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THE SOCIETAL COSTS OF SEVERE TO PROFOUND HEARING LOSS IN THE UNITED STATES

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Abstract

Objective: Severe to profound hearing impairment affects one-half to three-quarters of a million Americans. To function in a hearing society, hearing-impaired persons require specialized educational, social services, and other resources. The primary purpose of this study is to provide a comprehensive, national, and recent estimate of the economic burden of hearing impairment.
Methods: We constructed a cohort-survival model to estimate the lifetime costs of hearing impairment. Data for the model were derived principally from the analyses of secondary data sources, including the National Health Interview Survey Hearing Loss and Disability Supplements (1990–91 and 1994–95), the Department of Education's National Longitudinal Transition Study (1987), and Gallaudet University's Annual Survey of Deaf and Hard of Hearing Youth (1997–98). These analyses were supplemented by a review of the literature and consultation with a four-member expert panel. Monte Carlo analysis was used for sensitivity testing.
Results: Severe to profound hearing loss is expected to cost society $297,000 over the lifetime of an individual. Most of these losses (67%) are due to reduced work productivity, although the use of special education resources among children contributes an additional 21%. Lifetime costs for those with prelingual onset exceed $1 million.
Conclusions: Results indicate that an additional $4.6 billion will be spent over the lifetime of persons who acquired their impairment in 1998. The particularly high costs associated with prelingual onset of severe to profound hearing impairment suggest interventions aimed at children, such as early identification and/or aggressive medical intervention, may have a substantial payback.

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Severe to profound hearing impairment affects one-half to three-quarters of a million Americans. To function in a hearing society, hearing-impaired persons require specialized educational, social services, and other resources (8). Although several studies have examined the cost-effectiveness of screening and medical intervention programs to reduce hearing impairment (27;38;51;61), there are no recent estimates of the societal costs of hearing loss in the United States. Specifically, detailed estimates of the societal resources required for rehabilitation and education are lacking (47). The primary purpose of this study is to provide a recent comprehensive national estimate of the economic burden of hearing impairment, pooling what is known about the condition's impact on earnings and use of educational and medical resources. A secondary objective is to establish a baseline cost for interventions aimed at reducing the level of hearing impairment.

Severe to profound hearing impairment significantly impacts the individual's world. As stated by Stone, "Hearing impairment strikes at the very essence of being human, because it hinders communication with others" (54). With communication impaired, a person can become socially isolated, depressed, or apathetic. Loss of hearing may increase the risk for traumatic injury because oncoming cars, fire alarms, or other potential hazards are inaudible, although assistive technologies increasingly address such concerns. Larger effects are manifested through language and vary depending on whether hearing loss occurred before language development (prelingual) or after (postlingual). Prelingual deafness delays speech and language acquisition and can retard a child's social and emotional development, influencing educational and career attainment (46). The prelingually deafened seldom easily develop understandable speech, and are often socially stigmatized by those in the hearing world (19). Thus, those with congenital deafness are integrated into separate "deaf community" life. While educational or career attainment may not be as affected for the postlingually deafened as for the prelingually deafened, these persons usually participate within the hearing community as "disabled" members, and may experience greater depression, anxiety, or social isolation than the prelingually deaf (36). Because they perceive what they have lost, late-onset deafness may be more psychologically damaging than prelingual deafness (52).

PREVIOUS STUDIES

There is a paucity of information on the aggregate costs of hearing impairment. The most recent analysis on the economic costs of deafness was conducted nearly 30 years ago and focused exclusively on the effects of hearing loss on expected lifetime earnings for the prelingually deaf (59). The author found delayed entry into the workforce and underemployment resulted in lifetime earnings that were $275,000 (1970 dollars) below that for hearing persons.

Past research has found that hearing impairment negatively affects educational attainment, the likelihood of employment and earnings, use of healthcare services, and life expectancy (1;3;4;15;18;22;25;29;30;35;39;58;63). Also, according to unpublished estimates from the 1987–91 National Longitudinal Transition Study of Special Education Students and the Gallaudet Research Institute's 1997–98 *Annual Survey of Deaf and Hard-of-Hearing Children and Youth*, an estimated 84% to 90 % of deaf children are taught outside of traditional mainstream classes. The additional annual costs of educating a deaf child in a more intensive instructional setting alone have been estimated at $18,800 for the state of Texas and $20,600 for the state of California (57;60). Notably, in studies comparing educational costs for specific disabilities, deafness is among the most costly, ranking just below the costs for educating the multiply disabled (31;44;60).

