.1 No.2, September, 2026

Journal homepage: www.greatjourns.com

ABSTRACT

Background: Knowledge of how focal brain lesions disrupt language has been built almost entirely on patients from Europe and North America. Stroke profiles, health-system resources and everyday language use differ markedly in sub-Saharan Africa, where many adults routinely use two or more languages. In Kenya, most urban and peri-urban adults use both Kiswahili and English daily, yet no study has related lesion location to language profile in this population.

Objective: To examine the relationship between lesion location and specific language deficits among adults with post-stroke aphasia in Nakuru County, Kenya, and to explore whether bilingual language use modulates the pattern of impairment.

Methods: A cross-sectional lesion–symptom study was conducted among 40 adults attending speech therapy at Nakuru County Referral Hospital between January and December 2024. All participants had a single, first-ever stroke confirmed on computed tomography (CT) or magnetic resonance imaging (MRI) and aphasia persisting for more than three months. Language was assessed with a shortened, culturally adapted version of the Boston Diagnostic Aphasia Examination covering fluency, auditory comprehension, naming and repetition. Lesion sites were coded from radiology reports by two independent reviewers into frontal, temporal, parietal and subcortical categories. Data were analysed in SPSS version 26 using Pearson (point-biserial) correlation and one-way analysis of variance (ANOVA).

Results: Frontal lesions involving Broca's area were most frequent (17/40, 42.5%), followed by temporal lesions around Wernicke's area (14/40, 35.0%), parietal lesions (6/40, 15.0%) and subcortical lesions (3/40, 7.5%). Frontal lesions were associated with reduced fluency and impaired repetition ($r = 0.71$, $p < 0.001$); temporal lesions with impaired auditory comprehension ($r = 0.68$, $p < 0.001$); parietal lesions with anomia ($r = 0.59$, $p = 0.002$); and subcortical lesions with mixed, milder deficits ($r = 0.42$, $p = 0.03$). Among 23 participants who used Kiswahili and English daily, naming in Kiswahili was better preserved than naming in English following temporal lesions (mean difference 1.2 points, $p = 0.04$).

Conclusion: This study, to our knowledge the first lesion–symptom investigation of aphasia in Kenya, shows that the classical perisylvian organisation of language holds in a Kenyan population, while bilingual experience shapes the profile of impairment. The cohort provides a foundation for larger imaging-based studies and for developing linguistically and culturally appropriate rehabilitation in East Africa.

Keywords: *aphasia; lesion–symptom mapping; stroke; bilingual aphasia; Broca's area; Wernicke's area; Kiswahili; Kenya; Rift Valley*

1. Introduction

Aphasia is an acquired disorder of language that follows damage to the brain, most commonly stroke, and affects a person's ability to speak, understand, read and write. For more than a century and a half, the study of aphasia has been the principal window through which scientists have inferred how language is organised in the human brain. Beginning with the observations of Broca (1861) and Wernicke (1874), and consolidated in the connectionist model of Geschwind (1970), the dominant view holds that language is lateralised to the left hemisphere and organised around the Sylvian fissure: anterior regions of the inferior frontal gyrus support speech production, posterior regions of the superior temporal gyrus support comprehension, and the connections between them support repetition.

These principles, however, were derived and subsequently refined almost exclusively in hospitals in Western Europe and North America, where neuroimaging is readily available and where most patients speak a single, dominant language. Behavioural science more broadly has been criticised for generalising from populations that are Western, educated, industrialised, rich and democratic to humanity as a whole (Henrich et al., 2010). Neurolinguistics is no exception. African patients, African languages and the multilingual realities of African speech communities are almost entirely absent from the lesion literature on which universal claims about the neurobiology of language rest.

This absence matters both scientifically and clinically. Stroke is a growing public health problem across sub-Saharan Africa, where incidence is rising, age at onset is younger and case fatality is higher than in high-income regions (Owolabi et al., 2015; GBD 2019 Stroke Collaborators, 2021). In Kenya, hospital-based studies report that stroke is a leading cause of adult neurological admission and death (Jowi & Mativo, 2008; Kaduka et al., 2018). International data indicate that roughly one-third of stroke survivors develop aphasia (Engelter et al., 2006; Flowers et al., 2016), implying that a substantial and growing number of Kenyans live with acquired language impairment. Yet no published study has linked lesion site to language profile in a Kenyan cohort, and speech and language therapy services remain scarce and concentrated in a few referral facilities.

