

Prevalence of Hearing Loss Among a Representative Sample of Canadian Children and Adolescents, 3 to 19 Years of Age

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Objectives: There are no nationally representative hearing loss (HL) prevalence data available for Canadian youth using direct measurements. The present study objectives were to estimate national prevalence of HL using audiometric pure-tone thresholds (0.5 to 8 kHz) and or distortion product otoacoustic emissions (DPOAEs) for children and adolescents, aged 3 to 19 years.

Design: This cross-sectional population-based study presents findings from the 2012/2013 Canadian Health Measures Survey, entailing an in-person household interview and hearing measurements conducted in a mobile examination clinic. The initial study sample included 2591 participants, aged 3 to 19 years, representing 6.5 million Canadians (3.3 million males). After exclusions, subsamples consisted of 2434 participants, aged 3 to 19 years and 1879 participants, aged 6 to 19 years, with valid audiometric results. Eligible participants underwent otoscopic examination, tympanometry, DPOAE, and audiometry. HL was defined as a pure-tone average >20 dB for 6- to 18-year olds and \geq 26 dB for 19-year olds, for one or more of the following: four-frequency (0.5, 1, 2, and 4 kHz) pure-tone average, high-frequency (3, 4, 6, and 8 kHz) pure-tone average, and low-frequency (0.5, 1, and 2 kHz) pure-tone average. Mild HL was defined as >20 to 40 dB (6- to 18-year olds) and \geq 26 to 40 dB (19-year olds). Moderate or worse HL was defined as >40 dB (6- to 19-year olds). HL in 3- to 5-year olds (n = 555) was defined as absent DPOAEs as audiometry was not conducted. Self-reported HL was evaluated using the Health Utilities Index Mark 3 hearing questions.

Results: The primary study outcome indicates that 7.7% of Canadian youth, aged 6 to 19, had any HL, for one or more pure-tone average. Four-frequency pure-tone average and high-frequency pure-tone average HL prevalence was 4.7 and 6.0%, respectively, whereas 5.8% had a low-frequency pure-tone average HL. Significantly more children/adolescents had unilateral HL. Mild HL was significantly more common than moderate or worse HL for each pure-tone average. Among Canadians, aged 6 to 19, less than 2.2% had sensorineural HL. Among Canadians, aged 3 to 19, less than 3.5% had conductive HL. Absent DPOAEs were found in 7.1% of 3- to 5-year olds, and in 3.4% of 6- to 19-year olds. Among participants eligible for the hearing evaluation and excluding missing data cases (n = 2575), 17.0% had excessive or impacted pus/wax in one or both ears. Self-reported HL in Canadians, aged 6 to 19, was 0.6 E% and 65.3% (aged 3 to 19) reported never having had their hearing tested. E indicates that a high sampling variability is associated with the estimate (coefficient of variation between 16.6% and 33.3%) and should be interpreted with caution.

Conclusions: This study provides the first estimates of audiometrically measured HL prevalence among Canadian children and adolescents. A larger proportion of youth have measured HL than was previously reported using self-report surveys, indicating that screening using self-report or proxy may not be effective in identifying individuals with mild HL. Results may underestimate the true prevalence of HL due to the large number excluded and the presentation of impacted or excessive earwax or pus, precluding an accurate or complete hearing evaluation. The majority of 3- to 5-year olds with absent DPOAEs likely had conductive HL. Nonetheless, this type of HL which can be asymptomatic, may become permanent if left untreated. Future research will benefit from analyses, which includes the slight HL category, for which there is growing support, and from studies that identify factors contributing to HL in this population.

Key words: Adolescents, Audiometry, Children, Distortion product otoacoustic emissions, Hearing loss, Population based.

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INTRODUCTION

There is strong evidence indicating that a hearing loss (HL) of >40 dB negatively impacts many areas needed for classroom learning and vocational achievement (Carney & Moeller 1998; Matkin & Wilcox 1999; Kennedy et al. 2006). However, in children and adolescents, the consequences of even minimal HL can be far reaching with adverse effects on language development, academic performance, and social development. Increasingly, more attention is being focused on mild or slight hearing impairment \geq 20 dB HL including unilateral or bilateral loss that may affect 10 to 15% of school-aged children with deleterious effects on school performance and social emotional development (Dodd-Murphy & Mamin 2002; Lieu 2004; Wake & Poulakis 2004; Lieu et al. 2010).

In the first paper to present HL prevalence data from the National Health and Nutritional Examination Survey (NHANES) based on a nationally representative sample of U.S. children, Niskar et al. (1998) reported that 14.9% (n = 6166 children, aged 6 to 19 years) had low- or high-frequency HL of at least 16 dB. In a later analysis, 1988–1994 NHANES prevalence data for 12- to 19-year olds (14.9%) were compared with the 2005–2006 NHANES cohort prevalence data (19.5%); the authors concluded that HL prevalence was increasing (Sharogodsky et al. 2010). Ongoing population-based studies provide valuable information in that trends in the prevalence of HL and comparisons to other health outcomes can be monitored within and between populations, provided that similar methodologies are used.

Recently, Feder et al. (2015) published findings of the first nationally representative HL prevalence study among Canadian adults. However, to date, there are no nationally representative HL prevalence data available for Canadian children/adolescents

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using audiologic measurements. National HL prevalence estimates are currently based on self-reported data from the Canadian Community Health Survey (CCHS) and the Participation and Activity Limitations Survey (PALS). The CCHS is a cross-sectional national health survey wherein 1.1% of participants, aged 11 to 20 years ($n = 18,858$) reported a HL based on a series of five hearing-related questions (Statistics Canada 2004). This is in contrast to the PALS where 0.5% of Canadians, 15 to 24 years ($n = 21,810$), reported a limitation; this survey focused on the frequency and extent to which a hearing difficulty interfered with the individual's ability to carry out daily activities including but not limited to self-care, household, and leisure activities (Statistics Canada 2009). These self-reported measures of HL may not provide an accurate reflection of the prevalence among this population, particularly when the HL is mild, or when HL is evaluated by proxy (Niskar et al. 1998; Bess et al. 1998). Even when the proxy is the parent or guardian, they may not be aware of the child's hearing difficulty or may attribute problems listening in the classroom to attentional or behavioral issues (Bess et al. 1998). Older children who are able to respond to questionnaires may not be aware they are experiencing hearing difficulty when the impairment is mild (Bess et al. 1998). The self-reported HL prevalence data presently available for Canadian youth provides limited information regarding the HL severity or type with an obvious gap in prevalence estimates for children under the age of 11 years.

The Canadian Health Measures Survey (CHMS) launched in 2007 and modeled after NHANES, is an ongoing cross-sectional survey designed to provide national estimates on a variety of health indicators collected through in-person interviews and direct physical audiologic measurements from a representative sampling of Canadians. Hearing evaluations, introduced in 2012 during Cycle 3 of the CHMS, provided the first opportunity to estimate national prevalence regarding hearing health and acuity based on a nationally representative sample of youth. This article presents the audiologic findings, consisting of audiometric thresholds (0.5 to 8 kHz) and or distortion product otoacoustic emissions (DPOAEs) for children and adolescents, aged 3 to 19 years.

This study was approved by the Health Canada and Public Health Agency of Canada Review Ethics Board (Protocol #2005-0025).

MATERIALS AND METHODS

Participants

Participants were recruited from the following five regions of Canada: Atlantic, Quebec, Ontario, Prairies, and British Columbia. All CHMS participants who underwent hearing evaluations were allotted a \$100 honorarium. The response rate for Cycle 3 CHMS participants, aged 3 to 5 and 6 to 19 years, was 50.7 and 53.5%, respectively. These were based on combined response rates for the household interview and questionnaire as well as participation in the physical measures portion of the study. The CHMS excludes full-time members of the Canadian Forces; residents of the three territories, First Nations Reserves and other Aboriginal settlements, certain remote regions, and institutional residents. Despite these exclusions, CHMS data are considered to be representative of the Canadian population.

