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ORIGINAL ARTICLE

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Validating the Parent-evaluated Listening and Understanding Measure (PLUM): caregiver observations reliably reflect long-term otitis media-related hearing status in young Aboriginal and Torres Strait Islander children

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ABSTRACT

Objective: We aimed to establish how accurately the Parent-evaluated Listening and Understanding Measure (PLUM) identifies longer-term otitis media (OM)-related hearing status in young Aboriginal and Torres Strait Islander children.

Design: Retrospective review of clinical data, designed with Aboriginal, Torres Strait Islander, and non-Indigenous researchers and clinicians.

Study sample: De-identified audiological and demographic information gathered during 15,444 appointments with 6,716 Aboriginal and Torres Strait Islander children aged 7 years and younger.

Results: PLUM effectively distinguishes persistent, OM-related hearing loss requiring specialist referral (>30 dB HL better ear for >3 months) from transient and/or milder loss. Eighty-two percent of children meeting these referral criteria were *"not yet on track"*, compared to 26% with comparable, but transient, loss. PLUM demonstrated strong performance: 82.4% sensitivity, 91.2% specificity, 98.6% negative predictive value, and 90.5% accuracy. Children *"not yet on track"* had 46 times higher odds of meeting hearing referral-level criteria (OR = 45.73, 95% CI: 12.60–165.93).

Conclusions: PLUM draws on parent/caregiver observations to help practitioners identify – or exclude – persistent OM-related hearing loss >30 dB HL, early in children's lives. A single assessment provides insight into longer-term hearing status, complementing point-in-time measures. This is the first accuracy evidence for a listening skills checklist using longer-term hearing as reference standard.

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Introduction

Globally, otitis media (OM) is one of the most common reasons children seek healthcare (Gunasekera 2025). However, for Aboriginal, Torres Strait Islander, and many First Nations children globally (Gunasekera 2025), OM remains a deeply entrenched health challenge. Despite decades of awareness in Australia (Stuart 2007), prevalence remains stubbornly high. Among children aged 3 years and younger, 50–90% experience OM at any time, with higher prevalence as geographic remoteness increases (DeLacy et al. 2023; Morris et al. 2005; Richmond et al. 2023). Of these children, 1 in 10 have a persistent form (pOM), often with increased hearing loss, unlikely to resolve without specialist care (Leach et al. 2024). Such high rates are rooted in ongoing social inequities that affect all areas of Aboriginal and Torres Strait Islander peoples' health and wellbeing (Australian Institute of Health and Welfare (AIHW) 2024), and which are not improving rapidly (DeLacy, Dune, and Macdonald 2020).

Early detection in primary care and a proactive response, including timely specialist referrals, can be life-changing – and even lifesaving — preventing a cascade of harms across health, development, and wellbeing (Bell et al. 2016; Kong et al. 2022; Simpson et al. 2020; Su et al. 2020). However, identifying OM, differentiating subtypes, establishing persistence, and

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implementing effective, interdisciplinary management remains challenging. Regular ear health checks, a key starting point, are often not part of routine care (Aboriginal Medical Services Alliance NT (AMSANT), 2021; Harkus et al. 2021; O'Keeffe et al. 2025). When they are, limited tympanometry use in primary care means asymptomatic OM – very common – may be missed (Kong and Coates 2009). Implementing six-monthly checks in primary care from the age of 6 months to 4 years would provide an opportunity for powerful positive impact (Harkus et al. 2023).

Left unaddressed, pOM carries a heightened risk of lifelong and potentially life-threatening complications (Kong and Coates 2009). It is strongly associated with hearing loss averaging >30 dB HL (Australian Institute of Health and Welfare 2021). When persisting in early childhood, this disrupts the development of listening and communication skills, causes daily communication stress, and places additional strain on families (Campbell et al. 2022; Harkus et al. 2021). Children experiencing OM before 6 months of age are at increased risk of persistent disease (Richmond et al. 2023). Failure to identify and manage early-stage OM increases risk of long-term disease (Leach et al. 2008) and complications, including cholesteatoma (Kong and Coates 2009). A seismic shift – including a raising of expectations – is needed in how Australian health systems view, identify, and respond to OM in young Aboriginal and Torres Strait Islander children.

Diagnostic challenges

If and when OM is identified in primary care, differential diagnosis of transient versus persistent forms can be difficult due to the fluctuating, often asymptomatic nature of the condition (Menzies School of Health Research 2020). Otoscopy and tympanometry are essential activities but reflect ear health at a point in time. Diagnosis of pOM – OM lasting >3 months – requires families to return to primary care three months after initial detection (Menzies School of Health Research 2020). Success of this approach relies on multiple factors: parents' and caregivers' confidence in recognising symptoms and advocating for their child (Campbell et al. 2022; O'Keeffe et al. 2025), trust that care will be safe, respectful, and free of interpersonal and systemic racism (Lau et al. 2024; Watego, Singh, and Macoun 2021), and a consistent family-primary care relationship (Hearing Australia 2021). Parents and caregivers report needing to overcome fear of judgement and/or government reporting when seeking care for their child's ear health (Campbell et al. 2022; Hearing Australia 2021; O'Keeffe et al. 2025). Logistical and financial factors – including transport and affordability of multiple appointments (Hearing Australia 2021) – play important roles, with distance amplifying these challenges.

When families return with ongoing concerns, they can report delays in escalation to specialist care associated with repeated watch-and-wait periods or antibiotic prescriptions, while their child's ear health, hearing, listening and communication skills decline (Campbell et al. 2022; Harkus et al. 2021; O'Keeffe et al. 2025). Even without delays, determining whether children have pOM with referral-level hearing loss (>30 dB HL, better ear, for >3 months) typically requires at least four appointments over six months (Menzies School of Health Research 2020).

Feasible approaches supporting faster diagnosis of already-persistent OM causing referral-level hearing loss are urgently needed. The PLUM checklist (Ching, Hou, et al. 2020) – a freely available, culturally appropriate tool – offers promising assistance with identifying or excluding such a loss by taking a listening skills approach. As extended hearing loss in early childhood affects listening skill development, evaluating listening skills may help practitioners differentiate pOM more quickly. This study investigates how accurately PLUM predicts young children's OM-related longer-term hearing status.

Harnessing listening skills

Listening is an active process involving hearing, attending to, interpreting, and constructing meaning from sound (Jalongo 2010). Good access to sound and to quality listening experiences are fundamental prerequisites (Cole and Flexer 2019). When both are present, listening skills typically start developing in the first hours of life (Fernald 2004) and continue predictably until around age 3, when individual differences widen as factors such as motivation emerge (Weaver and Rutherford 1974). For children in spoken language environments, listening will be one of the most important communication skills in their personal, social, learning, and work life, and is critical for school (Wolvin 2009).

Parent and caregiver observations of their child's listening have predictive value for hearing status, though accuracy depends on how these observations are captured. Informal parental concerns demonstrate high specificity (~93%) for detecting normal hearing but low sensitivity for detecting conductive hearing loss (~20% for mild and ~30% for moderate hearing loss),

suggesting they have value but may miss affected children (Lo et al. 2006; Swierniak et al. 2021). Structured checklists asking about specific aspects of listening are used to screen for hearing loss in early childhood, particularly in settings without newborn hearing screening programs (Newton et al. 2001; Samelli, Rabelo, and Vespasiano 2011), and to detect later-onset hearing loss (Orzan et al. 2021). Such checklists tend to be more effective at ruling out hearing loss than confirming it (Newton et al. 2001; Orzan et al. 2021). Validation studies show variable accuracy, with high sensitivity but low-to-moderate positive predictive value (7–73%), influenced by differences in sample prevalence, target hearing levels, and reference standards (Newton et al. 2001; Orzan et al. 2021; Samelli, Rabelo, and Vespasiano 2011).

