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Research article

Hearing loss, gait and balance impairments and falls among individuals with sub-acute stroke: A comparative cross-sectional study

Adekola B. Ademoyegun [a,e], Olawale Ogundiran [b,*], Adepoju J. Kayode [c], Adedayo O. Olaosun [d], Taofeek O. Awotidebe [e], Chidozie E. Mbada [f]

[a] Department of Physiotherapy, Osun State University Teaching Hospital, Osogbo, Nigeria
[b] Department of Speech, Language and Hearing Sciences, University of Health and Allied Sciences, Ho, Volta Region, Ghana
[c] Department of Ear, Nose and Throat, Osun State University Teaching Hospital, Osogbo, Nigeria
[d] Department of Otorhinolaryngology, Ladoke Akintola University of Technology, Ogbomoso, Nigeria
[e] Department of Medical Rehabilitation, Obafemi Awolowo University, Ile-Ife, Nigeria
[f] Department of Health Professions, Faculty of Health and Education, Manchester Metropolitan University, United Kingdom

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ABSTRACT

Background: The impact of hearing loss in stroke is less explored. This study aimed to compare hearing loss in patients with sub-acute stroke with healthy controls and evaluate its association with gait and balance impairments and falls.

Methods: This study involved 78 ambulant sub-acute stroke patients and 78 age-sex-matched controls. Hearing loss was assessed with pure tone average, while gait and balance impairments were assessed with the Timed Up and Go test, Berg Balance Scale, Functional Gait Assessment and 10-m walk test (gait speed). Fall occurrence was evaluated by a self-report questionnaire.

Results: The prevalence of hearing loss (pure tone average of >25 dB) was higher in stroke patients than in controls (64.1% vs. 35.9%; $p < 0.001$). The mean pure tone average of stroke patients showed a significant positive correlation with Timed Up and Go test ($r = 0.357$; $p = 0.001$) and fall occurrence ($r = 0.253$; $p = 0.025$), and a significant negative correlation with Berg Balance Scale ($r = -0.299$; $p = 0.008$) and Functional Gait Assessment ($r = -0.452$; $p < 0.001$). There was a non-significant negative correlation with gait speed ($r = -0.166$; $p = 0.147$). Multiple regression showed that mean pure tone average was associated with Timed Up and Go test ($B = 0.096$; 95%CI: 0.010, 0.183) and Functional Gait Assessment ($B = -0.087$; 95%CI: −0.157, −0.017), but not with gait speed ($B = -0.003$; 95%CI: −0.007, 0.001) and Berg Balance Scale ($B = -0.058$; 95%CI: −0.165, 0.049).

Conclusion: Hearing loss is more prevalent among patients with sub-acute stroke compared with age-sex-matched controls. Hearing loss is also associated with gait and balance impairments and falls among sub-acute stroke patients. We recommend that hearing screening and rehabilitation be incorporated into post-stroke rehabilitation programmes as part of strategies to improve balance and gait and reduce or prevent falls.

* **Corresponding author.**
E-mail address: oogundiran@uhas.edu.gh (O. Ogundiran).

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1. Introduction

Stroke, a major public health problem with 38,000 daily stroke occurrences, is one of the top main causes of death in both developed and developing countries [1]. The sequelae of stroke vary depending on the site, type, and extent of the vascular event, but mainly involve cognitive, motor, autonomic, and sensorineural problems, including auditory dysfunction [2,3]. Reports have shown that stroke incidence affects all auditory pathways, and therefore leads to high prevalence of auditory dysfunction [3–5]. However, despite the impact of auditory dysfunction on rehabilitation outcomes post-stroke, only a few studies have tried to characterize its prevalence and attendant effects on stroke survivors [3,5].

Patients with stroke are often faced with balance and gait impairments, including the associated fall episodes [6–8]. The problems of balance and gait after stroke are reported to be influenced by several clinical and stroke-related factors [6,7,9,10]. Meanwhile, Kamphuis et al. [11] reported that about 50%–70% of patients who return to their homes from the hospital or a rehabilitation center have had an experience of falls. Stroke patients with episodes of falls often present with poor clinical and psychosocial outcomes compared to patients with no such experience [7,9]. Among other factors, falls in stroke is often precipitated and perpetuated by a lack or inability to maintain balance, and poor gait parameters [7–9,12,13].

