

Diagnostic Accuracy of Reported Hearing Difficulty for Identifying Pure-Tone Audiometry Threshold Elevation in Children and Adolescents With Sickle Cell Disease in Eastern Uganda: A Cross-Sectional Secondary Analysis

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Abstract

Background

Hearing abnormalities in children with sickle cell disease (SCD) may be clinically subtle, so symptom enquiry may fail to identify children with objectively elevated hearing thresholds. We evaluated the concordance and diagnostic accuracy of self- or caregiver-reported reduced hearing against pure-tone audiometry (PTA) in children and adolescents with SCD.

Methods

We conducted a secondary diagnostic-accuracy analysis of a hospital-based cross-sectional study at Mbale Regional Referral Hospital, Uganda. The index measure was self- or caregiver-reported reduced hearing (yes/no), and the reference outcome was PTA > 25 dB hearing level (HL) in either ear, using the threshold specified in the parent protocol. We cross-classified symptom status and PTA findings and estimated sensitivity, specificity, positive and negative predictive values, overall accuracy and Cohen's kappa. Proportion estimates are reported with 95% confidence intervals (CIs).

Results

Of 228 records, 208 had complete symptom and bilateral PTA data. Median age was 12 years (IQR 9–15); among 204 participants with recorded sex, 109 (53.4%) were female. Reported reduced hearing was present in 24/208 (11.5%), whereas 32/208 (15.4%) had PTA > 25 dB HL in at least one ear. Only 5 participants had both. Sensitivity was 15.6% (95% CI 6.9–31.8), specificity 89.2% (83.8–93.0), positive predictive value 20.8% (9.2–40.5), negative predictive value 85.3% (79.5–89.7), and accuracy 77.9% (71.8–83.0). Cohen's kappa was 0.05. Among participants with PTA elevation, 20 had unilateral and 12 bilateral abnormalities.

Conclusions

Reported reduced hearing had very low sensitivity for PTA-defined threshold elevation and minimal agreement with objective PTA findings. Symptom enquiry alone would have missed most participants with elevated thresholds. In pediatric SCD care, hearing complaints should prompt assessment, but absence of a complaint should not be used to rule out the need for objective audiologic evaluation.

Background

Sickle cell disease (SCD) is a multisystem hemoglobinopathy in which vaso-occlusion, chronic hemolysis and tissue hypoxia may affect the auditory system. Cochlear ischemia and microvascular injury have been proposed as mechanisms of sensorineural hearing loss, while middle-ear disease may contribute

to conductive deficits [4–7]. Reported frequencies and patterns of hearing loss vary across pediatric SCD studies because of differences in age, case mix, audiologic methods and threshold definitions [4–8].

In Uganda, Kikuhe and colleagues reported hearing loss in 17% of children with sickle cell anemia, including sensorineural, conductive and mixed patterns [4]. Studies from other settings have likewise described auditory abnormalities that may be mild, unilateral or otherwise clinically subtle [5–8]. These observations raise a different question from prevalence estimation: how well does reported hearing difficulty identify a child with an objectively elevated hearing threshold?

Objective hearing assessment matters in childhood because unrecognized hearing impairment can affect communication, learning and development [1–3]. Yet formal audiology is not universally available in resource-limited settings, making symptom enquiry an attractive but potentially inadequate case-finding approach. We therefore evaluated the diagnostic accuracy and agreement of reported reduced hearing against the PTA threshold specified in the parent protocol. This question is distinct from the parent study's objectives of describing prevalence, pattern and factors associated with hearing impairment.

Methods

We performed a secondary diagnostic-accuracy analysis of a hospital-based cross-sectional study conducted from 28 August 2025 to 28 August 2026 among children and adolescents with SCD attending the sickle cell clinic and pediatric services at Mbale Regional Referral Hospital in Eastern Uganda. The parent study was designed to determine the prevalence, pattern and factors associated with hearing impairment. The present analysis evaluates how accurately a reported hearing complaint identifies participants who cross the protocol-defined PTA threshold and does not repeat the parent study's analysis of factors associated with hearing impairment.