Several other issues may effect quality of life without imposing monetary costs. In an examination of the college students' perspective on the various educational settings for the deaf, students identified travel time to day and residential schools, time away from family, social isolation from hearing peers, and loss of familiarity with hearing persons while at deaf schools as concerns (15). Deafness also contributes to an increased risk for depression, anxiety, and physical dysfunction, particularly among the elderly (7;11;18;22;33).

STUDY METHODS

We conducted an incidence-based cost study, in which the lifetime costs of severe to profound hearing loss were measured. Incidence-based approaches estimate the number of newly diagnosed cases and forecast medical and other expenditures over their remaining life. This can be compared with a prevalence-based approach, which examines the prevalence of a condition and associated costs within a given year. While useful for comparing aggregate costs by disease category, prevalence-based estimates do not allow a researcher to estimate the benefits of medical or social interventions that could reduce the impact of hearing impairment (e.g., cost-effectiveness analyses) (50). Because one objective of this study was to establish baseline cost precisely for this reason, an incidence-based cost study is most appropriate.

The underlying conceptual framework we use is a cohort-survival model with a Markov process. The severely to profoundly hearing-impaired population was divided into five age cohorts, each representing life stages associated with the use of different types of economic resources. These five cohorts were prelingual (0–2), prevocational (3–17), early working age (18–44), later working age (45–64), and retirement age (65 and older). The model attaches resource utilization and costs to an age cohort in a given year. The population is then aged over their lifetime using standard survival curves (45).

Data Sources

Estimates for the model were derived principally from analyses of secondary data sources. We also reviewed the literature on hearing impairment and relied upon a panel of technical experts to provide estimates where secondary data were missing. Our technical panel consisted of an otolaryngologist, an audiologist, a speech pathologist, and a deafness educator.

The National Health Interview Survey (NHIS), a nationally representative household survey that is fielded on an annual basis, was our principal data source. In 1990 and 1991, the NHIS included a Hearing Loss Supplement that examined the extent of hearing loss in the United States. These data allowed us to estimate the incidence of severe to profound hearing impairment and compare the characteristics, such as gender, age, race, income, age at onset of hearing impairment, causes and levels of hearing impairment, employment, and treatment-seeking patterns of the severely to profoundly hearing-impaired population compared to the non-deaf population. In addition to the Hearing Loss Supplement, we analyzed the 1994–95 Disability Supplement to the NHIS. This supplement provides extensive data on use of vocational rehabilitation services and assistive devices for persons with disabilities.

Data on school placement by type of setting (e.g., residential, self-contained classroom, resource room, or regular education) were obtained from three different sources. The most comprehensive recent source is a published report from the Department of Education Office of Special Education and Rehabilitation Services (OSERS) (12). OSERS data encompass all disabled children receiving special education assistance in the United States through local school districts, including more than 63,000 hearing-impaired and more than 1,000 deaf/blind children.

Data from Gallaudet University's 1997–98 *Annual Survey of Deaf and Hard-of-Hearing Children and Youth* provide alternative estimates on school placement, use of special educational resources, and assistive devices. Gallaudet's survey targets any public or private school in the United States serving at least one deaf child known to the Gallaudet Research Institute (24). In the latest year, the survey contained information for more than 48,000 children, including 20,637 with severe to profound hearing loss. Gallaudet researchers estimate this represents about 60% of hard-of-hearing youth receiving special education services in the United States. Data may overrepresent children in state schools for the deaf, since these organizations are likely to be known to Gallaudet. However, the extent of this bias has not been analyzed.

Although dated, the National Longitudinal Transition Study (NLTS) is a particularly rich, nationally representative data set, providing information on intensity of special education services (e.g., number of speech and hearing therapy hours per week) and also on placement by setting. This survey enrolled 8,000 youth age 13 or older in the 1985–87 school year, including approximately 500 deaf children.

