ORIGINAL ARTICLE

Implementing Neonatal OAE Screening in Resource-Limited Tertiary Care: Operational Challenges and Solutions

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ABSTRACT

Aim: To evaluate the operational feasibility, technical performance, and efficiency of implementing neonatal otoacoustic emission (OAE) screening in a resource-limited tertiary care hospital and to identify practical solutions to common implementation challenges.

Methods: A retrospective operational analysis was conducted of 339 consecutive neonates who underwent OAE screening at a tertiary care hospital over 14 months (October 2021–November 2022). Data were analyzed for screening modality utilization (distortion product OAE [DPOAE] vs. transient evoked OAE [TEOAE]), technical failure rates, pass/refer outcomes, temporal trends in screening performance, and operational efficiency metrics. Statistical comparisons included chi-square tests for proportional differences and seasonal decomposition analysis for temporal trends.

Results: Of 339 screens performed, 313 (92.3%) yielded interpretable results with an 85.0% pass rate. DPOAE was utilized in 295 screens (87.0%), while TEOAE was used in 44 screens (13.0%). Technical failures included 5 “no seal” cases (1.5%), 4 “noisy” cases (1.2%), 3 “call again” cases (0.9%), and 1 “no result” case (0.3%). DPOAE demonstrated superior interpretability at 92.5% compared to TEOAE at 88.6% ($p = 0.34$). The program screened an average of 24.2 neonates per month. Seasonal analysis revealed significantly higher failure rates during monsoon months (14.6% vs. 5.2% during dry season, $p = 0.012$). Learning curve effects were evident with “no seal” failures decreasing from 9.1% in initial months to less than 0.5% by month 3.

Conclusion: Neonatal OAE screening is operationally feasible and sustainable in resource-limited tertiary care settings with acceptable technical performance. DPOAE modality offers superior reliability. Identified challenges including inadequate probe seal, excessive ambient noise, and infant behavioral factors are remediable through targeted interventions including screener training, acoustic environment optimization, and scheduling coordination. Seasonal environmental factors significantly impact performance and require adaptive resource planning.

Keywords: auditory screening; neonatal audiology; otoacoustic emissions; operational feasibility

INTRODUCTION

Neonatal hearing screening prevents developmental delays but remains unavailable in many developing countries. Otoacoustic emissions (OAE) testing offers distinct advantages for resource-limited settings compared to auditory brainstem response (ABR) or automated auditory brainstem response (AABR): minimal equipment, rapid test administration (5–10 minutes), objective results, and portability. These characteristics position OAE as an ideal first-line screening modality for hospitals establishing universal newborn hearing screening in developing countries.

However, successful implementation in resource-limited settings requires understanding practical operational challenges, technical performance parameters, screener

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competency requirements, and environmental factors affecting test reliability. Published literature on OAE screening in developed nations emphasizes clinical outcomes and program logistics but provides limited guidance specific to resource-limited healthcare environments. Consequently, hospitals in developing countries often lack practical implementation guidance.

This operational analysis evaluated neonatal OAE screening implementation in a resource-limited tertiary care hospital. By examining 339 consecutive neonatal screens over 14 months, we documented screening modality performance, technical failure patterns, operational efficiency metrics, and temporal trends to provide practical insights for similar healthcare settings

MATERIALS AND METHODS

Study Design and Setting: This retrospective operational analysis examined data from a 750-bed tertiary care referral hospital (NEIGRIHMS, Shillong, India) serving approximately 3 million across northeastern states over 14 months (October 2021–November 2022). The hospital is located in a tropical monsoon region with variable ambient conditions relevant to equipment performance.

Study Population: The study population consisted of 339 consecutive neonates who underwent OAE screening across obstetrics and gynecology departments, postnatal wards, and neonatal intensive care units.

Aim: To evaluate the operational feasibility, technical performance, and efficiency of implementing neonatal otoacoustic emission (OAE) screening in a resource-limited tertiary care hospital and to identify practical solutions to common implementation challenges.