Participants

The parent protocol included children and adolescents aged 5–18 years with SCD confirmed by hemoglobin electrophoresis who provided consent and assent as appropriate. Participants with congenital hearing impairment, those already receiving treatment for hearing impairment, and critically ill patients unable to undergo hearing testing were excluded. For this secondary analysis, all available records with both a recorded response to the reduced-hearing question and valid PTA measurements for both ears were included. No separate sample-size calculation was undertaken for this secondary diagnostic-accuracy analysis; the analytic sample was determined by availability of complete index-measure and reference-outcome data.

Audiologic assessment and variables

Pure-tone audiometry assessed air-conduction thresholds across standard test frequencies. In the parent protocol, PTA was calculated from 500, 1000 and 2000 Hz, and -10 to 25 dB HL was considered within the study's normal range. The reference outcome for this analysis was therefore PTA > 25 dB HL in either ear. The index measure was a binary self- or caregiver-reported response to whether the participant had reduced hearing. Ear-specific PTA values were retained to describe unilateral and bilateral threshold elevation. Because sufficiently complete frequency-specific air- and bone-conduction data were not available for this secondary analysis, PTA > 25 dB HL is described as PTA-defined threshold elevation rather than used to infer the underlying type or cause of hearing loss.

Statistical analysis

Continuous variables were summarized using medians and interquartile ranges and categorical variables using frequencies and percentages. A 2×2 table cross-classified reported reduced hearing against PTA > 25 dB HL in either ear. Sensitivity, specificity, positive predictive value, negative predictive value and overall accuracy were estimated with Wilson 95% CIs. Cohen's kappa quantified agreement beyond chance. Participants missing either the reported-hearing response or a valid PTA measurement for either ear were excluded from the primary symptom–PTA analysis; other variables are presented with explicit denominators. No multivariable modeling or causal inference was undertaken. Reporting was guided by STARD 2015 [9].

Figure 1. Participant flow for the secondary diagnostic-accuracy analysis

Results

Of 228 available participant records, 208 (91.2%) had both a recorded response to the reduced-hearing question and valid bilateral PTA measurements and were included in the primary analysis. Median age was 12 years (IQR 9–15). Sex was recorded for 204 participants, of whom 109 (53.4%) were female and 95 (46.6%) were male. Median PTA was 11.67 dB HL (IQR 10.00–18.33) in the right ear and 11.67 dB HL (IQR 6.67–16.67) in the left ear.

Reported reduced hearing was present in 24/208 participants (11.5%), while 32/208 (15.4%) had PTA > 25 dB HL in at least one ear. The complete cross-classification is shown in Table 1. Among the 32 participants with elevated PTA thresholds, only 5 reported reduced hearing and 27 did not. Thus, 84.4% (27/32) of participants with PTA > 25 dB HL in at least one ear had no reported hearing difficulty. Conversely, 19 of the 24 participants who reported reduced hearing had PTA $\leq$ 25 dB HL in both ears.

Reported reduced hearing had a sensitivity of 15.6% (95% CI 6.9–31.8) and a specificity of 89.2% (95% CI 83.8–93.0) for identifying PTA > 25 dB HL in at least one ear. Positive predictive value was 20.8% (95% CI 9.2–40.5), negative predictive value was 85.3% (95% CI 79.5–89.7), and overall accuracy was 77.9% (95% CI 71.8–83.0). Agreement beyond chance was minimal (Cohen's kappa = 0.05) (Table 2).

Among the 32 participants with PTA > 25 dB HL in at least one ear, 20 (62.5%) had unilateral threshold elevation and 12 (37.5%) had bilateral threshold elevation.

Table 1

Cross-classification of reported reduced hearing and pure-tone audiometry (PTA) threshold status among participants with complete symptom and bilateral PTA data (n = 208).

Reported reduced hearing	PTA ≤ 25 dB HL in both ears	PTA > 25 dB HL in ≥ 1 ear	Total
No	157	27	184 (88.5%)
Yes	19	5	24 (11.5%)
Total	176 (84.6%)	32 (15.4%)	208 (100%)

Values are counts unless otherwise indicated. Percentages in the Total row and Total column use the full analytic sample (n = 208). PTA threshold elevation was defined as PTA > 25 dB HL in at least one ear.

Table 2

Diagnostic performance of reported reduced hearing for identifying PTA > 25 dB HL in at least one ear (n = 208).