Costs of education were also derived from a variety of sources. The most recent nationally representative survey of the costs of special education was conducted more than a decade ago (44). Using a resource costing approach, the costs of educating deaf children relative to those for regular schoolchildren are provided for the 1985–86 school year. Chambers et al. (10) updated estimates to the 1995–96 school year, using data from the National Digest of Education Statistics and assuming stability in relative costs of special to regular education, an assumption that has some validity given earlier trends (11). We update the Chambers and Parrish data to 1998, and assume that stability in the relative cost of educating children in residential settings versus regular classrooms, for example, remains the same as reported by Moore et al. (44).

Because Moore et al. (44) did not estimate day school costs, we obtained estimates for this setting from an ongoing national survey of residential school programs serving children with sensory impairment. This longitudinal survey, conducted by the Alabama Institute for the Deaf and Blind–Office of Institutional Research, is in its third year of data collection. According to R. J. Beadles, a research analyst at the institute, data have been obtained from 22 facilities for the deaf and hard of hearing in the United States to date, representing a 50% response rate (personal communication, August 1999). Capital expenses, transportation costs, and benefits to employees were excluded, and thus the actual resource costs of day settings for deaf children are likely to be underestimated.

Earnings data were obtained from the March 1998 *Current Population Survey* funded jointly by the Bureau of Labor Statistics and the Department of Census. Earnings data include income earned from wages, salaries, or self-employment. Data were weighted by age, sex, and gender to represent the deaf population.

Finally, the Rehabilitative Services Administration of the Department of Education provided data on the cost of vocational rehabilitation in the United States for approximately 6,300 deaf persons. Data submitted by states to the federal government show average expenditures for deaf persons by age of onset (prelingual, prevocational, and postvocational) and the average number of months individuals received assistance. Costs were provided for "successfully rehabilitated" cases (i.e., those who obtained employment), which may differ from those that include persons who were not successfully rehabilitated.

Defining Severe to Profound Hearing Impairment

Hearing impairment has been variously assessed in secondary data sources, ranging from the outcomes of audiometric tests (Gallaudet University) to self-reported hearing loss

(1990–91 NHIS). Most other databases use the term *deaf* to describe this level of hearing impairment. Using audiometric results, severe to profound hearing loss is commonly considered the inability to detect a sound at 70 decibels hearing level or greater (averaged across the frequencies of 500, 1,000 and 2,000 Hertz) in the better ear. Because audiometric results were not available on the NHIS, persons with severe to profound hearing loss were identified using responses to several questions on self-reported hearing loss. Research has shown the accuracy of self-reported hearing loss lies within a few percentage points of actual audiometric results (48). More detail on the methods we used to identify people with severe to profound hearing impairment using data from NHIS can be found in Blanchfield et al. (8).

Components of Cost

We include both direct medical and nonmedical costs and indirect productivity losses associated with hearing loss. Direct medical costs for the hearing-impaired include the costs of diagnosis, periodic medical visits to assess the physical status of the ear, audiological evaluation of hearing and fitting of hearing aids, and costs associated with other assistive devices. Also included are visits to a medical doctor for concomitant middle ear problems. Direct nonmedical costs include those associated with special education and rehabilitation (including services of speech and language pathologists, educational audiologists, and vocational rehabilitationists). Finally, we include reduced lifetime earnings due to the effects of severe to profound hearing loss on productivity.

To estimate costs for lost productivity due to premature mortality and disability, we used a human capital approach (5). This approach values foregone productivity at mean market earnings for a specific age and gender group. Transfer payments such as Social Security Insurance and Disabled Workers Insurance are excluded. These transfer payments, which, according to the Social Security Administration, amounted to $600 million for deaf persons in 1998, are intended to offset losses in income or increased medical or educational costs associated with the disability. Including them would result in double-counting economic losses (20).

Some researchers have criticized the human capital approach for not considering economic adjustment when a laborer is taken out of the workforce (34). They propose a frictional adjustment method, which assumes productivity losses to the economy are only temporary in the face of high levels of unemployment within the general economy. Given low unemployment rates in the United States, we have not used frictional adjustment. Future productivity changes also are not included in lifetime forecasts of earnings (26).

All costs are inflated to 1998 dollars using the Urban Consumer Price Index (CPI-U). Future costs are discounted at a rate of 3%, which is approximately the inflation-adjusted return on long-term treasury bonds.