Development and previous validation of PLUM

The PLUM checklist was adapted from the validated PEACH tool (Ching and Hill 2007), used in rehabilitative audiology in Australia and internationally (Bravo-Torres et al. 2020; Quar et al. 2012). Developed in collaboration with urban and remote Aboriginal health services (2017–18), PLUM retains PEACH's focus on listening behaviours but was designed for use by any health, hearing, or early education practitioner.

PLUM's 10 items reflect the developmental path of listening skills in young children, covering environmental awareness, discrimination, and recognition (Jalongo 2010). Parents or caregivers rate how often they observe each behaviour using five response options, from "Not yet" to "Always". Scores are totalled and categorised as *"on track"*, *"borderline"*, or *"not yet on track"* by comparing to an aged-based normative matrix (Ching, Hou, et al. 2020) A *"not yet on track"* prompts referral to an audiologist.

PLUM uses plain, Standard Australian English with supporting images, but is designed to be talked through conversationally rather than read word-for-word. It can be administered in any language, including with interpreters – important in remote Aboriginal and Torres Strait Islander communities where Standard Australian English is usually not families' primary language. The checklist focuses on how children listen to, and communicate in, their home language(s). Practitioners are advised to interpret PLUM results alongside other components of an ear health check (Ching, Hou, et al. 2020; Harkus et al. 2023). Early childhood educators are encouraged to consider PLUM results alongside their observations of the child's listening skills and encourage primary health or hearing referral as appropriate.

During PLUM's development, data from 235 urban and remote children with typical hearing showed good internal consistency (Ching, Hou, et al. 2020). However, validation studies remain limited and have relied on point-in-time hearing measures, likely inadequate given the fluctuating nature of OM-related hearing. A recent validation study confirmed excellent internal reliability but found low accuracy in detecting *any* OM or *any* hearing loss (Veselinović et al. 2025), results likely relating to the study's use of point-in-time data and choice of target conditions beyond PLUM's intended scope.

Study aims

This study aimed to: (a) assess PLUM's sensitivity to both longer-term and point-in-time OM-related hearing status; (b) evaluate its accuracy in identifying longer-term OM-related hearing loss >30 dB HL; (c) examine how accuracy varies by age, acknowledging that motivation influences listening behaviour from around three years of age; and (d) examine how accuracy varies by geographical remoteness, considering language and interpreter access.

Since 2019, Hearing Australia has incorporated PLUM into assessments for Aboriginal and Torres Strait Islander children aged 0–6 across urban, regional, and remote areas, in both assessment and rehabilitation work. We obtained data from their database to explore how PLUM results relate to OM-related hearing status over time.

Materials and methods

This study involved retrospective analysis of clinical service data collected between February 2017–June 2023. Research questions were developed with Aboriginal and non-Indigenous colleagues in primary care, hearing, and research. The study protocol was approved by the following health research ethics committees:

- Aboriginal Health and Medical Research Council, New South Wales (2142/23)
- Aboriginal Health Council of South Australia (04-23-1073)
- Western Australian Aboriginal Health Ethics Committee (HREC1274)
- NT Health and Menzies School of Health Research (2023–4647)
- National Acoustics Laboratories/Hearing Australia (HAHREC2023-14).

The project was guided by an Aboriginal and Torres Strait Islander Research Leadership Group. The research team included Noongar, Wiradjuri, and Gudang and Meriam investigators.

The extracted dataset

Clinical and demographic data were extracted and de-identified from records of Aboriginal and Torres Strait Islander children aged ≤7 years whose parents/caregivers completed a PLUM. The dataset included 15,444 appointments for 6,716 children. Clinical data included otoscopy, tympanometry, otoacoustic emissions (OAE), and audiometry results. Demographic data included age, gender, state/territory, and remoteness area (Australian Bureau of Statistics 2021/2026) (Appendix A, Table A1).

The extracted data is broadly representative of the national Aboriginal and Torres Strait Islander child population by gender and cultural identity (Australian Bureau of Statistics 2021; 2021/2026). However, children from remote and regional areas are over-represented (82.0% v. 59.2% nationally), while those from urban areas are under-represented (16.6% v. 40.8%), likely reflecting Hearing Australia's focus on communities with greater OM prevalence and limited service access.

Most appointments (87.4%) were undertaken via an open-access assessment program, open to all 0–5-year-old Aboriginal and Torres Strait Islander children regardless of hearing status, while 12.6% were for rehabilitative care, for children at high risk of, or diagnosed with, referral-level hearing loss (Appendix A, Table A2). Children seen as part of the assessment program are recalled for reassessment annually if results are consistent with healthy ears and typical hearing, otherwise they are recalled in 3 months. Children in the rehabilitation program with confirmed hearing loss are reassessed annually, or sooner if hearing status is still being established or appears to have changed.

Audiometry was undertaken in 42.3% of appointments, with 58.8% of children. Individual-ear average hearing levels were calculated when thresholds were available for at least 1,000 and 4,000 Hz. Mean better-ear hearing was 18.7 dB HL (SD = 8.2). Hearing thresholds were better for children in urban areas ($M = 16.6$ dB HL, $SD = 6.4$) than remote areas ($M = 21.7$ dB HL, $SD = 9.5$), reflecting the increased burden of OM in remote communities. Hearing thresholds were better for children in the open-access assessment program ($M = 17.7$ dB HL, $SD = 7.2$) than for those in the rehabilitation program ($M = 26.5$ dB HL, $SD = 10.8$), consistent with each program's focus. Thresholds were also better for children ≥30 months ($M = 18.5$ dB HL, $SD = 8.2$) compared to younger children ($M = 23.0$ dB HL, $SD = 9.8$), consistent with the natural history of OM (Kong and Coates 2009).

Construction of children's longer-term hearing profiles required consecutive appointments within a pre-determined timeframe, with hearing data in both, and PLUM data in the second appointment. Sixty per cent of children in the dataset had more than one appointment. Inter-appointment intervals ranged from 1 to 2,251 days, with a mean of 232.7 ($SD = 307.1$). Forty percent of appointments included both PLUM and hearing-related data (audiometry and/or OAE). Mean age at first PLUM assessment was 35.9 months ($SD = 16.3$) – younger in remote areas ($M = 33.6$ months, $SD = 15.8$) than urban ($M = 39.0$ months, $SD = 16.1$).

Audiological assessments

The Hearing Australia assessment battery for Aboriginal and Torres Strait Islander children aged ≤6 years includes: otoscopy, tympanometry, otoacoustic emissions (OAE), audiometry, PLUM listening skills checklist, and the Hearing and Talking Scale (HATS) (Ching, Hou, et al. 2020). Tests conducted depended on the child's developmental readiness, cooperation, equipment availability, and time constraints.

Audiometry was performed in quietest-available rooms during community visits. Behavioural calibration was performed to ensure limited influence of environmental noise on test results. At hearing centres, audiometry was performed in sound-treated clinical rooms or in sound booths. Assessment techniques included visual reinforcement orientation audiometry and play audiometry. Stimuli were presented via insert earphones (e.g. EarTone 3 A), over-ear headphones (e.g. TDH39 with Peltor H7A earmuffs), or a soundfield speaker at ±90 degree azimuth.

Tympanometry was conducted using Titan or Interacoustics devices (1,000 Hz probe tone for children ≤7 months; 226 Hz for older children). OAE testing (GSI Corti devices with environmental noise monitoring and management) measured Transient Evoked OAEs; a pass required 6 dB signal-to-noise ratio in all bands from 1 to 4,000 Hz.

