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Screening, rubella vaccination, and childhood hearing impairment in Taiwan

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ABSTRACT

Childhood hearing impairment (CHI) is a major developmental disability, but data at the national level are limited, especially those on the changes in the prevalence over time. In Taiwan, the government began to certify disabled residents for providing various services in 1980 and maintains a registry of certified cases, which provides a rare opportunity for studying the trends of CHI prevalence. Using the registry data, we estimated the prevalence of CHI by age and severity and explored factors affecting its changes over time. From 2000 to 2011, the registered cases under 17 years old ranged from 3427 to 4075. The overall prevalence increased from 2000 to 2006, but then decreased till 2011. While the prevalence of mild CHI increased over the years, such a pattern was not observed in moderate or severe CHI. In general, the overall prevalence increased over the years in the age groups <3 years, 3–5 years, and 6–11 years ($p < 0.01$), and the largest increase was observed in the age group <3 years, particularly after the promotion of screening by the government in 2003. The decrease after 2006 was mainly attributable to decreases in the age groups 12–14 (with a decreasing trend from 2001, $p < 0.01$) and 15–17 years (with a decreasing trend from 2004, $p < 0.01$). The timing was related to the implementation of a nationwide rubella vaccination program. Similar decreases had been observed in countries with rubella vaccination programs.

1. Introduction

Hearing impairment is a global problem, and the World Health Organization estimated that 360 million people worldwide have disabling hearing loss (World Health Organization, 2014). In children, hearing impairment usually associates with difficulties in the development of language, speech production, and cognition, which in turn affect academic performance, vocational attainment, and socioemotional competence (Connor & Zwolan, 2004; Hintermair, 2006; Niskar et al., 1998; Petrou et al., 2007). The cost of rehabilitation and special education associated hearing impairment can impose a

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heavy social and economic burden on the family, community, and country (Mohr et al., 2000; Olusanya & Newton, 2007; Schroeder et al., 2006). Mohr et al. (2000) estimated that in the United States, severe to profound hearing impairment was associated with a lifetime cost of more than $1 million.

Early identification and management of congenital hearing impairment can decrease the impact (Watkin et al., 2007). Universal newborn hearing screening is regarded as the most effective way to identify the infants with hearing loss immediately after birth (White & Maxon, 1995). In Taiwan, the Bureau of Health Promotion (2011) has also been promoting the neonatal hearing screening services, but the time trend in the prevalence of childhood hearing impairment (CHI) has not been extensively studied.

In order to make responsible national policy, determine resource allocation, and ultimately decrease the individual and public health burden of hearing impairment, reliable epidemiological data on CHI are needed (Mehra, Eavey, & Keamy, 2009). Many studies have been conducted on the prevalence of CHI, but the reported prevalence varies widely (Lin, Huang, Lin, Lin, & Wu, 2004; Mehra et al., 2009; Niskar et al., 1998; Van Naarden, Decouflé, & Caldwell, 1999). The variations may be attributable to factors including the differences in case definition, age range, and case-finding method (Durkin, 2002).

In 1980, according to the Disabled Welfare Act (1980), the local governments in Taiwan began to certify the disabled residents and provide various services, and the Ministry of Health and Welfare keeps a registry of certified cases and publishes summary data annually (Ministry of Health and Welfare, 2014) (before the re-organiztion of the government in 2013, these tasks were performed by the Ministry of the Interior). The registry data present a rare opportunity for studying the epidemiology of CHI at the national level. Therefore, we adopted the data to assess the changes in prevalence of CHI in Taiwan over the years and explore the factors affecting the changes.

2. Methods

2.1. The disability registry system in Taiwan

In 1980, the Disabled Welfare Act (1980) was promulgated in Taiwan, which led to the establishment of the disability registry. The local governments began to certify seven types of disabled residents, including ''hearing impairment or balance disability.'' In 1997, ''Disabled Welfare Act (1980)'' was changed to ''Physically and Mentally Disabled Citizens Protection Act (1997)'' and ''hearing impairment or balance disability'' was divided into two different types of disabilities: hearing impairment and balance disability.

The disability registry in Taiwan was established mainly for facilitating services. Individuals can make applications for certification through the local government in the residential area and obtain a certificate if they are determined as fitting the criteria by an accredited doctor (Department of Health, 2006b, 2008). The local governments report certified cases to the central government, and the Ministry of Health and Welfare maintains a registry of cases (before the re-organiztion of the government in 2013, the registry was maintained by the Ministry of the Interior).