Kenya's linguistic landscape adds a further dimension. Kiswahili and English are both official languages; Kiswahili is typically acquired early in the home or community, often alongside one of more than forty indigenous languages, while English is acquired later and predominantly through formal schooling. Most adults in urban and peri-urban centres such as Nakuru use both Kiswahili and English daily. This setting offers a natural opportunity to examine whether theories of bilingual language representation, such as Paradis' (2004) neurolinguistic theory of bilingualism, predict differential impairment of early- and late-acquired languages after focal brain damage.

Nakuru County is a suitable site for such work. It serves a mixed rural and urban population in the Rift Valley, and its county referral hospital offers CT imaging and an established speech therapy service. This study therefore set out to map lesion locations to language deficits among 40 adults with post-stroke aphasia in Nakuru.

1.1 Objectives

The study was guided by three specific objectives:

(i) to describe the distribution of lesion sites among adults with post-stroke aphasia attending a county referral hospital in the Kenyan Rift Valley;

(ii) to determine the association between lesion site and performance in fluency, auditory comprehension, naming and repetition; and

(iii) to compare naming performance in Kiswahili and English among bilingual participants in relation to lesion site.

2. Literature Review

2.1 The Classical Perisylvian Model

Broca (1861) described patients with severely reduced speech output but relatively preserved understanding whose post-mortem brains showed damage to the posterior inferior frontal gyrus, corresponding to Brodmann areas (BA) 44 and 45. Wernicke (1874) subsequently described fluent but meaningless speech with poor comprehension following damage to the posterior superior temporal gyrus (BA 22), and predicted that disconnection of the two regions would selectively impair repetition. Geschwind (1970) formalised these observations into the

Wernicke–Geschwind model, which remains the basis of most clinical classification systems, including the Boston Diagnostic Aphasia Examination (Goodglass et al., 2001) and the Western Aphasia Battery (Kertesz, 2007).

Subsequent clinico-pathological work refined rather than overturned this model. Mohr et al. (1978) showed that lesions confined to Broca's area produce only a transient disturbance, and that persistent Broca's aphasia requires larger lesions extending into the insula and underlying white matter. Kertesz et al. (1993) demonstrated that recovery of comprehension in Wernicke's aphasia depends on the extent of damage to the superior temporal and supramarginal regions. These studies established that lesion size, lesion location and time post-onset jointly determine the aphasic profile.

2.2 Contemporary Lesion–Symptom Mapping and Network Models

The introduction of voxel-based lesion–symptom mapping (VLSM) allowed researchers to relate behavioural scores to lesion status at every voxel across groups of patients, without first classifying patients into syndromes (Bates et al., 2003; Rorden & Karnath, 2004). VLSM studies have confirmed the central role of the left perisylvian cortex while revealing important additional contributors. Dronkers (1996) implicated the left anterior insula in speech articulation planning, and Dronkers et al. (2004) showed that sentence comprehension depends on a distributed set of regions including the middle temporal gyrus, anterior superior temporal gyrus and inferior frontal cortex.

Neuroimaging in healthy participants led to the dual-stream model, in which a ventral stream running through the temporal lobe maps sound to meaning and a dorsal stream linking posterior temporal–parietal cortex with frontal regions maps sound to articulation (Hickok & Poeppel, 2007). Lesion evidence supports this account: large-scale mapping studies have shown that comprehension and semantic deficits load on ventral temporal regions while repetition and phonological production deficits load on dorsal temporo-parietal and frontal regions (Fridriksson et al., 2016; Mirman et al., 2015). Reviews of two decades of functional imaging (Price, 2012) and critical appraisals of the classical model (Binder, 2015; Tremblay & Dick, 2016) have argued that the terms "Broca's area" and "Wernicke's area" are best understood as convenient labels for nodes within larger, interacting networks.

2.3 Parietal and Subcortical Contributions

Naming difficulty, or anomia, is the most pervasive symptom of aphasia and occurs with lesions in many locations. VLSM analyses of the Boston Naming Test have associated naming failure with the left middle and inferior temporal gyri, the supramarginal and angular gyri (BA 40 and 39) and underlying white matter pathways (Baldo et al., 2013). The inferior parietal lobule is thought to support phonological short-term memory and the retrieval of word forms, which explains why parietal lesions frequently produce anomia and conduction-type deficits.

