

**A Cost-Effectiveness Analysis of Timely Otitis Media Treatment through a
Community Health Worker Delivered School Screening Program**

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Abstract

Background: In certain settings, otitis-media related hearing loss forms a large proportion of total hearing loss cases. Delays to timely otitis media diagnosis and appropriate treatment leads to more serious otitis media cases, sometimes chronic suppurative otitis media, which may lead to a permanent hearing loss. A primary driver in the delay to diagnosis and treatment is a lack of easily accessed, trained healthcare workers in the identification and treatment of otitis media. We used an exemplar setting, Zambia, to understand the costs and potential effects of community health worker-delivered screening program for school-age children. The goal of this analysis was to highlight otitis media as a driver of hearing loss and understand the cost-effectiveness of timely diagnosis/treatment to prevent downstream hearing loss.

Design: The treatment pathway for otitis media treatment was identified using a cascade of care framework, as well as the effects of increased otitis media treatment access through stakeholder engagement metrics. The treatment for otitis media in this analysis was conservative treatment, aural toileting and topical antibiotics. Additionally, the costs of otitis media and chronic suppurative otitis media and the proportion of both metrics treated in Nigeria were found. Training costs of a program were included in the treatment pathway to adequately model the scale-up strategy. Simulated persons experience yearly age- and sex- specific probabilities of acquiring hearing loss, the prevalence of which is 3.6% in Nigeria.

Participants: Six-year-old children in Nigeria suffering from otitis media across their lifetime.

Intervention: Strategies for comparison to increase appropriate treatment of otitis media including current care and the implementation of a community health worker-delivered screening program.

Main measures: Lifetime undiscounted and discounted (3%/year) costs and QALYs and incremental cost-effectiveness ratios (ICERs) by Nigerian standard (<3x \$2,097.09 was considered cost-effective).

Key Results: CD resulted in 19.22 discounted average person-years of otitis media treatment compared to 19.23 discounted average person-years with implementation of a CHW delivered screening program. Lifetime total per-person undiscounted costs were \$64.26 USD for CD and \$62.26 USD with the screening program intervention, indicating that the screen is both less costly and more effective than not screening. Results were most sensitive to variations in cost of screen, cost of CSOM, rAOM, pOME resolution from screening, and CI device cost.

Limitation: Input uncertainty given limited data sources for similar settings. Additionally, we had to use a utility decrement for moderate hearing loss since there is not one in the model that we identified specifically for CSOM.

Conclusions: We project that a community health worker delivered screening program is cost-effective by US standards. Further research is needed to determine whether screening at younger ages or different treatments for otitis media is cost-effective.

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INTRODUCTION

Low-and-middle-income countries (LMICs) bear the brunt of the global burden of hearing loss, with approximately eighty percent of hearing loss within LMICs, and most of which remains untreated.¹ The implications of this hearing loss burden are severe; they have profound effects at the individual level in terms of hindering human potential and permeating all aspects of daily life, but also result in a significant economic burden of nearly \$1 trillion USD per year.^{2,3} A leading preventable cause of hearing loss in LMICs is otitis media.⁴ Otitis media is a condition in which bacteria enter the inner ear through a perforation in the eardrum, causing an infection and a buildup of fluid behind the eardrum that may cause hearing loss. Currently, in LMICs there are often delays to timely otitis media diagnosis and appropriate treatment, which leads to more severe cases.⁴ Longstanding, untreated otitis media may lead to chronic suppurative otitis media and a permanent hearing loss.⁵ A primary driver in the delay to diagnosis and treatment is a lack of easily accessed, trained healthcare workers in the identification and treatment of otitis media.⁵

In this analysis, we sought to estimate the cost-effectiveness of timely diagnosis and treatment of otitis media in Nigeria to prevent downstream hearing loss. The implementation of a one-time community health worker (CHW) delivered screen for school-age children is one strategy to reduce the incidence of hearing loss in LMIC by increasing identification and early treatment. The cost-effectiveness of such a strategy, however, is unknown and will be an important component in the decision of healthcare policy makers to prioritize scarce resources and determine funding priorities across health conditions.

Background on the Clinical and Economic Burden of Hearing Loss

In 2015, there were approximately 1.34 billion people who had mild-to-complete hearing loss in the better-hearing ear, representing 18.1% of the world's population.⁶ Disabling hearing loss affects 500 million people, or 6.8% of the world's population.⁶ More than 5% of the world's population has moderate-to-complete hearing loss that interferes with communication.⁷ Hearing loss is the third leading cause of years lived with disability (YLDs) across all age groups, but among ages 70 and over is becoming the leading cause of YLDs.⁷ Hearing loss, according to the World Health Organization (WHO) is classified into six groups by severity; mild hearing loss is 20-34 decibels (dB) hearing loss (HL), moderate is 35-49 dB HL, moderately severe is 50-64 dB HL, severe is 65-79 dB, profound is 80-94 dB HL, and 95+ is considered complete hearing loss in the better ear.⁸ Hearing loss is considered disabling when it reaches 35 dB HL for children or 40 dB HL for adults in the better ear.⁹ Hearing loss can be caused by ear disease that affects the middle ear (conductive hearing loss), that affects the inner ear or cochlear nerve (sensorineural hearing loss), or that affects both, which is known as mixed hearing loss.⁹

Hearing loss in early childhood and infancy can hinder the appropriate development of speech and language, which negatively impacts academic achievement.¹⁰ Children who suffer from hearing loss also must spend more time in physician offices and potential days in the hospital, all of which take time away from being in school or doing schoolwork.¹¹ Beyond the impact of not effectively hearing their surroundings, there is intense stigma around hearing loss, Adults with hearing loss may be thought of by others as cognitively impaired, less able than their counterparts without hearing loss, and seem socially incompetent.¹² Additionally, in LMICs, those who suffer from hearing loss are at a higher risk for developing chronic illnesses and infections in addition to behavioral problems.¹²

Unaddressed hearing loss has significant impacts for global economic wellbeing. In both HICs and LMICs, the unemployment rate for individuals with hearing loss is higher than the rate for those without hearing loss.¹³ A report by the WHO estimates that the annual cost of unaddressed hearing loss is estimated at \$740 billion annually.¹⁴ Within this total annual cost, the costs to the healthcare system that are included in this annual cost of unaddressed hearing loss range from \$67 to \$107 billion.¹⁴ The annual cost of lost productivity owing to unemployment and premature retirement is \$105 billion; the annual societal costs, which include the results of social isolation, communication difficulties, and stigmatization are \$573 billion.¹⁴ The prevention and treatment of hearing loss during the ages of 45 to 65 can reduce the incidence of hearing loss by as much as 9.1%.¹⁵ The costs of additional educational support to children aged 5-14 years with moderate or greater hearing loss is \$3.9 billion, with two-thirds of the costs to the health and education sectors occurring in LMICs.¹⁴