2.2. Case definition

When a child is suspected to have hearing impairment, parents or guardians can apply for certification. In order to obtain the disability benefits, a child should have had a measured, unaided, pure-tone hearing impairment at frequencies of 0.5, 1 and 2 kHz (pure-tone average, PTA) in the better ear (better ear hearing level, BEHL) averaging 55 decibels (dB) or more and been confirmed by a otolaryngologist accredited by the government (Department of Health, 2006b, 2008). For the estimation of hearing levels in malingering or difficult-to-test children, auditory brainstem response is used to evaluate the function of the auditory nerve.

The determination of the degree of hearing impairment was based on the most recent audiogram. The severity of hearing impairment is defined as ''mild'' with PTA $\geq$55 dB BEHL and <70 dB BEHL, ''moderate'' with PTA $\geq$70 dB BEHL and <90 dB BEHL, and ''severe'' with PTA $\geq$90 dB BEHL (Department of Health, 2008).

2.3. Data collection

The Department of Statistics of Taiwan Ministry of Health and Welfare publishes Statistical Yearbook each year (Ministry of Health and Welfare, 2014) (before the re-organiztion of the government in 2013, the reports were published by the Ministry of the Interior), which includes numbers of cases by age. The yearbooks do not include the number of CHI cases under 17 years old by severity, but we obtained the information from the Department of Statistics of Ministry of the Interior, which is available since 2000, and analyzed the data till 2011. To calculate the prevalence, we obtained data on the numbers of total population in each age group from the Monthly Bulletin of Interior Statistics (Ministry of the Interior, 2011).

2.4. Statistical analysis

For each age group, we estimated the prevalence of CHI by dividing the number of cases by the number of individuals in each year and evaluated the trend over the years. According to the yearbooks (Ministry of Health and Welfare, 2014), we categorized the age into five groups (<3 years, 3–5 years, 6–11 years, 12–14 years, and 15–17 years) and reported the overall

Table 1
The prevalence (per 10,000 children)[a] of hearing impairment by age in Taiwan.

Year	0–2 years		3–5 years		6–11 years		12–14 years		15–17 years		0–17 years	
	N	Prev.	*N*	Prev.	*N*	Prev.	*N*	Prev.	*N*	Prev.	*N*	Prev.
2000	97	1.15	432	4.45	1515	7.82	932	9.79	914	8.49	3890	6.73
2001	118	1.41	417	4.56	1437	7.37	1015	10.56	866	8.65	3853	6.80
2002	109	1.36	488	5.58	1469	7.58	973	9.86	917	9.70	3956	7.13
2003	137	1.90	486	5.67	1454	7.49	920	9.55	987	10.41	3984	7.34
2004	154	2.26	523	6.18	1427	7.56	877	9.01	1094	11.42	4075	7.62
2005	160	2.50	484	5.98	1416	7.68	880	9.12	1082	11.00	4022	7.67
2006	210	3.39	480	6.57	1418	7.76	898	9.27	1035	10.76	4041	7.91
2007	227	3.74	447	6.46	1379	7.84	880	9.05	986	10.15	3919	7.83
2008	200	3.34	458	7.00	1296	7.70	848	8.76	927	9.63	3729	7.66
2009	215	3.66	415	6.55	1267	7.98	822	8.48	934	9.66	3653	7.70
2010	220	3.99	428	6.89	1206	7.84	770	8.44	909	9.36	3533	7.69
2011	208	3.77	402	6.56	1179	8.05	732	8.38	906	9.36	3427	7.67

[a] The prevalence (prev.) was estimated by dividing number of cases (*N*) by population in each age group in each year.

prevalence as well. We also calculated the prevalence rate and the proportion by severity group and evaluated their trends over the years.

We used linear regressions to evaluate the trends of changes in prevalence and proportion over the years as well as the trends of changes in prevalence across age groups. Using the data in 2000 as the reference, we calculated odds ratios (ORs) of being registered before 3 years of age in each year afterwards and used chi-square test for trend to evaluate the trends. All the analyses were conducted using SAS 9.1, and all the statistical tests were performed at the significance level of 0.05. The study protocol has been reviewed and approved by the Institution Review Board of the Ditmanson Medical Foundation Chia-Yi Christian Hospital.