PLUM and HATS checklists were completed with parents/caregivers by an audiologist or an Aboriginal and/or Torres Strait Islander hearing health practitioner, with responses recorded in placeholders in the Hearing Australia clinical database.

Classifying variables

This study's primary aim was to assess how accurately PLUM results reflect and predict children's longer-term OM-related hearing status. The variables of interest are hearing status and duration – whether longer-term or transient – as listening skills are most likely to be delayed by longer-term, better-ear hearing >30 dB HL than by milder or shorter-term hearing loss. "Longer-term" is defined as >3 months (Menzies School of Health Research 2020). We identified children with consecutive assessments within a pre-determined time-frame, enabling construction of longer-term hearing profiles. For these children, hearing status, including hearing loss, was confirmed over the longer-term. The remaining children had point-in-time hearing data only. In this group, given that at a population level, 9 in 10 OM cases are estimated to be transient, most recorded hearing losses were not expected to have persisted longer-term. This process is outlined in Figure 1.

Data extraction and exclusion

The extracted dataset contained 15,444 appointments for 6,716 Aboriginal and Torres Strait Islander children. We excluded 4,689 appointments (30.4%) due to missing audiometry or OAE results, leaving 10,755 appointment records for 5,967 children.

Hearing results categorisation

Blinded reviewers classified hearing results using audiometry and otoacoustic emissions data:

- Average hearing equivalent to 0–20 dB HL both ears, including bilateral OAE pass
- Average hearing equivalent to 21–30 dB HL better ear, sound field 'pass', unilateral OAE 'pass', and bilateral OAE 'refer'
- Average hearing >30 dB HL better ear

Dataset allocation

Hearing results allocated to dataset based on assessment history:

1. Longer-term dataset
   - Children with ≥2 hearing assessments spanning 2.5–6 months
   - Longer-term hearing profile constructed by blinded reviewer from consecutive assessments
2. Point-in-time dataset
   - Children with single hearing assessment, or multiple appointments not meeting inter-assessment interval criteria

Quality control

- Children appearing in both datasets: duplicates removed randomly, proportional to each dataset's size.
- Children with multiple assessments within a dataset: duplicate appointments removed randomly
- Clinical and demographic data unblinded
- Appointments without PLUM excluded from analysis

Longer-term dataset

449 appointments for 449 Aboriginal and Torres Strait Islander children.

Point-in-time dataset

4,832 appointments for 4,832 Aboriginal and Torres Strait Islander children.

Figure 1. Data preparation process.

Key methodological decisions

Longer-term dataset criteria. Consecutive assessments 2.5–6 months apart. The 2.5-month lower limit allows for OM to have been present two weeks before first detection. The 6-month upper limit reflects findings that 44% of OM-related hearing remains stable over this period (Leach et al. 2024) and accommodates longer visit intervals in remote areas.

Constructing longer-term profiles. Longer-term profiles were based on hearing status at consecutive assessments:

- ≤20 dB HL average both ears, both appointments
- 20–29 dB HL average better-ear both appointments, or better-ear hearing transitions between categories
- >30 dB HL average better-ear, both appointments.

Inter-rater reliability. Blinded to demographic and clinical data, two co-authors (SH and MW) independently coded long-term hearing status for 40 children (initial agreement 80%, final agreement 95%), with SH completing remaining coding.

Prevalence of longer-term hearing loss. We estimated 10–20% of hearing loss in the point-in-time group persisted >3 months, compared to 100% in the longer-term group.

Final dataset composition. Final datasets comprised 449 children (longer-term) and 4,832 children (point-in-time), with each child appearing once in each dataset only, ensuring full independence.

Statistical analysis

All analyses were conducted using publicly available online calculators (DATAtab Team 2023; MedCalc Software Ltd 2025; Stangroom 2025). Statistical significance was set at $p < .05$. Descriptive statistics summarised participant demographics and PLUM scores across hearing status groups. To assess differences in PLUM scores between children in different hearing level groups, we used independent samples *t*-tests, ANOVA with post-hoc Bonferroni tests, and Chi-square or Fisher's Exact tests for categorical comparisons. Diagnostic accuracy was evaluated using sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV). Effect sizes included odds ratios (ORs) with 95% confidence intervals, Phi coefficient (φ), and Cohen's *d*.

Results

Key dataset characteristics

Key clinical and demographic characteristics, pertinent to study aims, were compared for the longer-term and point-in-time datasets, to describe the data and check for sources of bias (Table 1). There were no

Table 1. Dataset characteristics.

Appointment characteristics	Longer-term hearing status dataset	Point-in-time hearing status dataset
Number of appointments	449	4,832
Number of children	449	4,832
Female [% (n)]	48.1% (216)	44.5% (2,152)
Lives in remote/very remote Australia[1] [% (n)]	27.4% (123)	27.5% (1,331)
Received open-access assessment services [% (n)]	90.0% (404)	93.8% (4,532)
Age-related data		
Mean age (months) at assessment [M (SD)]	41.9 (15.8)	39.9 (16.2)
Distribution by PLUM age-brackets		
< 12 months [% (n)]	2.0% (9)	4.2% (204)
12–18 months [% (n)]	7.8% (34)	7.8% (375)
19–24 months [% (n)]	6.9% (31)	8.5% (409)
25–30 months [% (n)]	11.6% (52)	9.3% (448)
> 30 months [% (n)]	71.9% (323)	70.3% (3,396)
Hearing-related data		
Individual ear audiometry results [% (n)]	59.7% (268)	55.1% (2,661)
Soundfield audiometry results [% (n)]	14.9% (67)	15.6% (755)
OAE results [% (n)]	59.9% (269)	65.4% (3,162)
Audiometry and/or OAE results [% (n)]	100% (449)	100% (4,832)
Clinical characteristics		
Average better-ear hearing ≤20 dB HL [% (n)]	44.1% (198)	78.7% (2,093)
Average better ear hearing >30 dB HL [% (n)]	3.8% (17)	6.3% (305)
Bilateral Type A tympanometry results [% (n)]	58.9% (251)	68.9% (3,099)
Bilateral OAE pass [% (n)]	55.1% (148)	67.2% (2,126)
Mean better-ear hearing level		
Whole dataset (dB HL) [M (SD)]	18.8 (8.0)	18.2 (8.1)
≤20 dB HL both ears (dB HL) [M (SD)]	14.5 (4.6)	14.5 (4.3)
21–30 dB HL equivalent, better ear (dB HL) [M (SD)]	19.8 (7.3)	21.2 (4.6)
>30 dB HL, better ear (dB HL) [M (SD)]	37.5 (6.3)	37.3 (7.5)

Notes: 1. ASGS remoteness classification system (Australian Bureau of Statistics 2021/2026).

substantial differences between datasets for gender (χ^2 (1, $n = 5,281$) = 1.70, $p = 0.19$) and geographical remoteness (χ^2 (1, $n = 5,281$) = 0.02, $p = 0.89$). In relation to service program – assessment or rehabilitation – we found a significant but negligible difference (χ^2 (1, $n = 5,281$) = 8.85, $p = 0.003$, Cramer's $V = 0.0427$), indicating distributions were practically equivalent.

Mean child age at PLUM administration was significantly higher in the longer-term group by just under 2 months (t (5,279) = 2.51, 95% CI [0.44, 3.56], p = .01), though the effect size was small ($d = 0.12$) suggesting the practical difference was minimal. There was no significant difference in distribution of children across PLUM age brackets (χ^2 (4, $n = 5,281$) = 8.70, p = .07).