Background on Otitis Media and Disease Burden of Otitis Media

Otitis media is a general term, and includes acute otitis media (AOM), chronic suppurative otitis media (CSOM), and otitis media with effusion (OME).¹⁶ AOM typically affects children under the age of two years and presents with acute onset symptoms and signs of otalgia (ear pain) and fever.¹⁷ CSOM is defined as a condition of the middle ear cleft, including the Eustachian tube, tympanic cavity, and mastoid hair cells, and is characterized by a persistent perforation of the tympanic membrane with recurrent or persistent mucoid or muco-purulent fluid that drains from the ear for at least eight weeks.¹⁸ CSOM is always active; active CSOM involves constant inflammation and the production of pus, while there is no pus production in inactive OM, which is known as otitis media with effusion.¹⁹ Inactive OM can also mean that

there are undulating periods of infection versus no infection. The causative agent for CSOM is thought to be an aerobic or anaerobic bacteria which gain access to the middle ear through the tympanic membrane perforation.¹⁸ In high-income countries (HIC), CSOM is usually a product of eustachian tube extrusion, leaving the tympanic membrane of the ear perforated.¹⁷ In LMICs, CSOM is a complication of AOM with perforation.¹⁷

Risk factors for otitis media include childhood infections since infants have immature immune systems, limited prior exposure to infections, waning maternal immunoglobulin G protection, and high risk of exposure to common viral and bacterial pathogens through contact with other individuals.²⁰ Other risk factors that are associated with acquiring OM include not being breastfed, having allergic diseases, day-care attendance, pacifier use, passive smoking, craniofacial abnormalities, gastroesophageal reflux, and the presence of adenoids.¹⁴ It is thought that the shorter Eustachian tube in children makes them more vulnerable to ascending ear infections, hence the greater prevalence of CSOM in children, particularly between the ages of zero and ten.²¹ This anatomic difference of the Eustachian tube in children results in a higher predisposition to ear infection than in adults since it allows for easier access of the bacteria to the middle ear through the nasopharynx.¹⁸ The main symptoms of CSOM include ear discharge and hearing loss, in addition to tinnitus, otalgia, and pressure sensation.²²

The hearing loss that accompanies AOM and OME is typically mild, although depending on the degree of hearing loss and the ability of middle-ear fluid to fluctuate, speech sounds can become distorted and speech comprehension can be adversely affected.⁹ These effects can lead to the downstream consequences of delaying speech and language acquisition and negatively affecting higher-level auditory processing such as localization and listening ability in the presence of background noise.⁹ These factors adversely affect learning and education in

childhood.⁹ CSOM, on the other hand, can cause moderate hearing loss due to the buildup of fluid behind the eardrum; when left untreated, this can progress to permanent, disabling hearing loss.²³

Otitis media is primarily seen in LMICs, especially in Africa, Asia, and Latin America, and is essentially non-existent in the developed world.²⁴ In LMICs, 50% of otitis media cases are accompanied by hearing impairment.⁹ CSOM represents a pressing concern to health economists and clinicians because of the financial burden caused and reduced quality of life, especially in children of rural areas or lower socioeconomic groups.²⁵ The widespread prevalence of this condition can be attributed to risk factors such as poverty, overcrowding, illiteracy, poor living conditions, ignorance, poor hygiene, malnutrition, lack of medical facilities, frequent upper respiratory tract infections, and low socioeconomic status.²⁶

Additionally, there is a correlation between patients that suffer from active chronic otitis media, hearing loss, and lower socioeconomic status, with the poorest rural communities having the highest prevalence.²⁷ To manage CSOM, early detection and timely appropriate interventions is imperative to mediate the negative downstream effects of the condition, which can be accomplished by regular aural toileting and the use of antibiotic treatment.²⁵

A lack of training among those who treat otitis media is also a risk factor. In a prospective study conducted in the Ear, Nose, and Throat (ENT) unit of the Obafemi Awolowo University Teaching Hospitals Complex in Nigeria over a two-year period, Lucky Onotai found that roughly half of the patients that constituted new cases of CSOM, 51.7%, were younger than 15 years of age and came from rural areas where they had previously been managed by unlicensed, untrained practitioners.²⁸

A systematic review conducted in 2012 of 114 OM studies suggested that the annual incidence of AOM was 709 million cases of AOM and 31 million cases of CSOM, with most of the studies occurring in LMIC.¹⁴ Regions with the highest burden included Oceania, and Central and West Sub-Saharan Africa which has an incidence rate between 29 and 43 new episodes per 100 people per year. This is significantly higher than high-income regions that include Europe Central and Asia Pacific that have incidence rates lower than 5 per 100 people per year.²⁹ Specifically in Nigeria, according to a cross-sectional study where consecutive children who presented at the University of Nigeria Teaching Hospital (UNTH) Enugu with ear-related problems were enrolled, Gerard O'Donoghue found that AOM occurred in 48.4% of the 122 children that presented with hearing loss and 37.7% with CSOM.³⁰

Otitis Media Treatment

With OME, it is possible that the effusion behind the tympanic membrane can resolve spontaneously, especially when an episode of AOM is followed by one of OME; 63% of OME cases resolve in three months, while 88% of cases resolve by one year.¹⁷ Unlike OME, however, there are a variety of techniques that can be used to repair the eardrum and remove the infection for CSOM.¹⁷ Conservative medical treatment, which includes aural toileting, the use of either ototoxic antibiotics or systemic antibiotics coupled with nasal decongestants, was found to be the most common mode of treatment in children with CSOM that attended the ENT clinic in UPTH, Port Harcourt in Nigeria²⁸. Aural toileting is a way of manually extracting the infected fluid. Techniques for aural toileting include using cotton wool or tissue paper to soak up the discharge, suctioning out the fluid, or irrigation using a manual or automated syringe.²² Given resource

constraints, the most feasible intervention for OM in LMIC is aural toileting along with topical antibiotics.