3. Results

3.1. The trend of overall prevalence

From 2000 to 2011, the registered cases under 17 years old ranged from 3427 to 4075 (Table 1). The prevalence under 17 years old increased from 6.73/10,000 in 2000 to 7.91/10,000 in 2006, with an increasing trend ($p < 0.05$). Then, the prevalence decreased from 7.91/10,000 in 2006 to 7.67/10,000 in 2011, with a decreasing trend ($p < 0.05$) (Table 1). The prevalence rates in the age groups <3 years, 3–5 years, 6–11 years, 12–14 years, and 15–17 years were 1.15–3.99/10,000, 4.45–7.00/10,000, 7.37–8.05/10,000, 8.38–10.56/10,000, and 8.49–11.42/10,000, respectively. The prevalence generally increased with age ($p < 0.05$ in all years). In general, the prevalence increased over the years in the age groups <3 years, 3–5 years, and 6–11 years ($p < 0.05$ for the three groups), but had a decreasing trend from 2001 in the age group 12–14 years and from 2004 in the age group 15–17 years ($p < 0.01$ in both groups). Comparing to the prevalence between 2000 and 2011, we found a more than twofold increase in the age group <3 years and a nearly 50% increase in the age group 3–5 years.

3.2. The trends of prevalence by severity

For mild CHI, the proportion (in all severity groups combined) and prevalence generally increased over the years in all age groups (all with $p < 0.05$) (Table 2). In each year, the prevalence generally increased with age (all with $p < 0.05$ in calendar years).

Table 2
The prevalence (per 10,000 children)[a] and proportion of mild hearing impairment by age in Taiwan.

Year	0–2 years		3–5 years		6–11 years		12–14 years		15–17 years		0–17 years	
	%	Prev.	%	Prev.	%	Prev.	%	Prev.	%	Prev.	%	Prev.
2000	23.71	0.27	21.99	0.98	24.75	1.94	24.89	2.44	29.21	2.48	25.50	1.72
2001	19.49	0.28	23.74	1.08	26.51	1.95	26.60	2.81	29.21	2.53	26.63	1.81
2002	16.51	0.22	24.80	1.38	27.71	2.10	27.44	2.71	31.19	3.02	27.78	1.98
2003	17.52	0.33	24.49	1.39	30.06	2.25	28.26	2.70	29.48	3.07	28.39	2.08
2004	27.27	0.62	23.90	1.48	31.18	2.36	30.22	2.72	28.24	3.23	29.10	2.22
2005	26.88	0.67	27.07	1.62	31.78	2.44	30.68	2.80	30.96	3.40	30.56	2.34
2006	30.48	1.03	27.50	1.81	31.81	2.47	31.74	2.94	31.98	3.44	31.25	2.47
2007	31.28	1.17	25.95	1.68	32.49	2.55	34.09	3.08	29.92	3.04	31.39	2.46
2008	31.50	1.05	26.20	1.83	32.56	2.51	33.96	2.97	30.42	2.93	31.51	2.41
2009	32.09	1.18	30.12	1.97	31.81	2.54	35.52	3.01	32.66	3.15	32.69	2.52
2010	29.55	1.18	32.01	2.20	32.26	2.53	35.71	3.01	35.64	3.34	33.68	2.59
2011	26.92	1.02	32.34	2.12	33.16	2.67	36.34	3.05	36.20	3.39	34.17	2.62

[a] The prevalence (prev.) was estimated by dividing number of cases by population in each age group in each year.

Table 3
The prevalence (per 10,000 children)[a] and proportion of moderate hearing impairment by age in Taiwan.

Years	0–2 years		3–5 years		6–11 years		12–14 years		15–17 years		0–17 years	
	%	Prev.	%	Prev.	%	Prev.	%	Prev.	%	Prev.	%	Prev.
2000	23.71	0.27	26.62	1.18	29.83	2.33	27.04	2.65	20.68	1.76	26.50	1.78
2001	29.66	0.42	24.70	1.13	28.39	2.09	27.49	2.90	26.44	2.29	27.36	1.86
2002	28.44	0.39	23.77	1.33	27.50	2.09	26.93	2.65	25.30	2.45	26.42	1.88
2003	29.93	0.57	26.95	1.53	26.48	1.98	27.72	2.65	26.55	2.76	26.96	1.98
2004	22.08	0.50	24.09	1.49	25.23	1.91	27.59	2.49	25.78	2.94	25.62	1.95
2005	26.88	0.67	20.04	1.20	24.58	1.89	25.45	2.32	25.32	2.78	24.52	1.88
2006	22.38	0.76	21.25	1.40	23.55	1.83	25.39	2.35	24.06	2.59	23.76	1.88
2007	24.23	0.91	23.49	1.52	23.28	1.82	24.66	2.23	27.08	2.75	24.62	1.93
2008	26.00	0.87	24.67	1.73	22.38	1.72	25.35	2.22	25.57	2.46	24.32	1.86
2009	25.12	0.92	23.86	1.56	22.02	1.76	24.21	2.05	24.41	2.36	23.51	1.81
2010	21.36	0.85	20.09	1.38	21.64	1.70	21.04	1.77	23.32	2.18	21.74	1.67
2011	22.60	0.85	20.65	1.36	20.70	1.67	22.13	1.86	24.17	2.26	22.03	1.69

[a] The prevalence (prev.) was estimated by dividing number of cases by population in each age group in each year.