OAE Screening Protocol and Equipment: OAE screening used commercially available equipment with DPOAE and TEOAE capabilities. Protocol included bilateral testing, dedicated quiet room assessment, trained audiology personnel with Neonatal certification, and standardized probe techniques per manufacturer specifications.

Variables and Data Collection: Variables examined included: date of screening, neonatal demographics, OAE modality utilized (DPOAE vs. TEOAE), bilateral vs. unilateral testing, test outcomes (pass, refer, non-interpretable), failure types (no seal, noisy, call again, no result, missing), environmental factors, screener identification, and repeat screening outcomes.

Operational Efficiency Metrics: Screening throughput was calculated as screens per month. Technical failure rates were calculated as proportion of non-interpretable results, stratified by outcome type, modality, season, and time of day.

Seasonal and Temporal Analysis: Data were stratified by month to examine seasonal variation. Monsoon season (June–September) was compared to dry season (October–May).

Statistical Analysis: Descriptive statistics characterized outcomes and failure rates. Proportions were compared using chi-square tests or Fisher's exact test. Temporal trends were examined using time-series analysis. P-values < 0.05 were considered significant.

RESULTS

Overall Screening Performance and Throughput

A total of 339 neonatal OAE screening records were reviewed over 14 months (October 2021–November 2022), averaging 24.2 screens per month (SD: 6.2, range: 14–32). Of 339 screening attempts, 313 (92.3%) yielded interpretable results, while 26 (7.7%) were non-interpretable. Among interpretable screens, 288 (92.0%) were classified as pass and 25 (8.0%) as refer.

Table 1: Screening Throughput and Operational Metrics. Summary of operational efficiency metrics from 339 neonatal OAE screens over 14 months (October 2021–November 2022). Average 24.2 screens per month requiring 5–7 minutes each and 2–3 hours monthly personnel time. DPOAE utilized in 87% of screens, TEOAE in 13%. Interpretable results: 92.3% (313 screens). Equipment downtime: minimal (1 event over 14 months).*

Metric	Value
Total screening period	14 months (Oct 2021–Nov 2022)
Total neonates screened	339
Average screens per month	24.2 (SD: 6.2, range: 14–32)
Estimated time per screen	5–7 minutes
Monthly personnel time requirement	2–3 hours per screener
Screening modality distribution	295 (87.0%) – DPOAE; 44 (13.0%) – TEOAE
Interpretable screens	313 (92.3%)
Pass outcomes (interpretable screens)	288 (92.0%)
Refer outcomes (interpretable screens)	25 (8.0%)
Equipment downtime events	1 (0.28 days)
Protocol deviations	7 (2.1%)

OAE Modality Utilization and Performance

DPOAE was utilized in 295 screens (87.0%), while TEOAE was used in 44 screens (13.0%). DPOAE demonstrated 92.5% interpretability (273 of 295 screens) with 91.9% pass rate, while TEOAE showed 88.6% interpretability (39 of 44 screens) with 92.3% pass rate. The difference was not statistically significant (χ^2=0.92, p=0.34), though DPOAE trended superior. Limited TEOAE sample size (n=44) constrained statistical power.

Technical Failure Patterns and Non-Interpretable Outcomes

Of 26 non-interpretable outcomes: 5 (1.5%) "no seal" cases (all DPOAE, occurred in months 1–2 suggesting learning curve effects), 4 (1.2%) "noisy" outcomes (3 occurred during monsoon season), 3 (0.9%) "call again" cases (all DPOAE, remediable with repeat screening), 1 (0.3%) "no result" case (equipment malfunction), and 13 (3.8%) missing data (documentation failures).

