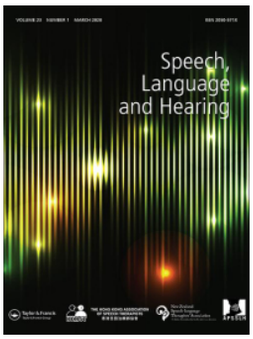

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Ear health, binaural processing, and phonological awareness in urban Australian First Nations and non-First Nations primary-school children

Jenni De Luca Bamber [a], Mridula Sharma [b,c], Katherine Demuth [b], Soumya Raman[d] and Gillian Wigglesworth [e]

[a]School of Allied Health, Curtin University PhD, Perth, Australia; [b]Department of Linguistics Macquarie University, Sydney, Australia; [c]College of Nursing & Health Sciences, Flinders University, Adelaide, Australia; [d]Mounds Park Academy, Saint Paul, MN, USA; [e]School of Languages and Linguistics, The University of Melbourne, Parkville, Australia

ABSTRACT

While early poor ear health is known to affect later overall health and educational outcomes for children, little is known about the simultaneous influence of ear health, binaural processing, and phonological awareness. There is also limited research into the ear health of urban-residing First Nations children of primary school age. This study extends the work of [Sharma, M., Darke, A., Wigglesworth, G., & Demuth, K. (2020) Dichotic listening is associated with phonological awareness in Australian aboriginal children with otitis media: A remote community-based study. International Journal of Pediatric Otorhinolaryngology, https://doi.org/10.1016/j.ijporl.2020.110398], collecting ear health, binaural processing, and phonological awareness data from 182 urban-residing children aged 4–7 years. Children attended one of eight urban government primary schools in lower quintile socio-economic areas. Analysis investigated differences in middle ear health on the day between First Nations and non-First Nations children, and compared binaural processing with phonological awareness scores. Significant differences were found, with First Nations children experiencing a higher prevalence of middle ear disorder and poorer phonological awareness performance on the day of testing. Although binaural processing scores were similar between groups, a moderate but significant correlation between binaural processing and phonological awareness was shown for First Nations children. Results are discussed in relation to the use of aggregated geographical-based measures of socio-economic status (SES). It is suggested that the social determinants that influence social disadvantage at an individual or community level, may better explain disparities in ear health and phonological awareness. Our findings underscore the importance of targeted interventions aimed at improving First Nations children's ear health and phonological awareness skills.

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First Nations children; ear health; otitis media; binaural processing; phonological awareness; urban cohort; socio-economic status; early-childhood education

Introduction

In Australia, it is well established that Aboriginal and Torres Strait Islander children (hereafter referred to as 'First Nations children') have a higher prevalence and pervasiveness of poor ear health, particularly otitis media, compared to their non-First Nations peers (Australian Institute of Health and Welfare, 2022; DeLacy et al., 2023; Williams & Jacobs, 2009). Otitis media (OM) is inflammation and infection of the middle ear caused by viral or bacterial pathogens and includes the subtypes of Acute OM (inflammation present) and OM with Effusion (OME), where a build-up of fluid is present without acute inflammation. OM is a common global public health disease in childhood (Monasta et al., 2012).

OM in early life (persistent, recurrent or episodic), resulting in conductive hearing loss, has been reported to increase the risk of adverse impact on binaural auditory processing ability (hereafter referred to as 'binaural processing'), even when hearing returns to normal (Graydon et al., 2017; Kong et al., 2021; Sharma et al., 2020; Sharma, Darke et al., 2020). Similarly, ongoing OM (defined in Australian OM guidelines as persistent for ≥ 3 months), and recurrent or repeated episodic OM, may impact the acquisition of phonological awareness skills in the early years of schooling which are essential for successful reading and educational outcomes (Carroll & Breadmore, 2017; Freire & Pammer, 2019; Kong et al., 2021), and increasing the risk of poorer long-term outcomes for speech and language development (Williams & Jacobs, 2009).

Despite the high rates of poor ear health in First Nations children and the reported impacts of OM on binaural processing and acquisition of phonological awareness skills, there is only limited research investigating cohort differences related to ear health and academic development in the early years of school

CONTACT Mridula Sharma mridula.sharma@flinders.edu.au Department of Linguistics Macquarie University, Sydney, Australia College of Nursing & Health Sciences, Flinders University, Sturt Road, Bedford Park, Adelaide, SA, Australia

(Sharma et al., 2020; Sharma, Darke et al., 2020). Two studies have reported links between hearing thresholds, binaural processing, and phonological awareness in geographically remote Australian First Nations communities (Sharma et al., 2020; Sharma, Darke et al., 2020). Other recent Australian research, which investigated the prevalence, risk factors and long-term sequelae of OM, tended to focus on specific outer-regional and geographically remote or very-remote areas of the country (herein referenced as 'geographically remote') (DeLacy et al., 2023; Eades et al., 2010; Jennings et al., 2021). There has also been a focus on infants and pre-schoolers aged < 3 years in Australian hearing health research (Choi et al., 2016). Choi et al. (2016) reported that data on Australian children is lacking in OM and hearing prevalence summaries. This is due to the reporting method used for hearing loss rates in Australian children, and the absence of any large-scale hearing loss prevalence studies for Australian primary-school-aged children. Their own systematic review into hearing loss rates in Australian primary school children excluded studies on First Nations children. More recently Brennan-Jones et al. (2020) examined the cross-sectional prevalence of OM in a prospective cohort of 5–7-year-old children in Perth, Western Australia and reported a combined prevalence of 22.5% ($n = 302$) for bilateral and unilateral OM. In general, there is agreement in the literature that a wide gap in knowledge exists for ear health and education in urban school-aged children (DeLacy et al., 2023; Eades et al., 2010; Jennings et al., 2021).

OM and hearing impairment

OM has been shown to have a significant adverse effect on hearing thresholds (Bell et al., 2021; Cai & McPherson, 2017). The hearing thresholds have been reported to range from 20–30 dB HL (Sharma et al., 2020) to 15–40 dB HL (Bell et al., 2021). Cai and McPherson's (2017) systematic review indicated that average thresholds in the literature across frequencies 500 Hz, 1kHz and 2kHz ranged from 18 to 35 dB HL, reaching as high as 50 dB HL in some cases. Additionally, many children may be asymptomatic or present with hearing thresholds within normal limits (Cai & McPherson, 2017; Hartley & Moore, 2005). Threshold range differences in these studies have often been attributed to the fluctuating and transient nature of OM-related conductive hearing loss (Cai & McPherson, 2017; Sharma et al., 2020). Slight differences in the classification of hearing loss severity, particularly for mild losses, may also be a factor (Clark, 1981; Margolis & Saly, 2007).