For moderate CHI, while the overall proportion decreased over the years ($p < 0.01$), the decreasing trend in the age group <3 years was not significant, and no consistent trend was observed in the age group 15–17 years (Table 3). In general, the prevalence increased over the years in the <3 years group and decreased in the age groups 6–11 years and 12–14 years ($p < 0.05$ in these three age groups). In each year, the prevalence generally increased with age ($p < 0.05$ in all years except 2000 ($p = 0.15$)).

Although severe CHI contributed most cases all through the years, the proportion decreased over the years in general in all age groups except for the 6–11 years group (Table 4). The prevalence had an increasing trend over the years in the age groups <3 years, 3–5 years, and 6–11 years ($p < 0.05$ in the three groups). A decreasing trend was observed in the age group 12–14 years since 2002 and in the age group 15–17 years since 2005 ($p < 0.05$ both groups), and a similar pattern was observed in moderate CHI – a decreasing trend in the age group 12–14 years since 2002 and in the age group 15–17 years since 2005. However, such a pattern was not observed in mild CHI. In general, the prevalence increased with age, but the trends did not reach statistical significance in 2008 ($p = 0.06$), 2010 ($p = 0.06$), and 2011 ($p = 0.08$).

3.3. *The trend in the youngest group*

For the <3 years group, the prevalence generally increased in all three severity groups over the years (all with $p < 0.05$) (Tables 2–4), but no consistent trends in the changes of prevalence associated with severity were observed in the other age groups. In addition, the proportion of cases under 3 years of age generally increased over the years, from 2.49% in 2000 to 6.07% in 2011 ($p < 0.01$ for chi-square test for trend), and the OR of being registered under 3 years of age increased up to 2.53, reaching statistical significance starting from 2003 (Table 5).

4. Discussion

Prevalence data on CHI from large-scale studies are limited. Using the keywords "hearing loss," "child," and "dB", combining with "prevalence" to search in PubMed database, we identified 14 studies on the prevalence of low-frequency hearing impairment which defined hearing impairment by dB values and included more than 1000 participants (Table 6). We

Table 4
The prevalence (per 10,000 children)[a] and proportion of severe hearing impairment by age in Taiwan.

Year	0–2 years		3–5 years		6–11 years		12–14 years		15–17 years		0–17 years	
	%	Prev.	%	Prev.	%	Prev.	%	Prev.	%	Prev.	%	Prev.
2000	52.58	0.61	51.39	2.29	45.41	3.55	48.07	4.71	50.11	4.26	47.99	3.23
2001	50.85	0.72	51.56	2.35	45.09	3.32	45.91	4.85	44.34	3.84	46.02	3.13
2002	55.05	0.75	51.43	2.87	44.79	3.40	45.63	4.50	43.51	4.22	45.80	3.27
2003	52.55	1.00	48.56	2.76	43.47	3.26	44.02	4.20	43.97	4.58	44.65	3.28
2004	50.65	1.15	52.01	3.21	43.59	3.30	42.19	3.80	45.98	5.25	45.28	3.45
2005	46.25	1.15	52.89	3.16	43.64	3.35	43.86	4.00	43.72	4.81	44.93	3.45
2006	47.14	1.60	51.25	3.37	44.64	3.47	42.87	3.97	43.96	4.73	44.99	3.56
2007	44.49	1.66	50.56	3.27	44.23	3.47	41.25	3.73	43.00	4.36	43.99	3.45
2008	42.50	1.42	49.13	3.44	45.06	3.47	40.68	3.56	44.01	4.24	44.17	3.38
2009	42.79	1.57	46.02	3.01	46.17	3.69	40.27	3.41	42.93	4.15	43.80	3.37
2010	49.09	1.96	47.90	3.30	46.10	3.61	43.25	3.65	41.03	3.84	44.58	3.43
2011	50.48	1.90	47.01	3.09	46.14	3.71	41.53	3.48	39.62	3.71	43.80	3.36

[a] The prevalence (prev.) was estimated by dividing number of cases by population in each age group in each year.