A similar proportion of children in each duration group had individual ear audiometry results. Mean better-ear hearing level did not differ significantly between the longer-term and point-in-time groups (t (2,927) = 1.16, p = .25). Comparing hearing level groups, there were no significant differences in mean hearing level for children in the ≤20 dB HL group (t (1,815) = <0.01 95% CI [−0.94, 0.94], $p = 1.0$) or the >30 dB HL group (t (208) = 0.09, 95% CI [−4.75, 4.35], p = .93). However, children in the equivalent 21–30 dB HL group had significantly higher mean hearing levels (t (899) = 3.2, 95% CI [0.53, 2.27], $p <$ .05), though the effect size was small ($d = 0.23$) indicating no practical difference.

Ear health and hearing profiles differed significantly between duration groups, χ^2 (2) = 7.47, p = .024, but with negligible effect size (Cramér's $V = 0.031$). Children in the point-in-time group, whose assessments were >6 months apart, had better tympanometry, audiometry, and OAE findings than for the longer-term group, whose assessments were within 2.5–6 months. These results reflect clinical protocols that recommend annual assessments unless results indicate middle ear pathology or hearing concerns.

Consistent with the fluctuating nature of OM-related hearing, a smaller proportion of children in the longer-term group had average better-ear hearing >30 dB HL (3.8%, $n = 17$) than in the point-in-time group (6.3%, $n = 305$). This difference was statistically significant, χ^2 (1) = 4.58, p = .032, though the effect size was negligible ($\varphi = 0.029$).

PLUM results by hearing level and duration

To investigate PLUM's sensitivity to hearing level and duration of hearing status, we examined both categorical PLUM results (*"on track"*, *"borderline"*, *"not yet on track"*) and numerical PLUM scores (0-40) across hearing level groups (≤20 dB HL, 21–30 dB HL, and >30 dB HL) for both longer-term and point-in-time datasets.

Dataset composition and context

Among the 449 children with two hearing assessments within 2.5–6 months, 126 (28.1%) had bilateral hearing ≤20 dB HL at both timepoints, 17 (3.8%) had pOM-related better-ear hearing >30 dB HL at both assessments, and 306 (68.2%) had either better-ear hearing in the 21–30 dB HL range or transitional hearing over the measurement period. Two important caveats require consideration: (a) the small size of the group with longer-term hearing >30 dB HL ($n = 17$) warrants some caution with interpretation, and (b) these proportions reflect dataset limitations rather than population prevalence. Population prevalence of longer-term, persistent OM-related hearing loss >30 dB HL is estimated to be 1.3 to 2.4 times higher than found in our dataset (3.8% vs 5–9% population prevalence) (DeLacy et al. 2023; Morris et al. 2005; Richmond et al. 2023).

Distribution of PLUM categorical results

Figure 2 shows PLUM categorical results for each hearing level group in the longer-term and point-in-time datasets. The size of differences in results provides clear evidence of the effects of duration for children with average better-ear hearing >30 dB HL. Formal statistical testing was not feasible for all groups due to sample size considerations.

There were minimal duration effects for the ≤20 dB HL and 21–30 dB HL groups. Among children with better-ear hearing ≤20 dB HL, *"on track"* results differed by only 2.9 percentage points between longer-term (83.3%) and point-in-time (80.4%) groups. Similarly, children with better ear hearing 21–30 dB HL showed small differences: 67.6% vs 70.6% *"on track"* (3.0 percentage points).

Substantial duration effects emerged for the better ear >30 dB HL group. Children with confirmed losses over 2.5–6 months were *"on track"* at dramatically lower rates (11.8%) than children with hearing loss of the same level, but mostly transient (55.4%)– a 43.6 percentage point difference. Conversely, *"not yet on track"* results showed a 56.8 percentage point difference (82.4% vs 25.6%).

These substantial differences (>40 percentage points), compared to minimal differences in other groups (<5 percentage points), indicate that duration

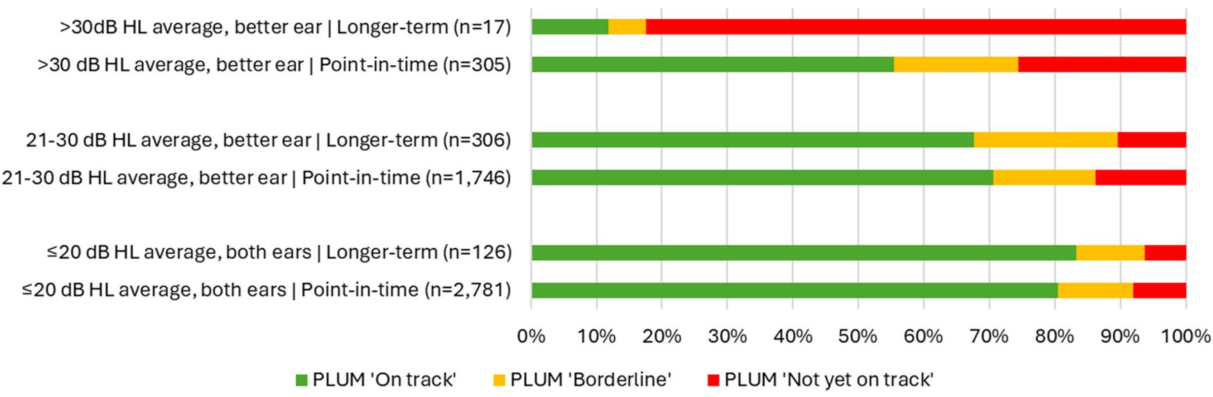

Figure 2. PLUM categorical results by hearing level and duration.

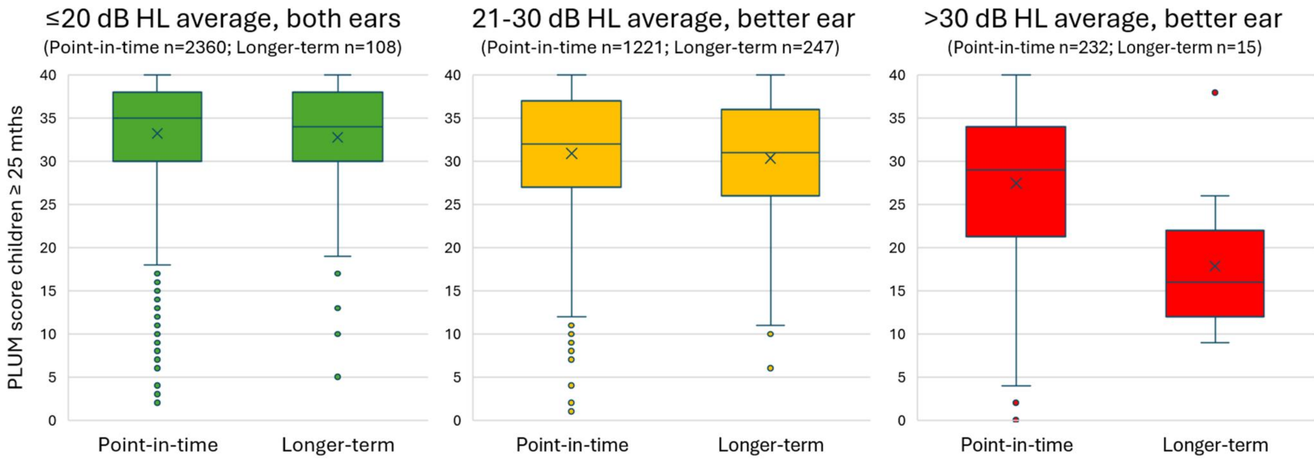

Figure 3. Mean PLUM scores by hearing level and duration (children ≥25 months, $n = 4183$).

of hearing loss becomes critically important to listening when hearing loss exceeds 30 dB HL in the better ear.