A 2012 review of published and unpublished literature noted that post-1995, few studies focused on OM prevalence rates in the general Australian population (Mahadevan et al., 2012). The most recent national prevalence data on ear health, was collected by the Australian Bureau of Statistics (ABS) as part of the National Aboriginal and Torres Strait Islander Health Survey (2018/2019). This data indicated that 29% of children aged 7–14 in urban areas and 40% in geographically remote areas had some level of hearing impairment. However, the Australian Institute of Health and Welfare (AIHW) (2022) noted that ABS prevalence data for OM and hearing impairment among First Nations children (0-6 years) was a key gap to address.

The AIHW (2022) also reported that Years Lived with Disability (YLD) for OM is 3.5 times higher for First Nations children than for non-First Nations peers. Findings from the aforementioned prospective cohort study (Brennan-Jones et al., 2020) of a cross-sectional prevalence rate of 22.5% (ages 5–7, $n = 302$) is similar to the 23.8% reported by Humaid et al. (2014) in Saudi Arabia, and higher than the 10.1–10.4% in other international studies in similar age groups (Apostolopoulos et al., 1998; Okur et al., 2004). However, Brennan-Jones et al. (2020) note the classification of OM varied across all the comparable studies, and their own study did not exclude or differentiate children who had possible dry perforations or in-situ grommets. The more recent *Djaalinj Waakinj* prospective cohort studies of First Nations children by Swift et al. (2020), Veselinović et al. (2022) and Richmond et al. (2023) contributed to urban prevalence data, although published data from these studies is limited to children aged <18 months. In sum, Australian national prevalence data on ear health is lacking.

Binaural processing

Binaural processing is the ability to collate information heard from both ears within the central auditory pathway to localise and discriminate sounds for better listening, particularly in noisy environments, e.g., classrooms (Khavarghazalani et al., 2016; Roberts et al., 2004). There is general agreement across the literature that OM negatively impacts binaural processing even when hearing thresholds are not impaired (Khavarghazalani et al., 2016; Roberts et al., 2004; Sharma et al., 2020; Williams & Jacobs, 2009). Both bilateral and unilateral OM have been shown to impact binaural processing negatively (Nittrouer & Burton, 2005; Ucles et al., 2012).

Graydon et al. (2017) and Tomlin and Rance (2014) investigated the effect of early childhood conductive hearing loss in school aged children on binaural processing, demonstrating an association between markers of hearing impairment and binaural processing deficits. The studies report that deficits in binaural processing and neural adaptation result from periods of auditory deprivation due to OM-related conductive

hearing loss occurring during critical development stages. These findings, emphasised the link between good access to auditory signals in early childhood and normal maturation of the auditory pathway, specifically binaural processing.

Binaural processing significantly influences the quality and clarity of acoustic input in the auditory pathway. Deficits in binaural processing have downstream effects on the precise perception required in speech and language development (Khavarghazalani et al., 2016; Kuhl et al., 2005). This downstream effect occurs because binaural processing facilitates the segregation of sounds in the auditory stream and localisation of sounds, providing the ability to distinguish between similar sounds and identify speech patterns, both of which are essential for mapping to the smaller components of language and differentiating between subtle phonemic contrasts when acquiring phonological awareness (Freire & Pammer, 2019; Khavarghazalani et al., 2016; Kuhl et al., 2005). Carroll and Breadmore (2017) report phonological weakness in phoneme segmentation and blending (breaking out and combining words into sounds), in children with a history of OM. Critically, Sharma et al. (2020b) and Sharma, Darke et al. (2020) established a predictive relationship between dichotic listening (an audiological task employed to assess binaural processing) and phonological awareness, separate from any hearing sensitivity. The authors suggested that dichotic listening is critical to the acquisition of phonological awareness and recommended that tests of dichotic listening or binaural processing be included within the standard clinical audiology battery (Sharma, Darke et al., 2020).

Phonological awareness

Phonological awareness is the ability to recognise, identify and manipulate the smaller components of language, phonemes, rhyme, syllables, and alliteration, and is a crucial building block of foundational literacy. Phonological awareness is deemed essential for proficiency in literacy and progressive academic success (Freire & Pammer, 2019). Phonological awareness in the following discussions relates to Standard Australian English (SAE) which can be impacted by the language background of the learner, particularly English as Another Language or Dialect (EALD), as is common with culturally diverse populations like Australia's (Freeman et al., 2022).

Many First Nations children may have English or a dialect of English as a second or third language (Freire & Pammer, 2019). The morphophonological differences between Standard Australian English and the different First Nations languages mean that acquisition and differentiation between unfamiliar Standard Australian English sounds can be challenging (Freire & Pammer, 2019). There is general agreement in the literature of the disconnect between Australian westernised school environments and First Nations languages and culture (DeLacy et al., 2020; Freire & Pammer, 2019; Webb & Williams, 2017). It has been suggested that the integration of cultural frameworks, and explicit teaching of First Nations culture and languages, such as Australian Aboriginal English, particularly through community involvement, would help to address disparities seen in educational achievement by providing greater cultural relevance and engagement for First Nations children (DeLacy et al., 2020; Freire & Pammer, 2019; Webb & Williams, 2017). It has also been reported that access to more than one language (in the case of bilingualism or multilingualism) may have a positive effect on the acquisition of early literacy skills such as phonological awareness (Lesaux & Siegel, 2003).

This study contributes to the understanding of disparities in ear health and education in urban, primary school-aged children by examining the prevalence of middle ear disorder and comparing binaural processing and phonological awareness data in a cohort of First Nations and non-First Nations children. Additionally, the paper considers the role of geographical-based aggregated measures of socioeconomic status (SES), in ear health and educational disparities. We aimed to investigate, firstly, whether differences exist in ear health and phonological awareness skills between urban First Nations and non-First Nations children and, secondly, what inferences can be made about any differences between the two groups. We hypothesised that there would be no significant statistical difference between the two cohorts' performance on binaural processing and phonological awareness tasks as markers of social disadvantage are relatively comparable at a within-school level. However, it was hypothesised that differences would exist for phonological awareness tasks in children with English as their second or third language. Ear health data for First Nations children is likely to show higher markers of poor ear health than non-First Nations children, consistent with the literature.