Table 5
The ratios of cases of hearing impairment under 3 years of age to those from 3 to 17 years of age.

Year	<3 year N (%)	3–17 year N (%)	OR [95% CI][a]
2000	97 (2.49)	3793 (97.51)	1.00
2001	118 (3.06)	3735 (96.94)	1.24 [0.94,1.62]
2002	109 (2.76)	3847 (97.24)	1.11 [0.84,1.46]
2003	137 (3.44)	3847 (96.56)	1.39 [1.07,1.81]*
2004	154 (3.78)	3921 (96.22)	1.54 [1.19,1.99]*
2005	160 (3.98)	3862 (96.02)	1.62 [1.25,2.09]*
2006	210 (5.20)	3831 (94.80)	2.14 [1.68,2.74]*
2007	227 (5.79)	3692 (94.21)	2.40 [1.89,3.06]*
2008	200 (5.36)	3529 (94.64)	2.22 [1.73,2.84]*
2009	215 (5.89)	3438 (94.11)	2.45 [1.92,3.12]*
2010	220 (6.23)	3313 (93.77)	2.60 [2.04,3.31]*
2011	208 (6.07)	3219 (93.93)	2.53 [1.98,3.23]*

[a] Odds ratio (OR) with 95% confidence interval (C.I.) for being registered at under 3 years of age in comparison with 2000; $p < 0.01$ for chi-square test for trend from 2000 to 2011.
* $p < 0.05$.

found a wide range of reported prevalence, and the variation might mainly due to differences in case definition, age range, and case-finding method (Durkin, 2002), while factors such as genetic makeup, health-care accessibility, and socioeconomic status may also have contributions (Kaewboonchoo et al., 1998; Mehra et al., 2009; Rao, Subramanyam, Nair, & Rajashekhar, 2002). In particular, differences in case definition make comparisons among studies difficult.

Our literature review showed that data on the trends in the prevalence of CHI are scarce. In our study, the prevalence of CHI under 17 years old increased from 2000 to 2006. Similar increasing trends were found in other developmental disabilities using the same database (the national disability registry of Taiwan), including intellectual disabilities, autism spectrum disorders, and all disabilities combined (Lai, Tseng, Hou, & Guo, 2012a, 2012b; Lai, Tseng, & Guo, 2013). We believe the increase is unlikely to be a true increase in the occurrence of cases, because most of the major risk factors (Drews, Yeargin-Allsopp, Murphy, & Decoufle, 1994; Mehra et al., 2009) such as medical care and socioeconomic status had moved toward the favorable direction over the 12-year period in Taiwan. The increase is more likely to be attributable to an increase in the proportion of cases registered, especially mild cases. This phenomenon may be in turn attributable to the nationwide screening in children (Bureau of Health Promotion, 2011), higher awareness in parents and professionals (Matson & Kozlowski, 2011), better service of the agencies (Yeargin-Allsopp, Murphy, Oakley, & Sikes, 1992), more willingness to register, etc. (Lai, Tseng, & Guo, 2011).

In particular, according to the official report of the Bureau of Health Promotion (2011), the proportion of pre-school children receiving hearing screening had been promoted from 30.3% in 2002 to 86.64% in 2010. In addition, we found that prevalence of mild cases generally increased in all age group over the years, and mild cases contributed about 0.75 of the 1.18 (63.6%) per 10,000 increase in the overall prevalence from 2000 to 2006. There was a sharp increase in both the prevalence and the proportion of mild CHI after the promotion of screening by the government in 2003.