HL prevalence estimates for the total child/adolescent sample (6 to 19 years) are presented as well as for two separate age

groupings (6 to 11 and 12 to 19 years) to be consistent with previous CHMS publications and to facilitate comparison with similarly designed population-based NHANES studies (Niskar et al. 1998; Shargorodsky et al. 2010; Statistics Canada 2015a).

In Figure 1, exclusions and derivation of study subsamples (unweighted) are shown. The initial analysis included participants eligible for the hearing evaluation, aged 3 to 19 years ($n = 2591$) representing 6.5 million Canadians (3.3 million males). Participants who were excluded had incomplete or unacceptable audiometry results for one or both ears and/or one or more of the following conditions: ear infection, cochlear implant, blood, foreign object along with a collapsed or narrow ear canal, excessive or impacted wax along with a collapsed or narrow ear canal, pain/trauma to ear, ear surgery within previous 3 months, or refusal to remove hearing aid or participate in otoscopy. Once exclusions were applied, study subsamples consisted of 2434 participants, aged 3 to 19 years and 1879 participants, aged 6 to 19 years, with valid audiometric results bilaterally.

Data Collection

Household Interview • Self-reported data were collected in-person using a computer-assisted personal interview to gather demographic, socioeconomic, health and lifestyle information (Statistics Canada 2014). The Health Utilities Index Mark 3 (HUI3) hearing attribute was administered as a measure of self-reported HL (Feeny et al. 2002; Feng et al. 2009). The HUI3 is a generic multiattribute preference-based measure of functional health consisting of eight health status attributes (vision, hearing, speech, ambulation, dexterity, emotion, cognition, and pain) with five possible levels of self-report per attribute ranging from normal to highly impaired (Feeny et al. 2002; Feng et al. 2009). See supplemental Appendix A, <http://links.lww.com/EANDH/A295>, for HUI3 questions.

Physical Measures • Participants were evaluated in a mobile examination clinic. The possibility that the presence of temporary threshold shift (i.e., a temporary increase in hearing threshold after loud noise exposure) may have influenced measurements was considered by asking participants to recall their exposure to loud noise/music in the 24 hr before testing. Among those aged 6 to 19 with valid audiometric results ($n = 1879$), 173 reported this exposure. This small sample size precluded statistical comparisons with the 1706 participants that did not report this exposure.

All testing was carried out by health measures specialists with training/supervision provided by a certified audiologist who conducted periodic on-site visits to ensure quality control. Hearing tests, with the exception of otoscopy and tympanometry, were carried out while participants were seated in a portable audiometric booth (Eckel, AB-4230), with the door closed. Individuals who refused or had apparent cognitive deficits that could potentially interfere with testing were excluded from DPOAE testing and audiometric evaluation.

Ambient Sound Level Measurements • A Casella CEL-633 sound level meter monitored ambient sound pressure levels inside the sound booth. Testing was paused if sound pressure levels exceeded 55 dB for more than 2 sec. Young children reluctant to sit in the audiometric booth alone were tested in the booth while sitting on a parent's lap.

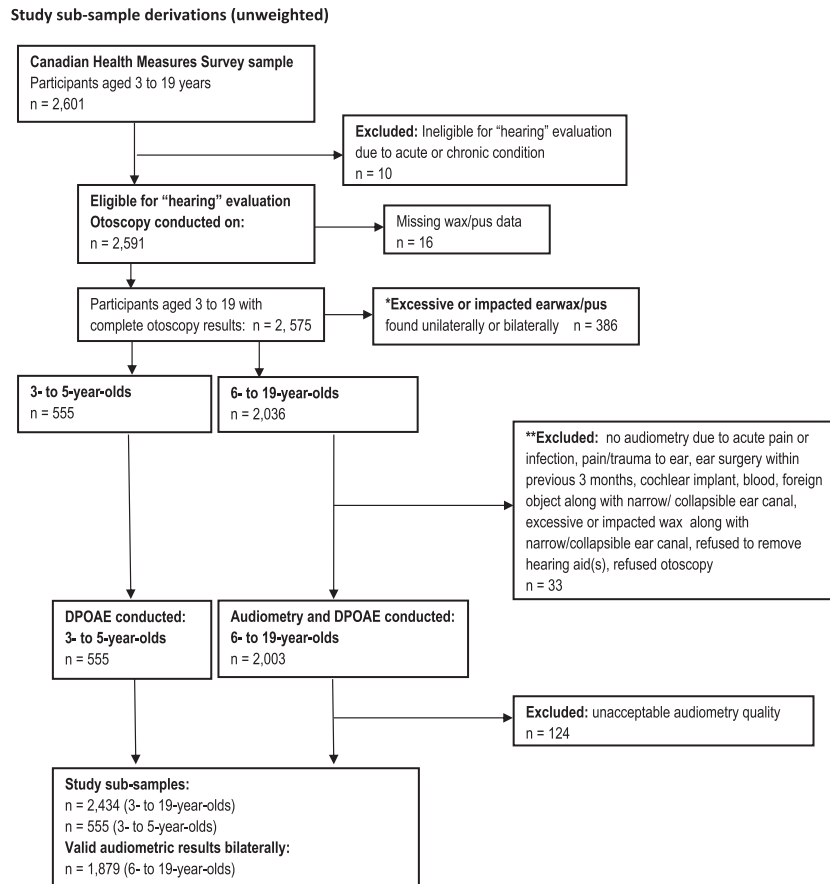


Fig. 1. Study subsample derivations (unweighted). All 555 3- to 5-year olds eligible for the hearing module were included in the study sample; *audiometry was conducted using supra-aural headphones on portions of this subsample; **33 participants were excluded from all or portions of hearing evaluation; DPOAE indicates distortion product otoacoustic emissions.

Hearing Evaluation Protocol • The testing for 6- to 19-year olds consisted of: otoscopy, tympanometry, DPOAEs, and audiometric evaluation. For 3- to 5-year olds, all tests except audiometric evaluation were carried out. Before testing, a visual inspection of the pinna and ear canal was performed to identify possible signs of infection, obstruction, and other conditions/circumstances that might interfere with testing.

Otoscopy was performed using the Welch Allyn otoscope (Model 25020) to identify gross abnormalities, including the presence of blood, pus, excessive or impacted ear wax, a growth, tumor or foreign object in the ear canal, a collapsible ear canal, or other occlusion. Criteria for exclusion included completely obstructed ear canal, acute pain or infection, open wounds or bandages covering the ear(s), refusal to remove hearing aid, or chronic abnormalities including congenital atresia or microtia of the ear canal (one or both ears). No further testing was performed if the individual was excluded by otoscopy.

Tympanometry was conducted using the A GSI 39 Auto Tympanometer. A normal tympanogram was defined as compliance between 0.2 and 1.8 cm³ with middle ear pressure between -150 and +50 daPa in an equivalent ear canal volume of between 0.75 and 2.0 cm³. Criteria for exclusion included blood, pus or impacted wax, eardrum perforation, growth in the ear canal, and significant skin abnormality or discharge observed during otoscopy.