Studies have shown higher balance and gait dysfunctions among healthy older adults with auditory problems [14–17]. Furthermore, gait or balance dysfunction is explained to be associated with the loss of stationary cues that integrate a spatial reference about our position. Sakurai et al. [18] reported that the loss of stationary cues is associated with auditory dysfunction. These cues are also vital in maintaining motor control needed for balance and gait functioning [15,17,19]. Therefore, the potential obliteration of these auditory supporting systems in stroke may affect balance and gait functioning and have a profound impact on fall occurrence in patients with stroke. However, information on the relative contribution of auditory dysfunction to balance and gait problems, and fall occurrence in stroke survivors is sparse. Understanding this important phenomenon after a stroke incident may help in providing effective rehabilitation to improve balance, and gait, and reduce or prevent fall episodes in patients with stroke. Thus, this study aimed to examine the prevalence of auditory dysfunction in patients with sub-acute stroke compared to age-sex-matched healthy control and assess the association of auditory dysfunction with balance and gait impairments and fall occurrence.

2. Material and methods

2.1. Study design

This study was a comparative cross-sectional study of stroke survivors as the primary study population using age and sex-matched healthy control for comparison.

2.2. Participants

The primary study population comprised stroke survivors attending the Physiotherapy clinics of the Osun State University Teaching Hospital, and State Specialist Hospital, Osogbo, Nigeria. Included were stroke survivors of not more than six months duration, with radiological (Brain CT or MRI scans) confirmation of stroke incident, who were able to walk independently for up to 20 m, with no prior history of vestibular, audiometric and visual problems, and with a Mini-Mental State Examination score $\geq$20. Participants with recurrent stroke, current use of psychotropic medications, severe apraxia, and any other medical condition other than stroke that may affect their balance and gait ability e.g., severe arthritis, or Parkinson's disease, were excluded. The control population was age-sex-matched healthy controls with no history of neurological problems, vestibular dysfunction, diabetes, hypertension, and non-exposure to noise, which were recruited from the hospitals' staff and survivors' caregivers. With the effect size of 0.3, 95% power and 0.05 error of probability, the G*Power 3.1.9.4 software indicated that 70 participants would be required for a multiple linear regression involving 9 predictors. In total, 78 participants were consecutively recruited between January 2022 and August 2023. The age-and-sex-matched controls were also recruited over the same period. Ethical approval for the study was obtained from the Ethics Research Committee of the Osun State University Teaching Hospital, Osogbo, Nigeria (Protocol Approval Number: UTH/EC/2022/01/570). Written informed consent was also obtained from all participants.

2.3. Auditory function

The Maico MA 53 Diagnostic Audiometer was used to assess the peripheral audiometric hearing loss or functions of the participants. The threshold of peripheral auditory impairment assessment was done at 250, 500, 1,000, 2,000, 4000 and 8,000Hz for air conduction (AC) testing, with 500, 1000, 2000 and 4000Hz for bone conduction (BC) testing. Pure-tone average (PTA) was calculated for each ear using 500, 1000, 2000 and 4000Hz for air and bone conduction testing [3,20]. Hearing loss was defined as air-bone-conduction average greater than 25 dB HL according to the criteria of the World Health Organization [21]. Similarly, all the healthy controls went through the same audiometric testing. Before audiometric testing, otoscopic evaluation was conducted for all participants. The audiometric assessment for all participants was performed in a sound-proof acoustic booth located within the department of ear, nose and throat of the hospital by an experienced Audiologist.

2.4. Balance and gait ability

The Berg Balance Scale (BBS), Timed up and Go Test (TUG), 10-m walk test (10MWT) and Functional Gait Assessment (FGA) were used to assess the balance and gait ability of stroke patients. The BBS is a tool that examines both dynamic and static balance, and mobility of an individual. It involves a total of 14 items/tasks of varying difficulty and the extent of success in performing each task/item is graded as 0 to 4. The tasks include: sitting unsupported, sit-to-stand, stand-to-sit, transferring, standing unsupported, standing with the eyes closed, standing with the feet together, reaching forward with an outstretched arm, turning to look behind, picking up an object from the floor, turning around, placing alternate feet on a stool, one foot forward, and a single-limb stance. The total score of BBS is 56; with higher scores indicating better balance of an individual. The BBS is well validated in the assessment of balance among stroke survivors, with adequate responsiveness to detect changes [22]. The TUG is a single-item assessment which is a reliable and objective measure of functional balance, mobility and risk of fall [23]. It involved the participant standing up from a standardized armchair, walking 3 m, turning back, and sitting down again. The total time to perform this movement was recorded by a stopwatch.