On the other hand, the decrease of CHI from 2006 to 2011 was mainly attributable to decreases in the age groups 12–14 and 15–17 years. We speculated the main cause, which even offset the increasing trend attributable to increase in the proportion of cases registered, was the improvements in medical care (Lipkin, 1996). In particular, a nationwide comprehensive rubella vaccination program was implemented in 1986 on 15-year-old girls in Taiwan (Centers for Disease Control, 2009; Su & Guo, 2002). As Taiwanese women generally start giving births after graduation from high schools (around 18 years of age), this group of girls started giving births around 1989, and the occurrence of CHI due to congenital rubella syndrome was expect to start decreasing 3 years later in 1989. In the age group 12–14 years, we did find the prevalence started decreasing in 2002 (Fig. 1, left), when the median year of birth in this age group was approximately 1989. Likewise, in the age group 15–17 years, the prevalence started decreasing in 2005 (Fig. 1, right), when the median year of birth was approximately 1989. Therefore, we speculate that the rubella vaccination program had played a role in the reduction of the overall CHI prevalence after 2006. This argument is supported by similar observations in an Australian study (Menser, Hudson, Murphy, & Cossart, 1984), in which girls aged 10–14 years started to receive rubella vaccination in 1971, and a striking reduction in the incidence of deafness due to congenital rubella was observed starting from 1977, when the mean age of these girls was approximately 18 years (the mean age of the group 10–14 years was about 12, and duration was 6 years, 12 + 6 = aged 18). In addition, CHI cases associated with congenital rubella infection are generally severe (Borton & Stark, 1970; Wild, Sheppard, Smithells, Holzel, & Jones, 1989), and a study showed that nearly 3/4 of the cases (41/55) had PTA > 70 dB BEHL (Borton & Stark, 1970), in the range of moderate and severe CHI in our study. This is compatible with our observations of decreasing trends in moderate and severe CHI in the age group 12–14 years since 2002 and in the age group 15–17 years since 2005, and no decreasing trends in mild CHI. Furthermore, Taiwan government initiated the reporting of rubella in 1988, and although there was an outbreak in 1992 (Department of Health, 1995, 2006a), no remarkable increases in cases of CHI were observed in the age group 12–14 years in 2005 or 2006, or in the age group 15–17 years in 2008 or 2009. This indicated that the vaccination program had introduced protective effects in pregnancy women. We believe the nationwide rubella vaccination program introduced protective effects in pregnancy women. In fact, two studies in Taiwan

Table 6
Prevalence (per 10,000 children) of low-frequency hearing impairment defined by dB values in different studies.

Study	Country	Case-finding method	Case number (population)	Age (years)	Case definition	Prevalence
Parving (1983)	Denmark	Medical record review	117 (82,265)	2–12	Average of 0.5, 1, and 2 kHz	
					≥35 dB HL in better ear	14.2
					≥55 dB HL in better ear	9.2
					≥75 dB HL in better ear	6.1
Sehlin et al. (1990)	Sweden	Medical record review	160 (63,463)	0–20	Average of 0.5, 1, and 2 kHz	
					≥30 dB HL in better ear	25.2
					≥56 dB HL in better ear	11.8
					≥92 dB HL in better ear	8.4
Drews et al. (1994)	United States	Active surveillance using multiple sources	100 (89,534)	10	Average of 0.5, 1, and 2 kHz;	
	(MADDSP)[f]				≥40 dB HL in better ear	11.0
					≥71 dB HL in better ear	7.0
					≥90 dB HL in better ear	5.0
Karikoski and Marttila (1995)	Finland	Medical record review	353 (270,726)	0–18	Average of 0.5, 1, and 2 kHz	
					≥30 dB HL in better ear	12.0
					≥35 dB HL in better ear	11.0
					≥50 dB HL in better ear	8.0
Vartiainen, Kemppinen, and Karjalainen (1997)	Finland	Medical record review	98 (46,240)	0–9	Average of 0.5, 1, 2, and 4 kHz;	
					>25 dB HL in better ear	21.2
					>70 dB HL in better ear	6.5
Mäki-Torkko, Lindholm, Väyrynen, Leisti, and Sorri (1998)	Finland	Medical record review	253 (212,328)	0–15	Average of 0.5, 1, 2, and 4 kHz;	
					≥40 dB HL in better ear	11.9
Niskar et al. (1998)	United States	National household survey (screening)	NA[a] (6166)	6–19	Average of 0.5, 1, and 2 kHz;	
	(NHANES)[e]				>15 dB HL in better ear	150.0
					>25 dB HL in better ear	40.0
Van Naarden et al. (1999)	United States	Active surveillance using multiple sources	862 (790,200)	3–10	Average of 0.5, 1, and 2 kHz;	
	(MADDSP)[f]				≥40 dB HL in better ear	11.0
					≥65 dB HL in better ear	6.2
					≥85 dB HL in better ear	3.7
Nekahm, Weichbold, and Welzl-Müller (2001)	Austria	Medical record review	165 (124,809)	0–15	Average of 0.5, 1, 2, and 4 kHz;	
					≥40 dB HL in better ear	13.2
					≥70 dB HL in better ear	6.2
					≥95 dB HL in better ear	3.0
Fortnum et al. (2001)	United Kingdom	Medical record review	7564 (4,644,400)	8–13	Average of 0.5, 1, 2, and 4 kHz	
					>40 dB HL in better ear	16.3
					>95 dB HL in better ear	3.8
Liu et al. (2001)	China	Three-stage screening	227 (34,157)	0–14	Average of 0.5, 1, 2, and 4 kHz	
					≥27 dB HL in better ear	66.5
Bubbico et al. (2007)	Italy	National registry (reporting)	2820 (8,000,000[b])	0–14	Average of 0.5, 1, and 2 kHz	
					≥60 dB HL in better ear	3.5
Shargorodsky, Curhan, Curhan, and Eavey (2010)	United States (NHANES)[e]	National household survey (screening)	46 (2928)	12–19	Average of 0.5, 1, and 2 kHz	
			[1988–1994]		>15 dB HL in better ear	110.0[c]
			42 (1771)		≥25 dB HL in better ear	20.0[c]
			[2005–2006]		>15 dB HL in better ear	220.0[c]
					≥25 dB HL in better ear	20.0[c]