Audiometric evaluation was carried out using a computer-controlled CCA-100 mini audiometer with insert earphones or

supra-aural headphones, according to the specified exclusion criteria for tympanometry. The audiometer was calibrated daily using the Bio-Acoustic simulator BAS-200, which served as a baseline. Hearing thresholds were assessed at 0.5, 1, 2, 3, 4, 6, and 8 kHz. Testing followed procedures recommended for standard audiometry using automatic mode, except when the respondent could not physically press the response button, had very slow response times, or when difficulties were noted with automatic mode. Manual mode was carried out using the modified down-10 up-5 methodology (Carhart & Jerger 1959). To avoid interference with audiometric evaluation, subjects were asked to refrain from chewing. If a child was excluded from tympanometry for the reasons noted above, audiometry was performed using supra-aural headphones (TDH-39) instead of insert earphones (EAR 5A case). Participants with acute pain or infection, narrow or collapsed ear canal(s), blood, foreign object, or excessive/impacted wax completely obstructing ear canal along with narrow or collapsed ear canal were excluded from audiometry.

DPOAE testing was conducted using the OtoRead Standard and Clinical-OAE instrument and OtoAccess software program. The OtoRead instrument indicates “Pass” or “Refer” after DPOAE test administration for each ear. “Refer” is equivalent to an absent DPOAE. The custom protocol set for the instrument required that the individual “Pass” three out of four test frequencies (2, 3, 4, and 5 kHz) using a signal to noise ratio of

6 dB. Criteria for exclusion included the inability to conduct otoscopy, occlusions in both ears, presence of blood, a foreign object/substance in both ears, impacted wax in both ears, unwilling or unable to remove his/her hearing aids from both ears.

Definitions

HL was defined as a pure-tone average >20 dB for 6- to 18-year olds, and ≥ 26 dB for 19-year olds, in one or more of the following pure-tone averages: four-frequency (0.5, 1, 2, and 4 kHz) pure-tone average (FFPTA), high-frequency (3, 4, 6, and 8 kHz) pure-tone average (HFPTA), and low-frequency (0.5, 1, and 2 kHz) pure-tone average (LFPTA). These definitions were selected in accordance with American Academy of Audiologists (AAA) and the American Speech Language Hearing Association (ASHA) pediatric/childhood audiologic screening guidelines (ASHA 1997; AAA 2011). Mild HL was defined as >20 to 40 dB for 6 to 18 and ≥ 26 to 40 dB for 19-year olds. Moderate or worse HL was defined as >40 dB for 6- to 19-year olds. For bilateral HL, the average in the worse ear was used to categorize the degree of hearing impairment.

Sensorineural hearing loss (SNHL) was defined as HFPTA, LFPTA, or FFPTA >20 dB HL (6- to 18-year olds), ≥ 26 dB HL (19-year olds) in one or both ears with absent DPOAEs, and normal tympanometry results.

“Flat” tympanometry refer to tympanograms which have no peak pressure values.

Conductive hearing loss (CHL) was defined as having a “flat” tympanogram and absent DPOAE.

Occlusion of ear canal indicates excessive earwax or pus observed during otoscopic examination.

Statistical Analysis

Weighted frequencies and cross-tabulations were used to explore hearing-related characteristics by demographic characteristics. Bivariate analyses included the examination of HL based on HFPTA, LFPTA, and FFPTA, and the presence of a “flat” tympanogram and absent DPOAE by selected demographic characteristics. Correlational analysis using tetrachoric correlation was also carried out between HL and DPOAE. Tetrachoric correlation measures the strength of the association between dichotomous variables that have an underlying bivariate normal distribution.

All estimates were weighted at the person level to represent the population. The weighting procedure carried out was based on the principle that the individual selected in a probability sample such as the CHMS sample, “represents” himself or herself in addition to several other individuals not in the sample. The weighting procedure that was applied corresponds to the number of individuals represented by the participant in the population as a whole. Therefore, the weighting, which takes into account the age and sex distribution of the population, non-response and the sampling strategy of the survey, allows frequency calculations that are representative of the population. See the CHMS User Guide (Statistics Canada 2015b) for further details about the weighting procedure and its application.

Analyses were conducted using SAS 9.3 and SAS-Callable SUDAAN 11.0.0 software. To account for the complex survey design, *p* values, 95% confidence intervals, and coefficients of variation (CV), were estimated using the bootstrap technique with 11 degrees of freedom (Rao et al. 1992; Rust & Rao 1996).

Statistical significance was specified as a *p* value of less than 0.05. Two-tailed *t*-tests were conducted for the comparison of proportion such as mild versus moderate or worse HL. The CV is a measure of data quality and provides an indication of the scope of the sampling error associated with the estimate. The CV is obtained by dividing the standard error of the estimate by the estimate itself, and is expressed as a percentage of the estimate: $SE/Estimate \times 100 = CV$. Coefficients of variation estimates between 16.6 and 33.3% were flagged with an E indicating a marginally acceptable estimate due to the high sampling variability associated with it, and advising users to interpret with caution. A CV that exceeded 33.3% were designated F indicating that this data cannot be released as it is of unacceptable quality.

RESULTS

Sample Characteristics

There was a fairly equal male to female ratio (51.5 and 48.5%, respectively) in the initial sample of 2591 children and adolescents, aged 3 to 19 years. Approximately half of the sample (49.3%) were in the 12- to 19-year-old age group, whereas 33.3 and 17.4% were in the 6- to 11- and 3- to 5-year-old age group, respectively. A large percentage of the sample (81.8%) reported their highest household education as being postsecondary or greater, whereas total household income (Canadian dollars) was comparable among the following income categories: <\$50,000 (29.4%), \$50,000 to <\$100,000 (36.1%) and \$100,000 or more (34.5%). The demographic distributions with respect to various PTA HL categories are shown in Tables 1–5.

Audiometry

The primary outcome of this study indicates that an estimated 7.7% (95% CI: 5.7, 10.3) or 1 out of 13 Canadian youth, aged 6 to 19 years, had measured unilateral or bilateral HL based on one or more pure-tone average (PTA) including FFPTA, HFPTA and or LFPTA (Tables 1–5). Overall, approximately 4.7% (95% CI: 3.7, 5.8) of 6- to 19-year olds were found to have a FFPTA HL. The prevalence of HFPTA HL (3, 4, 6, and 8 kHz) and LFPTA HL (0.5, 1, and 2 kHz) was 6.0% (95% CI: 4.3, 8.3) and 5.8% (95% CI: 4.5, 7.6), respectively (Tables 1–5). Children and adolescents were significantly more likely to experience unilateral versus bilateral HL for each PTA. For example, 4.3% (95% CI: 3.3, 5.5) had unilateral FFPTA HL compared with 0.4% (95% CI: 0.2, 0.7) who had bilateral FFPTA HL (Table 6). Furthermore, mild HL was more common than moderate or worse degree, for all HL categories ($p < 0.05$; Table 7). An examination of individual frequencies revealed that significantly worse thresholds were observed at 6 and 8 kHz compared with the lower frequencies of 1, 3, and 4 kHz ($p < 0.05$ in all cases); 0.5 kHz could not be estimated due to the small sample size.

Hearing Status: 3- to 5-Year Olds

Audiometry was not conducted in 3- to 5-year olds ($n = 555$), therefore findings were based on DPOAE and tympanometry results. The prevalence of absent DPOAEs was 7.1% (95% CI: 3.9, 12.3) and 14.5% (95% CI: 10.0, 20.4) had flat tympanometry results.

TABLE 1. Prevalence of HL in Canadian youth, aged 6 to 19: FFPTA and or HFPTA and or LFPTA*

	n	N ('000)	CV	%	SE %	95% CI	CV†
Total	154	385		7.7	1.0	5.7, 10.3	
Sex							
Male‡	76	181	E	7.0	1.4	4.5, 10.8	E
Female	78	204	E	8.4	1.6	5.5, 12.6	E
Age group (years)							
6 to 11‡	77	157		8.1	1.3	5.7, 11.4	
12 to 19	77	228	E	7.4	1.4	4.8, 11.2	E
Highest level of education for household§							
Less than postsecondary			F				F
Post secondary or more‡				7.5	1.0	5.5, 10.0	
Total household income¶							
Less than \$50,000‡	58	109		7.6	1.6	4.8, 11.8	E
\$50,000 < \$100,000	50	134	E	7.4	1.7	4.4, 12.2	E
\$100,000 or more	46	141	E	8.0	1.4	5.4, 11.8	E

E denotes a CV between 16.6 and 33.3% indicating a marginally acceptable estimate advising user to interpret with caution; F denotes a CV that exceeds 33.3% indicating that this data is of unacceptable quality and cannot be released. Respondents' age was as of the date of their mobile examination clinic visit; education and income, as of the date of their household interview. *Four frequency and or high and or low-frequency HL: unilateral or bilateral, pure-tone average ≥ 21 dB (6 to 18 years) or ≥ 26 (19 years).