Aphasia following subcortical stroke, particularly involving the basal ganglia and thalamus, is typically milder and more variable than cortical aphasia. Nadeau and Crosson (1997) argued that many such cases reflect cortical hypoperfusion or disconnection rather than a direct role of subcortical structures in language, while Radanovic and Mansur (2017) concluded that subcortical aphasia is heterogeneous and generally carries a better prognosis. These observations predict that subcortical lesions will show weaker and less specific associations with language deficits than cortical lesions.

2.4 Bilingual Aphasia

More than half of the world's population uses more than one language, and bilingual aphasia presents recovery patterns that monolingual models cannot explain. Patients may show parallel recovery of both languages, or differential, selective, successive or antagonistic recovery (Fabbro, 2001; Lorenzen & Murray, 2008). Paradis (2004) proposed that both languages share the same broad neural substrate but are organised as separable subsystems, and that languages acquired early and informally rely more on implicit, procedural memory, whereas languages acquired later and through formal instruction rely more on explicit, declarative memory. Ullman's (2001) declarative/procedural model makes related predictions: lexical knowledge, supported by temporal lobe declarative memory systems, should be particularly vulnerable in a later-learned language after temporal damage.

Other accounts emphasise language control. Green's (1998) inhibitory control model and the neurocognitive framework of Abutalebi and Green (2007) propose that impaired recovery of a language may reflect damage to control networks that select and inhibit languages, rather than loss of the representations themselves. A meta-analysis by Kuzmina et al. (2019) found that age

of acquisition, premorbid proficiency and frequency of use all predict relative impairment across languages. Critically, nearly all of this evidence comes from European, North American and Asian language pairs; bilingual aphasia involving African languages has received almost no attention.

2.5 Stroke, Aphasia and Research Gaps in Africa

Sub-Saharan Africa carries a disproportionate share of the global stroke burden, driven largely by uncontrolled hypertension (Owolabi et al., 2015; Feigin et al., 2022). Access to neuroimaging, stroke units and rehabilitation is limited, and speech and language therapists are few. Aphasia assessment tools have been developed and normed mainly in English and other European languages, and methodological guidance stresses that tests must be adapted linguistically and culturally rather than simply translated (Beaton et al., 2000; Ivanova & Hallowell, 2013). To date, there is no published, standardised aphasia battery in Kiswahili and no lesion–symptom study from Kenya. The present study addresses this gap by applying a feasible, replicable lesion-coding approach within routine clinical services.

3. Materials and Methods

3.1 Study Design and Setting

A cross-sectional lesion–symptom study was carried out at the speech therapy and physiotherapy clinic of Nakuru County Referral Hospital, the main public referral facility for Nakuru County and neighbouring counties in the Rift Valley region of Kenya. The hospital provides CT imaging on site and receives referrals from both rural and urban catchment areas. Data were collected between January and December 2024.

3.2 Participants

Forty adults with post-stroke aphasia were enrolled. Inclusion criteria were: age 18 years or above; a first-ever stroke; aphasia persisting for at least three months after onset; and an available CT or MRI report confirming a single lesion. Participants were excluded if they had a history of previous brain injury or neurological disease, a diagnosis of dementia, or visual or hearing impairment severe enough to prevent testing. The restriction to chronic aphasia (more

than three months post-onset) was intended to reduce the influence of acute oedema, diaschisis and rapid spontaneous recovery on the lesion–symptom relationship.

Participants were also classified by language use. Those who reported using both Kiswahili and English in daily life before their stroke were classified as bilingual for the purposes of the cross-language comparison.

3.3 Language Assessment

Language was assessed by the principal researcher using a shortened version of the Boston Diagnostic Aphasia Examination (BDAE; Goodglass et al., 2001). Four domains were scored: (a) *fluency*, based on phrase length, grammatical form and articulatory agility in conversational and picture-description speech; (b) *auditory comprehension*, based on word discrimination, commands and complex ideational material; (c) *naming*, based on confrontation naming of pictured objects; and (d) *repetition*, based on repetition of words and sentences of increasing length. Each domain was rated on a 0–5 scale, with higher scores indicating better performance.

Items were translated into Kiswahili where required and back-translated into English to check equivalence, following established principles of cross-cultural adaptation (Beaton et al., 2000; Ivanova & Hallowell, 2013). Pictured items were reviewed for cultural familiarity so that stimuli were recognisable to participants from the Kenyan context. For bilingual participants, naming was assessed separately in Kiswahili and in English to allow within-person comparison.