Table 6 (*Continued*)

Study	Country	Case-finding method	Case number (population)	Age (years)	Case definition	Prevalence
Cone, Wake, Tobin, Poulakis, and Rickards (2010)	Australia	Two-stage screening	55 (6250[b])	7, 11	Average of 0.5, 1, and 2 kHz 16–40 dB HL in better ear	88.0
Our study	Taiwan	National registry (reporting)	3427 (4,469,350[d])	0–17	Average of 0.5, 1, and 2 kHz;	
					≥55 dB HL in better ear	7.7
					≥70 dB HL in better ear	5.1
					≥90 dB HL in better ear	3.4

[a] Not available.
[b] Estimated by the author.
[c] Prevalence are weighted.
[d] Estimated using the population in 2011.
[e] NHANES: National Health and Nutrition Examination Survey.
[f] MADDSP: Metropolitan Atlanta Developmental Disabilities Surveillance Program.

found that women born before the implementation of the vaccination program were more susceptible to rubella infection, with sero-negative rates 23% vs. 4% (Su & Guo, 2002) and 20.1% vs. 6.7% (Lin et al., 2011), respectively.

Because hearing impairment is rarely fatal and a substantial proportion of serious cases are not curable, the prevalence of CHI should increase with age (Durkin, 2002). However, longitudinal data are quite limited, and only two of the studies we reviewed provided such information (Fortnum, Summerfield, Marshall, Davis, & Bamford, 2001; Van Naarden et al., 1999), with one reporting data stratified by severity (Fortnum et al., 2001). Our study found that the prevalence rates for each of the three levels of severity and all severities combined generally increase with age, which is compatible with observations in those two studies.

Because the case definition of hearing impairment is different, it is difficult to compare the distribution of severity among studies (Mehra et al., 2009). In our study, we found mild CHI had increasing trends in both the proportion and prevalence over the years in all age groups. We believe the increasing trends are more likely to be attributable to a decrease in undiagnosed cases than an increase in the incidence, because most of the major risk factors had moved toward the favorable direction in Taiwan. We believed that increasing awareness of parents and professionals and easier access to hearing screening contributed to the increase in the registration of mild cases (Bureau of Health Promotion, 2011).

In our study, we found the prevalence in the <3 years group increased in all severity groups over the years. We believed the increase was mainly contributable to newborn hearing screening in recent years. Universal newborn hearing screening can decrease the impact of congenital hearing impairment (Wessex Universal Neonatal Hearing Screening Trial Group, 1998). In Taiwan, the Bureau of Health Promotion began the promotion of newborn hearing screening in 2003 and promulgated the guidelines in 2004 (International Symposium and National Consensus meeting, 2008). The prevalence of CHI in the <3 years group increased remarkably from 1.36/10,000 in 2002 to 1.90/10,000 in 2003. In addition, the Bureau of