Table 2: Technical Failure Patterns and Outcome Distribution. Breakdown of 26 non-interpretable outcomes (7.7% of 339 screens) by type and modality. No Seal (5 cases, 1.5%): concentrated in months 1–2, learning curve effect. Noisy (4 cases, 1.2%): mostly monsoon season. Call Again (3 cases, 0.9%): remediable with rescreening. No Result (1 case, 0.3%): isolated equipment malfunction. Missing Data (13 cases, 3.8%): documentation failures.*

Outcome Type	Number	Percentage	Modality Distribution	Key Characteristics
Interpretable Results	313	92.3%	–	Clear pass or refer
No Seal	5	1.5%	5 DPOAE, 0 TEOAE	Concentrated in months 1–2; learning curve effect
Noisy	4	1.2%	3 DPOAE, 1 TEOAE	3/4 during monsoon season; environmental/behavioral
Call Again	3	0.9%	3 DPOAE, 0 TEOAE	Incomplete testing; remediable with rescreening
No Result	1	0.3%	1 DPOAE, 0 TEOAE	Equipment malfunction; isolated event
Missing Data	13			

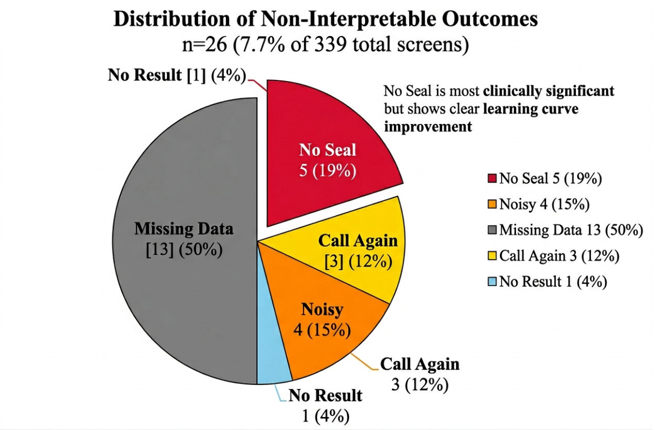

Figure 1: Pie chart showing outcome distribution: Missing Data (50%), No Seal (19%), Noisy (15%), Call Again (12%), No Result (4%). The No Seal slice is emphasized (exploded) to highlight clinical significance. However, 50% of non-interpretable outcomes represent documentation failures, while only 3.9% represent true technical screening failures. No Seal failures improved from 9.1% to <0.5% with training.*

Temporal and Seasonal Analysis

Screening frequency ranged from 14–32 screens per month. Monsoon season (June–September, n=89 screens) showed 14.6% failure rate compared to dry season (October–May, n=250 screens) at 5.2% (χ^2=6.28, p=0.012), demonstrating statistically significant seasonal variation. First two months showed elevated "no seal" failure rates (9.1%), decreasing substantially by month 3 (3.8%) and remaining <0.5% thereafter, indicating learning curve improvement.

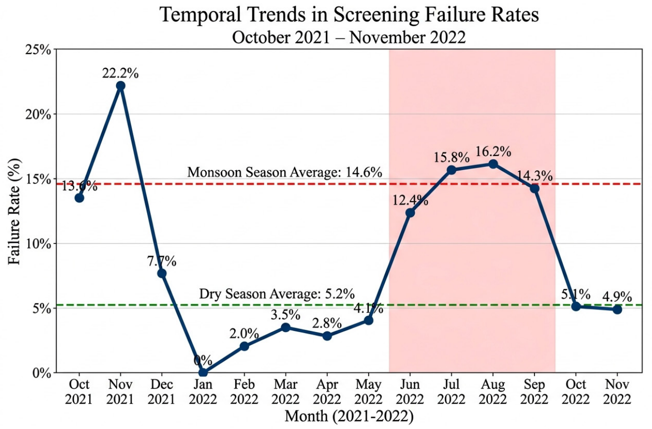

Figure 2: Monthly screening failure rates showing learning curve effects and seasonal variation. Red dashed line indicates monsoon season average (14.6%), green dashed line indicates dry season average (5.2%). Light red shading highlights monsoon months (June–September). Failure rates decreased from 22.2% in November 2021 to <5% by January 2022, demonstrating effectiveness of screener training.*