Materials & method

Testing of participants was completed by ten Masters of Clinical Audiology final year students from Macquarie University, overseen by three accredited audiologists. A total of nine days were spent collecting data across participating schools. There were six parts to the test procedure, and all six tests were conducted on the same day for each child. This research was approved by the Human Research Ethics Committee, and Aboriginal Ethics Sub-Committee of the Northern Territory Department of Health and Menzies School of Health Research **(**HREC 2016-2702**).** All children who participated had prior written informed parental consent to

participate in the research and verbally provided assent to participate on the day.

Participants

Participants were urban-residing children attending one of eight government primary schools in the Northern Territory, Australia. Schools were located and zoned in lower quintile SES areas (≤ 3 Statistical Area Level 2). SES of schools was determined using the index of relative socio-economic disadvantage (IRSD), a broad disadvantage measure aggregated from economic and social data collected in the Australian Census of Population and Housing (ABS, 2023; Australian Bureau of Statistics, 2018). Liaison with schools occurred through the Department of Education NT, and all children who participated (to the best of our knowledge) were permanently enrolled and local to the urban schools. Children who had relocated from remote communities, either temporarily or permanently, were excluded from testing on the advice from the school authorities. Overall, 182 children aged 4–7 years ($M = 5.55$ years, SD 0.60) participated and were distributed across school classes, Transition ($n = 142$ children), Year 1($n = 36$ children) and Year 2 ($n = 4$ children). 94 were male, and 88 were female. Of the participating children, 84 identified as First Nations (male $n = 39$, $M = 5.43$ years, SD 0.59/ female $n = 45$ $M = 5.65$ years, SD 0.67) and 98 as non-First Nations (male $n = 49$ $M = 5.54$ years, SD 0.61/ female $n = 49$ $M = 5.55$ years, SD 0.54).

Noise levels

All testing was completed within the schools during class-time, in a room provided for the purpose. Noise levels were monitored throughout testing and calibrated at the start and end of the day in quiet using the Soundlog® app on an iPad. The monitored levels were recorded as LAeq averages with varying durations and ranged between 55.8 LAeq (dB) and 59.4 LAeq (dB) across the locations.

Audiological assessment

Otoscopy

Bilateral otoscopic testing to identify abnormalities of the ear canal and tympanic membrane was conducted using a Heine Mini 3000 Otoscope, with results recorded qualitatively. A total of $n = 173$ children completed otoscopic examination. Forty-five children had unilateral or bilateral abnormal otoscopic findings such as fungal growth, foreign objects, tympanosclerosis, inflammation, or perforation (First Nations, $n = 17$, non-First Nations $n = 28$). Nine children were unable to complete otoscopic examination (First Nations $n = 3$, non-First Nations $n = 6$). All children continued with the other assessments.

Tympanometry

Standard 226 Hz Immittance using an Interacoustics Titan assessed the function of the middle ear on the day of testing and a modified Jerger (1970) classification of 226 Hz tympanograms was used to define the middle ear results. Many studies use a modified Jerger to classify tympanograms; however, there is a lack of consensus regarding normative data for tympanometry in children (Swanepoel et al., 2014). An alternative used by some researchers is a modified classification which further delineates the Type C tympanogram by Tympanic Peak Pressure (TPP), measured as daPa, into Type C^1 and Type C^2 (Helenius et al., 2012; Kei et al., 2005), as higher TPP has been associated with increased risk of OM (Swanepoel et al., 2014). Type C tympanograms were, therefore, further classified as Type C^1 (−150 daPa to − 200 daPa) and Type C^2 (> − 200 daPa), with C^2 indicating a higher risk of OM compared to C^1. Type B indicates likely fluid in the middle ear, and both Type B and Type Cs are grouped under the umbrella of middle ear disorder.

All children attempted testing and were instructed to sit quietly and still during the test. Bilateral tympanometric peak pressure, static compliance and ear canal volume was recorded for $n = 177$ children. Five left ears (First Nations $n = 3$), and 3 right ears (First Nations $n = 2$) did not have their tympanometry completed.

Conditioned play audiometry

Pure tone audiometry determines hearing thresholds as the softest tone able to be heard and was completed with an Interacoustics Audiometer (AD226). Conditioned Play Audiometry (CPA) was attempted under headphones (TDH39 headsets fitted inside Amplivox audiocups) as aligned with the previous paper (Sharma, Darke et al., 2020). Hughson-Westlake procedure was used to identify the softest tone that a participant could hear across the four main screening frequencies of 500 Hz, 1kHz, 2kHz and 4kHz, presented as pulsed-tones to improve audibility and responsiveness (Wiley & Burk, 2004). Children were conditioned to respond to audible pulsed-tone presentations by placing a token held next to their ear into a game board.

Complete audiometry results from 500 Hz – 4kHz for both right and left ears were recorded for $n = 172$ children. In children for whom audiometry was attempted and unable to be completed across the four frequencies due to attention or conditioning challenges ($n = 10$), testing the 1kHz frequency was deemed a priority. At 1kHz, right ear thresholds were recorded for $n = 178$ children, with 81 First Nations children ($n = 3$ did not complete) and 97 non-First Nations children ($n = 1$

did not complete). For the left ear at 1kHz, $n = 177$ completed the testing, with $n = 80$ First Nations children ($n = 4$ did not complete) and $n = 97$ non-First Nations ($n = 1$ did not complete).

Binaural processing assessment

The Dichotic Digits difference test (DDdt) and Listening in Spatialised Noise – Universal test (LiSN-U), were completed through licensed Sound Scouts software on a laptop with Sennheiser HD300 over-the-ear headphones. Normative data is built-in and calculated through z-scores for both tests to account for differences in performance due to age, with confidence intervals allowing for linear regression modelling, although raw scores are also recorded (Cameron et al., 2016a).

Dichotic digits difference test

The DDdt is used to determine function of binaural processing, particularly integration of information presented to both ears under two conditions. In the dichotic condition, a series of numbers (one to ten, excluding seven due to its bi-syllabic nature) are presented simultaneously with different numbers presented to the right and left ears, whilst the diotic condition simultaneously presents the same numbers to both ears controlling for poor dichotic performance due to influencing cognitive factors such as working memory and attention (Cameron et al., 2016a; 2016b). The free recall dichotic condition is tested first followed by the diotic control, with children instructed to repeat any numbers they heard during presentation, which are then recorded in the Sound Scouts software by the tester with a short listening break between dichotic and diotic conditions.