Distribution of PLUM numerical scores

To complement the categorical analysis, numerical PLUM scores were examined. As listening skills improve with experience and maturity, PLUM scores are expected to increase accordingly. Therefore, statistical comparisons should be conducted within discrete age groups. Sufficient data were available to compare mean PLUM scores by hearing level and duration for children aged 25 months and older, representing 84.2% of the longer-term group and 78.9% of the point-in-time group (Figure 3).

A two-way ANOVA (Appendix C) examined the effects of hearing level and duration on PLUM scores. The analysis revealed significant main effects for both hearing level ($F(2, 4177) = 118.45$, $p < .001$, $\eta^2 = 0.05$) and duration of hearing loss ($F(1, 4177) = 15.96$, $p < .001$, $\eta^2 < 0.01$), as well as a significant interaction between hearing level and duration ($F(2, 4177) = 5.41$, $p = .004$, $\eta^2 < 0.01$). Hearing level accounted for the largest proportion of variance in PLUM scores. Levene's test indicated heterogeneity of variance ($p < .001$); however, given the large sample size and ANOVA's robustness to this assumption violation, standard ANOVA procedures were used.

We found a clear hierarchy in PLUM scores based on hearing status. Bonferroni post-hoc comparisons (Appendix C) confirmed that children with bilateral hearing ≤20 dB HL significantly outperformed those with better ear hearing 21–30 dB HL (point-in-time: M difference = 2.32, $p < .001$; longer-term: M difference = 2.84, $p < .001$), who in turn significantly outperformed children with better ear hearing >30 dB HL (all comparisons $p < .001$). Notably, no significant differences emerged between point-in-time and longer-term groups for the ≤20 dB HL ($p = 1.0$) or 21–30 dB HL ($p = 1.0$) categories.

However, children with longer-term better-ear hearing >30 dB HL demonstrated substantially poorer

PLUM scores compared to those with point-in-time (largely transient) hearing at the same level (*M* difference = 9.59, $p < .001$) – the largest effect observed in the analysis. This pattern demonstrates that developmental impacts of hearing loss duration become pronounced when persistent OM-related hearing loss exceeds 30 dB HL in the better ear.

Cohen's *d* calculations (Appendix B) revealed that duration of hearing loss showed a large effect only for children with hearing >30 dB HL ($d = 1.2$). For both hearing duration groups, a clear gradient emerged: for the longer-term group, effects ranged from small (≤20 dB HL vs. 20–29 dB HL: $d = 0.29$) to very large (≤20 dB HL vs. >30 dB HL: $d = 2.08$). The point-in-time group showed the same pattern but with overall smaller effect sizes ($d = 0.32$ to 0.75).

Notably, children with longer-term hearing >30 dB HL scored over two standard deviations below those with hearing ≤20 dB HL, representing a substantial developmental gap. This indicates that while hearing level affects listening skills regardless of duration, these effects become substantially more pronounced when such hearing loss persists for more than 3 months, with meaningful implications for rapid intervention to improve hearing and support listening and communication needs.

Summary

Analysis of both categorical and numerical PLUM scores show the same pattern: "*not yet on track*" listening skills are strongly associated with longer-term OM-related hearing >30 dB HL. While other factors affecting listening development (attention disorders, developmental delays, family communication) weren't measured in this study, our findings suggest that more than 3 months of such a hearing loss has a measurable impact on listening skills – the foundation for spoken language and literacy.

The findings confirm our hypothesis that PLUM is significantly more sensitive to persistent, OM-related hearing >30 dB HL than to milder, transient, or unilateral loss. PLUM's strength lies not in detecting *any* OM or *any* hearing loss, but in assisting to identify when OM is – and is not – likely to be causing sustained auditory deprivation requiring prompt specialist care.

PLUM accuracy for longer-term hearing status

We calculated accuracy estimates for PLUM, using longer-term hearing status as the reference standard, with point-in-time hearing status for comparison. The target condition is OM-related average better-ear hearing >30dB HL.

True positives were PLUM "*not yet on track*" results with better-ear hearing >30 dB HL average. False positives were "*not yet on track*" results with equivalent better-ear hearing ≤30 dB HL average. False negatives were "*on track*" or "*borderline*" with better-ear hearing >30 dB HL average. True negatives were "*on track*" or "*borderline*" with better-ear hearing ≤30 dB HL.

When referenced to longer-term hearing status, PLUM showed high overall accuracy (90.2%) (Table 2). Specificity (90.7%) and negative predictive value (NPV) (98.6%) were particularly strong, indicating PLUM effectively rules out longer-term, better ear hearing >30 dB HL. Sensitivity was also high (82.4%), correctly identifying 8 in 10 children with better-ear hearing >30 dB HL average. Despite the relatively low prevalence of the target condition in the general population of young Aboriginal and Torres Strait Islander children (7%), the positive predictive value (PPV) of 40.1% was relatively strong. Notably, a "*not yet on track*" result increased the odds of longer-term hearing >30 dB HL by 45.7 times (OR = 45.73, 95% CI: 12.60, 165.93, $p < .0001$), a statistically and clinically significant association.

When referenced to point-in-time hearing data (in which most hearing losses are transient) PLUM maintained high accuracy for ruling out longer-term hearing loss but showed lower precision in correctly identifying children with the target condition.

Fishers Exact tests revealed significant differences between the longer-term and point-in-time estimates: sensitivity ($p < .00001$), with a medium effect size ($\varphi = 0.28$); PPV ($p = 0.03$), with a small effect size ($\varphi = 0.09$); and NPV ($p < .00001$), with a negligible

Table 2. PLUM accuracy by longer-term and point-in-time hearing status.

	Longer-term hearing status (n = 449)		Point-in-time hearing status (n = 4,832)	
Statistic	Value	95% CI	Value	95% CI
Sensitivity	82.35%	56.57% to 96.20%	25.57%	20.77% to 30.86%
Specificity	90.74%	87.61 % to 93.30%	89.71%	88.78% to 90.58%
Positive predictive value (PPV)	40.10%	31.66% to 49.17%	15.75%	13.16% to 18.74%
Negative predictive value (NPV)	98.56%	96.09% to 99.48%	94.12%	93.74% to 94.48%
Accuracy	90.15%	87.02% to 92.75%	85.22%	84.18% to 86.21%

effect size ($\varphi = -0.06$). Specificity did not differ significantly ($p = 0.56$).

These findings show PLUM is highly effective at identifying children *without* longer-term hearing >30 dB HL and significantly more accurate at detecting children with *longer-term* OM-related hearing >30 dB HL than those with transient or mild loss. While a "*not yet on track*" result increases the odds of longer-term hearing >30 dB HL 46-fold, due to a pOM population prevalence of 5–9%, only 2 in 5 children with this result are likely to have the condition. Conversely, 98 out of 100 children rated "*on track*" or "*borderline*" are correctly identified as not having sustained better-ear hearing >30 dB HL.

PLUM accuracy by age

PLUM is scored across five age groups: 6–11, 12–18, 19–24, 25–30, and >30 months. Due to limited data for children aged ≤30 months and the expected age of emergence of individual differences in listening behaviours, we grouped data into two categories: 0–36 months ($n = 164$) and ≥37 months ($n = 279$) (Table 3). We examined accuracy in reference to children's longer-term hearing status only.

Fishers Exact tests revealed no significant associations between age and sensitivity ($p = 1.0$), PPV ($p = 0.7$), or NPV ($p = 1.0$). Specificity differed significantly ($p = .02$) with higher estimates for younger children (94.97%) than older (88.39%), though with small effect size ($\varphi = 0.11$). Confidence intervals for sensitivity and PPV were wide, particularly for younger children, indicating increased uncertainty. Confidence intervals for most estimates overlap substantially. Overall, there is no compelling evidence for substantial differences in predictive accuracy by age group.