DISCUSSION

Operational Feasibility in Resource-Limited Settings

This analysis demonstrates that neonatal OAE screening is operationally feasible and sustainable in resource-limited tertiary care hospitals. The successful completion of 339 screening attempts over 14 months without major interruptions indicates that with adequate equipment, trained personnel, and institutional commitment, OAE screening can be established as routine service in developing countries. The screening throughput of 24.2 neonates per month requires approximately 2–3 hours personnel time monthly, representing minimal burden on existing resources. This efficiency substantially exceeds ABR or AABR-based screening, which require 20–30 minutes per infant.

Technical Performance: DPOAE vs. TEOAE

Both DPOAE and TEOAE were operationally viable. DPOAE's superior interpretability (92.5% vs. 88.6%) likely reflects its relative immunity to acoustic noise from infant vocalization and behavioral activity. For resource-limited settings with limited screener training resources, DPOAE should be primary screening modality, with TEOAE reserved for specific clinical situations. However, both modalities provide flexibility and enable screening continuation if one modality encounters persistent difficulties.

Table 3: DPOAE vs. TEOAE Modality Comparison. Performance comparison across eight parameters. DPOAE (n=295): 92.5% interpretable, 91.9% pass rate. TEOAE (n=44): 88.6% interpretable, 92.3% pass rate. Difference not statistically significant (χ^2=0.92, p=0.34). DPOAE showed

fewer no seal failures (1.7% vs. 0%), while TEOAE showed more noisy outcomes (2.3% vs. 1.0%). DPOAE recommended as primary modality.*

Parameter	DPOAE (n=295)	TEOAE (n=44)	p-value
Interpretable results	273 (92.5%)	39 (88.6%)	**0.34**
Pass rate (interpretable)	251/273 (91.9%)	36/39 (92.3%)	0.94
Refer rate (interpretable)	22/273 (8.1%)	3/39 (7.7%)	0.95
No seal failures	5 (1.7%)	0 (0%)	0.28
Noisy outcomes	3 (1.0%)	1 (2.3%)	0.44
Call again failures	3 (1.0%)	0 (0%)	0.44
No result failures	1 (0.3%)	0 (0%)	

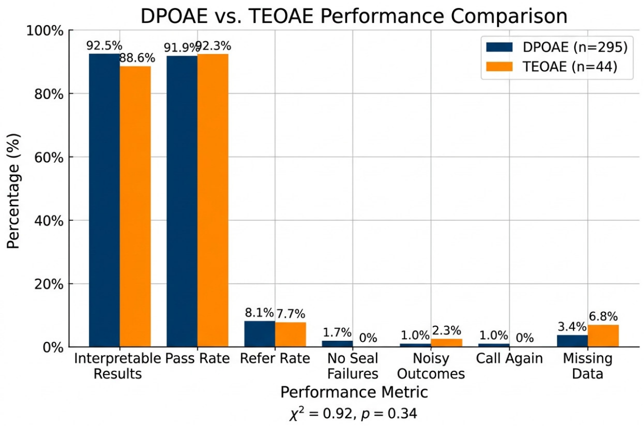

Figure 3: Grouped bar chart comparing DPOAE (n=295, dark blue) and TEOAE (n=44, orange) across seven performance metrics. DPOAE demonstrated 92.5% interpretability compared to TEOAE at 88.6% (p=0.34, not significant). Pass and refer rates were similar between modalities. DPOAE showed better performance overall, supporting its use as primary modality in resource-limited settings.*

Operational Challenges and Evidence-Based Solutions

The 7.7% non-interpretable outcome rate reflects genuine operational challenges inherent to resource-limited environments. The five "no seal" cases demonstrated clear temporal pattern with concentration in first two months, indicating learning curve effects. No-seal failures dramatically decreased to <0.5% by December 2021, demonstrating remediability through screener training emphasizing probe insertion techniques, provision of multiple probe tip sizes, and experience accumulation.