Raw free recall scores and z-scores were recorded for each child, with $n = 162$ children completing both conditions and $n = 6$ unable to complete due to inattention, fatigue or declining the test; a further $n = 14$ children completed only the dichotic condition. Of these $n = 162$ children, $n = 69$ First Nations children completed both Dichotic and Diotic tasks with $n = 15$ who did not complete both, or only Diotic tasks. The remaining $n = 93$ children were non-First Nations and $n = 5$ did not complete both tasks.

Listening in Spatialised Noise Universal test

LiSN-U evaluates listeners ability to integrate and use spatial cues in noise and is a language agnostic version of the Listening in Spatialised Noise Sentences test (LiSN-S), allowing it to be used for both speakers of English and other languages (Cameron et al., 2019). LiSN-U uses consonant–vowel pairs which occur with high frequency across many languages for the target stimuli (which the listener is instructed to repeat back), and the masking noise (Cameron et al., 2019). As the masking and target tokens for both conditions use the same tone of voice (informational masking) the LiSN-U is considered more sensitive to deficits in spatial processing than LiSN-S as used in previous studies (Sharma et al., 2020; Sharma, Darke et al., 2020).

Children were instructed that they would hear many funny-sounding words and were asked to ignore all words except the funny-sounding word that occurred after the beep. Several test rounds were given to familiarise children with the task. Two conditions were tested, the first being the spatial separation cue condition with noise presented separate to the signal. The second was the co-located condition, testing listening with no spatial cues such that the signal and masking were presented together in the same azimuth. Raw scores and z-scores were recorded, with $n = 78$ children completing both conditions and $n = 104$ unable to complete both conditions due to either inattention or declining one of the test conditions. Of the children who completed only one condition, t $n = 79$ children (First Nations $n = 29$, non-First Nations $n = 50$) completed the co-located condition, and t $n = 108$ children (First Nations $n = 44$, non-First Nations $n = 64$) completed the spatially-separated condition. Children were expected to perform better in the spatially separated condition than in co-location (Cameron et al., 2019).

Phonological awareness assessment

The Foundations of Early Literacy-Northern Territory (FELA) is a tool used by the Department of Education Northern Territory for the assessment and monitoring of basic pre-literacy skills, in Terms 1 and 4 of Transition, the first year of primary school (Department of Education Northern Territory, 2024). FELA assesses knowledge of Phonological and Phonemic awareness and Alphabet/Grapheme recognition, two core foundational skills, mastery of which supports successful literacy development and outcomes (Freeman et al., 2022; Neilson, 2016/2017). FELA has been reported to be in line with the Australian Curriculum (Neilson, 2016/2017), and the benchmarked or '*Mastery*' levels it uses were developed based on trial data collected from urban primary children in the Northern Territory (Freeman et al., 2022). Freeman et al. (2022), note that trial data collected from First Nations children in geographically remote locations (remote and very remote), was not included in benchmark setting, meaning that the FELA results are unlikely to reflect the early literacy milestones achieved by geographically remote First Nations students. For our study, all children were instructed in English following the standard FELA assessor script. These were presented with visual aids on a laptop with practise examples provided before each subtest. Scoring was recorded with points allocated per correct answer, summation of which generates a total score for each subtest and an overall test raw score.

The overall raw scores were used for our study, rather than the assigned 'mastery' levels. Children are expected to hit a ceiling, or increased skills mastery, as years at school and age, increase. The FELA is designed so children are only assessed to their point of knowledge and not beyond. In the first term of the initial year of schooling, children's raw total scores were expected to range between 0–63 based on the in-built benchmarks or mastery levels. Subtest six is used as a probe to continue or discontinue testing beyond that point and in the first term of the initial year of school, subtest six is expected to be an emerging skill (Neilson, 2016/2017).

A total of $n = 178$ children (First Nations $n = 80$, non-First Nations $n = 98$) completed at least one subtest up to the discontinuation point (subtest six). Four First Nations children were unable to complete any FELA subtest. A total of $n = 29$ children (First Nations $n = 10$ and non-First Nations $n = 19$) moved beyond the advanced probe to subtest seven. Of these children $n = 20$ (First Nations $n = 8$ and non-First Nations $n = 12$) were in their second or third year of schooling (from a total number of participating Year 1 $n = 36$ children, and Year 2 $n = 4$ children).

Data analysis

Raw scores were used to analyse children's results with age as a covariate in ANCOVA and accounted for in ANOVA analysis as in-built z-scoring is not available for all tests. Statistical analysis was undertaken using the statistic package JAMOVI version 2.4.1.

Results

Otoscopy

Otoscopy is a measure performed through observation by a clinician; while results were noted, no statistical analysis were completed. Of the children who completed otoscopy, $n = 128$ showed normal, clear, and intact tympanic membranes and/or non-occluding cerumen bilaterally, with the remainder ranging from bilateral tympanosclerosis ($n = 17$), bilateral inflammation ($n = 2$), bilateral retraction ($n = 1$), and bilateral ventilation tubes ($n = 1$). The remainder of otoscopy findings were unilateral, ranging from scarring, dull, foreign object in canal, fungal, retracted and inflammation, with the corresponding ear generally clear or non-occluding wax ($n = 24$).

Tympanometry

Most children showed normal tympanograms (Jerger classification Type A) with a total of $n = 107$ ears for First Nations children (30.1% of total ears tested) and $n = 159$ ears for non-First Nations children (44.7% of total ears tested). However, differences in ear health between groups was seen in the results, particularly the number of ears with middle ear dysfunction (Type B) as shown in Figure 1. Welch's t-test was used to conservatively compare difference between First Nations ($M = 1.58$, SD 0.88) and non-First Nations children's ($M = 1.29$, SD 0.71), number of Type A Normal tympanometry results to all other results (Type C, B and As), which showed a statistically significant difference $t(309) = 3.31$, $p = 0.001$ [range 0.12-0.46, 95% confidence interval].