Baseline estimates do not take into consideration technological change that is likely to occur in the future or that has occurred since the collection of our data. Considering the pace of technological change, this is a strong assumption that could bias the results (23). In the Discussion section, we speculate about how the future may be reflected in these estimates.

Key Assumptions

Incidence and Differential Mortality. Because cases of deafness are not entered in a registry, accurate estimates of incidence rates are not available. Age-specific incidence can only be estimated retrospectively from age of onset of prevalent cases reported in the NHIS. Our estimated incidence rates are presented in Table 1. The validity of this approach depends on the assumption that average age-specific incidence rates were constant over the time period being used to calculate the rates (see reference 43 for more detail).

Table 1. Incident Cases of Severe to Profound Hearing Loss in the United States Population, 1991

Age cohort	Synthetic incidence (rate per 10,000 population)	No. of incident cases	Distribution of incident cases by age cohort
0–2	1.4	1,638	11%
3–17	.03	167	1%
18–44	.2	2,524	16%
45–64	1.1	5,216	34%
65+	1.9	5,897	38%
Total	.6	15,442	100%

Source: Project HOPE calculations from the 1990/91 *National Health Interview Survey* and U.S. Census, 1991.

Earnings Differentials. To examine the effect of severe to profound hearing impairment on earnings potential, we estimated a two-part model using pooled data on the working age population from the 1990–91 NHIS. Separate equations were specified for people aged 18–44, 45–64, and 65 and older. Results from these analyses are presented in Table 2.

School Placement by Setting. The available data on school placement by setting for hearing-impaired children are compared in Table 3. Each of these sources has limitations. For example, the Gallaudet data are most recent and specifically pertain to children with severe to profound hearing impairment. However, the survey is structured to allow respondents to check multiple settings, when relevant, making it difficult to assess the "primary" setting. The degree of hearing impairment cannot be ascertained from OSERS data, although they do report data for children who are both deaf and blind. The NLTS data are more than 10 years old.

We adjusted the Gallaudet data by assuming the primary setting was the most intensive setting reported (shown in parentheses). Adjusted data are nearly the same as those reported by OSERS, with the exception that Gallaudet reports a relatively higher proportion of children in residential facilities. Panelists felt this reflected the bias of the Gallaudet Survey, while the OSERS data provided a more reasonable estimate of school setting for children

Table 2. Labor Force Participation Rates and Mean Monthly Earnings for Persons with Severe to Profound Hearing Loss Versus the Non-Hearing Impaired in the United States, 1990–91

	Labor force participation rate		Mean monthly earnings from job		
Age cohort	Severely to profoundly hearing impaired (N)	Nondeaf (N)	Severely to profoundly hearing impaired (N)	Nondeaf (N)	Hearing impaired earnings as a proportion of nondeaf earnings
18–44	59% (149)	77% (97,737)	$1,301 (90)	$1,930 (75,244)	67%
45–64	49% (273)	68% (45,299)	$2,044 (137)	$2,357 (30,727)	87%
65 and older	7% (851)	13% (28,443)	$969 (59)	$1,249 (3,720)	77%

Source: Project HOPE calculations from the 1990/91 *National Health Interview Survey* and U.S. Census, 1991. Parentheses show the sample size included in the analysis.

Table 3. Comparison of Various Sources of Data on School Placement by Setting for School-age Children with Severe to Profound Hearing Loss

School setting	Gallaudet Annual Survey, 1997–98 (Project HOPE adjusted)	Office of Special Education and Rehabilitative Services, 1994–95 (deaf/blind)	National Longitudinal Transition Study, 1987
Special school	45% (45%)	42%	53%
Residential	32% (32%)	21%	NA
Day school	13% (13%)	22%	NA
Self-contained classroom	37% (37%)	37%	25%
Resource room	7% (7%)	9%	5%
Regular	31% (10%)	10%	16%
Other	4% (1%)	2%	1%

The Gallaudet Annual Survey includes children with severe to profound hearing impairment age 3–17. The format allows respondents to check multiple settings. Project HOPE adjustments force the data to equal 100% by assuming primary setting is that associated with more intensive use of resources. OSEP and NLTS data are for primary setting. OSERS data include children age 6–21. NLTS data include deaf children age 13–17. NA = data not available.

with severe to profound hearing impairment. Hence, we selected data from OSERS for the model.