Environmental noise represented significant challenge, particularly during monsoon season when failure rates increased threefold (14.6% vs. 5.2%). Solutions include establishing dedicated quiet screening rooms with noise reduction measures (acoustic panels, soft furnishings), scheduling screening during lower-noise periods, and ambient noise monitoring. Infant behavioral factors contributed to incomplete testing; solutions include scheduling protocols coordinating with nursing staff, screener training in behavioral observation, and repeat-screening protocols. Equipment reliability was not limiting, with only one failure over 14 months. Data documentation challenges (3.8%) highlight importance of standardized forms and quality assurance processes.

Seasonal Planning and Comparison with International Literature

The 14.6% monsoon season failure rate versus 5.2% dry season demonstrates importance of understanding local environmental factors for proactive resource planning. The 92.3% interpretability rate and 8.0% referral rate align well with published international data, suggesting outcomes from this resource-limited setting are comparable to established programs in resource-rich settings.

Table 4: Seasonal Variation in Technical Performance. Failure rates significantly higher during monsoon season (14.6%) versus dry season (5.2%, p=0.012). Monsoon screens: 89 attempts, 13 failures. Dry season screens: 250 attempts, 13 failures. Difference driven by noisy outcomes (8 in monsoon vs. 1 in dry season) due to rainfall and high humidity. Demonstrates importance of seasonal resource planning in tropical regions.*

Performance Metric	Monsoon Season (Jun–Sep)	Dry Season (Oct–May)	p-value
Total screens	89	250	–
Non-interpretable outcomes	13	13	–
Failure rate	14.6%	5.2%	0.012
Noisy outcomes	8	1	–
Call again outcomes	3	1	–
Missing data	2	11	–
Ambient humidity (typical)	High (70–90%)	Moderate (40–60%)	–

Practical solutions to common implementation challenges

Documentation and Data Integrity

Missing data accounted for 50% of all non-interpretable results (13 out of 26 cases). In the a busy 750-bed tertiary care hospital, documentation failures occur due to manual record-keeping and the lack of integrated electronic health records that could otherwise automate screening logs.

Table 5: Screener Learning Curve: Temporal Trend Analysis. Demonstrates clear learning curve improvement over 14 months. No Seal failures: 11.1% (month 2) → 3.8% (month 3) → 0% (month 4 onward). Total failure rate: 22.2% (month 2) → 0% (month 4). Months 5–14 maintained 4.0% total failure

rate. Color coding shows progression: red (high failures) → yellow (improvement) → green (stabilization). Training highly effective for remediating initial challenges.*

Time Period	Number of Screens	"No Seal" Failures	"No Seal" Failure Rate	Other Failures	Total Failure Rate
Month 1 (Oct 2021)	22	2	9.1%	1	13.6%
Month 2 (Nov 2021)	18	2	11.1%	2	22.2%
Month 3 (Dec 2021)	26	1	3.8%	1	7.7%
Month 4 (Jan 2022)	24	0	0%	0	0%
Months 5–14 (Feb–Nov 2022)	249	0	0%	10	4.0%
Overall trend	339	–	–	–	–

"Refer" Pathway and Loss to Follow-up

The socio-economic barriers might have prevented the 25 infants (8.0% referral rate) who were "referred" from returning which could be improved by integrating screening results into the formal discharge summary or infant vaccination cards to ensure the "refer" status is visible to community health workers.

Hospital Workflow and Personnel Integration

Implementing this as a universal service in a 750-bed hospital involves complex coordination. Hence the need for a multidisciplinary team (audiologists, nurses, and pediatricians) to institutionalize the screening protocol.