Otitis Media in Sub-Saharan Africa and Nigeria

Sub-Saharan Africa (SSA) has a population of approximately 518 million individuals and represents approximately 10% of the world's population. Forty-six percent of the total population in SSA is comprised of children under the age of 15.³¹ Lucky Onotai found the prevalence of unilateral or bilateral AOM or COM was 1.3% of children seen during the dry season and 3.1% during the wet season as per an assessment of elementary schoolchildren from various regions of The Gambia with otoscopy and immittance audiometry.³¹ An examination of Western Africa would suggest that a higher prevalence of severe or profound bilateral hearing loss at three to four times that than in more developed locations.³¹ There are also higher rates of OM in childhood and infancy go down as an individual gets older.³¹

CSOM is the most common ENT condition presenting to the general practitioner in Nigeria and the most common infectious disease in children, especially those under five years of age.¹⁸ CSOM often begins in childhood or as a complication of untreated or inadequately treated AOM.¹⁸ Children represented 31.1% of all new otologic presentations at otorhinolaryngology department in the Jos University Teaching Hospital in Nigeria.³² Because of a lack of resources in LMIC such as Nigeria, primary care physicians (PCPs) are usually the first to see a patient with hearing loss rather than an otolaryngologist, who is consulted when treatment fails.³³ Currently, PCPs in Nigeria rely on antibiotics alone to treat CSOM, which can result in antibiotic resistance should the whole infection not be cleared out, something that can be accomplished with the addition of aural toileting to a treatment plan.²²

Lancet Commission on Hearing Loss

Recently, hearing loss has received considerable attention by policymakers globally; recognition of the widespread burden of hearing loss has brought attention to hearing loss and its consequences, leading to a resolution by the World Health Assembly (WHA) to increase awareness of hearing loss and deafness.⁶ As a result, there has been more political emphasis on increasing awareness of hearing loss and access to treatment through publications in *The Lancet* and reports by the WHO and the World Health Assembly.^{7,34} This has led to legislation in the United States such as the passage of the “Over-the-counter hearing act” to increase access to hearing healthcare interventions.³⁴ The Lancet Commission on Hearing Loss was launched as a product of raised awareness of global hearing loss and its downstream consequences.³⁴ The main purpose of the commission is to build the momentum of awareness of the global burden of hearing loss and of strategies to reduce this burden, in partnership with WHO.³⁵

This cost-effective analysis is in conjunction with the Lancet Commission on Hearing Loss to model hearing loss across the lifespan using decision analysis and modeling. Commissioners come from all over the world and include experts in otology, audiology, neuroscience, technology, engineering, public health and policy, economic analysis, and individuals with hearing loss.²² Approximately half of the Commissioners are from LMICs, which comprises of 80% of total global hearing loss.²²

Background on Cost-Effectiveness Analysis

Cost-effectiveness analysis is a method that can help set funding priorities for funding healthcare programs.³⁴ It represents just one component of setting funding priorities. In a cost-

effectiveness analysis, the costs and outcomes for each intervention considered are compared.³⁴ Incremental cost per unit of clinical outcome ratios are calculated for each intervention, and these can then be ranked to assess funding priorities and determine the most cost-effective method of treating a condition.³⁴ Despite the utility of cost-effectiveness analyses in informing funding priorities, there are relatively few decision model-based cost-effectiveness analyses of hearing healthcare set in LMIC. A recent review by our Duke team suggests that only 1 in 5 model-based-cost-effectiveness of hearing loss are based in LMIC and often do not consider multiple interventions for simultaneous comparison across the lifespan, which limits the model's usefulness in comparing alternative hearing healthcare interventions.⁴ Therefore, I sought to use CEA to determine how a screen for school-age children in Nigeria would affect cost-effectiveness outcomes.

METHODS

Analytic Overview

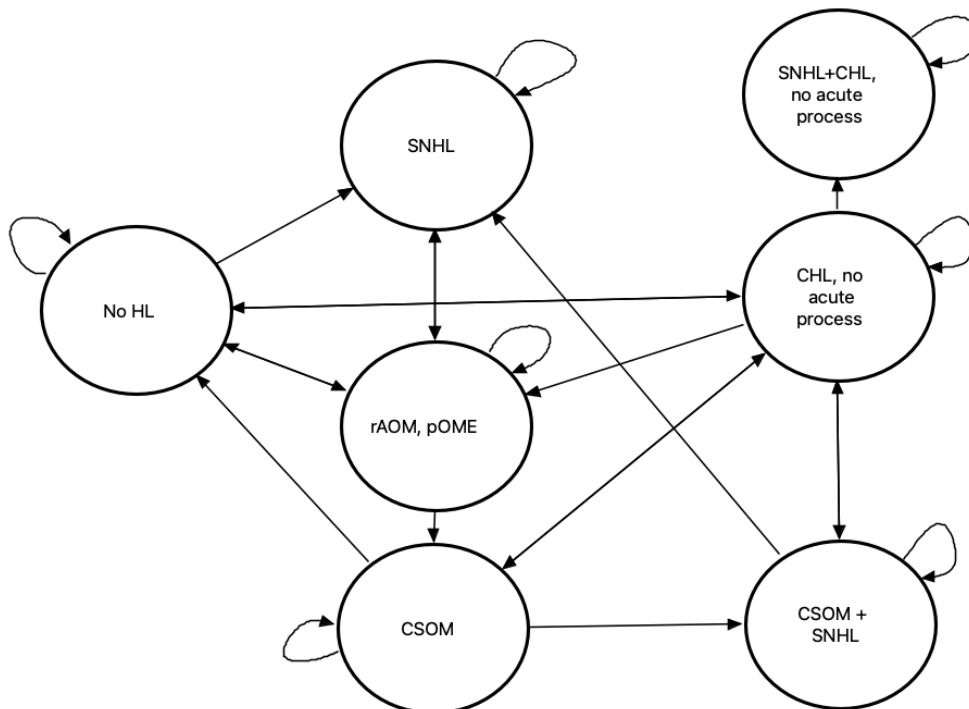
We used a validated microsimulation model of hearing loss, Decision model of the Burden of Hearing Loss Across the Lifespan (DeciBHAL) to simulate CHW-delivered otitis media screening at age 6 years in Nigeria as compared to current care. We compared coverage rates of 50% and 90% of the population with no screening. We simulated a cohort of persons at birth throughout the rest of their lifetime, who experienced yearly probabilities of acquiring HL, AOM, OME, CSOM, and CHL as well as the screening and treatment for detected cases of OM. The model projected the number of individuals identified by the screening program, those treated for OM, and those whose OM was successfully treated. Effectiveness was measured both undiscounted and discounted (3%/year) in quality-of-life years (QALYs). Costs were measured

in 2020 USD. Incremental cost-effectiveness ratios (ICERs) of <\$6,000/quality-adjusted life year (QALY) were considered cost effective.³⁶ The threshold of \$6,000/QALY is three times the per-capita GDP of Nigeria and represents the assumed willingness to pay in that setting.