‡Reference category.

†Significantly different from reference group/preceding age group (*p* < 0.05).

§Highest level attained by a household member, dichotomized as less than postsecondary or more.

¶Based on total annual income: three defined categories.

CI, confidence interval; CV, coefficient of variation indicates the scope of the sampling error associated with the estimate; FFPTA, four-frequency pure-tone average; HFPTA, high-frequency pure-tone average; HL, hearing loss; LFPTA, low-frequency pure-tone average; n, study sample size; N, population size; SE, standard error.

Hearing Status: 6 to 11 Versus 12- to 19-Year Olds

Qualitatively, approximately 8.1% (95% CI: 5.7, 11.4) of 6- to 11-year olds had HL for any PTA compared with 7.4% (95% CI: 4.8, 11.2) of 12- to 19-year olds with a slightly higher HL prevalence in the younger versus older age group observed for all PTA HL categories (Tables 1–5). Among participants aged 12 to 19 years, 5.3% (95% CI: 4.1, 6.9) had flat tympanometry results. Although the prevalence of flat tympanometry could not be determined in 6- to 11-year olds due to small sample size, 5.7% (95% CI: 4.4, 7.4) of 6- to 19-year olds had flat tympanometry results.

Tympanometry and DPOAEs

“Flat” tympanometry results were found in 7.8% (95% CI: 6.0, 10.1) of youth, aged 3 to 19 years. The estimated prevalence of “flat” tympanometry results and absent DPOAEs in one or both ears among Canadians aged 3 to 19 years was less than 3.5%.

The prevalence of absent DPOAEs found in 3- to 5-year olds (7.1%; 95% CI: 3.9, 12.3) was significantly higher (*p* < 0.05) than for 6- to 19-year olds (3.4%; 95% CI: 2.1, 5.3). The “E” denotes a large CV (hence the wide confidence

TABLE 2. Prevalence of FFPTA* HL in Canadian youth, aged 6 to 19

	n	N ('000)	CV	%	SE %	95% CI	CV†
Total	96	234		4.7	0.5	3.7, 5.8	
Sex							
Male‡	42	101	E	3.9	0.7	2.6, 5.8	E
Female	54	133		5.5	0.8	3.9, 7.6	
Age group (years)							
6 to 11‡	51	104		5.4	0.8	3.9, 7.4	
12 to 19	45	131	E	4.2	0.8	2.8, 6.3	E
Highest level of education for household§							
Less than postsecondary			F				F
Post secondary or more‡			E	4.4	0.7	3.1, 6.3	
Total household income¶							
Less than \$50,000‡	36	75	E	5.2	1.2	3.1, 8.7	E
\$50,000 to less than \$100,000			F				F
\$100,000 or more			E	5.9	1.0	4.0, 8.5	E

E denotes a CV between 16.6 and 33.3% indicating a marginally acceptable estimate advising user to interpret with caution; F denotes a CV that exceeds 33.3% indicating that this data is of unacceptable quality and cannot be released. Respondents' age was as of the date of their mobile examination clinic visit; education and income, as of the date of their household interview. *Four-frequency HL: unilateral or bilateral, pure-tone average ≥ 21 dB (6 to 18 years) or ≥ 26 (19 years) over frequencies 0.5, 1, 2, and 4 kHz.

‡Reference category.

†Significantly different from reference group/preceding age group (*p* < 0.05).

§Highest level attained by a household member, dichotomized as less than postsecondary or more.

¶Based on total annual income: three defined categories.

CI, confidence interval; CV, coefficient of variation indicates the scope of the sampling error associated with the estimate; FFPTA, four-frequency pure-tone average; HL, hearing loss; n, study sample size; N, population size; SE, standard error.

TABLE 3. Prevalence of HFPTA* HL in Canadian youth, aged 6 to 19

	n	N ('000)	CV	%	SE %	95% CI	CV†
Total	123	299		6.0	0.9	4.3, 8.3	
Sex							
Male‡	60	136	E	5.3	1.0	3.5, 7.9	E
Female	63	163	E	6.7	1.3	4.4, 10.0	E
Age group (years)							
6 to 11‡	63	123	E	6.4	1.1	4.4, 9.2	E
12 to 19	60	175	E	5.7	1.2	3.6, 8.9	E
Highest level of education for household§							
Less than postsecondary			F				F
Post secondary or more‡			E	5.9	1.0	4.1, 8.5	E
Total household income¶							
Less than \$50,000‡	46	83	E	5.7	1.2	3.6, 9.1	E
\$50,000 < \$100,000			F				F
\$100,000 or more			E	6.8	1.4	4.2, 10.7	E

E denotes a CV between 16.6 and 33.3% indicating a marginally acceptable estimate advising user to interpret with caution; F denotes a CV that exceeds 33.3% indicating that this data is of unacceptable quality and cannot be released. Respondents' age was as of the date of their mobile examination clinic visit; education and income, as of the date of their household interview.

*High-frequency HL: unilateral or bilateral, pure-tone average ≥ 21 dB (6 to 18 years) or ≥ 26 (19 years) over frequencies 3, 4, 6 and 8 kHz.

†Significantly different from reference group/preceding age group ($p < 0.05$).

‡Reference category.

§Highest level attained by a household member, dichotomized as less than postsecondary or more.

¶Based on total annual income: three defined categories.

CI, confidence interval; CV, coefficient of variation indicates the scope of the sampling error associated with the estimate; HFPTA, high-frequency pure-tone average; HL, hearing loss; n, study sample size; N, population size; SE, standard error.

interval) indicating that a high sampling variability is associated with these DPOAE estimates, and signaling cautious interpretation. For 6- to 19-year olds, 49.3^E% (95% CI: 26.6, 72.3) of those with absent DPOAEs had audiometric results showing HL: LFPTA, HFPTA, and or FFPTA. Correlational analysis was conducted between absent DPOAEs and measured HL and ranged from 0.62 to 0.71 using tetrachoric correlation, a statistic used for measuring the strength of the association between dichotomous variables which have a bivariate normal distribution.

Sensorineural Hearing Loss

It is estimated that less than 2.2% of Canadian youth have SNHL (data not shown).

Otoscopic Examination

Otосcopy was conducted on all participants eligible for the hearing evaluation (n = 2591); 16 participants were missing wax/pus data. Among the remaining 2575 participants, aged 3 to 19, 385 were found to have excessive or impacted pus or wax in one or both ears, corresponding to a weighted estimate

TABLE 4. Prevalence of LFPTA* HL in Canadian youth, aged 6 to 19

	n	N ('000)	CV	%	SE %	95% CI	CV†
Total	105	292		5.8	0.7	4.5, 7.6	
Sex							
Male‡	50	139	E	5.4	1.2	3.3, 8.8	E
Female	55	153	E	6.3	1.3	4.0, 9.8	E
Age group (years)							
6 to 11‡	53	120	E	6.2	1.1	4.2, 9.1	E
12 to 19	52	172	E	5.6	1.1	3.5, 8.7	E
Highest level of education for household§							
Less than postsecondary			F				F
Post secondary or more‡			E	5.5	0.7	4.1, 7.3	E
Total household income¶							
Less than \$50,000‡	39	86	E	6.0	1.3	3.7, 9.4	E
\$50,000 < \$100,000	30	86	E	4.8	1.2	2.7, 8.1	E
\$100,000 or more	36	120	E	6.8	1.2	4.5, 10.1	E

E denotes a CV between 16.6 and 33.3% indicating a marginally acceptable estimate advising user to interpret with caution; F denotes a CV that exceeds 33.3% indicating that this data is of unacceptable quality and cannot be released. Respondents' age was as of the date of their mobile examination clinic visit; education and income, as of the date of their household interview.