Measure	Numerator/denominator	Estimate	95% CI
Sensitivity	5/32	15.6%	6.9–31.8%
Specificity	157/176	89.2%	83.8–93.0%
Positive predictive value	5/24	20.8%	9.2–40.5%
Negative predictive value	157/184	85.3%	79.5–89.7%
Overall accuracy	162/208	77.9%	71.8–83.0%
Cohen's kappa	—	0.05	—

The numerator/denominator column shows the underlying 2×2 counts for each diagnostic measure. Confidence intervals are Wilson 95% CIs. Cohen's kappa quantifies agreement beyond chance.

Discussion

In this secondary diagnostic-accuracy analysis of children and adolescents with SCD, reported reduced hearing showed poor agreement with objective PTA findings. The most clinically important result was the very low sensitivity: only 5 of 32 participants with PTA > 25 dB HL in at least one ear reported reduced hearing. Consequently, relying on symptom enquiry alone would have failed to identify 84.4% of participants who crossed the protocol-defined PTA threshold. Cohen's kappa of 0.05 further indicates that agreement between reported hearing difficulty and PTA status was little better than chance.

This discordance is plausible in pediatric SCD. Auditory abnormalities may be mild, unilateral, gradual, or insufficiently apparent to the child or caregiver to generate a hearing complaint [4–8]. In Uganda, Kikuhe and colleagues described sensorineural, conductive and mixed hearing loss among children with sickle cell anemia [4], while studies in other settings have also documented auditory abnormalities in pediatric SCD [5–8]. The present study addresses a complementary clinical question: rather than estimating the prevalence or type of hearing impairment, it examines whether a simple reported symptom can identify children with an elevated PTA threshold.

The relatively high specificity of 89.2% means that most participants with $PTA \leq 25$ dB HL in both ears did not report reduced hearing. However, specificity alone is not sufficient for a case-finding approach intended to minimize missed abnormalities. The positive predictive value was also low at 20.8%, indicating that most participants who reported reduced hearing did not cross the study's PTA threshold. This does not make the symptom clinically unimportant. A hearing complaint still warrants evaluation because symptoms may reflect difficulties not captured by the three-frequency PTA used in this analysis, fluctuating or middle-ear problems, or other auditory concerns. Rather, the findings show that the absence of a complaint is a poor basis for excluding objective assessment.

The negative predictive value was 85.3% and overall accuracy was 77.9%, but these measures should not be interpreted in isolation from the low sensitivity and the prevalence of PTA threshold elevation in this sample. Predictive values vary with disease prevalence, and overall accuracy can appear acceptable when most participants do not have the reference outcome. For this reason, the 77.9% accuracy does not indicate that symptom enquiry is an adequate screening substitute for PTA. The complete 2×2 results and the sensitivity estimate provide a more clinically informative picture.

The finding that 20 of 32 participants with elevated PTA thresholds had unilateral abnormalities may partly explain why subjective recognition was poor. Unilateral or mild hearing changes can be less noticeable in everyday communication than bilateral impairment. Nevertheless, the available data do not establish why individual participants did or did not report hearing difficulty, and the study was not designed to determine the mechanism underlying symptom–PTA discordance.

These findings have practical implications for pediatric SCD services in settings where formal audiology capacity is limited. Symptom enquiry is simple and should remain part of routine clinical assessment, but it should not be used as the sole gatekeeper for objective hearing evaluation. The results support consideration of feasible objective screening or referral strategies for children with SCD. They do not, however, establish the optimal screening interval, the most appropriate audiologic test battery, or the cost-effectiveness of routine repeated PTA; these questions require prospective evaluation.

Strengths and limitations

This study has several strengths. It addresses a focused clinical question that is distinct from the parent study's prevalence, pattern and associated-factor objectives. The analysis used bilateral objective PTA

measurements, retained ear-specific information, and reported the complete 2×2 cross-classification rather than relying only on summary accuracy measures. Presenting the underlying numerators and denominators also makes the diagnostic-performance estimates transparent and readily interpretable.

Several limitations should be considered. First, this was a single-center secondary analysis of cross-sectional data, which limits generalizability beyond the study population and does not establish how symptom reporting or hearing thresholds change over time. Second, the index measure was a single yes/no self- or caregiver-reported question rather than a validated pediatric hearing-screening questionnaire. Its poor sensitivity therefore should not be generalized to structured symptom instruments or formal screening questionnaires.