Model Overview

DeciBHAL is a microsimulation model that incorporates hearing loss natural history, detection, diagnosis, and treatment.³⁷ Each simulated person in the model experiences yearly age- and sex- specific probabilities of acquiring bilateral sensorineural hearing loss, the progression of existing hearing loss, and the uptake or discontinuation of treatment. The model was previously validated in the United States and was then validated and calibrated to international settings, one of which was Nigeria. The health states in the model are determined by the presence and type of hearing loss (SNHL, CHL, CSOM associated CHL) and the associated treatment (Figure 1).³⁷

Figure 1. CHL health state diagram



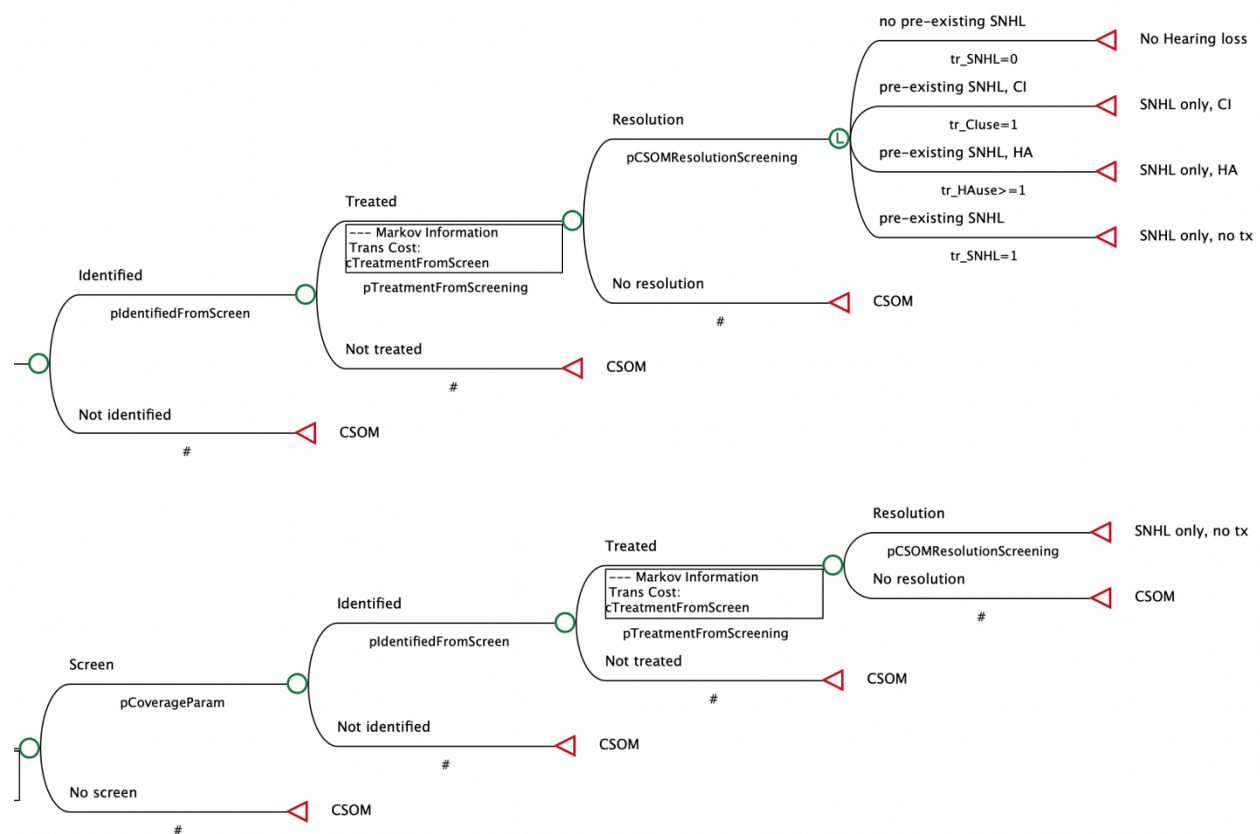
The health state diagram describes the foundation of the Markov simulation model DeciBHAL. The health states take into account whether a patient has hearing loss, the type of hearing loss (SNHL vs CHL), treatment modality, patient age, and hearing level. This health state diagram models CHL, which is caused by OM. The order in which a patient can acquire CHL goes from no HL to rAOM, pOME or SNHL. From the rAOM, pOME health state, the OM can worsen and turn into CSOM. The CSOM can either resolve on its own and allow the patient to return to a no HL health state or worsen into CHL or even CHL and SNHL if the patient develops mixed hearing loss. The patient moves from one health state to another transition probabilities that are derived from literature.

This model was adapted to the incidences and prevalence of hearing loss and hearing loss related conditions in Nigeria.³⁷ Specifically, regarding OM, DeciBHAL simulates AOM, OME, and CSOM, and resulting CHL but without acute infection.³⁷ All patients in the model are exposed to age-specific probabilities of having an episode of AOM or OME, along with associated probabilities of resolution at 3 months or 1 year. If a simulated patient in the model experiences recurrent AOM or OME for over one year, they move into a recurrent AOM/persistent OME health state which lasts for X time. From the recurrent AOM/persistent OME health state, simulated persons have a probability of progression to CSOM of 8% for children at age six (probability was derived to replicate the Nigeria-specific CSOM prevalence).³⁷ For Nigeria, the estimated prevalence of CSOM was 3.6%.²⁴ In DeciBHAL, active CSOM causes CHL with a pure tone average (PTA) threshold of 34 decibels (dB) hearing level.³⁷ A PTA is a behavioral test used to measure hearing sensitivity.³⁸ It is the average of hearing sensitivity at 500 Hz, 1,000 Hz, and 2,000 Hz; hearing sensitivity represents the softest sound audible at least 50% of the time for an individual.³⁸ Additionally, the model can simulate mixed hearing loss or when a person can acquire both SNHL and CHL.³⁷

Comparators

In DeciBHAL adapted for the implementation of a CHW-delivered screening program in Nigeria, a screening tree was added to the model. The screening tree in the model, presented in Figure 2, represents the following events: the patient would first be screened based on the coverage rate of the CHW-delivered screening program, then receive a probability of being identified with hearing loss, receiving treatment, and then subsequent resolution of their OM.