*Low-frequency HL: unilateral or bilateral, pure-tone average ≥ 21 dB (6 to 18 years) or ≥ 26 (19 years) over frequencies 0.5, 1, and 2 kHz.

†Significantly different from reference group/preceding age group ($p < 0.05$).

‡Reference category.

§Highest level attained by a household member, dichotomized as less than postsecondary or more.

¶Based on total annual income: three defined categories.

CI, confidence interval; CV, coefficient of variation indicates the scope of the sampling error associated with the estimate; HL, hearing loss; LFPTA, low-frequency pure-tone average; n, study sample size; N, population size; SE, standard error.

TABLE 5. Prevalence of LFPTA or HFPTA HL in Canadian youth, aged 6 to 19

	n	N ('000)	CV	%	SE %	95% CI	CV*
Total	153	384		7.6	1.0	5.7, 10.2	
Sex							
Male†	76	181	E	7.0	1.4	4.5, 10.8	E
Female	77	203	E	8.3	1.6	5.4, 12.7	E
Age group (years)							
6 to 11†	76	155		8.1	1.3	5.7, 11.3	
12 to 19	77	228	E	7.4	1.4	4.8, 11.2	E
‡Highest level of education for household							
Less than postsecondary			F				F
Post secondary or more†				7.4	1.0	5.5, 10.0	
§Total household income							
Less than \$50,000†	58	109		7.6	1.6	4.8, 11.8	E
\$50,000 < \$100,000	49	133	E	7.3	1.7	4.3, 12.2	E
\$100,000 or more	46	141	E	8.0	1.4	5.4, 11.8	E

E denotes a CV between 16.6 and 33.3% indicating a marginally acceptable estimate advising user to interpret with caution; F denotes a CV that exceeds 33.3% indicating that this data is of unacceptable quality and cannot be released. Respondents' age was as of the date of their mobile examination clinic visit; education and income, as of the date of their household interview.

*Significantly different from reference group/preceding age group ($p < 0.05$).

†Reference category.

‡Highest level attained by a household member, dichotomized as less than postsecondary or more.

§Based on total annual income: three defined categories.

CI, confidence interval; CV, coefficient of variation indicates the scope of the sampling error associated with the estimate; HFPTA, high-frequency pure-tone average; HL, hearing loss; LFPTA, low-frequency pure-tone average; n, study sample size; N, population size; SE, standard error.

of 17.0%. No significant differences were observed among age groups, that is, 3- to 5-year olds ($M = 19.9\%$; 95% CI: 14.7, 26.5), 6 to 11 ($M = 14.7\%$; 95% CI: 11.6, 18.4) or 12- to 19-year olds ($M = 17.1\%$; 95% CI: 13.0, 22.2).

Self-Reported Survey Results

Among Canadians aged 3 to 19, ($n = 2601$), 65.3% (95% CI: 61.7, 68.7) indicated that they never had their hearing tested by a health professional in the past. Among the 34.8% who did report having had their hearing tested in the past, an estimated 4.4% (95% CI: 2.8, 7.0) reported being diagnosed with a hearing problem. There was no difference between 6- to 11- and 12- to 19-year olds, with regard to the percent diagnosed with a hearing problem. A reliable estimate was not available for 3- to 5-year olds due to the small sample size.

Among participants aged 6 to 19 years, 0.6% (95% CI: 0.30, 1.24) self-reported hearing difficulty using the HUI3. Less than 2.3% ($n = 33$) of youth in this sample, aged 3 to 19, reported an ear infection and or pain in one or both ears on the day of testing and were excluded from all or portions of the hearing evaluation.

DISCUSSION

This is the first population-based study to provide national estimates of hearing acuity among a representative sample of Canadian children and adolescents, aged 6 to 19 years. These findings indicate that 7.7% of participants, representing 387,000 Canadians, aged 6 to 19 years, had some type of HL in one or both ears. The prevalence of FFPTA HL, known to be important in understanding speech, is estimated to be 4.7%. A slightly higher percentage was found for HFPTA HL (6.0%) and LFPTA HL (5.8%). In contrast, the prevalence of HL in adults was reported to be 19.2%, 15.4%, and 35.4% for FFPTA, LFPTA, and HFPTA, respectively (Feder et al. 2015). The HL prevalence of 7.7% for Canadian youth is likely an underestimate of the true prevalence because 167 participants

were excluded from audiometric evaluation. Furthermore, a certain percentage of the sample (estimated to be less than 2.3%) had an ear infection and or pain on the day of testing and could not participate in all or some of the hearing evaluation (Fig. 1).

Nonetheless, the present study findings indicating that the majority of HL in youth is unilateral and of slight to mild magnitude (i.e., below 40 dB) are consistent with previous research by Bess et al. (1998) and Niskar et al. (1998). Unilateral HL prevalence in school-aged children varies across studies from 0.1% to over 5.0% according to Lieu (2004), with the upper limit consistent with the present study's unilateral HL findings of 4.3% to 4.8%. There is consensus among researchers that unilateral and or mild to moderate HL loss may have negative impacts on a child's educational, language and social/communication outcomes (Culbertson & Gilbert 1986; Bovo et al. 1988; Brookhauser et al. 1991; Lieu 2004; Most 2004; Wake et al. 2004; Moeller et al. 2007; Lieu et al. 2010). According to Archbold et al. (2015), children with mild/moderate HL are less likely to be diagnosed at early ages, if at all. As these children develop speech and language skills which are intelligible to their teachers, their HL may go unnoticed. They are also less likely to receive school or health professional support compared with children who have severe or profound hearing impairments (Russ et al. 2002; Bamford et al. 2005). Studies have found this population of late-diagnosed children to have smaller vocabularies, greater difficulties listening over distance, and in noisy or reverberant classrooms such as portables. In addition, there is evidence that a greater signal to noise ratio is required for children with unilateral or mild HL compared to normal-hearing peers to understand speech (Bess et al. 1986; Bovo et al. 1988; Lieu 2004), placing them at a disadvantage in classrooms when trying to hear a teacher's voice above background noise (Crandell 1993). These children also tend to have difficulties with pragmatic and social skills, all of which may significantly affect learning and educational achievement (Moeller et al. 2007; Cone et al. 2010; Wolters et al. 2011; Marschark et al. 2015).