The gait speed of the stroke patients was evaluated by 10MWT. The patients were asked to walk in a provided 10 m rectangular space at their comfortable speeds, and the time taken was recorded in seconds by a stopwatch. Survivors' gait speed was calculated by dividing the distance walked by the time required [24]. To allow for acceleration and deceleration, a distance of 2.5 m was allowed before and after the 10 m mark [25]. The psychometric properties of 10MWT are well established in the measures of mobility among stroke survivors [26]. The FGA is a valid measure of functional gait and balance of patients with stroke [27]. The instrument contains 10 items of different walking tasks and it is scored on an ordinal scale of 0–3. The maximum score obtainable is 30; with higher score suggesting better functional mobility or balance. FGA has been utilized to characterize functional walking activities and balance post-stroke [28].

2.5. Fall episodes

In addition to the assessment of balance and walking abilities, stroke survivors were asked to indicate if they have had any fall episodes since stroke onset, including the time they were on admission.

2.6. Covariates

Using findings of a previous study [29], some important covariates, including age, sex, body mass index (BMI), time since stroke, laterality (left or right), vascular territory (anterior cerebral artery, middle cerebral artery, or posterior), stroke type (ischaemic or haemorrhagic), and stroke severity were evaluated. Stroke severity was assessed by the National Institute of Health Stroke Scale (NIHSS).

2.7. Data analysis

Descriptive statistics of frequency, percentage, mean, median, and standard deviation were used to summarize data. Independent *t*-test and chi-square were employed to investigate the differences in audiometric parameters and demographics between stroke patients and healthy controls. The association between mean hearing threshold and balance and gait parameters and fall episode was assessed by correlation coefficients and multiple linear regression models. The regression analysis was performed separately for BBS, gait speed, FGA, and TUG as dependent variables. Each of the regression models was adjusted for age, gender, stroke type, location, laterality, stroke severity, BMI, and stroke duration. The alpha level was set at $p < 0.05$. The data analysis was carried out using SPSS 21.0 version software (SPSS Inc., Chicago, Illinois, USA).

3. Results

A total of 156 participants, consisting of 78 patients with sub-acute stroke and 78 healthy controls, were involved in this study (Table 1). Similar to the number of male and female participants, the mean age of the stroke survivors (58.13 ± 10.09 years) and controls (58.84 ± 10.28 years) was comparable in both groups. Most of the patients had at least one form of hearing loss (64.1% vs. 35.9%; $p < 0.001$) and had a higher mixed hearing loss (43.6% vs. 17.9%; $p = 0.001$) than controls. Similarly, patients' mean PTA was higher for sensorineural (43.73 ± 21.78 dB vs. 33.23 ± 19.29 dB; $p = 0.002$) and conductive hearing (31.10 ± 22.19 dB vs. 22.02 ± 14.94 dB; $p = 0.003$), and in both ears (39.75 ± 21.08 dB vs. 29.21 ± 16.70 dB; $p = 0.001$) than controls (Table 1). Most of the patients had an ischaemic stroke (71.8%) and left laterality (57.7%), which mostly involved the middle cerebral artery (92.3%) followed by posterior vascular territory (5.1%). The mean BMI and time since stroke were 25.33 ± 4.27 kgm^{-2} and 4.0 ± 1.85 months, while the median and interquartile range of NIHSS was 2.0 (2.0). A total of 38.5% of stroke survivors have had at least one episode of fall since the stroke incident. The mean TUG and FGA were 17.3 ± 7.49s and 21.2 ± 6.56 (Table 1).

The correlations between auditory function and balance, gait, and fall parameters are depicted in Fig. 1 (A-E). The scatter plots showed that the mean pure auditory average was weakly and negatively correlated with BBS ($r = -0.299$; $p = 0.008$) (Fig. 1A), but had a non-significant negative correlation with gait speed ($r = -0.166$; $p = 0.147$) (Fig. 1B). Furthermore, the mean pure auditory average was moderately and positively correlated with TUG ($r = 0.357$; $p = 0.001$) (Fig. 1C), and moderately and negatively correlated with FGA ($r = -0.452$; $p < 0.001$) (Fig. 1D). There was also a weak and positive correlation between mean pure auditory average and fall occurrence ($r = 0.253$; $p = 0.025$) (Fig. 1E). After adjusting for age, gender, stroke type, laterality, stroke duration, severity, location,

Table 1
Patients' characteristics and differences in demographics and audiometric parameters of patients and healthy controls (N = 156).