PLUM accuracy by geographical remoteness

We compared PLUM performance in remote and non-remote areas using long-term hearing status as the reference standard (Table 4). We adopted pOM prevalence rates of 9% for remote locations and 6% for non-remote locations, reflecting rates found in research with young Aboriginal and Torres Strait Islander children (DeLacy et al. 2023; Morris et al. 2005; Richmond et al. 2023). Due to small numbers of true positives, sensitivity estimates had wide confidence intervals, indicating high uncertainty. Fisher's Exact Test showed no significant differences between remote and non-remote areas for sensitivity ($p = 1.0$), specificity ($p = 0.47$), PPV ($p = 0.71$), or NPV ($p = 0.56$). Overall, there is no compelling evidence for substantial differences in predictive accuracy by remoteness area.

Discussion

This is the first study to report accuracy statistics for a listening skills checklist using longer-term hearing status as the reference standard. We hypothesised that listening skills would be more affected by longer-term (>3 months), better-ear OM-related hearing >30 dB HL than by transient hearing loss of the same level, or by milder, even longer-term, hearing loss. Our findings confirm this, highlighting the importance of using hearing data collected over time, from at least two assessments over 3–6 months to accurately

Table 3. PLUM accuracy by age group.

	6 to 36 months (n = 164)		37 to 72 months (n = 279)	
Statistic	Value	95% CI	Value	95% CI
Sensitivity	80.00%	28.26% to 99.49%	83.33%	51.59% to 97.91%
Specificity	94.97%	90.33% to 97.90%	88.39%	83.93% to 91.97%
Positive predictive value	54.48%	34.85% to 72.80%	35.07%	26.26% to 46.04%
Negative predictive value	98.44%	91.61% to 99.73%	98.60%	95.21% to 99.60%
Accuracy	93.92%	89.10% to 97.05%	88.04%	83.64% to 91.60%

Table 4. PLUM accuracy by remoteness.

	Remote locations (n = 122) prevalence rate 9%		Non-remote locations (n = 339) prevalence rate 6%	
Statistic	Value	95% CI	Value	95% CI
Sensitivity	100.00%	15.81% to 100.00%	80.00%	51.91% to 95.67%
Specificity	92.62%	86.46% to 96.57%	89.97%	86.06% to 93.08%
Positive predictive value (PPV)	57.28%	41.69% to 71.54%	33.73%	25.08% to 43.63%
Negative predictive value (NPV)	100.00%	96.79% to 100.00%	98.60%	96.24% to 99.49%
Accuracy	93.29%	87.35% to 97.00%	89.37%	85.49% to 92.51%

evaluate listening skills checklist performance for children with OM.

PLUM showed strong sensitivity to better-ear OM-related hearing >30 dB HL lasting >3 months, with 82% of affected children receiving a *"not yet on track"* result compared to only 26% of children with similar but predominantly short-term hearing loss. Among children with hearing ≤20 dB HL both ears, PLUM results were distributed similarly for both duration groups (see Figures 2 and 3), suggesting listening skills recover quickly once hearing normalises.

PLUM demonstrated strong diagnostic performance (sensitivity 82.4%, specificity 90.7%), reliably identifying children with and without better-ear OM-related hearing >30 dB HL, for >3 months. The high negative predictive value (98.5%) means children rated "*on track*" or "*borderline*" are very unlikely to have such a hearing loss – important reassurance for families and clinicians. While the positive predictive value was lower (40%), this is influenced by the population prevalence of the condition. The high NPV ensures PLUM effectively rules out persistent hearing problems, supporting its utility as a primary care screening tool. There was no evidence for significant variations in accuracy by age or remoteness area.

Children rated "*not yet on track*" were 46 times more likely to have sustained hearing problems than those rated "*on track*" or "*borderline*". Children with better-ear OM-related hearing >30 dB HL for >3 months had PLUM scores more than two standard deviations below those with hearing ≤20 dB HL, indicating substantial delays in foundational listening skills essential for speech, language, literacy, and social development. Although the sample of children with confirmed hearing >30 dB HL for >3 months was small ($n = 17$), the magnitude of difference (>2 SD) and consistency with categorical results strengthen confidence in these findings. This demonstrates how quickly listening skill delays emerge with persistent OM and shows that PLUM creates opportunities to interrupt the cascade of developmental harms.

Our findings support current specialist referral-level criteria for Aboriginal and Torres Strait Islander children with OM – hearing loss >30 dB HL persisting >3 months (Menzies School of Health Research 2020). Among children in our study with longer-term, better-ear hearing averaging 21–30 dB HL, 68% were "*on track*". For children with hearing >30 dB HL, but mostly shorter-term, 55% were "*on track*". However, among children with better-ear hearing averaging >30 dB HL for >3 months, only 12% were "*on track*", reinforcing the importance of considering both severity and duration.

To understand how PLUM compares to other tools, we reviewed published listening skills checklists for children. Direct comparison is challenging due to differences in age range, target populations, and conditions. We identified three peer-reviewed tools from Kenya (Newton et al. 2001), Italy (Orzan et al. 2021), and Brazil (Samelli, Rabelo, and Vespasiano 2011) all using point-in-time hearing data (Appendix D). The Italian checklist reported 73% PPV (influenced by 27.5% prevalence in their sample), while the Kenyan tool targeting more severe hearing loss (≥40 dB HL) achieved 100% sensitivity but only 7% PPV. Our findings show stronger accuracy than reported by Veselinović et al. (2025), likely reflecting their use of point-in-time data and reference standards beyond PLUM's capabilities.

These findings support Orzan et al. (2021) recommendation to include caregiver observations through structured checklists during ear health checks. While objective tests assess ear health at a point in time, listening checklists provide unique insights through caregiver observations. PLUM creates a meaningful exchange: caregivers share valuable observations while learning about listening behaviours to watch for. This beneficial cycle values caregivers' knowledge while strengthening their ability to advocate for their child's needs.

PLUM's characteristics address several systemic barriers in current care pathways. By providing actionable information during a single visit, it reduces return appointments – addressing logistical and financial barriers families face. Rather than repeated "watch-and-wait" periods, PLUM results can support more confident clinical decision-making about when specialist referral is warranted. Between 1 in 11 and 1 in 20 young Aboriginal and Torres Strait Islander children are affected by persistent OM (DeLacy et al. 2023; Morris et al. 2005; Richmond et al. 2023). These findings support the critical need for prevention and early detection, including implementation of six-monthly ear health checks and an active response, for all Aboriginal and Torres Strait Islander children aged younger than 5 years (Harkus et al. 2023).

PLUM represents one component of the systemic transformations needed in Aboriginal and Torres Strait Islander children's ear health care. By valuing parent and caregiver knowledge, enhancing practitioners' confidence, and reducing barriers to specialist referral, PLUM can help shift the approach from reactive treatment to proactive care, enabling earlier

supports that prevent rather than respond to developmental harm.

Strengths and limitations

Strengths

This study's aims were collaboratively developed with Aboriginal and Torres Strait Islander and non-Indigenous practitioners who actively use PLUM. The findings reflect natural variability in tool use. We examined PLUM performance using multiple complementary methods that provide converging, consistent evidence. As the first evaluation of a listening skills checklist against longitudinal hearing status, it directly captures the impact of persistent hearing problems in real-world conditions. The retrospective design enabled meaningful insights while minimising research burden on Aboriginal and Torres Strait Islander children and families. Access to data from the non-referral, community-based Hearing Assessment Program approximated population representation.