TABLE 6. Prevalence of unilateral and bilateral hearing loss among Canadian youth, aged 6 to 19

Age (yrs)	No Loss										Unilateral					Bilateral						
	≤20 dB					≤25 dB					≥21 dB					≥26 dB						
	n	N ('000)	CV	%	SE	95% CI	CV	%	SE	95% CI	N ('000)	CV	%	SE	95% CI	N ('000)	CV	%	SE	95% CI	CV*	
6 to 18	FFPTA	1783	4782	0	95.3	0.5	94.2, 6.3	0	81	214	0	4.3	0.5	3.3, 5.5	0	15	20	0.4	0.1	0.2, 0.7	E	
	LFPTA	1774	4724	0	94.2	0.7	92.4, 5.5	0	86	262	0	5.2	0.7	3.8, 7.1	0	19	30	0.6	0.1	0.4, 0.9	E*	
19	HFPTA	1756	4718	0	94.0	0.9	91.7, 5.7	0	89	239	E	4.8	0.8	3.2, 7.0	E	34	59	1.2	0.3	0.6, 2.2	E*	
	0.5 kHz	1702	4586	0	91.4	1.2	88.4, 3.7	0	148	371	0	7.4	1.1	5.3, 0.1	0	29	60	1.2	0.4	0.6, 2.3	E*	
	1 kHz	1786	4786	0	95.4	0.8	93.4, 6.8	0	75	205	E	4.1	0.8	2.7, 6.2	E	18	26	0.5	0.1	0.3, 1.0	E*	
	2 kHz	1802	4844	0	96.6	0.5	95.1, 7.6	0													F	
	3 kHz	1782	4765	0	95.0	0.8	93.0, 6.4	0														F
	4 kHz	1792	4814	0	96.0	0.5	94.6, 7.0	0														F
	6 kHz	1641	4437	0	88.5	1.3	85.3, 1.0	0	178	415	0	8.3	0.9	6.4, 0.6	0	60	165	3.3	0.7	2.1, 5.1	E*	
	8 kHz	1690	4570	0	91.1	1.1	88.3, 3.3	0	148	358	0	7.1	0.9	5.5, 9.3	0	41	89	1.8	0.5	0.9, 3.4	E*	

*Significantly different from unilateral, $p < 0.05$.
 FFPTA, four-frequency pure-tone average (0.5, 1, 2, and 4 kHz); LFPTA, low-frequency pure-tone average (0.5, 1, and 2 kHz); HFPTA, high-frequency pure-tone average (3, 4, 6, and 8 kHz); n, study sample size; N, population size; CV, confidence interval; CV, coefficient of variation indicates the scope of the sampling error associated with the estimate; E, a CV between 16.6 and 33.3% indicating a marginally acceptable estimate advising user to interpret with caution; F, a CV that exceeds 33.3% indicating that this data is of unacceptable quality and cannot be released.

Some studies have included the slight HL category (i.e., 16 to 25 dB) in addition to a mild HL category (26 to 40 dB) or have used a different mild HL definition (20 to 40 dB) applied to the better or worse ear to define HL. As Niskar et al. (1998) points out, prevalence estimates based on better ear measurements define children with unilateral HL as having normal-hearing acuity; therefore estimates using worse ear may be a more accurate indicator of the extent of the problem. The present study used a greater than 20 dB HL threshold for the worse ear to estimate HL prevalence, which is based on the American Academy of Audiology (AAA) Childhood Hearing Screening Guidelines and the ASHA Guidelines for Audiological Screening for age 5 to 18 years, and has been used in other large scale studies (ASHA 1997; Bess et al.1998; AAA 2011; Wood et al. 2015).

However, a HL threshold of greater than 15 dB may be more appropriate for young children, such as preschoolers, kindergarten or early primary school age according to Goldberg and Richburg (2004). In particular, voiceless consonants may be missed impacting communication and language learning (Northern & Downs 2002; Goldberg & Richburg 2004), which may result in attentional difficulties, mild language delays and speech problems (Northern & Downs 2002). In an Australian study (n = 6581) of elementary school children (grades 1 and 5), those identified as having slight/mild bilateral SNHL (LFPTA and or HFPTA of 16 to 40 dB HL in better ear) had poorer phonologic discrimination and short term memory compared with their normal-hearing peers, however scores on language, reading, behavior, and quality of life measures were not significantly different (Wake et al. 2006). However, as the authors have noted, due to the small percentage of affected children (0.88%), the power is reduced for drawing conclusions regarding the impact of having slight/mild bilateral SNHL (Wake et al. 2006); other limitations include wide CIs for many outcome estimates and the exclusion of subjects with unilateral HL. There are research findings highlighting the importance of identifying minimal or mild HL in children (15 to 40 dB HL) due to difficulty understanding speech under adverse conditions and to avoid erroneous labeling of learning disabled or behaviorally challenged (Crandell 1993; Bess et al. 1998; Goldberg & Richburg 2004).

The HL threshold of 16 dB used by Niskar et al. (1998) is likely a major factor in the HL prevalence being nearly double that found in the present study (14.9% versus 7.7%). However, consistent with Niskar et al.'s findings, the present study found that thresholds were significantly worse at the 6 and 8 kHz frequencies compared with lower frequencies, and there were no significant differences in HL prevalence by age group. The suggestion of a slightly higher HL prevalence in 6- to 11-year olds compared with 12- to 19-year olds may be due to the higher prevalence of CHL that is generally found in younger aged children. However, given the wide CV and small sample size of 12- to 19-year olds in this study, analysis of future CHMS cycles will be useful in contributing to this body of knowledge.

It is well known that HL estimates for children/adolescents vary considerably across studies due to differing definitions of hearing impairment, variable age ranges, small sample sizes, selection bias, and inadequate sampling procedures (Bess et al.1998; Lieu 2004; Mehra et al. 2009). In a systematic review of US studies, the prevalence of mild to worse, unilateral or bilateral hearing impairment (conductive, sensorineural, or unspecified) above 25 dB ranged from 1.7 to 5%, in subjects aged 20

TABLE 7. Prevalence of mild, moderate or worse hearing loss among Canadian youth, aged 6 to 19

Age (yrs)	No Loss										Mild										Moderate or Worse									
	≤20 dB										21 to 40 dB										≥41 dB									
	≤25 dB										26 to 40 dB										≥41 dB									
	n	N ('000)	CV	%	SE	95% CI	CV	n	N ('000)	CV	%	SE	95% CI	CV	n	N ('000)	CV	%	SE	95% CI	CV	n	N ('000)	CV	%	SE	95% CI	CV		
FFPTA	1783	4782		95.3	0.5	94.2, 96.3		83	178		3.6	0.4	2.8, 4.4		13	56		1.1	0.4	0.5, 2.3		13	56		1.1	0.4	0.5, 2.3		E*	
LFPTA	1774	4724		94.2	0.7	92.4, 95.5																								F
HFPTA	1756	4718		94.0	0.9	91.7, 95.7		98	249		5.0	0.9	3.4, 7.2		25	50		1.0	0.3	0.6, 1.8		25	50		1.0	0.3	0.6, 1.8		E*	
0.5 kHz	1702	4586		91.4	1.2	88.4, 93.7																								F
1 kHz	1786	4786		95.4	0.8	93.4, 96.8		75	199		4.0	0.8	2.6, 6.0		18	31		0.6	0.2	0.3, 1.2		18	31		0.6	0.2	0.3, 1.2		E*	
2 kHz	1802	4844		96.6	0.5	95.1, 97.6																								F
3 kHz	1782	4765		95.0	0.8	93.0, 96.4		77	214		4.3	0.8	2.8, 6.4		20	38		0.8	0.2	0.4, 1.4		20	38		0.8	0.2	0.4, 1.4		E*	
4 kHz	1792	4814		96.0	0.5	94.6, 97.0		64	131		2.6	0.4	1.8, 3.8		23	71		1.4	0.4	0.8, 2.5		23	71		1.4	0.4	0.8, 2.5		E*	
6 kHz	1641	4437		88.5	1.3	85.3, 91.0		199	515		10.3	1.3	7.7, 13.5		39	65		1.3	0.3	0.8, 2.0		39	65		1.3	0.3	0.8, 2.0		E*	
8 kHz	1690	4570		91.1	1.1	88.3, 93.3		143	358		7.1	0.9	5.3, 9.5		46	89		1.8	0.4	1.0, 3.0		46	89		1.8	0.4	1.0, 3.0		E*	

*Significantly different from mild (p < 0.05).

†Significantly different from 6kHz (p < 0.05) and significantly different from 8kHz (p < 0.05).