Variable	All (n = 156)	Patients (n = 78)	Controls (n = 78)	t	p-value
Stroke-related characteristics					
Time since stroke (months) $\bar{x}$ ±SD	–	4.0 ± 1.85	–	–	–
Lesion location n(%)					
Middle	–	72 (92.3)	–	–	–
Anterior	–	2 (2.6)	–	–	–
Posterior	–	4 (5.1)	–	–	–
Laterality, Left, n(%)	–	45 (57.7)	–	–	–
Severity (NIHSS), Median (IQR)	–	2 (2)	–	–	–
Type, Ischaemic, n(%)	–	56 (71.8)	–	–	–
Gait, balance and fall characteristics					
Fall episodes, yes, n(%)	–	30 (38.5)	–	–	–
TUG (s) $\bar{x}$ ±SD	–	17.3 ± 7.49	–	–	–
Gait speed (m/s) $\bar{x}$ ±SD	–	0.53 ± 0.27	–	–	–
FGA, $\bar{x}$ ±SD	–	21.2 ± 6.56	–	–	–
BBS, $\bar{x}$ ±SD	–	42.7 ± 8.96	–	–	–
Demographics					
Age (years) $\bar{x}$ ±SD	58.50 ± 10.16	58.13 ± 10.09	58.84 ± 10.28	0.424	0.672
Sex, Male, n(%)	98 (62.8)	48 (61.5)	50 (64.1)	0.110[a]	0.740
Auditory function					
Auditory dysfunction					
Yes, n(%)	78 (50.0)	50 (64.1)	28 (35.9)	12.410[a]	<0.001*
Sensorineural (dB) $\bar{x}$ ±SD	38.48 ± 21.16	43.73 ± 21.78	33.23 ± 19.29	3.190	0.002*
Conductive (dB) $\bar{x}$ ±SD	26.56 ± 19.42	31.10 ± 22.19	22.02 ± 14.94	2.995	0.003*
Mixed, Yes, n(%)	48 (30.8)	34 (43.6)	14 (17.9)	12.037[a]	0.001*
Right ear (dB) $\bar{x}$ ±SD	34.57 ± 20.94	39.07 ± 22.28	30.06 ± 18.58	2.743	0.007*
Left ear (dB) $\bar{x}$ ±SD	34.39 ± 20.74	40.42 ± 22.68	28.35 ± 16.66	3.786	<0.001*
Both ears (dB) $\bar{x}$ ±SD	34.48 ± 19.68	39.75 ± 21.08	29.21 ± 16.70	3.461	0.001*

$\bar{x}$ ±SD mean ± standard deviation, NIHSS National Institute of Health Stroke Scale, TUG Timed Up and Go Test, FGA Functional Gait Assessment, BBS Berg Balance Scale, IQR interquartile range, dB Decibel, n frequency, % percentage, [a] chi-square, * significant difference.