Figure 2. Screening tree in DeciBHAL



The top figure represents the screening tree for a patient who does not acquire SNHL but gets screened for CSOM since they have progressed to that health state. The bottom figure represents the structure of the tree for a simulated patient that does acquire SNHL but gets screened for CSOM. The difference between the two branches of the tree is that the branch for a patient who does not have SNHL is that there is still the chance that they do acquire SNHL, hence the addition of a logic node that evaluates the status of multiple trackers (for no SNHL, SNHL with no treatment, SNHL with HA as treatment, and SNHL with CI as treatment) to determine which health state the patient enters following screening for OM.

We incorporated the sensitivity and specificity of a hearScreen OM screening otoscope.³⁹ The probability of receiving OM treatment after a positive OM test was assumed to be 50%, indicating that 50% of patients would remain untreated. We assumed treatment was aural toilet with topical antibiotics. Additionally, the probability of resolution from screening for OM was 58%, an estimate taken from the WHO.⁴⁰ The target population of the analysis is children since OM affects them more frequently than it would adults.

Model Input Data

Natural History of Hearing loss

In Nigeria, the yearly probabilities of bilateral SNHL ranged from 0.5% to 1.3% for males and 0.5% to 1.1% for females based on age which can be seen along with other model inputs in Table 1.^{8,37} Decline in hearing loss is measured by an annual increase in PTA, and was an average of 1.05 dB/year.^{37,41} A given patient can acquire SNHL, CHL, or mixed HL in the model. A patient can first get AOM, which has the potential to worsen into OME without treatment. The probability of getting OME given AOM is 26%; OME was simulated as a follow-up to AOM but could also occur spontaneously.^{37,42} The chance that the OME resolves after one year on its own is 70.5%.^{37,43} Another possibility given a patient with AOM is the probability of developing into rAOM, which is modeled as 17%; otherwise it resolves spontaneously (Figure 2).^{29,37,42} The yearly probability that rAOM, pOME resolves in the model is 25% after the first year.^{37,43} After progression to CSOM, the yearly chance of resolution is 14%.^{29,37,44,45} After resolution of CSOM, there is an age-specific probability of hearing loss ≥ 25 dB HL that was calibrated to estimates of OM-associated permanent hearing loss in Sub-Saharan Africa.^{29,37}

Table 1. Selected model inputs

Clinical input parameters	Value		Reference
	Males	Females	
Bilateral SNHL probability, yearly, %			^{8, 37}
Age 0	0.5	0.5	
Ages 1-3	0.5	0.7	
Ages 4-7	0.5	0.6	
Ages 8-12	0.2	0.2	
Ages 13-17	0.1	0.1	
Ages 18-25	0.5	0.5	
Ages 26-35	0.5	0.5	
Ages 36-45y	0.7	0.6	
Ages 46-55y	1	0.8	
Ages 56-65y	2.1	1.9	
Ages 66-75y	2.7	2	
Ages 76+y	2.5	2.3	
SNHL Progression, PTA decline in dB, mean (SD)			41
Ages 35-65y	1 (0.4)		
Ages 65+, PTA <40 db HL	1 (0.4)		
Yearly probability of HA uptake, %	PTA < 40dB	PTA ≥ 40 dB	46-48

Age 0y	2.5	2.5	
Age 5y	1	1	
Age 19y	0.03	0.1	
Age 35y	0.03	0.1	
Age 55y	0.03	0.1	49,50
Age 65y	0.03	0.1	
Age 75y	0.04	0.1	
Age 85y	0.04	0.1	
Yearly probability of HA d/c, ages 18+, %*			51,52
1 year after use	12.9		
10+ years after use	3.50		
Yearly probability of CI implantation, %			
Adults with severe+ HL with HAs, %	0.01		53
Clinical input parameters			
Health state utility values	Males	Females	54-57
No hearing loss	0.84		
Mild hearing loss (PTA 25-34 dB)	0.71		
Mild-moderate hearing loss	0.68		
Moderate hearing loss	0.65		
Moderate-severe hearing loss	0.58		
Severe hearing loss	0.54		
Profound hearing loss	0.53		

Utility benefit of hearing aids	0.11	58-61
Utility benefit of cochlear implants	0.16	58-61
Economic input parameters	Value (2020 USD)	Reference
Hearing aid device(s) and fitting cost	309.50	32
Yearly Hearing aid recurring cost	58.67	32
Cochlear implantation cost	24,685.84	
Yearly recurring costs, cochlear implantation (1-10 years after implantation)	1,132.22	62
Screening cost	0.05	63
Cost of OM treatment	3.38	63
Cost of CSOM	558.26	32

Hearing Aid Uptake

A simulated person with hearing loss experiences yearly probabilities of acquiring an HA that depend on age and severity of HL; in Nigeria, the rate of HA uptake ranges from 2.5% at birth to 0.03% at age 85 at a hearing loss level less than 40 dB and 0.1% at a hearing loss level above 40 dB.^{8,37,46-48,64} In addition, patients experience probabilities of HA discontinuation; the range of this is 13% one-year post-HA acquisition, and 4% after one-year post-acquisition.^{37,48,64}

Cochlear Implant Uptake

With severe and profound hearing loss, DeciBHAL assigns a Nigeria-specific probability of cochlear implant uptake of 0.01% with the assumption that the patient acquires a hearing aid first.⁶⁵ The rate of CI discontinuation for adults in the model is 1%.³⁷

Screening Test Characteristics

We assumed a portable otoscope as the mode of screening in this model. The sensitivity and specificity of this test was assumed similar to hearScreen, a smartphone hearing screening technology which makes it easier to implement in LMIC because of its accessibility.³⁹ The sensitivity for detecting OM was 76%, while the false positive rate (1-specificity) was 6%.⁶⁶ We assumed two different conditions in terms of screening; the first was that 50% of the population would be screened, and the second was that 90% of the population would be screened. These were measured against the current standard of care wherein simulated patients are not screened. The probability of identification from the screen was the specificity of the screening test, which as previously mentioned, is 76%.⁶⁶ The probability of receiving OM treatment after a positive screening test was assumed to be 50%. The probability of rAOM or pOME resolution after treatment was 58%, as estimated by a previously published cost-effectiveness analysis (CEA).^{40,67}

Health State Utilities

The population average utility for individuals without hearing loss was assumed to be 0.84. Utility values for mild and moderate hearing loss, calculated from published literature, were 0.71 and 0.65 respectively.⁶⁸ A recent systematic review was used to determine the utility values for hearing aids (HAs) and cochlear implants (CIs), which were +0.11 and +0.17 and

these were varied in sensitivity analysis.^{58-61,68} The utility decrement for rAOM, pOME and CSOM in this analysis was assumed to be of moderate hearing loss, with a value of 0.65. We did not have a utility decrement for chronically draining ears in addition to the hearing loss.