Cost of Educational Resources and Assistive Devices. Table 4 presents assumptions used in the model for the costs of educational setting. Costs range from $6,100 per year for a resource room to $53,200 for placement in a residential facility. Our model includes only the incremental cost of more instructional settings over regular classroom settings. In addition to costs of instructional settings, special educational resources, such as the use of sign language interpreters, speech/language therapy, vocational rehabilitation, and assistive devices, are included. Costs of these services and devices are presented in Table 5.

Detailed assumptions about the proportion of hearing-impaired persons using special education resources and assistive listening devices can be found in Mohr et al. (43). Briefly, the NLTS estimated 80% of children age 13–17 years who are not in residential facilities receive auditory training or speech/language therapy requiring an average of 174 hours per year. Approximately 60% of children in this same age group used the resources of a tutor, reader, or sign language interpreter. For children making use of these services, they received, on average, 860 service hours per year, or 22 hours per week. Panelists felt these patterns of use were mirrored in younger school-age children; thus, we used these estimates for all children ages 3–17. Data were not available on the use of speech language/therapy, sign language, or interpreters for the adult population, apart from their use within publicly funded vocational rehabilitation programs. Therefore, any privately funded use of these services by adults were excluded from the model.

Hearing aid use, reported by the NHIS Hearing Loss Supplement, varies among the age groups, with a high proportion of children with severe to profound hearing impairment ages 3 to 17 as well as of the elderly who use hearing aids (75%–78%). Data on hearing aid use were not available for children younger than 3 years. Panelists felt nearly all infants identified with binaural severe to profound hearing loss receive early intervention services and hearing aids (95%). This proportion was adjusted to 55% to reflect delays in diagnosis of hearing difficulties and in service intervention.

Diagnosis, Audiology, and Other Medical Services. Estimates for the use of medical resources were drawn principally from the technical panel and interviews with

Table 4. Cost of Educational Resources, Vocational Rehabilitation, and Assistive Listening Devices

Component	Best estimate	Standard deviation or range	Source/notes
Cost of residential school (per year)	$53,200	$37,000–$90,000	Relative ratio from Moore et al., (44); range from state reports, Alabama Institute for the Deaf and Blind
Cost of day school (per year)	$28,200	$1,392	Alabama Institute for the Deaf and Blind Residential School Survey (n = 20)
Cost of self-contained classroom (per year)	$14,500	$7,800–$15,200	Relative ratio from Moore et al. (44); range uses data from state reports
Cost of resource room (per year)	$6,100	$5,200-$6,700	Relative ratio from Moore et al. (44) for hearing impaired Range uses data from state reports
Regular mainstream education (per year)	$5,030	N/A	Chambers et al. (10); median and average value
Cost of vocational rehabilitation (per year)—youth	$2,187	$1,588–$2787	Moore et al. (44)
Cost of vocational rehabilitation (per year)—age 18–44	$2,033	$1901–$2,170	Rehabilitative Services Administration of the Office of Special Education and Rehabilitative Services in the Department of Education
Cost of vocational rehabilitation (per year)—age 45–64	$1,515	$1,224–$1,800	Rehabilitative Services Administration of the Office of Special Education and Rehabilitative Services in the Department of Education
Cost of audiologist follow-up exams	$100	$60–$120	Sounds of Texas, Hearing Health Institute
Comprehensive audiometric exam (MD)	$235	$99–$370	Medicare Resource Based-Relative Value Scale (CPT 92557 and 92506)
Cost of diagnosis	$880	$700–$1,100	Average of Medicare Resource Based-Relative Value Scale and charges at St. Louis Children's Hospital; includes auditory brainstem evoked response test, otoacoustic emissions test (CPT 92588), comprehensive audiometric exam (CPT 92557), evaluation of speech/language (CPT 92506)
Cost of periodic hearing aid evaluation	$216	$200–232	Manufacturers and St. Louis Children's Hospital
Cost of TTD/TTY (per device)	$285	$230–340	Manufacturers/life 10 years
Cost of telephone amplifier (per device)	$25	$15–$150	Manufacturers/price varies from portable amplifiers to telephones with built-in amplifiers; assumed mid-range portable; life 10 years
Cost of FM system (per device)	$700	N/A	Crandell/divided across a 25-person classroom over 10 years
Cost of hearing aids (binaural)	$4,000	$1,700–$6,000	Manufacturers/price for two high-range digitally programmable aid; 4-year life span; $50 per year for batteries
Cost of hearing dog	$10,000	$4,000–$15,000	Life 10 years