3.4 Lesion Classification

Lesion location was extracted from the formal CT or MRI radiology report for each participant. Lesions were grouped into four categories according to the principal region involved: frontal (inferior frontal gyrus, BA 44/45, Broca’s area), temporal (posterior superior temporal gyrus, BA 22, Wernicke’s area), parietal (supramarginal and angular gyri, BA 40/39) and subcortical (basal ganglia, internal capsule and/or thalamus without cortical involvement). Two reviewers coded each report independently, blind to language scores, and disagreements were resolved by discussion until consensus was reached.

3.5 Ethical Considerations

Ethical approval was obtained from the Maasai Mara University Institutional Ethics Review Committee, and permission to conduct the study was granted by the Nakuru County Department of Health. Because aphasia can compromise comprehension of written and spoken information, consent forms were simplified and supported with pictures and gesture. Written informed consent was obtained from each participant or, where the participant was unable to give informed consent, from the next of kin. Participation was voluntary, did not affect access to therapy, and all data were anonymised before analysis.

3.6 Data Analysis

Data were entered and analysed in IBM SPSS Statistics version 26. Descriptive statistics (frequencies, percentages, means and standard deviations) summarised participant characteristics and lesion distribution. For correlation analyses, each lesion site was dummy-coded (1 = lesion present in that region, 0 = absent) and the corresponding domain deficit score was correlated with lesion status using Pearson's product-moment correlation, which for a dichotomous predictor is equivalent to the point-biserial coefficient. One-way analysis of variance (ANOVA) compared language domain scores across the four lesion groups. Among bilingual participants, Kiswahili and English naming scores were compared within lesion groups using paired comparisons. Statistical significance was set at $p \leq 0.05$.

4. Results

4.1 Participant Characteristics

Forty adults with chronic post-stroke aphasia took part. Their mean age was 58.3 years (SD = 12.1). Twenty-two (55.0%) were male and eighteen (45.0%) were female. Twenty-three participants (57.5%) reported daily use of both Kiswahili and English before their stroke; the remaining seventeen (42.5%) did not report daily use of both languages. Participant characteristics are summarised in Table 1.

Great Journs
ISSN: 2328-4870
Vol.1 No.2, September, 2026

Table 1. *Characteristics of participants (N = 40)*

Characteristic	Value
Age, years, mean (SD)	58.3 (12.1)
Sex, male, n (%)	22 (55.0)
Sex, female, n (%)	18 (45.0)
Daily Kiswahili–English use, n (%)	23 (57.5)
Stroke history	Single, first-ever stroke (all)
Time post-onset	> 3 months (all)
Imaging confirmation	CT or MRI report (all)

Note. SD = standard deviation; CT = computed tomography; MRI = magnetic resonance imaging.

4.2 Distribution of Lesion Sites

The majority of participants had frontal lesions involving Broca's area (17/40, 42.5%), followed by temporal lesions around Wernicke's area (14/40, 35.0%). Parietal lesions accounted for 6 cases (15.0%) and purely subcortical lesions for 3 cases (7.5%). Taken together, 31 of 40 participants (77.5%) had lesions in the classical anterior or posterior perisylvian language zones. The distribution is shown in Figure 1.

Great Journs
ISSN: 2328-4870
Vol.1 No.2, September, 2026
Journal homepage: www.greatjourns.com

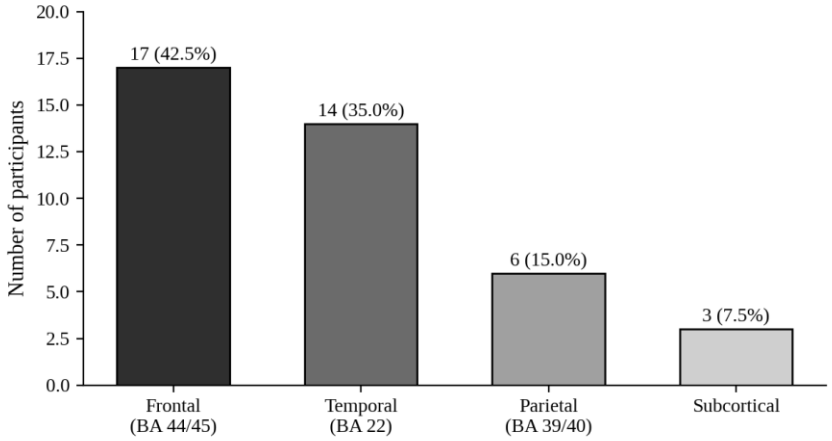


Figure 1. Distribution of lesion sites among adults with post-stroke aphasia at Nakuru County Referral Hospital (N = 40). BA = Brodmann area.