Screening Costs

The school-entry screening cost was applied to all individuals in the model at age 6 years, with and without OM, regardless of their health state. The cost of screening was derived from a published CEA.⁶³ We derived a per-person screening cost that includes the cost of trained primary health workers, drivers, per diem trained primary health worker costs per day, per diem driver costs per day, the cost of a portable audiometer, the cost of an otoscope, per day transport costs, and the total cost per screening team.⁶³ When adjusting for inflation, the per-person cost of OM screening was \$1.28 in 2020 USD.⁶³

Hearing Healthcare Costs

The cost of treatment, aural toileting plus topical antibiotics, was extracted from a published CEA from estimates determined by the WHO.^{40,63} Rob Baltussen estimated that the cost of aural toileting alone was \$0.36 USD per patient treated, and that the antibiotics would cost \$3.02 USD.⁶³ The annual per-person cost of CSOM was \$558.26 USD.³² This cost included the registration and initial consultation with a physician, follow-up visits assuming an average of 10 visits per year, an ear swab, pure tone audiometry, mastoid imaging, medical treatment that includes ear dressings and decongestants, and a hearing aid.³² A cost was added for everyone in the model who gets AOM, regardless of whether or not it is treated. This transition cost included the probability of being identified from the screen, the assumed coverage parameter of 50%, and

the annual per-person cost of CSOM. The false positive rate was also added into the model as a cost; 6% of individuals, which is equivalent to the false positive rate, get an additional cost of treatment. Everyone who does not get rAOM, pOME or CSOM also gets a cost; this cost is for the screen and is the cost of screen plus the assumed coverage parameter of 50% times the cost of treatment.

Model Internal Validation

The model was debugged to ensure the screening tree and costs were incurred when they were supposed to be and that the code was running correctly, as shown in the excerpts from simulated patient trace files in Appendix 1. The changes to the original DeciBHAL model structure in this analysis included the addition of the screening tree to the rAOM, pOME and CSOM health states for simulated patients with and without SNHL. We used trace files, which are a run of the model in which only one patient is simulated and the path they take through the model recorded. We were looking for a patient that did not have SNHL who was simulated, acquiring OM, getting screened, identified, treated, and having the condition resolved, in addition to a patient with SNHL who followed the same pathway to consider the model structure validated. We found both instances in the trace files which indicated that the new additions to the model structure were working correctly, examining over 10 trace files.

One-Way Sensitivity Analysis

A one-way sensitivity analysis to determine the cost-effectiveness of a community health worker training program at 50% coverage and 90% coverage versus no CHW OM screen. To measure cost-effectiveness, we performed a one-way sensitivity analysis. A one-way sensitivity analysis is a way to measure the changes that an input parameter will have on the outputs of the

model by varying said parameter over a range of values.⁶⁹ These values include a high value, a low value, and a base-case, or mean, value. The parameters were varied at a low value and a high value, with the low value being 50% of the original base case value and the high value being 200% of the original base case value (Table 2).

Table 2. Planned one-way sensitivity analyses

Parameter	Base-case value	Low value (50% of base-case value)	High value (200% of base-case value)
Linkage to treatment from screen	0.5	0.1	0.9
Cost of treatment	\$3.38	\$1.69	\$6.76
HA device cost	\$309	\$154.75	\$619
CI device cost	\$24,685.84	\$12,342.92	\$49,371.68
CSOM resolution from screen	0.58	0.29	1
rAOM, pOME resolution from screening	0.58	0.29	1
Cost of CSOM	\$558.26	\$279.13	\$1,116.52
Cost of screen	\$1.28	\$0.64	\$2.56

The planned one-way sensitivity analyses for the parameters chosen for variation are presented above. These parameters were chosen because it was thought that they would have the greatest effect on cost-effectiveness outcomes. Each parameter was varied at the base case value, a low value, and a high value, indicating that the model was run changing each variable to the respective value and keeping all other parameters at base case to examine deviations from the base case scenario. The low value was calculated as 50% lower than the base case value, and the high value is 200% of the base case value.

RESULTS

Model structure validation

The model structure implemented was validated via simulated patient trace files, which involved running a single patient through the model. The goal of running the traces was to ensure the code was working and ensure that the patients are passing through each part of the screening tree as expected. The first run through the trace files can be seen in Appendix 1. This run was done to ensure that the patient first acquired rAOM, pOME and then transitioned into the screening tree. In this trace, the patient acquired rAOM, pOME at the age of one. They did not progress to CSOM and did not acquire SNHL prior to screening. After being screened, they were

identified, treated, and their rAOM, pOME resolved, which sent them to a no HL health state. This trace validated the arm of the screening tree for which the patient has rAOM, pOME but did not acquire SNHL prior to screening.

Another validation was conducted to ensure that patients with CSOM were entering the screening tree as expected (Appendix 1). In the same trace file as above, in this scenario, the simulated patient acquired AOM at the age of 7 without previously existing SNHL. In the same year, this progressed to OME that was treated non-surgically. However, this was not effective; the OM progressed to CSOM. They then enter the screening tree in the CSOM branch of the model, being screened, identified with HL, treated. In this case, the patient's CSOM did not resolve; they were sent back to the CSOM health state. This trace file served as validation for a patient who starts with CSOM receiving the screen.