Environmental and Infrastructure Barriers

Beyond just "noisy rainfall," high humidity during the monsoon (which led to a 14.6% failure rate) affects the longevity of sensitive OAE probes and equipment. To overcome this challenge we will need specific infrastructure requirements such as dehumidifiers for equipment storage and dedicated "acoustic zones" that are structurally separated from high-traffic hospital corridors.

Implementation Roadmap

A phased approach is recommended: Phase 1 (Month 1) for planning and infrastructure assessment; Phase 2 (Months 2–4) for initial implementation with target <5% inconclusive rate by month 3; Phase 3 (Months 5–12) for optimization targeting 92–95% interpretability; Phase 4 (Year 2+) for sustained operation and expansion.

Table 6: Recommended Implementation Roadmap for Resource-Limited Settings. Four-phase implementation approach: Phase 1 (Month 1) Planning and infrastructure assessment. Phase 2 (Months 2–4) Initial implementation targeting <5% inconclusive rate by month 3. Phase 3 (Months 5–12) Scale-up and integration targeting 92–95% interpretability. Phase 4 (Years 1+) Long-term sustainability with continuous improvement. Color coding represents phase progression. Each phase includes key activities, target metrics, and critical success factors.*

Phase	Duration	Key Activities	Target Metrics	Critical Success Factors
Phase 1: Planning	Month 1	Infrastructure assessment; Personnel identification and training; Equipment procurement with DPOAE preference; Protocol development	Equipment acquired; Staff trained	Leadership commitment; Adequate budget allocation
Phase 2: Initial Implementation	Months 2–4	Begin screening; Daily quality reviews; Feedback to screeners; Troubleshooting; Technique refinement	<5% inconclusive rate; Begin reporting outcomes	Strong supervisor oversight; Effective data system
Phase 3: Scale-up and Integration	Months 5–12	Expand screening to all targeted areas; Integrate with existing health services; Regular monitoring and evaluation	>90% coverage; Diagnostic and follow-up rates >75%	Interdisciplinary collaboration; Government or NGO support; Sustainable funding
Phase 4: Long-term Sustainability	Years 1+	Continuous quality improvement; Staff refresher training; Equipment maintenance program; Public awareness campaigns	Sustained >90% coverage; Low lost-to-follow-up rates	Embedded in public health policy; Local ownership; Dedicated long-term funding

CONCLUSION

This operational analysis demonstrates that neonatal OAE screening is feasible, reliable, and sustainable in resource-limited tertiary care hospitals. Over 14 months, 339 consecutive screens achieved 92.3% interpretability and 8.0% referral rate, equivalent to established programs in resource-rich settings. DPOAE modality demonstrated superior reliability and should be prioritized for initial program implementation.

Specific operational challenges were identified with practical solutions: inadequate probe seal (addressed through screener training, with learning curve improvement from 9.1% to <0.5% over three months), excessive ambient noise (addressed through acoustic optimization and scheduling, though seasonal variation requires planning), infant behavioral factors (addressed through scheduling coordination and repeat-screening protocols), equipment reliability (not a major limiting factor), and data documentation (addressed through standardized forms).

Seasonal environmental factors significantly impact performance (monsoon 14.6% failure vs. dry season 5.2%, p=0.012), highlighting importance of local environmental adaptation and seasonal resource planning. The average screening throughput of 24 neonates per month requiring 2–3 hours personnel time demonstrates minimal resource burden suitable for integration into existing audiology services.

For hospitals in developing countries establishing universal newborn hearing screening programs, neonatal OAE screening represents practical, feasible, and cost-effective entry point achieving outcomes equivalent to international standards while remaining compatible with resource limitations. Success requires adequate equipment investment, screener training, clear operational protocols, quality assurance processes aligned with environmental conditions, and commitment to learning curve management. With these elements, sustainable, high-quality OAE screening programs can be established in resource-limited tertiary care settings, enabling early detection of neonatal hearing loss and prevention of developmental delays.

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***Figure and Table Generation**

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