4.3 Association between Lesion Site and Language Deficit

Each lesion group showed a distinct and statistically significant association with a particular language domain (Table 2). Frontal lesions were strongly associated with non-fluent speech and impaired repetition ($r = 0.71$, $p < 0.001$). This profile corresponds to the classical pattern of non-fluent (Broca-type) aphasia.

Temporal lesions were strongly associated with impaired auditory comprehension ($r = 0.68$, $p < 0.001$). Parietal lesions were moderately associated with poor naming ($r = 0.59$, $p = 0.002$), reflecting word-finding difficulty in the context of relatively fluent output and adequate comprehension. Subcortical lesions showed a weaker association with mixed, milder deficits across domains ($r = 0.42$, $p = 0.03$).

Table 2. *Lesion site, main language deficit and strength of association (N = 40)*

Lesion site	n (%)	Main language deficit	*r*	*p*
Frontal (BA 44/45)	17 (42.5)	Non-fluent speech; poor repetition	0.71	< 0.001
Temporal (BA 22)	14 (35.0)	Poor auditory comprehension	0.68	< 0.001
Parietal (BA 39/40)	6 (15.0)	Poor naming (anomia)	0.59	0.002
Subcortical	3 (7.5)	Mixed mild deficits	0.42	0.03

Note. *r* = Pearson (point-biserial) correlation between lesion presence in the region and deficit severity in the corresponding domain. BA = Brodmann area.

4.4 Naming in Kiswahili and English among Bilingual Participants

Among the 23 participants who used both Kiswahili and English daily, a cross-language difference emerged in relation to temporal lesions. In this group, naming in Kiswahili was less affected than naming in English, with a mean difference of 1.2 points on the 0–5 scale in favour of Kiswahili (p = 0.04). This pattern is consistent with differential rather than parallel impairment of the two languages.

5. Discussion

This study is, to our knowledge, the first to relate lesion location to language profile among adults with aphasia in Kenya. The findings show that the core associations described in Western populations hold in a Kenyan clinical cohort, and they add new evidence that bilingual experience with an early-acquired African language and a later-acquired schooled language shapes the pattern of impairment.

5.1 Frontal Lesions and Non-fluent Aphasia

The strong association between frontal lesions and reduced fluency and repetition (r = 0.71) is consistent with the classical description of Broca's aphasia (Broca, 1861; Geschwind,

1970) and with modern evidence that the left inferior frontal gyrus, together with the adjacent insula and underlying white matter, supports speech planning and articulation (Dronkers, 1996; Mohr et al., 1978). The co-occurrence of poor repetition with non-fluency in this group fits the dual-stream account, in which frontal regions form the output end of the dorsal sound-to-articulation pathway (Hickok & Poeppel, 2007; Fridriksson et al., 2016). That frontal lesions were the most frequent category (42.5%) may reflect the vascular territory of the superior division of the middle cerebral artery, which is commonly affected in ischaemic stroke, as well as referral patterns, since patients with obvious speech output difficulty may be more readily referred for therapy.

5.2 Temporal Lesions and Comprehension

Temporal lesions were strongly associated with impaired auditory comprehension (r = 0.68), in keeping with Wernicke's (1874) original description and with lesion-mapping studies showing that the posterior superior and middle temporal gyri are critical for mapping speech sounds to meaning (Dronkers et al., 2004; Binder, 2015). These results support the view that the ventral processing stream is organised similarly in Kenyan speakers of Kiswahili and English as in speakers of European languages. This is an important confirmation, because Kiswahili is an agglutinative Bantu language with rich noun-class morphology that differs structurally from the Indo-European languages on which most models are based.

5.3 Parietal and Subcortical Lesions

The moderate association between parietal lesions and anomia (r = 0.59) is consistent with evidence that the supramarginal and angular gyri contribute to phonological retrieval and lexical access (Baldo et al., 2013). The weaker and less specific association observed for subcortical lesions (r = 0.42) matches the literature describing subcortical aphasia as milder and more heterogeneous, possibly reflecting cortical hypoperfusion or disconnection rather than a direct linguistic function of subcortical structures (Nadeau & Crosson, 1997; Radanovic & Mansur, 2017). Given the small number of parietal (n = 6) and subcortical (n = 3) cases, these associations should be interpreted with caution.