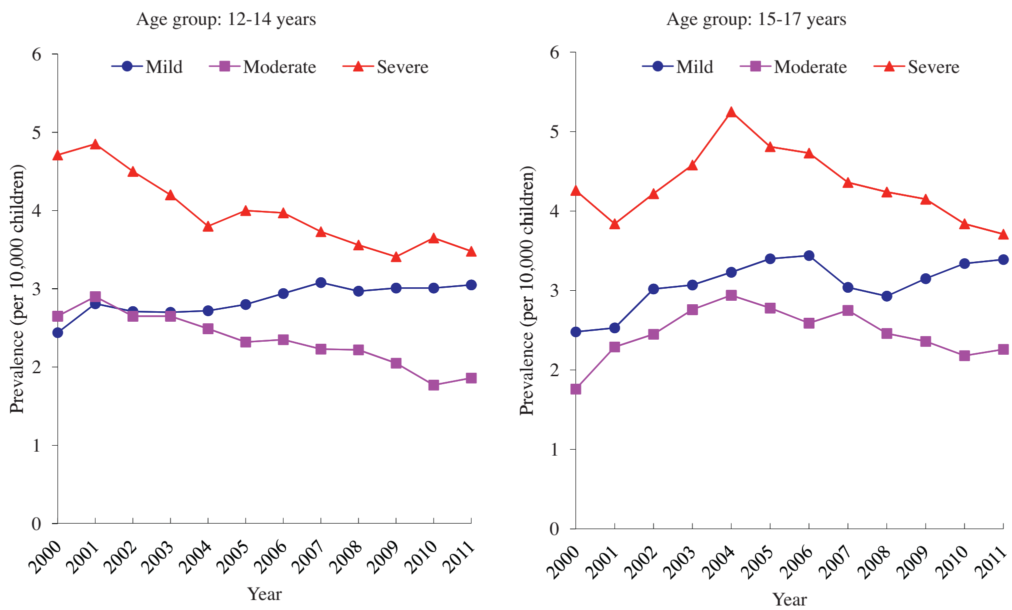

Fig. 1. Prevalence of severe, moderate, and mild hearing impairment of children 12–14 and 15–17 years old from 2000 to 2011.

Health Promotion constructed two resource centers for hearing screening intervention in 2006 which had assisted 58 hospitals to implement newborn hearing screening by the end of 2007 (International Symposium and National Consensus meeting, 2008), and the prevalence in the <3 years group increased remarkably again from 2.50/10,000 in 2005 to 3.39/10,000 in 2006. According to the annual report of the Bureau of Health Promotion (2011), 60.45% of the baby-delivering institutions could offer newborn hearing screening services in 2010.

In our study, the case definition for hearing impairment was PTA $\geq$55 dB BEHL, and the prevalence under 17 years of age was 7.7/10,000 in 2011. Adopting the criteria, we found only two reports in the literature we reviewed had comparable data, and the prevalence was 9.2/10,000 in Denmark (Parving, 1983) and 11.8/10,000 in Sweden (Sehlin, Holmgren, & Zakrisson, 1990). We believe the prevalence in Taiwan was underestimated, because we adopted the data from a national registry to generate "administrative" prevalence, and such a method generally observes lower prevalence rates as it tends to identify only persons who are receiving services provided by the administration (Larson et al., 2001). The size of study population will also affect the observed prevalence rate (Fombonne, 2005). In general, studies with larger populations tend to report lower prevalence rates, most likely due to the difficulty in conducting comprehensive case finding protocols in larger populations. The disability registry in Taiwan covers the whole Taiwan area with a population of about 5 million below 17 years of age, and therefore we can expect the observation of lower prevalence rates. For example, a large scale study using national data of Italy with a population of 8 million below 14 years of age reported a prevalence as low as 3.5/10,000 in 2003 using $\geq$60 dB in the better ear as the definition (Bubbico, Rosano, & Spagnolo, 2007), while we observed a prevalence of 6.7/10,000 in 2003 in 4.5 million children in the same age range (Ministry of Health and Welfare, 2014; Ministry of the Interior, 2011). Moreover, the disability registry in Taiwan categorizes hearing impairment cases concurrent with other disabilities as cases of "multiple disabilities" instead of hearing impairment (Department of Health, 2008), and this could also underestimate the number of cases.

Our study has some unique features in comparison with previous studies. The duration of data collection lasted 12 years, not just one year as in most previous large-scale studies, and this allows our study to assess the changes over the years. Moreover, the number of cases is large, over 3400 cases in 2011 alone, which can provide reliable statistical estimates. In particular, we reported prevalence of different severity level, which is rare in large-scale studies. The major limitation of our study is that we use "administrative prevalence" data, which do not include persons who do not receive services provided by the administration. Moreover, the government does not release the individual data, which make it impossible to explore related issues in greater details.

5. Conclusions

On the basis of the national registry with consistent evaluation methodology for every case, our study presented trends in the prevalence of CHI in Taiwan, and such data are rarely available at the national level. The prevalence had an increasing trend from 2000 to 2006 and then decreased from 2006 to 2011, and we found that the decrease was associated with the initiation of a rubella vaccination program. We believe our observations support a prevention effect of rubella vaccination programs against CHI. In addition, we found that after the implementation of a newborn hearing screening program, the prevalence in the age group <3 years had remarkably increased. These findings can cast some light on the prevention and management of CHI.

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