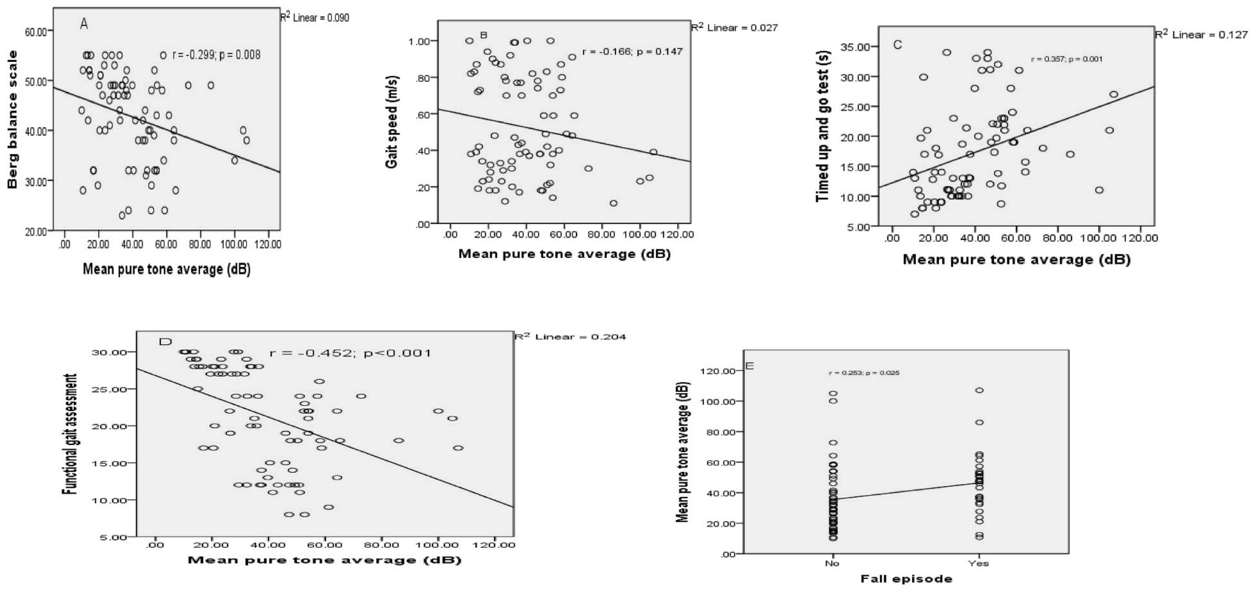

Fig. 1. Correlations of mean auditory threshold with balance, gait and fall parameters among individuals with sub-acute stroke. The scatter plots depict a significant negative correlation of auditory function with Berg balance scale (A), a non-significant positive correlation with gait speed (B), a significant positive correlation with timed up and go test (C), a significant negative correlation with functional gait assessment (D), and a significant positive correlation with fall episode(E).

and BMI, the results of the linear regression show that mean auditory threshold was associated with TUG (B = 0.096; 95%CI: 0.010, 0.183; p = 0.029) and FGA (B = −0.087; 95%CI: −0.157, −0.017; p = 0.016), but not with gait speed (B = −0.003; 95%CI: −0.007, 0.001; p = 0.060) and BBS (B = −0.058; 95%CI: −0.165, 0.049; p = 0.283) (Table 2).

Table 2
Association of auditory function with balance and gait parameters in patients with sub-acute stroke.

Variable[a]	B	β	SE	B (95%CI) Lower, Upper	p	F	R	R^2
TUG	0.096	0.272	0.043	0.010, 0.183	0.029*	2.992	0.533	0.284
Gait speed	−0.003	−0.259	0.002	−0.007, 0.001	0.060	0.973	0.338	0.114
BBS	−0.058	−0.137	0.054	−0.165, 0.049	0.283	2.265	0.480	0.231
FGA	−0.087	−0.278	0.035	−0.157, −0.017	0.016*	4.770	0.622	0.387

[a] Each linear regression model was adjusted for age, gender, stroke type, stroke duration, laterality, stroke severity, location, and body mass index; TUG Timed up and go test; BBS Berg balance scale; FGA Functional gait assessment; * indicates significant association.

4. Discussion

This study aimed to compare the hearing threshold of patients with sub-acute stroke and age-sex-matched controls and evaluated the associations of auditory function with balance, gait and fall episodes among patients with sub-acute stroke. Stroke patients had a higher audiometric threshold in both ears than controls. Stroke patients similarly had a higher mean PTA in sensorineural and conductive hearing threshold. Furthermore, there was a higher prevalence of mixed hearing loss found among stroke patients compared to controls. In all, the prevalence of at least one hearing problem in stroke patients is significantly higher than in controls (64.1% vs. 35.9%). These findings are in line with the results of previous studies [29–31]. Kuo et al. [30] reported that stroke patients were 1.71 times more likely to develop hearing problems, especially sensorineural hearing deficit, than healthy controls. Although it may be subtle, a stroke of any aetiology has been found to affect the auditory pathways [3,4,29].

Thus, due to the apparent negative impact of hearing problems on stroke clinical outcomes and quality of life [4,32,33], audiometric screening is desirable for every patient with stroke even before leaving the stroke ward [3,29]. However, since a proper audiogram in a sound-proof environment may be time-consuming, costly, and may not be feasible for every stroke patient due to stroke-related sequale (cognition, disability, etc) [3,29], the screening may be undertaken by simple questionnaire and portable audiometer [3]. Also, these days, simple online hearing screening tests and apps are available. Advantage can be taken of this where formal audiology is not available or pending.