With a total of $n = 354$ ears tested, First Nations children had 1.7 times higher prevalence of middle ear or eustachian tube dysfunction (48 ears or 13.6% of total ears tested), compared to 27 ears or 7.6% of total ears tested for non-First Nations children, as defined by Type B and Type C Jerger classification respectively. Overall, First Nations children had a 3.8 times higher prevalence of bilateral Type B and or Type C occurrence compared to non-First Nations children. The one child (First Nations) with ventilation tubes recorded Type B tympanograms with high ear canal volumes, confirming the tubes were patent (unobstructed and functioning), and was thus excluded from analysis of prevalence on middle ear pathologies but included in remaining analyses.

Children's ears with a Type C were further classified by Tympanic Peak Pressure. Type C^1 of -150 daPa to –200 daPa ($n = 8$ First Nations children's ears, $n = 9$ non-First Nations children's ears), and > −200 daPa as Type C^2 ($n = 17$ First Nations children's ears, $n = 11$ non-First Nations children's ears), with no significant difference seen in counts of C^1 or C^2 between the two groups.

Conditioned play audiometry

Hearing thresholds recorded for right and left ears from CPA were combined and averaged (4-frequency average of 500 Hz, 1kHz, 2kHz and 4kHz). Overall, audiometry thresholds agreed with Tympanometry (combined right and left ears), with poorer means for the tympanogram types B (middle ear fluid), and C (eustachian tube or middle ear dysfunction), compared to Type A and Type As, seen in Figure 1.

First Nations children with Type B and Type C (both Type C^1 and C^2) tympanograms had mean hearing thresholds outside of normal limits (hearing thresholds >20 dB HL), whilst non-First Nations children had means within or borderline (~20 dB HL) for Type B and Type C (Type C^1 and C^2). One First Nations child with bilateral Type C^2 tympanograms was unable to complete CPA and was excluded from the CPA hearing threshold and Tympanometry count. An independent t-test was performed to compare mean threshold differences between First Nations ($n = 44$, M = 23.5 dB HL, SD = 8.6 dB HL) and non-First Nations children ($n = 26$, M = 18.4 dB HL, SD 16.9 dB HL),

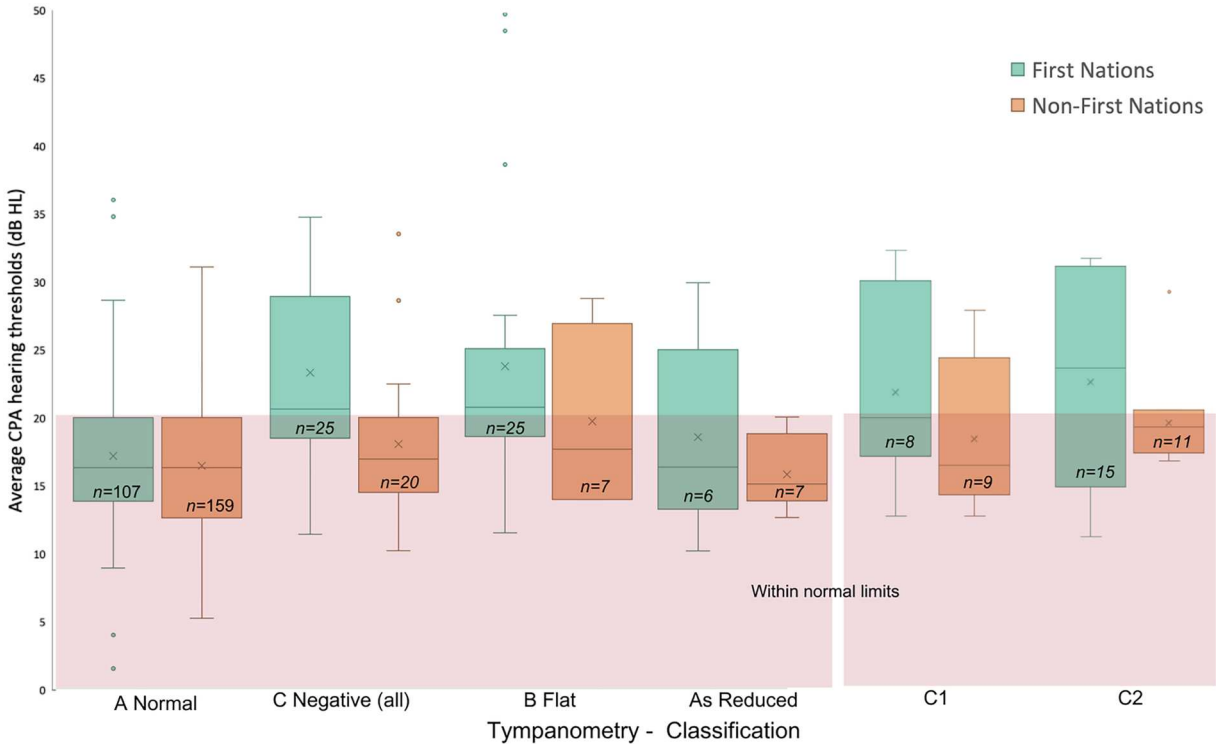

Figure 1. Mean CPA hearing thresholds (4-frequency average for combined right and left ears) by 226 Hz Tympanometry classification (combined right and left ears) and cohort group.

aggregating data for Type B and Type C tympanograms (C^1 and C^2). However, whilst calculated as a statistically significant difference with $t(68) = 2.71$, $p = 0.004$, the difference in the mean thresholds cannot be considered of clinical significance due to the small dB HL difference in the mean (a difference of ~5 dB HL between groups), as clinical test-retest reliability in audiometry is ±10 dB HL, whilst the Hughson-Westlake procedure uses 5 dB step-sizes (Jerlvall & Arlinger, 1986; Stuart et al., 1991).

Binaural processing

LiSN-U co-location threshold means for First Nations children were $M = 8.83$ dB, (SD 3.89 dB) and non-First Nations children threshold $M = 9.39$ dB, (SD 4.28 dB). Spatially separated performance scores for First Nations children's thresholds were $M = 5.41$, (SD 4.27) and non-First Nations children's thresholds were $M = 6.42$, (SD 4.86). As the masker and token are separated by 90 degrees in the spatially separated condition, the test participant can better access spatial and temporal processing cues (Cameron et al., 2019).

DDdt Dichotic means (% correct) for First Nations children were $M = 47.5\%$, (SD 9.85) and non-First Nations children $M = 48.5\%$, (SD 8.24). Diotic means were similar for First Nations children $M = 45.7\%$, (SD 8.61) and non-First Nations children $M = 47.2\%$, (SD 6.99).