Third, PTA > 25 dB HL in either ear was defined according to the parent protocol rather than selected specifically for this diagnostic-accuracy analysis; diagnostic performance could differ with another threshold definition. Fourth, the primary analysis was restricted to 208 of 228 available records with complete reported-hearing and bilateral PTA data. Because the available secondary dataset did not permit a detailed comparison of included and excluded participants, the direction and magnitude of any selection bias from complete-case analysis cannot be determined.

Fifth, sufficiently complete frequency-specific air- and bone-conduction data were unavailable to classify the observed abnormalities as conductive, sensorineural or mixed. In addition, the parent protocol's PTA calculation used 500, 1000 and 2000 Hz; frequency-specific abnormalities outside this three-frequency average, including isolated higher-frequency deficits, may therefore not have been captured by the reference outcome used in this analysis.

Finally, the materials available for this secondary analysis did not allow independent confirmation of several procedural features relevant to diagnostic-accuracy reporting, including the sequence and timing of symptom enquiry relative to PTA, whether the PTA examiner was unaware of the symptom response, and whether technically indeterminate PTA examinations occurred. These limitations affect interpretation of the diagnostic-performance estimates but do not alter the observed 2×2 cross-classification in the available complete records.

Recommendations

Pediatric SCD services should consider feasible pathways for objective audiologic screening or referral, adapted to local resources and audiology capacity. Future prospective studies should evaluate validated symptom-screening tools alongside standardized audiologic testing, document relevant diagnostic-accuracy procedures, include frequency-specific air- and bone-conduction measurements where feasible, and determine appropriate screening intervals, referral thresholds and cost-effective implementation strategies.

Conclusion

Reported reduced hearing had very low sensitivity and minimal agreement with PTA-defined threshold elevation in this pediatric SCD sample. Most participants with PTA > 25 dB HL did not report reduced hearing. Hearing complaints should prompt evaluation, but absence of a complaint should not be used as the sole basis for excluding objective audiologic assessment.

Declarations

Ethics approval and consent to participate: The parent study received ethical approval from the Busitema University Faculty of Health Sciences Research Ethics Committee (BUFHS-2025-641) on 14 August 2025. Written informed consent was obtained from parents or legal guardians, and age-appropriate assent was obtained from participating children and adolescents, as applicable. The present manuscript reports a secondary analysis of data collected within the approved parent study.

Consent for publication: Not applicable. The manuscript does not contain identifiable individual participant information.

Availability of data and materials: The de-identified dataset supporting the findings of this secondary analysis is available from the corresponding author on reasonable request, subject to the conditions of the ethical approval and applicable institutional requirements.

Competing interests: The authors declare that they have no competing interests.

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Clinical trial number: Not applicable.

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Figures

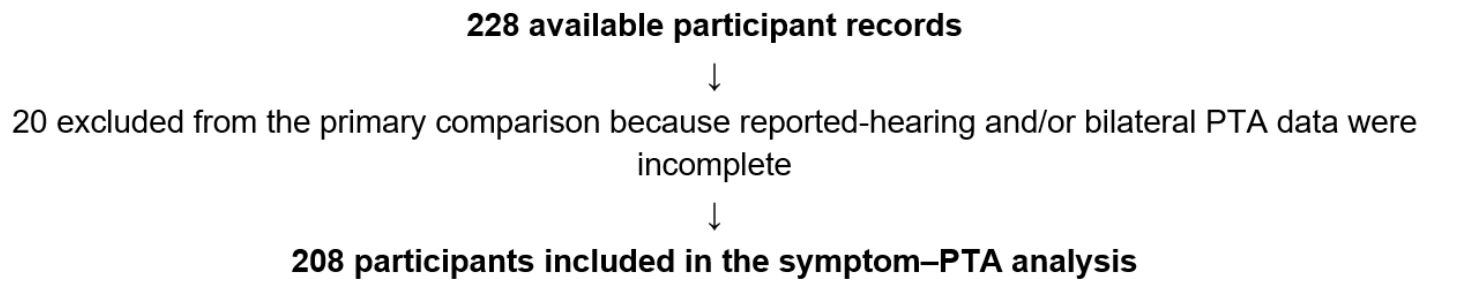


Figure 1

Participant flow for the secondary diagnostic-accuracy analysis