Table 5. Lifetime Costs of Severe to Profound Hearing Loss by Component

	Age of onset									
Component	Prelingual (0–2)		Prevocational (3–17)		Early working age (18–44)		Older working age (45–64)		Elderly (65+)	
Lost productivity	$433,400	42%	$444,300	48%	$382,900	85%	$220,300	87%	$24,600	57%
Special education	$504,900	50%	$401,000	44%	$20,200	4%	$0	0%	$0	0%
Vocational rehabilitation	$11,500	1%	$12,600	1%	$6,700	1%	$1,800	1%	$0	0%
Assistive devices, medical costs, and others	$70,200	7%	$61,100	7%	$43,200	10%	$30,900	12%	$18,400	43%
Total	$1,020,000	100%	$919,000	100%	$453,000	100%	$253,000	100%	$43,000	100%
95% confidence interval	$464,000–$1,733,000		$401,000–$1,623,000		$120,000–$965,000		$35,000–$698,000		$900–$131,000	

pediatric audiologists, although an analysis of the National Ambulatory Medical Care Survey, a survey of office visits to medical practitioners in the United States, was used to test some of our assumptions for reasonableness. We assume hearing-impaired children routinely visit audiologists, with infants and toddlers visiting an audiologist on average five times per year, and children over 12 going every other year. Hearing-related visits to a medical practitioner were assumed to occur twice a year for children under 3 years and every other year for older persons. Costs of these medical visits and tests are presented in Table 4. More detailed assumptions about use of medical services can be found in Mohr et al. (43).

Because the literature suggests there may be an association between deafness, other health conditions, and premature mortality, we sought to use an "attributed risk" methodology, where costs associated with the excess prevalence of comorbidity among hearing-impaired persons are apportioned to lifetime costs. Using data from the 1990–91 NHIS and controlling for differences in age and race, we found no statistically significant differences in physician visits, depression/anxiety, traumatic injury, or mortality. (Mortality was examined by linking the NHIS to the National Death Index.) As a result, out model does not include costs for related illnesses or premature mortality.

RESULTS

Averaged across age at onset, severe to profound hearing loss is expected to cost society an additional $297,000 over the lifetime of an individual. The magnitude of loss is directly related to age of onset, with persons experiencing severe to profound hearing loss in childhood incurring the largest expected costs (Figure 2). The expected lifetime cost of hearing loss for a child with prelingual onset of hearing loss, for example, exceeds $1 million. By contrast, societal losses for persons who acquire their hearing loss late in life are expected to average $43,000.

By far, the largest component of societal loss (67%) is due to reduced work productivity (Figure 2). Persons who experience severe to profound hearing loss before retirement are expected to earn only 50% to 70% of their non–hearing-impaired peers and lose between $220,000 and $440,000 in earnings over their working life, depending on when their hearing loss occurs. The use of special education resources among children contributes an additional 21% to the total cost of severe to profound hearing loss. About 60% of these costs are for educating children in more intensive instructional settings, such as self-contained classrooms, with the remainder for supplemental services provided to students not in residential or day schools, such as speech/language therapy or sign language interpreters. Unlike many clinical conditions, severe to profound hearing loss largely impacts the social welfare system rather than the medical care system. Medical costs and costs for assistive devices are a relatively small proportion of the total (11%), more than half of which are for expenses related to hearing aid use.

As expected, the contribution of each of these components of costs to total economic losses varies by onset of severe to profound hearing impairment as well. Special educational costs amount to over a half million dollars for the prelingually impaired over the course of their education or half of the anticipated societal losses for this age group (Table 5). In contrast, lost productivity constitutes 85% or more of expected societal costs for persons who acquire their hearing loss during their working years. Among the elderly who become severely to profoundly hearing impaired, economic losses are about evenly divided between loss of income for those still in the labor force and medical costs, such as expenditures for hearing aids and periodic hearing evaluations. This does not include costs related to assisted living expenses for elderly hearing-impaired people.