To account for unequal variance in standard deviations, the different test condition raw scores were analysed with Welch's one-way ANOVA. ANOVA was used to evaluate the effect of cohort group on the DDdt ($n = 69$ First Nations children, $n = 93$ non-First Nations children) and LiSN-U ($n = 29$ First Nations children, $n = 49$ non-First Nations children). There is no statistically significant difference between First Nations and non-First Nations children's means for the DDdt (Dichotic $F(1,152) = 0.468$, $p = 0.50$ and Diotic $F(1,128) = 1.34$, $p = 0.25$). There is also no significant difference for the LiSN-U co-located condition ($F(1,63.3) = 0.352$, $p = 0.56$) or spatially separated condition ($F(1,99.8) = 1.28$, $p = 0.26$).

Phonological awareness

FELA test scores (up to the advanced probe) were analysed for differences between cohort groups using Analysis of Covariance (ANCOVA) to control for age (range 4–7 years), as age had a significant effect on FELA results ($p = <.001$). When controlling for age, results showed a significant difference between First Nations and non-First Nations children, [$F(1,175) = 9.77$, $p = 0.002$]. The mean scores in Figure 2 for FELA tasks up to the advanced probe were lower for First Nations children $M = 4.33$ (SD = 2.60) compared to non-First Nations children $M = 5.48$ (SD = 2.48).

Normality was tested with Shapiro–Wilk, returning $p = 0.064$, indicating that FELA scores did not significantly deviate from a normal distribution. Levene's test showed equal variances $p = 0.548$, supporting the assumptions of ANCOVA. Pearson's correlation

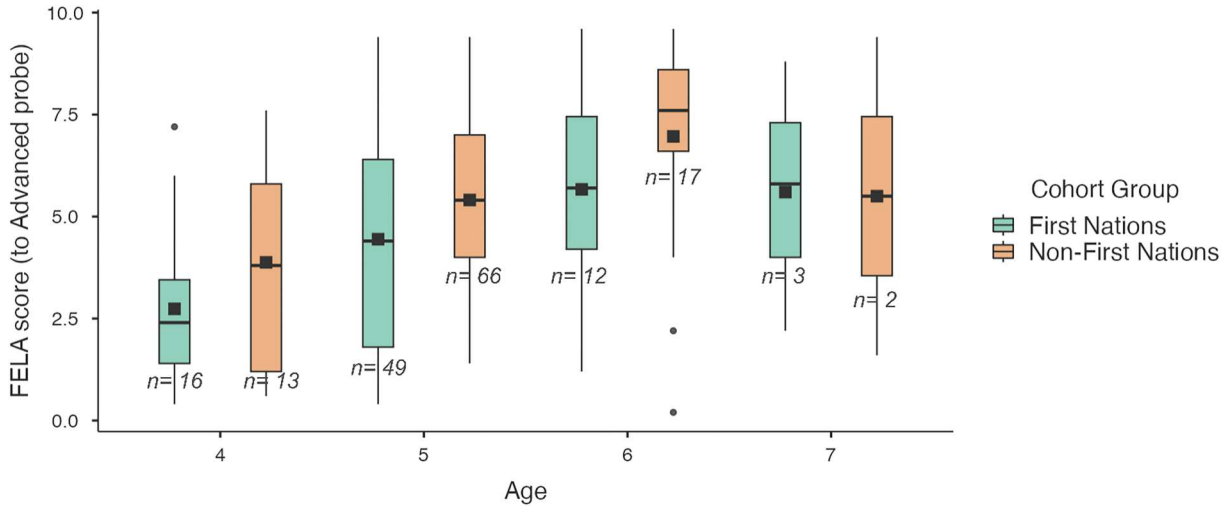

Figure 2. FELA total score (up to Advanced probe) Means by age and cohort group.

was analysed between binaural processing (the Dichotic score % correct) and phonological awareness (FELA score to advanced probe). As seen in Figure 3, First Nations children showed a significant positive correlation $r(76) = 0.038$, ($n = 78$, $p = <0.001$), whilst non-First Nations children showed no significant correlation $r(95) = 0.138$, ($n = 97$, $p = 0.177$). Given the potential of outliers, sensitivity analysis was completed. Spearman's rho calculation confirmed that the correlation for First Nations children remained statistically significant $r(76) = 0.0371$, ($n = 78$, $p = <0.001$), demonstrating that the correlation between binaural processing and phonological awareness remains significant even after accounting for potential outliers.

Differences in mean for FELA scores (up to Advanced probe) between Schools were analysed using Spearman's rho due to non-normal distribution. Results showed no significant correlation $r(176) = 0.118$, ($n = 178$, $p = 0.116$).

A Multivariate Analysis of Covariate (MANCOVA) was run to examine the effect of cohort group on each sub-test (up to the Advanced probe), whilst controlling for age. Significant difference was seen between First Nations and non-First Nations children in sub-tests; Syllable Clap [$F(1,175) = 12$, $p = <0.001$], Syllable Isolation [$F(1,175) = 6.23$, $p = 0.014$], Letter Name Identification [$F(1,175) = 11.83$, $p = <0.001$], and Letter Sound Identification [$F(1,175) = 9.13$, $p = 0.003$], with differences in mean shown in Figure 4. All assumptions were met. There was no significant difference for the Sound Identification sub-test [$F(1,175) = 1.15$, $p = 0.285$].

Discussion

This study aimed to explore the simultaneous influence of ear health, binaural processing, and phonological awareness in a cohort of urban-residing First Nations and non-First Nations children of primary school age, an extension of previous work by Sharma, Darke et al. (2020). As all children attended urban schools located and zoned in lower quintile