FFPTA, four-frequency pure-tone average (0.5, 1, 2, and 4 kHz); LFPTA, low-frequency pure-tone average (0.5, 1, 2, and 4 kHz); HFPTA, high-frequency pure-tone average (3, 4, 6, and 8 kHz); n, study sample size; N, population size; CV, confidence interval; CV, coefficient of variation indicates the scope of the sampling error associated with the estimate, E, a CV between 16.6 and 33.3% indicating a marginally acceptable estimate advising user to interpret with caution; F, a CV that exceeds 33.3% indicating that this data is of unacceptable quality and cannot be released.

TABLE 8. Population-based or large scale retrospective studies of hearing loss in children and adolescents

Reference	Sample Size	Age (yrs) or Grade	Hearing Threshold (dB)	Averaged Pure-Tone Frequencies (PTAs)	Ear	Prevalence (%)
Henderson et al. (2011)United StatesNHANES	1791	12–19	>15	LFPTA	Any	6.5
				HFPTA	Any	12.9
Berg & Serpanos (2010)§United States	8710	12–19	>15	LFPTA	Any	5.2
				HFPTA	Any	12.3
				HFPTA	Bilateral	11.7
Wake et al. (2006)Australia	6581	Gr. 1 & 5	16–40*	LFPTA & HFPTA	Bilateral	0.88
				LFPTA & HFPTA	Unilateral	0.6
				LFPTA & HFPTA	Unilateral	1.4
Shargorodsky et al. (2010)United States NHANES	3211	12–19	>15	LFPTA or HFPTA‡	Any	14.9
				LFPTA or HFPTA‡	Any	19.5
Uimonen et al. (1999)Finland	428	10	>25†	LFPTA	Any	0.2
				LFPTA	Any	0.7
Niskar et al. (1998)United StatesNHANES	6166	6–19	≥16	LFPTA or HFPTA	Any	14.9
				LFPTA	Any	7.1
				LFPTA	Bilateral	1.5
				LFPTA	Unilateral	5.6
				HFPTA	Any	12.7
				HFPTA	Bilateral	3.1
				HFPTA	Unilateral	9.6
				HFPTA	Bilateral	1.2
Feder et al.Current AnalysisCanadaCHMS	1775	6–18	>20	LFPTA, HFPTA‡ and or FFPTA	Any	7.7
				FFPTA	Any	4.7
				HFPTA	Any	6.0
				LFPTA‡	Any	5.8
				FFPTA	Unilateral	4.3
				FFPTA	Bilateral	0.4
				HFPTA	Unilateral	4.8
				HFPTA	Bilateral	1.2

LFPTA: based on PTA of 0.5, 1, 2 kHz; HFPTA: based on PTA of 3, 4, 6 kHz. FFPTA: based on PTA of 0.5, 1, 2, 4 kHz.

*Slight to mild sensorineural hearing loss in the better ear.

†Better ear hearing level.

‡HFPTA: based on PTA of 3, 4, 6, 8 kHz.

§Retrospective study of female adolescents from residential foster care facilities from metropolitan area of Northeast United States; hearing screening records obtained over a 24-year period from 1985 to 2008.

NHANES, Third National Health and Nutrition Examination Survey 1988–1994; CHMS, Canadian Health Measures Survey.

and under (Mehra et al. 2009). This is in contrast to Bess et al. (1998) who reported a prevalence of 11.3% for conductive and sensorineural HL and 5.4% for SNHL in a US study of 1218 elementary school children, using thresholds of less than 20 dB for bilateral and less than or equal to 20 dB for unilateral HL. In comparison, the present study which used the same HL threshold had a somewhat lower HL prevalence (7.7%). However, if the estimates of conductive HL (less than 3.5%) were included, the prevalence may be somewhat consistent with Bess et al. (1998) despite a few salient differences. The present CHMS sample was nationally representative and included a broader age group compared with Bess et al.'s study which focused on younger children recruited from one US school district. Table 8 shows the prevalence estimates of several population-based or large scale retrospective studies involving children and or adolescents.

As noted above, precise estimates of HL are tenuous due to the disparate definitions of HL across studies (Lieu 2004; Ross et al. 2010). The importance of controlling for abnormal middle ear function, that is, "flat" tympanograms, often associated with temporary CHL was highlighted by Ross et al. (2010). In the present study, less than 3.5% of participants, aged 3 to 19 years, had "flat" tympanograms and absent DPOAEs (one or

both ears). Although HL prevalence for this subgroup could not be estimated, participants with this profile were categorized as *suggestive* unilateral or bilateral CHL, which may be temporary. An Australian study (n = 6581) of elementary school children reported a CHL prevalence of 6.3% whereas the prevalence of slight mild bilateral SNHL was only 0.88% (defined as LFPTA and or HFPTA HL of 16 to 40 dB HL in the better ear with air bone gaps of <10 dB; Cone et al. 2010). The authors attributed this low SNHL prevalence to the rigorous exclusion of CHL cases using air and bone conduction tests (Cone et al. 2010).

There have been adult studies suggesting that otoacoustic emissions (OAEs) may be more sensitive than audiograms in detecting subtle changes in cochlear function, that is, "preclinical" signs of HL (Plinkert et al. 1999; Balatsouras 2004; Lapsley et al. 2004). Although fewer studies have been conducted in children, both Yin et al. (2009) and Georgalas et al. (2008) concluded that OAEs were a fast, efficient and feasible method for early identification of potential HL in preschool and school-aged children. In a subgroup of 2- to 6-year olds (n = 142) who underwent transient otoacoustic emission testing (TOAE) and audiometry (25 dB HL threshold), no child who passed TOAE screening had audiometric results indicating a HL (Yin et al. 2009). Similarly, Georgalas et al. reported that in their study

of 6- to 12-year olds ($n = 196$), virtually all children with 30 dB HL or worse were identified using TOAE testing, and 90% of children with a 25 dB HL or worse were identified. In the present study, approximately half of the 6- to 19-year olds with absent DPOAEs also had HL worse than 20 to 25 dB. Similarly, other researchers have reported a strong association between absent OAEs and HL worse than 30 dB (Amedee 1995; Van Cauwenberge et al. 1995). It is likely that the majority of the preschoolers in the present study with absent DPOAEs (7.1%) also had some degree of HL. However, approximately three-quarters of these participants had flat tympanograms indicating that HL in this proportion was likely conductive. CHL, which is usually temporary, may nevertheless lead to permanent HL if left untreated. Nonetheless, the accuracy and time efficiency (30 to 60 sec) of OAE testing (DPOAE or TOAE) makes it an ideal HL screening tool for young children.

When comparing OAE results, a study of 744 preschoolers by Yin et al. (2009) found that just over 12% had absent TOAEs in one or both ears which are higher than the present study results. However, the present study sample was smaller ($n = 555$) and consisted of a nationally representative cohort (aged 3 to 5) compared with 2 to 6 years olds recruited from publicly funded preschools in low income areas of Los Angeles (Yin et al. 2009). These factors may play a role in the higher percentage of absent OAEs reported by Yin et al. (2009). The higher prevalence of absent DPOAE for 3- to 5-year olds in the present study compared with 6- to 19-year olds, is consistent with findings by Georgalas et al. (2008); and was attributed to a higher prevalence of otitis media often seen in younger children. It is important to identify children with otitis media because it may cause temporary CHL, and if untreated, this condition can lead to permanent HL (Gates 1996).