Sensitivity Analysis

The sensitivity of our results to underlying assumptions was tested using univariate techniques and multivariate simulations (Monte Carlo). In the Monte Carlo simulations, ranges for estimates derived from surveys used the 95% confidence interval for the estimate, assuming a normal or binomial distribution, depending on whether the estimate was a mean or proportion. Normal distributions are reasonable (via central limit theorem) and have been used in the literature (41). Estimates derived from the literature or the technical panel also assumed a normal distribution, with the standard error forced to symmetry based on available ranges of estimates, and evidence for similar estimates reported in the literature. The model was evaluated for 10,000 trials. Given the extreme range in costs depending on the incident cohort, as noted above, we assumed stable incidence assumptions during the Monte Carlo simulation to examine the effect of other parameters on aggregate costs. We then examined the sensitivity of the model to assumptions about incidence separately. This approach is also useful, since interventions to improve functioning vary depending on when a person becomes hearing impaired.

Ranges of lifetime costs (within the 95% confidence interval) for each age cohort are presented in Table 5. Overall, we see there is a high degree of uncertainty in our estimates. For example, lifetime costs for the prelingually impaired range from just below $500,000 to $1.7 million. Assuming stable incidence rates, lifetime costs for a person newly diagnosed with severe to profound hearing impairment range from $85,000 to $645,000.

Results are most sensitive to assumptions about the distribution of incident cases. Just a 10% shift of incident cases to earlier or later age groups leads to a range in societal costs of $271,000–$322,000. Apart from incidence assumptions, assumptions about the reductions in earnings among persons in their prime working age (18–44) have the greatest effect on uncertainty. This uncertainty largely stems from small sample sizes and our inability to detect statistically significant differences in earnings between the severely to profoundly hearing impaired, although we believe such differences are likely to be found in a larger study. There also was a high relative error in the costs of residential instructional settings, again due to the small number of facilities included in the early survey of special educational costs (n = 35).

Study Limitations

These findings should be considered in light of several important study limitations. First, assumptions about the incidence of severe to profound hearing loss and the distribution of incident cases by age of onset are critical to the results of this model. While the methodology we used to estimate incidence is reasonably robust, severe to profound hearing impairment is a relatively rare condition. As a result, our incidence estimates are relatively imprecise.

Also, our incidence estimates are based on the assumption that incidence rates have not changed a great deal over the past several decades. For example, our methodology assumes the incidence rate for children in the 3–17 age group is the same currently as it had been during the 1959–90 interval. Improvements in immunization and antibiotic therapy since 1959 could well have resulted in a decline in the incidence of severe to profound hearing impairment resulting from childhood communicable diseases, but the increased proportion of immigrant children in that population may have had a countervailing effect.

Second, our model does not reflect differences in the use of resources depending on whether one is prelingually versus postlingually hearing-impaired, although we believe differences exist. At the outset of this study, we intended to model these differences; however, small sample sizes limited our ability to carry these differences throughout the model. We did find the use of hearing aids was lower among those with prelingual versus postlingual hearing impairment. However, small sample sizes also limited our ability to find significant differences in healthcare use, depression/anxiety, or mortality, which have been found in more limited but targeted studies, especially among persons with late-onset hearing impairment. Thus, the direction of bias of this omission is not clear.

Another limitation is the use of the human capital approach to value social losses. A human capital approach places a heavy emphasis on earnings potential and does not value intangible losses, such as the social isolation and psychological stress imposed by the condition. Among the elderly, who represent nearly 40% of new cases, costs will be especially undervalued by a human capital approach. Although hearing impairment significantly reduces their independence and quality of life, its implications on earnings or medical costs are relatively minor.

Finally, although we examine costs from the societal perspective, we have not included some of the considerable public investment that has occurred in assistive technology for the hearing impaired, such as the use of a relay system for emergency services and public telephones. We also have not included employers' investment in devices, such as text telephones, FM systems, note takers, interpreter services, or closed captioning.