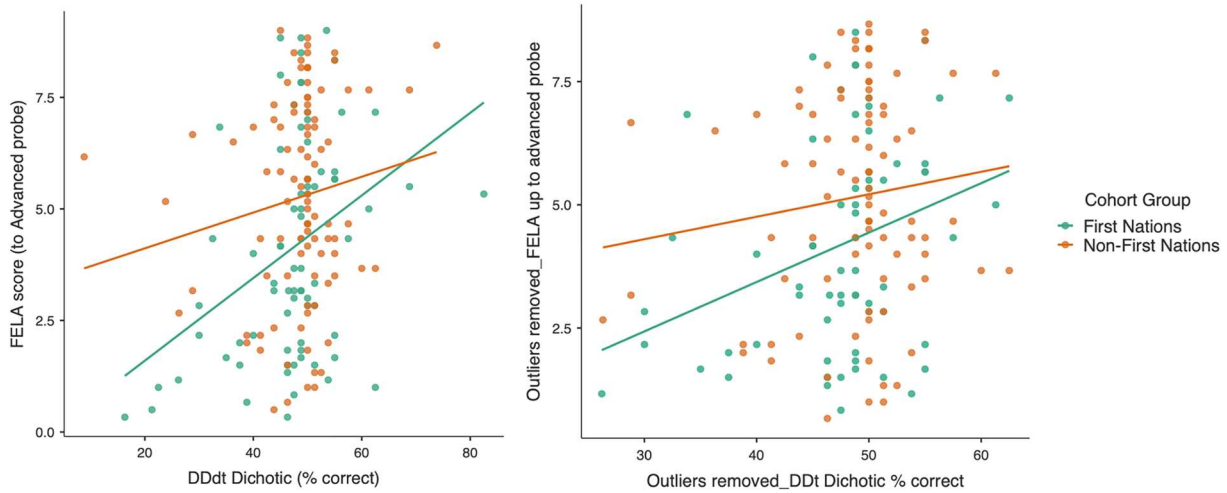

Figure 3. Correlation scatterplots for First Nation and non-First Nation children's FELA score (up to Advanced probe) and DDdt Dichotic (% correct), with and without outliers.

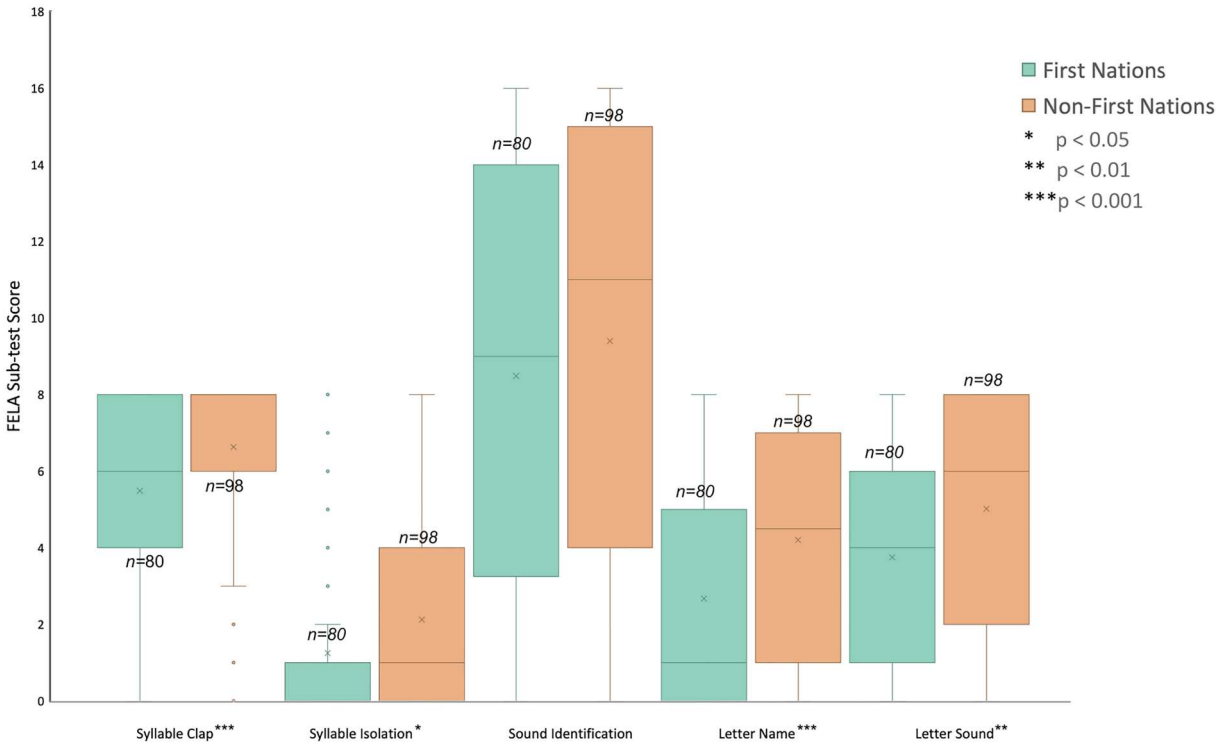

Figure 4. FELA Sub-test scores (Syllable Clap, Syllable Isolation, Sound Identification, Letter Name Identification, Letter Sound Identification) Means by cohort group.

SES areas (≤ 3 Statistical Area Level 2), we hypothesised that there would be no differences on any of the tasks between First Nations children and their non-First Nations peers. We found that: 1. The prevalence of OM was higher for First Nation children despite similar SES between the two participating groups; 2. Dichotic Digit difference Test showed no difference for the two groups despite a difference in ear health on the day of testing between First Nations and non-First Nations children; and, 3. Performance on the measure of phonological awareness correlated to the measure of binaural listening. These three findings are relevant for understanding how future research and interventions can be directed to support primary school-aged children's ear health and literacy progress.

Results showed a significant difference between the cohort's ear health with the First Nation children displaying higher prevalence of middle ear disorders on the day. Despite this difference, and consistent with our hypothesis, there were no differences between the groups for binaural processing tasks. However, assessment of phonological awareness test scores showed a significant difference between First Nations and non-First Nations children. Analysis also showed a significant moderate correlation between binaural processing and phonological awareness tasks for First Nations children.

Much research highlights SES as a key contributing factor to poor ear health and educational outcomes in First Nations children (Simpson et al., 2017; Webb & Williams, 2017). However, with SES constant, our study's finding of significant difference in phonological tasks may be explained by the way the IRSD measures social disadvantage in Australia. SES measures based on aggregated data of income, education and employment by geographical area has been reported as less likely to indicate social disadvantage (Goldfeld et al., 2018). In future research, frameworks such as Goldfeld et al.'s (2017) '*Multidimensional Framework of Child Disadvantage*', which consider a child's exposure over time to social determinants across multiple interacting environments at child, family and community levels should be considered. Australian children who are considered socially disadvantaged are reported to have poorer reading skills, lower rates of home reading by a parent or caregiver and lower preschool attendance (Goldfeld et al., 2021; Goldfeld et al., 2023). Many social determinants are also reported to be significant risk factors for and increase the likelihood of, poorer ear health. These factors increase the prevalence of OM and associated hearing loss (Simpson et al., 2017).