Another trace file was run (Appendix 1) in which a patient started with SNHL at age one. They received non-surgical treatment in the same year and get rAOM, pOME in the same year. It did not progress to CSOM; they entered the screening tree where they were screened, identified, treated, and their OM resolved, sending them back to a no HL health state. When the patient has SNHL, there is a binary tracker in the model that is equal to one when the patient has SNHL, and zero when they do not. There are also trackers for when patients have SNHL with an HA or CI. Consequently, there is a logic node at the resolution step at the screening tree of the model; this recognizes the value of the tracker to send them to the appropriate terminal health state. In this trace, the patient did not have an intervention for their HL and was sent back to a state of having SNHL with not treatment.

Clinical results

Simulating 100,000 patients throughout their lifetime, we found that the CHW OM screen in Nigeria resulted in a decrease in average per-person cases of CSOM from 2.17 to 2.08. The average person time that a simulated person spends in the rAOM, pOME health state was 3.82 years. In the OM-screening strategy, the total number of individuals who were identified by screening was 9% of the total cohort simulated, with 9,410 persons out of 100,000 going through the screening tree and receiving the intervention. Out of the entire cohort, 1.8% of all individuals received treatment after being screened; 1.6% of simulated persons experienced OM resolution after treatment. Screening resulted in 19.28 discounted QALYs per person, while no screening resulted in 19.26 discounted QALYs per person in the base case (Table 3). Undiscounted QALYs per person for both no screening and no screening were 43.14, indicating that per-person effectiveness was the same for both strategies with no discounting (Table 4).

Cost and cost-effectiveness

With base-case assumptions for the screening program, at a coverage parameter of 50% for the population, the total lifetime discounted costs were lower with the screening intervention than without. At the base case (central) value for every input parameter, the per-person discounted cost was \$63.72 without screening versus \$61.95 per-person with screening (Table 3). As the OM screening strategy was more effective and less expensive, OM screening was cost saving. This was due to savings in CSOM costs in the OM screening strategy. Undiscounted results suggest that per-person costs with no screening are \$127.95 USD, while screening per-person costs are \$125.93 USD (Table 4). In the undiscounted case, screening was as effective but still cost saving when compared to no screening.

Table 3. Discounted cost-effectiveness results of screening versus no screening in Nigeria.

Strategy	Per-person discounted lifetime effectiveness (QALYs)	Per-person discounted lifetime costs (2020 USD)	ICER (\$/QALY)^a
No screen	19.22	64.26	Abs. dominated
Screen	19.23	62.26	undominated

Abbreviations: ICER: incremental cost-effectiveness ratio; QALY: quality-adjusted life-year.

^aDiscounted lifetime costs and QALYs at 3%/year were used calculate incremental cost-effectiveness ratios.

^bDominated: Indicates an alternative strategy or combination of strategies has higher effectiveness with lower costs.

Table 4. Undiscounted cost-effectiveness results of alternative US hearing screening strategies.

Strategy	Per-person undiscounted lifetime effectiveness (QALYs)	Per-person undiscounted lifetime costs (2020 USD)	ICER (\$/QALY)^a
No screen	43.17314	128.14	Abs. dominated
Screen	43.17317	124.98	undominated

Abbreviations: ICER: incremental cost-effectiveness ratio; QALY: quality-adjusted life-year.

^aDiscounted lifetime costs and QALYs at 3%/year were used calculate incremental cost-effectiveness ratios.

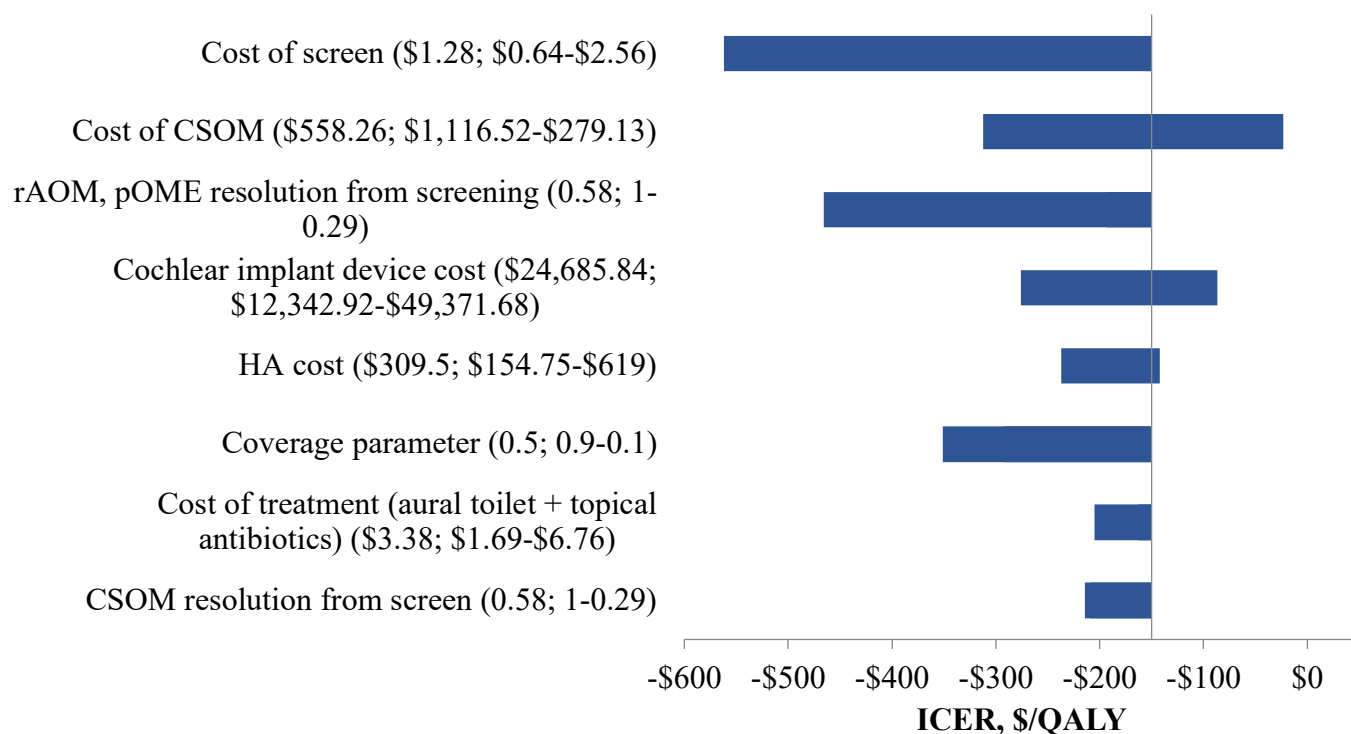
^bDominated: Indicates an alternative strategy or combination of strategies has higher effectiveness with lower costs.