5.4 Bilingualism and Differential Impairment

The most novel finding of this study is the relative preservation of Kiswahili over English naming after temporal lesions. For most participants, Kiswahili was acquired early in the home and community, whereas English was learned later through schooling. The pattern is consistent with Paradis' (2004) proposal that earlier-acquired languages are more extensively and more implicitly represented, and with Ullman's (2001) declarative/procedural model, which predicts that vocabulary in a later-learned language depends more heavily on temporal-lobe declarative memory and is therefore more vulnerable to temporal damage.

Other factors may also contribute. Kuzmina et al. (2019) identified frequency of use and premorbid proficiency as predictors of relative language impairment, and in the Nakuru context Kiswahili is likely to be used more frequently in everyday domestic and community interaction than English. Control-based accounts (Green, 1998; Abutalebi & Green, 2007) raise the possibility that temporal damage disrupts selection of the less dominant language. The present design cannot separate age of acquisition, frequency and proficiency, but the finding clearly shows that bilingual status must be considered when assessing and treating aphasia in Kenya. A patient assessed only in English may appear more impaired than they are.

5.5 Clinical and Policy Implications

The findings carry several practical implications. First, because lesion site predicted the dominant deficit, radiology reports available in county hospitals can help clinicians anticipate therapy needs even where advanced imaging analysis is not possible. Second, bilingual patients should be assessed in all the languages they use; relying on English alone risks overestimating severity and underestimating communicative potential. Third, the relative preservation of Kiswahili suggests that therapy may usefully begin in, or draw upon, the better-preserved language, an approach supported by evidence that treatment can generalise across languages in bilingual aphasia (Faroqi-Shah et al., 2010; Kiran & Thompson, 2019). Finally, since speech and language therapy is effective for post-stroke aphasia (Brady et al., 2016), expanding access to trained therapists in county hospitals should be a health-system priority.

5.6 Strengths and Limitations

The study's main strengths are that it provides the first lesion–symptom data on aphasia from Kenya, applies careful language assessment in two languages, uses independent double-coding of lesion location, and employs a method that can be replicated in other county hospitals with basic imaging services.

Several limitations should be acknowledged. Lesion location was derived from written radiology reports rather than from the original images, so lesion volume, precise boundaries and white-matter involvement could not be measured, and voxel-based mapping was not possible (Bates et al., 2003). Lesions were assigned to a single principal category, although many strokes involve more than one region. The sample was modest and drawn from a single referral hospital, and small numbers in the parietal and subcortical groups limit statistical power. The shortened BDAE has not yet been formally standardised for Kiswahili, and the 0–5 scales are ordinal, so parametric analyses should be confirmed with non-parametric methods in larger samples. Finally, the cross-sectional design does not capture the trajectory of recovery, and potential confounders such as lesion size, education, stroke type and time post-onset were not modelled. These limitations are common in low-resource settings and point directly to priorities for future research.

5.7 Directions for Future Research

Future work should obtain digital copies of CT and MRI scans to allow lesion tracing and voxel-based or multivariate lesion–symptom mapping; recruit larger, multi-site samples across Kenyan counties; develop and standardise a Kiswahili aphasia battery with local normative data; include speakers of indigenous Kenyan languages to examine trilingual patterns; and follow patients longitudinally to track differential recovery of their languages over time.

6. Conclusion and Recommendations

Lesion location predicts language profile among Kenyan adults with post-stroke aphasia. Frontal lesions primarily affect fluency and repetition, temporal lesions affect comprehension, and parietal lesions affect naming, while subcortical lesions produce milder and mixed deficits. These results confirm that the classical perisylvian organisation of language applies in an East

African population. At the same time, bilingualism matters: among Kiswahili–English bilinguals, the earlier-acquired Kiswahili was more resilient to temporal damage than English.

We recommend: (i) the establishment of a national aphasia and brain registry that stores copies of CT/MRI images alongside standardised language scores, enabling future high-resolution imaging collaborations; (ii) the development and validation of Kiswahili aphasia assessment tools; (iii) routine assessment of bilingual patients in all languages they use; and (iv) investment in speech and language therapy services at county level. Such steps would place Kenya on the global aphasiology map and support the development of culturally and linguistically relevant rehabilitation.

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