POLICY IMPLICATIONS

Severe to profound hearing loss in the United States imposes a substantial social cost. Although the incidence of severe to profound hearing loss is relatively low when compared with other conditions, per-case losses are large, amounting to more than a million dollars for a prelingually hearing-impaired child. In the aggregate, societal losses will amount to $4.6 billion over the lifetime of the estimated 15,400 persons who acquired their impairment in 1998.

Although comparisons to expenditures for other conditions must take into account substantial methodologic and conceptual variations in approaches, the magnitude of difference between the lifetime costs of deafness and other conditions is so large it warrants discussion. Relatively few studies use an incidence-based approach. Most use a prevalence-based approach, which is not comparable. For incidence-based studies we found, we report results only for those that include both direct costs and indirect productivity losses. We have updated all estimates by the consumer price index to 1998 costs. Expected lifetime expenditures of $297,000 for a severely to profoundly hearing-impaired individual are nearly three times as high as the lifetime costs of injury due to near-drowning ($98,500) or accidents with firearms ($89,100) (42). Lifetime costs are about twice those reported for stroke ($129,200), 25-year costs for young women with rheumatoid arthritis ($130,500), and epilepsy among noninstitutionalized persons with frequent seizures ($172,900) (6;17;56). Estimates for the devastating illness of schizophrenia are comparable at $295,000 (2). A study that defined indirect productivity losses as those that occur for all family members (not just the individual with the disease) for multiple sclerosis estimated lifetime losses to be $593,000 (28).

The particularly high costs associated with prelingual onset of severe to profound hearing impairment suggest interventions aimed at children, such as early identification and/or aggressive medical intervention, may have a substantial payback. Early identification of hearing loss in children can significantly improve language development and possibly other developmental outcomes (62). While the cost per infant identified with significant hearing loss varies with prevalence estimates, these costs pale in comparison to expected lifetime expenditures for severely to profoundly hearing-impaired children. A cost per infant hearing screening of $25 and a prevalence rate of 3.2/1,000, which has been found in the Colorado screening program, would cost $7,800 per identified case (13). If early identification can shift just an additional 10% of prelingually deaf children into mainstream classrooms, the return on investment would more than double. This quick analysis using our model does not assume any effects on future earnings. Because of the perceived benefits, the American Academy of Pediatrics has endorsed the aggressive promotion of universal hearing screening programs (14). According to K. Albright at the Early Hearing Detection and Intervention Programs: Design and Implementation workshop in St. Louis, MO, on September 30, 1999, 23 states had enacted legislation for such programs to date (personal communication). Although encouraging, more can be done in this arena.

Cochlear implantation also offers a medical approach to reducing the level of hearing impairment and improving function. Several studies have shown cochlear implantation can make a significant and positive impact on quality of life (40;49;55;61). Also, cochlear implantation has been found to improve earnings among adults (21). In another study, profoundly deaf children who had more than 2 years of experience with a cochlear implant were able to move out of special education into a mainstream setting at twice the rate of their age-matched peers without a cochlear implant (21).

The costs of cochlear implantation and associated rehabilitative services reported in the literature range from $29,000 to $63,000 (16;27;37;38;53). Studies conducted to date have consistently found cochlear implantation to be cost-effective among appropriately selected candidates. Regrettably, the benefits of this medical intervention are not realized by health insurance plans, and thus payment often has not adequately covered the costs of surgery and rehabilitation, resulting in a strong disincentive for hospitals to provide cochlear implantation (32).

In the future, as children are identified earlier and receive more aggressive intervention, the lifetime costs of severe to profound hearing impairment may decline. The increasing use of cochlear implantation will likely shift some costs from the educational and welfare systems to the realm of medicine, but may also improve vocational prospects. The dearth of recent data, particularly in the delivery of special education services, may influence the currency of our findings. M. J. Mosley, professor of speech language pathology at Gallaudet University noted that budgetary cutbacks within the public school system may have already reduced the hours of supplemental services provided to hard-of-hearing youth from our estimates (personal communication, August 1999). However, such reductions in educational services are unlikely to produce sustained savings to society and are likely to appear in later years as hearing-impaired adults who are poorly equipped try to compete in the hearing world in which most jobs require fluent communication abilities. To reduce long-term societal costs, we must avoid short-term solutions and ultimately focus our attention on promoting and implementing effective strategies to reduce the level of hearing impairment

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