Limitations

The small sample of children with confirmed better-ear hearing >30 dB HL average for >3 months ($n = 17$) reflects both dataset constraints and lower-than-expected prevalence in the sample. While this limits precision of estimates, the consistency of findings with large effect sizes provides confidence in the results. The retrospective design meant no control over timing of assessments and required fitting existing data to research aims, resulting in substantial exclusion of potentially valuable information. Data collection occurred in an audiology setting, which may limit generalisability to primary health care use. However, since PLUM was specifically designed for practitioners without specialised audiology training, this limitation likely has minimal impact on broader clinical applicability. Other conditions affecting listening skills development (e.g. attention disorders, developmental delay) were not quantified, though the population-representative nature of the sample suggests these conditions are not over-represented.

Clinical implications

Children found to be "*not yet on track*" on PLUM are 46 times more likely to have hearing loss meeting referral-level criteria than those found "*on track*" or "*borderline*" (Menzies School of Health Research 2020). In practice, 2 out of 5 children "*not yet on track*" are likely experiencing longer-term hearing >30 dB HL. Reassuringly, 99 out of 100 children found "*on track*" or "*borderline*" on PLUM are unlikely to be experiencing such a loss.

Based on estimated prevalence (DeLacy et al. 2023; Gunasekera et al. 2009; Richmond et al. 2023), for every 100 children attending primary health care today, an average of 70 children will have some kind of OM. Seven of these children will have longer-term OM and better-ear hearing >30 dB HL, and 63 will have OM and/or hearing loss that is shorter-term or less severe. If using PLUM alone – *not* our recommendation – six of the seven children with pOM would be correctly identified as at risk, and one would be missed. Of the remaining 93 children – of whom 63 will have non-persistent OM and 30 will have no OM – 84 would be correctly identified as *not* having longer-term hearing >30 dB HL. Nine children would be incorrectly flagged for further assessment.

We recommend using PLUM alongside standard measures including parent/caregiver concern, signs and symptoms, otoscopy, tympanometry, and talking/language screening (Harkus et al. 2024). PLUM adds 3–5 minutes but provides insight into a child's longer-term access to sound, complementing point-in-time objective measures. As a free, culturally responsive tool usable by any health practitioner with consistent accuracy across Aboriginal and Torres Strait Islander language groups, PLUM is particularly valuable in remote or underserved areas.

A PLUM "on track" alongside objective results indicating OM enables confident reassurance, practical monitoring guidance, and less intensive follow-up. Conversely, a "*not yet on track*" alongside bilateral OM should trigger urgent referral for hearing evaluation and specialist review and provision of active communication and listening skill support strategies to parents and educators (Freeman n.d.; Johnson, n.d.).

PLUM was designed for use by primary care and other practitioners without specialist audiology training. Instructions, questions, and interpretation guidance are in plain English. The tool is freely downloadable, and training is minimal, accessible, available on-demand, and free. PLUM's ten questions and scoring/interpretation algorithm can be readily integrated into electronic health records.

Prospective studies including PLUM alongside ear health and hearing measures would enhance understanding of its accuracy and clinical value, particularly for earlier identification of hearing loss meeting specialist referral-level criteria and supporting caregivers to nurture listening skills.

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CRediT: **Samantha Harkus**: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Validation, Visualization, Writing – original draft, Writing – review & editing; **Meagan Ward**: Conceptualization, Formal analysis, Investigation, Methodology, Writing – review & editing; **Jessma Nash**: Formal analysis, Investigation, Methodology, Writing – review & editing; **Jason Gavrillis**: Data curation, Formal analysis, Visualization, Writing – review & editing; **Isabel O'Keeffe**: Conceptualization, Writing – review & editing; **Letitia Campbell**: Conceptualization, Supervision, Writing – review & editing; **Trumaine Rankmore**: Methodology, Supervision, Writing – review & editing; **Luke Austin**: Supervision, Writing – review & editing; **Vivienne Marnane**: Conceptualization, Writing – review & editing; **Michele Clapin**: Data curation, Resources, Writing – review & editing; **Vijayalakshmi Easwar**: Conceptualization, Funding acquisition, Methodology, Supervision, Writing – review & editing.

Disclosure statement

SH, MW, and VM were involved in the co-development of PLUM. There were no other competing interests.

Generative AI statement

Generative AI (Claude, Anthropic) was used to improve the clarity and flow of the manuscript text. No AI was used in study design, data collection, analysis, or interpretation of results. All scientific content, conclusions, and interpretations remain entirely the work of the authors.

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Appendix A

Table A1. Child demographic and service data for the extracted data.

Child demographics (n = 6,716)		
Gender [% (n)]		
	Female	44.6% (2,995)
	Male	52.8% (3,545)
	Unspecified	2.6% (176)
Cultural identity [number (%)]		
	Aboriginal	91.2% (6,125)
	Torres Strait Islander	4.0% (268)
	Aboriginal and Torres Strait Islander	4.8% (323)
Remoteness area[1] [number (%)]		
	Major cities	16.6% (1,118)
	Inner/outer regional	54.5% (3,663)
	Remote/very remote	27.5% (1,849)
	Unknown	1.3% (86)
Mean age at first PLUM in months [M (SD)]		
	Overall	35.9 (16.3)
	By remoteness area:	
	Major cities	39.0 (16.1)
	Inner/outer regional	36.1 (16.5)
	Remote/very remote	33.8 (15.8)
Appointments per child [n (%)]		
	One	2686 (40%)
	Two	1894 (28.2%)
	Three or more	2136 (31.8%)
Mean appointments per child by remoteness [M (SD)]		
	Overall	2.3 (1.7)
	Major cities	2.4 (1.7)
	Inner/outer regional	2.3 (1.8)
	Remote/very remote	2.5 (1.9)

Notes
1. ASGS classification (Australian Bureau of Statistics 2021/2026)

Table A2. Appointment demographic and service data for whole study dataset.

Appointment demographics (n = 15,444)		
Gender [% (n)]		
	Female	43.6% (6,734)
	Male	53.5% (8,259)
	Unspecified	2.9% (451)
Cultural identity [% (n)]		
	Aboriginal	91.2% (14,079)
	Torres Strait Islander	4.2% (653)
	Aboriginal and Torres Strait Islander	4.6% (713)
Remoteness area[1] [% (n)]		
	Major cities	16.2% (2,509)
	Inner/outer regional	53.8% (8,305)
	Remote/very remote	28.8% (4,446)
	Unknown	1.2% (184)
Appointment includes PLUM and hearing data[2] [% (n)]		
	Of all appointments in dataset	40.4% (6,242)
	Of appointments with children 0–30-months	40.1% (1,900)
	Of appointments with children 31 months and older	40.6% (4,342)
Mean average better-ear hearing level in dB HL (n = 6,540) [M (SD)]		
	All ages	18.7 (8.2)
	By remoteness area:	
	Major cities	16.6 (6.4)
	Inner/outer regional	17.6 (7.4)
	Remote/very remote	21.7 (9.5)
	By service program:	
	Hearing assessment program	17.7 (7.2)
	Rehabilitative program	26.5 (10.8)
	By age group:	
	Age 0–30 months	23.0 (9.8)
	Age 31 months and older	18.5 (8.2)
Appointments by service program type [% (n)]		
	Hearing Assessment Program	87.4% (13,498)
	Rehabilitative program	12.6% (1,940)
Mean inter-appointment interval in days [M (SD)]		
	Overall	218 (190.7)
	By remoteness area:	
	Major cities	176 (158.3)
	Inner/outer regional	215 (190.2)
	Remote/very remote	246 (203.3)
	By service program:	
	Hearing assessment program	232 (191.1)
	Rehabilitative program	161 (178.7)
	By age group:	
	Age 0–30 months	151 (122.5)
	Age 31 months and older	237 (202.0)