Advocates of screening for HL in school-age children have pointed out that mild SNHL (20 to 40 dB) may be missed in infancy because universal newborn hearing screening methods are less sensitive to HL below 40 dB (Johnson et al. 2005). A large proportion of children with mild HL have passed newborn screenings but were later identified as having HL in the preschool or school-age period (Bamford et al. 2005; White & Muñoz 2008; Porter & Bess 2011). In 2011, the Canadian Paediatric Society Community Paediatrics Committee acknowledged the limitations of the universal newborn hearing screening and recommended that all children experiencing developmental or learning difficulties have their hearing evaluated. However, according to Wang et al. (2011), low-income or immigrant families face barriers in accessing medical services for their children including audiometric evaluation. Apart from isolated programs established by nonprofit organizations which offer routine hearing screening for inner city schools (Wang et al. 2011), there are no hearing screening programs for school-age children or adolescents being carried out across Canada.

Proxy-reported HL through a child's parent or guardian may be carried out by family practitioners to screen for HL, however some reports have found that only 12% of physicians screened for HL during annual physical exams with about half using a questionnaire (Cohen et al. 2005; Kochkin & Trak 2005). However, among participants aged 6 to 19 years in the present study, the prevalence of reported HL (either through proxy or self-report) was less than 1%, which is substantially lower than the 7.7% that were found to have a measured HL above 20 dB. A wider discrepancy between self-reported and measured HL was reported

by NHANES (Niskar et al. 1998)—3.4% compared with 14.9%, respectively. The larger discrepancy may be partially attributed to Niskar et al.'s (1998) use of a 16 dB HL threshold and or other methodological differences such as the cutoff age for proxy data. Furthermore, data collected by proxy may not reflect the child's actual hearing status, especially when the severity of HL is mild (Stewart et al. 1999; Gates et al. 2003; Meinke & Dice 2007). In fact, some studies have reported that only 50% of children with HL are actually identified by the use of questionnaires and checklists (Watkin et al. 1990; Kittrell & Arjmand 1997). Adolescents and parents provided poor self-report of hearing status in contrast to older adults when self-reported and measured HL were studied (Stewart & Ohlms 1999; Gates et al. 2003; Meinke & Dice 2007). The lack of a high quality adolescent hearing risk assessment capable of adequately capturing high-risk noise exposure behaviors was discussed by Sekhar et al. (2014). In this US study of 282 Grade 11 students, the validity of the *Bright Futures* adolescent screening tool being used by physicians was examined. No association between most of the screening questions and HL above 25 dB (based on the inability to hear two or more frequencies: 0.25, 0.5, 1, 2, and 4 kHz) using audiometry was found (Sekhar et al. 2014). The discrepancy between self-reported and audiometrically measured HL in the present study is also notable.

The present study finding indicating that 17% of Canadian children and adolescents, aged 3 to 19, having excessive or impacted earwax or pus, has potential hearing health and acuity implications. HL prevalence among this subgroup could not be examined; however, these conditions can mask the detection of existing HL or result in a future HL that can range from 5 to 40 dB (Roland et al. 2008). In a study of 1000 South African children, CHL from impacted earwax accounted for 10% of children failing a hearing screening test (Bhoola & Hugo 1997); impacted earwax was the most common problem found in 5120 Karachi children, aged 5 to 15, who underwent hearing evaluations (Hussain et al. 2011). Other studies have reported a range of impacted earwax prevalences: 10% of school children (Roeser & Ballachanda 1997), 12.3% of a representative sample ($n = 1119$) of Latin American children/adolescents (Godinho et al. 2001); 15.7% of 802 Tanzanian school children (Minja & Machemba 1996); and 24.4% of a representative sample of Bosnian/Herzegovinan 7- to 10-year olds ($n = 1344$) reported by Brkic (2010). In older adults, removal of earwax improved audiometric hearing thresholds for nearly half the study subjects (Gleitman et al. 1992); however, due to limited child/adolescent research in this area, it is unknown whether this procedure would yield similar results.

It is interesting that nearly two-thirds of young Canadians, aged 3 to 19, reported they had never before had their hearing tested. At present, in Canada, a hearing evaluation for a child is more likely to be initiated when a concern by a parent or teacher is expressed, or when the child is at high risk due to a family history or an underlying medical condition. However, as Wang et al. (2011) has reported, medical access and follow-up audiology services may be limited for economically disadvantaged or immigrant families. Furthermore, as these and other study findings have shown, children and adolescents are more likely to have unilateral or mild HL, which may go undetected by the classroom teacher, the parent or even the child (Dodd-Murphy et al. 2014).

Limitations

The cross-sectional design of this study allows a snapshot of hearing acuity among Canadian youth; however, conclusions about changes in HL prevalence over time cannot be made until future CHMS hearing cycles are analyzed. One limitation of the present study is that audiometry was not conducted on 3- to 5-year olds. Therefore, HL findings were based on DPOAE and tympanometry results. Second, the small sample size for specific subgroups, that is, 3- to 5-year olds with absent DPOAEs, limited the analysis that could be carried out. The population weighted estimate of these subgroups often yielded a large CV (between 16.6 and 33.3) denoted by superscript ^E and categorized as “marginal.” This indicates that the estimate has low precision due to the high sampling variability associated with the estimate and these findings should therefore be interpreted with caution. However this limitation is expected to be ameliorated once Cycle 4 CHMS hearing data is available for analysis.

The upper age cutoff of 19 years for this article was selected to be consistent with previous CHMS publications (Statistics Canada 2015a). The use of a >20 dB HL threshold cutpoint for 6- to 18-year olds, and ≥26 dB for 19-year olds in the present study is in accordance with the AAA guidelines and the ASHA pediatric audiologic screening guidelines which “pertain to infants and children age birth through 18 years” (ASHA 1997; AAA 2011); and was also adopted by the National Workshop on Mild and Unilateral Hearing Loss (2005) and used in several large scale studies (Bess et al. 1998; Wood et al. 2015). Nonetheless, the use of these HL threshold cutpoints instead of the >15 dB HL threshold cutpoints used by Niskar et al. (1998) and by Shargarodsky et al. (2010), which would have allowed comparison to NHANES studies that examined HL prevalence among a national sample of U.S. children, represents a limitation of this study and may have resulted in an underestimate of HL prevalence. However, as Ross et al. (2008) and others have noted, there is no standard definition of unilateral or bilateral HL, with variable definitions used among countries, states/provinces and providers. The use of two different HL thresholds in this study represents a minor limitation; however, the small number of 19-year olds in our sample (n = 104) diminishes its overall impact on the findings.

The response rate for this study was close to 50% and did not include an analysis of those who refused to participate in the physical health measures portion of the study. Therefore, potential selection bias in those who agreed to participate may be a possibility, because this group may have a higher prevalence of hearing challenges than those who refused or vice versa. Another limitation is the lack of bone conduction testing in the present study which may have led to CHL being missed in some cases; and represents a limitation insofar as it adds to the uncertainty of the true prevalence of permanent HL. In addition, the CHMS hearing evaluation scoring protocol used during otoscopic examination did not allow for differentiation between pus and wax. Although it is assumed that earwax would be more prevalent than pus, it may be beneficial to revise this particular scoring protocol so that differentiation is possible in future studies. CHMS study results are considered representative of the Canadian population; however, sampling exclusions such as residents from the three territories, First Nations Reserves, and other Aboriginal settlements as well as full-time members of the Canadian Forces, represent a limitation. However, as these

exclusions represent approximately 4% of the target population, this limitation may be considered minor.

Self-reported HL was evaluated using hearing questions from the HUI3. This tool has not previously been validated with regard to self-reported HL sensitivity and objective audiometric measures. Furthermore, estimates of self-reported and measured HL based on the same respondents could not be carried out due to small age group sample sizes. Therefore, self-reported HL data, that is, HUI3 data from the 2013 Canadian Community Health Survey was used in the analysis. These factors represent a limitation in terms of the validity and reliability of self-reported HL data in the present study. The development of a robust self-report HL tool tailored to children and adolescents for use in future studies would be beneficial. Last, an assessment of participants’ exposure to leisure noise would lead to a more comprehensive understanding of HL.

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