Further research investigating social determinants related to phonological awareness acquisition is needed. Future studies should collect additional participant data on children's English as an additional language or dialect (EALD) status (Freeman et al., 2022) and the history of OM episodes and associated historical audiological data, to account for possible auditory deprivation impacting binaural processing during critical language development periods (Graydon et al., 2017; Tomlin & Rance, 2014).

Freeman et al. (2022) found that First Nations children for whom SAE is not a first language, often reach foundational literacy milestones later (around Year 3) than their SAE-first language peers, indicating that delayed SAE-based phonological awareness assessment may be appropriate. Additionally, explicit phonological instruction within a multilingual early-primary setting can help EALD children achieve early literacy milestones at rates comparable to English-first-language peers (Lesaux & Siegel, 2003). Thus, reinforcing the value of the explicit teaching of phonological skills and the integration and teaching of First Nations culture and languages in classrooms to support a multilingual setting.

A lack of culturally appropriate approaches to First Nations education has been reported as a factor that can influence phonological awareness outcomes (Webb & Williams, 2017). There is a need for accessible and culturally inclusive early-childhood education in Australian urban-centres that embrace First Nations languages, and ways of learning (ACCC, 2023; DeLacy et al., 2020; Webb & Williams, 2017). First Nations led or community-controlled early-childhood education can support First Nations families and children to learn and succeed in a multilingual environment in the same way Aboriginal Community Controlled Health Services (ACCHSs) empower and educate First Nations populations health in a culturally safe manner (ACCC, 2023; DeLacy et al., 2020; DeLacy et al., 2023). Early childhood community-controlled centres or playgroups engaging in universal before-school health screening programmes (particularly for ear health and functional listening), are likely to drive better phonological awareness acquisition and ear health in urban First Nations children starting school, although there is a paucity of research on this topic. The Learning to Talk, Talking to Learn programme (LiTTLe) (Jones et al., 2018), which ran from 2006 to 2014 in the Northern Territory of Australia is one such example of this type of cross-discipline approach to early childhood education and health. Future research should consider co-designing conjoined educational and health initiatives to ensure benefit to First Nations communities, and increased and sustainable uptake (Butler et al., 2022).

The second key finding in the current study was that First Nations children showed disparities in ear health compared to their non-First Nations peers. Tympanometry results from this study are limited to a one-off period, thus cannot be interpreted as evidence of long-standing middle ear or eustachian tube dysfunction, as results may vary depending on changes in negative pressure, blockage, or resolution of underlying causes like seasonal illnesses. Our finding of a higher prevalence of Type B & Type C tympanometry classifications for First Nations children within the cohort is consistent with our hypothesis, current published literature, and population data, indicating that First Nations children have higher rates of poor ear health (AIHW, 2022; Williams & Jacobs, 2009). In an urban area, barriers to equitable and culturally appropriate healthcare and healthcare information exist for culturally and linguistically diverse populations (Khatri & Assefa, 2023). Barriers to accessing health services and health literacy have been documented as contributors to disparities in ear health outcomes (DeLacy et al., 2020; DeLacy et al., 2023), which may explain the differences seen in this study.

The third finding was that, despite the differences in ear health, children's performance was similar on binaural listening tasks. Simpson et al. (2017) found that SES contributed to children's developmental outcomes regardless of First Nations status or presence of hearing loss, which may be similar to our findings. Children with a history of long-standing middle ear are also more likely to show poorer performance on binaural listening tasks, although one-off, on the day ear health data cannot be used to infer long-standing or on-going middle ear dysfunction (Graydon et al., 2017; Tomlin & Rance, 2014) and thus quantifying the impact of on the day ear health results with binaural task outcomes is difficult.

The final key finding is that the urban First Nations cohort demonstrated a moderate correlation between binaural processing and phonological awareness, in line with the previous Sharma, Darke et al. (2020) remote community study. Given the poorer on-the day ear health, phonological awareness and moderate correlation between binaural processing and phonological awareness for First Nations children in our urban cohort, it is suggested that individual factors or an interaction of factors related to a child's social determinants of health and education, rather than aggregated measures of socio-economic status per se, are driving ear health and phonological awareness outcomes (DeLacy et al., 2023; DeLacy et al., 2020; Webb & Williams, 2017; Williams & Jacobs, 2009). Some consideration should also be given to the low number of children able to complete the LiSN-U, which can be attributed to factors such as attention span and test fatigue, as these are known challenges in this age group (Cameron et al., 2019). Intrinsic motivation may be another reason for poor uptake of the task.

Conclusion

This study highlights differences in ear health and phonological awareness among a cohort of urban First Nations and non-First Nations children. The findings are discussed in the context of sociocultural factors known to impact social disadvantage in culturally and linguistically diverse populations in Australia. Exposure to language-rich environments combined with inequitable access to culturally appropriate healthcare services,

may be contributing to the differences seen in our study. Future research should consider frameworks that explicitly measure such social determinants of social disadvantage rather than relying on aggregated geographical-based measures of socio-economic status. These findings emphasise the need for targeted, First Nations-informed initiatives for meaningful improvements in phonological awareness and ear health outcomes for urban First Nations children.

Limitations and future research

There are two limitations of the current research. Firstly, demographic, cultural and linguistic information of participating children was not available. This limited analysis against the hypothesis that differences will likely be seen between English as an additional language or dialect (EALD) and first-language Standard Australian English children. Secondly, data on middle ear history and access to early childhood education was unavailable. Future research should incorporate information on social determinants which influence ear health and phonological awareness acquisition. For a deeper understanding of the long-term effects of social determinants factors on developmental outcomes, future research should use a framework designed to gather data on determinants of social disadvantage rather than using geographically defined aggregated measures of SES and consider longitudinal studies that track the same cohort of children over time. This data would enable better quantification of their impact on outcomes enabling a better understanding of the differences seen in phonological awareness scores.

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ORCID

Jenni De Luca Bamber http://orcid.org/0009-0002-0288-085X
Mridula Sharma http://orcid.org/0000-0002-0448-6429
Katherine Demuth http://orcid.org/0000-0003-3884-8886
Gillian Wigglesworth http://orcid.org/0000-0003-2753-5200

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