The findings of this study indicated that auditory dysfunctions was positively correlated with TUG, and negatively correlated with BBS and FGA in stroke survivors. However, there was an insignificant negative correlation with gait speed. In the multivariate analysis, only TUG and FGA had significant association with auditory dysfunction. These findings suggest that a significant association exists between auditory dysfunction and balance and gait impairments in stroke. There is a dearth of data by which to compare our findings, however, previous reports have indicated that auditory dysfunction is associated with poor quality of life [4] and functional decline in stroke survivors [32]. Specifically, Landi et al. [32] reported that community-dwelling stroke survivors with hearing impairment are 1.83 times more likely to have a decline in physical functioning than those without hearing problems after a year period. Balance and walking abilities are important components and measures of physical functioning in stroke patients. Empirical evidence has also shown that rehabilitation strategies using auditory cues tend to improve the temporal gait functioning of stroke survivors [34,35], suggesting an interaction between auditory function and walking abilities. Furthermore, previous results among older adults without any neurological problems had shown that hearing difficulty is associated with gait dysfunction or variability [18,36,37]. Contrary to the reports of previous studies in healthy older adults [18,36,37], in the present study, hearing loss is not associated with gait speed in patients with sub-acute stroke. This needs further study. This discrepancy may indicate different mechanisms by which auditory dysfunction affects the gait or balance ability of individuals with stroke when compared with only ageing-related hearing problems and walking parameters.

The observed association between auditory function and balance and gait parameters in stroke patients can be explained by the importance of auditory cues which have been mentioned as necessary factor like visual or touch cues, in maneuvering space and environment [15,17–19,38]. The loss of hearing cues, resulting in inability to have proper environmental awareness, may perpetuate balance and gait problems in patients with stroke. It has also been postulated that auditory problems may extend to vestibular organs due to the proximity of cochlear and vestibular sense organs in the inner ear (bony labyrinth) [39], and thus affect balance and gait. Balance and gait are maintained by the complex integration and coordination of several body systems including the visual, motor, higher-level premotor, vestibular and auditory systems [40]. The hearing system is responsible for the integration of information on movement and positions of the head and body to the brainstem, cerebellum and somatosensory cortex to maintain balance [40].

In this sample, 38.5% of the stroke survivors have had at least one episode of fall since the stroke incident, which is within the rate reported for patients with sub-acute stroke (10.5%–65%) [41–43]. The results of our study further indicated that auditory dysfunction is positively correlated with fall occurrence in sub-acute stroke patients. Previous studies have reported similar observations between auditory problems and fall episodes in healthy older adults [18,44], however, this association is said to be ageing-related [18]. As stated earlier, auditory dysfunction compromises spatial and environmental awareness [15,17–19,38], and this may contribute to fall occurrence in stroke. Among other factors, balance and gait dysfunctions are independent predictors of falls in individuals with stroke [7–9,12,13,45], thus, it can be implied that balance and gait problems occasioned by auditory dysfunction after a stroke event may increase the risk of fall occurrence among patients with stroke.

4.1. Limitations to the study

Data on auditory function after a stroke episode is sparse, thus, this study adds to the literature on hearing characteristics of stroke survivors compared to healthy individuals. More importantly, evidence on the potential contribution of hearing loss to gait and balance problems and falls in stroke is rather anecdotal than empirical. This study, to our knowledge, is the first to provide empirical data associating hearing loss with gait and balance impairments and falls among stroke survivors. Despite this novelty, the present study has few potential limitations. First, the study employed a relatively small sample of stroke patients recruited from just two centres, and therefore the findings may not be generalizable to every stroke patient. Secondly, our samples consist of only ambulant sub-acute stroke survivors, who may have different gait, balance, fall and audiometric characteristics to the non-ambulant and chronic stroke patients. Finally, since our data are cross-sectional, causality cannot be inferred in this study. Thus, further longitudinal studies with diverse and larger samples are needed to consolidate the findings of this study.

5. Conclusion

We found that hearing loss is more prevalent among patients with sub-acute stroke compared to age-sex-matched healthy controls. The higher prevalence of auditory dysfunction in stroke patients includes sensorineural, conductive and mixed hearing loss. Furthermore, auditory dysfunction is significantly associated with falls, balance and gait impairments among sub-acute stroke patients. Appropriate rehabilitation strategies in the screening and treatment of auditory dysfunction may prevent or reduce episodes of falls, and improve balance and gait impairments among stroke survivors.

Ethics statement

This study was reviewed and approved by the Ethics Research Committee of the Osun State University Teaching Hospital, Osogbo, Nigeria with the approval number: UTH/EC/2022/01/570. All participants provided informed consent to participate in the study.

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Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Adekola B. Ademoyegun: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Olawale Ogundiran:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation. **J. Kayode Adepoju:** Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis. **Adedayo O. Olaosun:** Writing – review & editing, Writing – original draft, Supervision, Resources, Methodology, Investigation, Formal analysis, Data curation. **Taofeek O. Awotidebe:** Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis. **Chidozie E. Mbada:** Writing – review & editing, Writing – original draft, Supervision, Resources, Methodology, Investigation, Formal analysis, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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