Notes
1. ASGS classification (Australian Bureau of Statistics 2021/2026)
2. Hearing data: results of audiometry and/or otoacoustic emissions testing

Appendix B. Comparison of mean PLUM numerical scores for children aged 25 months and older as a function of level and duration of hearing status

Comparison of PLUM mean scores for children aged ≥ 25 months			
Longer-term vs point-in-time measures (n = 4,192)			
Point-in-time (predominantly transient) hearing measures (n = 3,813)			
Longer-term hearing measures (n = 377)	≤20 dB HL, both ears (n = 2,360) $M = 33.24$, $SD = 6.73$	21–30 dB HL, better ear (n = 1,221) $M = 30.92$, $SD = 7.79$	>30 dB HL, better ear (n = 232) $M = 27.46$, $SD = 8.50$
≤20 dB HL, both ears (n = 108) $M = 32.37$, $SD = 6.45$	t (2,466) = 1.47, $p = 0.14$ 95% CI 0.33, 2.27] $d = 0.13$		
21–30 dB HL, better ear (n = 247) $M = 30.40$, $SD = 6.73$		t (1,466) = 0.98, $p = 0.33$ 95% CI [0.52, 1.56] $d = 0.07$	
>30 dB HL, better ear (n = 15) $M = 17.90$, $SD = 7.19$			t (245) = 4.26, $p < .0001$ 95% CI [5.14, 13.98] $d = 1.21$*
Longer-term hearing measures (n = 379)			
	≤20 dB HL, both ears (n = 108) $M = 32.37$, $SD = 6.74$	21–30 dB HL, better ear (n = 247) $M = 30.40$, $SD = 6.73$	>30 dB HL, better ear (n = 15) $M = 17.90$, $SD = 7.19$
≤20 dB HL, both ears (n = 108) $M = 32.37$, $SD = 6.74$		t (353) = 2.54, $p = 0.0116$ 95% CI [0.44, 3.50] $d = 0.29$*	
21–30 dB HL, better ear (n = 247) $M = 30.40$, $SD = 6.73$			t (260) = 6.96, $p < .0001$ 95% CI [8.96, 16.04] $d = 1.79$****
>30 dB HL, better ear (n = 15) $M = 17.90$, $SD = 7.19$	t (121) = 7.73, $p < .0001$ 95% CI [10.76, 18.18] $d = 2.08$****		
Point-in-time (predominantly transient) hearing measures (n = 3,813)			
	≤20 dB HL, both ears (n = 2,360) $M = 33.24$, $SD = 6.73$	21–30 dB HL, better ear (n = 1,221) $M = 30.92$, $SD = 7.79$	>30 dB HL, better ear (n = 232) $M = 27.46$, $SD = 8.50$
≤20 dB HL, both ears (n = 2,360) $M = 33.24$, $SD = 6.73$		t (3,579) = 9.26, $p < .0001$ 95% CI [1.83, 2.81] $d = 0.32$*	
21–30 dB HL, better ear (n = 1,221) $M = 30.92$, $SD = 7.79$			t (1,451) = 6.11, $p < .0001$ 95% CI [2.35, 4.57] $d = 0.42$**
>30 dB HL, better ear (n = 232) $M = 27.46$, $SD = 8.50$	t (2.590) = 12.16, $p < .0001$ 95% CI [4.85, 6.71] $d = 0.75$***		

Notes
*Significant at p <.05, with small effect size
**Significant at p <.05, with moderate effect size
***Significant at p <.05, with large effect size
****Significant at p <.05, with very large effect size

Appendix C. ANOVA and Bonferroni post-hoc tests

Two-way ANOVA

	Type III sum of squares	df	Mean square	F	p	η^2_p
Hearing level	12153.39	2	6076.7	118.45	<.001	0.05
Duration	818.89	1	818.89	15.96	<.001	0
Hearing level x Duration	555.31	2	277.66	5.41	.004	0
Error	214294.02	4177	51.3			

Results of two-way ANOVA

Bonferroni post-hoc tests

Duration.

		Mean Difference	SE	t	p
Point-in-time	Longer-term	1.56	0.39	3.99	<.001

p-value adjusted for comparison of 2 groups.

Hearing level.

		Mean Difference	SE	t	p
≤ 20 dB HL	21–30 dB HL	2.39	0.24	10.11	<.001
≤ 20 dB HL	>30 dB HL	6.34	0.48	13.27	<.001
21–30 dB HL	>30 dB HL	3.96	0.49	8.03	<.001

p-value adjusted for comparison of 3 groups.

Hearing level.

		Mean Difference	SE	t	p
Point-in-time – ≤ 20 dB HL	Longer-term – ≤ 20 dB HL	0.46	0.7	0.66	1
Point-in-time – ≤ 20 dB HL	Longer-term – 21–30 dB HL	2.84	0.48	5.92	<.001
Point-in-time – ≤ 20 dB HL	Point-in-time – 21–30 dB HL	2.32	0.25	9.19	<.001
Point-in-time – ≤ 20 dB HL	Point-in-time – >30 dB HL	5.78	0.49	11.73	<.001
Point-in-time – ≤ 20 dB HL	Longer-term – >30 dB HL	15.38	1.86	8.29	<.001
Longer-term – ≤ 20 dB HL	Longer-term – 21–30 dB HL	2.37	0.83	2.87	.061
Longer-term – ≤ 20 dB HL	Point-in-time – 21–30 dB HL	1.86	0.72	2.58	.149
Longer-term – ≤ 20 dB HL	Point-in-time – >30 dB HL	5.32	0.83	6.37	<.001
Longer-term – ≤ 20 dB HL	Longer-term – >30 dB HL	14.91	1.97	7.56	<.001
Longer-term – 21–30 dB HL	Point-in-time – 21–30 dB HL	−0.52	0.5	−1.04	1
Longer-term – 21–30 dB HL	Point-in-time – >30 dB HL	2.94	0.65	4.5	<.001
Longer-term – 21–30 dB HL	Longer-term – >30 dB HL	12.54	1.9	6.58	<.001
Point-in-time – 21–30 dB HL	Point-in-time – >30 dB HL	3.46	0.51	6.75	<.001
Point-in-time – 21–30 dB HL	Longer-term – >30 dB HL	13.06	1.86	7.02	<.001
Point-in-time – >30 dB HL	Longer-term – >30 dB HL	9.59	1.91	5.03	<.001

Appendix D. Predictive accuracy of similar listening skills checklists

Source	Country	Sample (n, age)	Test information	Reference test	Diagnostic accuracy
Newton et al. (2001)	Kenya	$n = 855$ Age range: 2.21–7.5yrs (mean 5.2yrs)	8 items, conducted by ENT clinical officer in nursery or community health clinic	Pure-tone audiometry (point-in-time)	For hearing loss $\geq$40 dB: Sensitivity: 100% Specificity: 75% PPV: 7% NPV: 100%
Orzan et al. (2021)	Italy	$n = 309$ Age range: 1–36 months	9 to 11 items, conducted with at-risk children during audiology assessment at a medical institute.	Pure-tone audiometry (point-in-time)	For conductive hearing loss, in children 10–36 months: Sensitivity: 32% Specificity: 90% PPV: 73%
Samelli, Rabelo, and Vespasiano (2011)	Brazil	$n = 214$ Age range: 2–10yrs	16 items, conducted by health community agents of family health program	Pure-tone audiometry (point-in-time)	Sensitivity: 44% Specificity: 87% AUC=0.72