Sensitivity analysis

In the one-way sensitivity analysis, the parameters that were varied include the upfront cost of an HA, the upfront cost of a CI, the probability of rAOM, pOME resolution due to the CHW-delivered screening, the probability of CSOM resolution due to the CHW-delivered screening, the linkage to treatment, the cost of a screen for OM, the cost of treatment, and the cost of CSOM. A detailed description of the sequence of health states for a patient with OM can be found in Figure 2. Cost-effectiveness results were most sensitive to variation in cost of screen,

cost of CSOM, and rAOM, pOME resolution from screening, and cochlear implant device cost. The cost-effectiveness results were least sensitive to variation in linkage to treatment from the screen and the cost of treatment. All values, regardless of being the low or high parameter for the one-way sensitivity analyses were less than the Nigerian WTP of \$6,000/QALY.

Figure 3. Tornado Diagram



The results of the one-way sensitivity analyses would suggest that when varying the parameters between their low and high values, the cost of screening and the annual per-person cost of having CSOM affected the cost-effectiveness outcomes (ICERs) the most. The parameters are centered around the base-case ICER of -\$150/QALY to examine variation from the base value of all the parameters when being varied from their lowest to highest value in sensitivity analysis.

DISCUSSION

Statement of principal findings

We found that the implementation of the screening program increased the overall health of the population in Nigeria since it increased quality-adjusted life expectancy while reducing

costs as compared to without a CHW-delivered screening program. The implementation of the screening program decreased the average-person time in the CSOM health state. At a coverage parameter of 50%, approximately 9% of the simulated cohort of 1,000,000 persons were screened for OM. The cost-effectiveness of both strategies was evaluated against a WTP of \$6,000/QALY in Nigeria.

Several inputs in the model were varied across their ranges, from the lowest value to the highest, including the costs of an HA and a CI, the cost of screen, the cost of treatment for OM, and the coverage parameter (Figure 3). We found that the cost of screen, HA device cost, cost of CSOM, and rAOM, pOME resolution from screening varied the cost-effectiveness outcomes the most. Based on the results of this analysis, the implementation of a CHW-delivered screening program is a cost-effective way to mitigate conductive hearing loss caused by otitis media.

Limitations and the strengths of the study

There are several limitations in this analysis. The first is that the estimates for the resolution of OM, cost of a screen, and the cost of a treatment were taken from a CEA published in India in a study conducted with adults. They are not specific to Nigeria or children, which adds some uncertainty to the outcomes in this analysis since the focus is on screening school-age children. Children were the population chosen for this analysis because it was thought that the screening program would be easiest to implement in schools to reach the most children with the most efficient use of resources, since CHWs would then not have to travel from door to door. The incidence of otitis media would, however, suggest that the burden of this condition is greatest for children who are even younger than 6. Investigating cost-effectiveness at younger ages is necessary for future analyses to determine if the screening program is even more cost-

effective than the one presented in this analysis. Additionally, we assumed a 50% linkage to treatment; this was not taken from any literature. We also assumed that the utility decrement for OM would be that for moderate hearing loss and that each simulated patient who was screened would get this decrement. This could be an oversimplification since presumably the level of hearing loss resulting from OM would vary, in that it could be slightly more or less severe, and we did not use an OM specific utility decrement. Another limitation is that the sensitivity and specificity used in the study were from videos that were sent to a general practitioner and do not include the costs of care that would result from physically having to go to a physician's office, such as the fee for consultation, the costs of using medical equipment, and the costs of follow-up care.

The strengths of the study are that based on the model inputs and assumptions, the use of CHWs for screening were estimated to be cost-effective even when exploring the uncertainty in our parameters. All estimates were based on WHO assumptions and data. The validated and calibrated DeciBHAL model structure was used to conduct this analysis; this model structure has been adapted to other CEAs, which speaks to its reliability in terms of being a good representation of the path that a simulated patient takes through different HL conditions. Another strength is the use of DeciBHAL to conduct this analysis; given that the model considers the natural history and progression of hearing loss as well as probabilities of acquiring different conditions or interventions. It is a comprehensive simulation of what an individual with hearing loss would experience throughout their lifespan.

Implications for clinicians and policymakers

Decision analysis is tied into medical decision making since it provides a way to evaluate alternative strategies using evidence and a model-based evaluation of cost-effectiveness outcomes.⁷⁰ Consequently, the results of a CEA allow a clinician to see what the best course of action would be in a tradeoff between multiple different strategies for dealing with a medical issue.⁷⁰ In this case, the multiple strategies were represented as implementing a CHW-delivered screening program or not, both of which manifested as either the presence of a screen at age six or not for each strategy, respectively.⁷⁰ In this sense, it would make most sense for providers, healthcare facilities, and policymakers to focus on reducing the annual cost of CSOM based on the results from this CEA.

Conducting this analysis allows for the outcomes to be applied to similar settings, such as other LMIC with similar resources to Nigeria. OM represents a condition that is rarely seen in HIC; the implementation of a CHW-delivered screening program could be the first step in not only OM reduction but also in mitigating the global burden of hearing loss. If successful in Nigeria, the findings from DeciBHAL can be adapted to other settings using parameters extracted from already published literature to evaluate cost-effectiveness given the resources in that setting allow governments to prioritize OM management by informing policymakers. The parameters that vary the cost-effectiveness of OM treatment the most, the annual per-person cost of CSOM and resolution rates for rAOM, pOME, and CSOM can be used as a guide to determine the components that countries should focus on in terms of maximizing cost-effectiveness; if resources can only be allocated to certain parameters, the ones that cause the greatest variation in ICERs should be selected.

The results of this analysis would suggest that in LMIC, the implementation of training programs for CHWs is a cost-effective method of increasing treatment for OM in similar settings,

indicating that allocating resources to such programs would be a good use of those resources. The implementation of such a program would decrease the average person-time spent in the health states of rAOM, pOME and CSOM. CHWs were advocated by WHO as a key way to reach LMIC.⁷¹ According to the WHO, for CHWs to do their jobs, they need regular training and supervision.⁷¹ They are defined as health workers who have some medical training (up to two years) but are not considered professionals.⁷¹ They also provide their health services outside of medical facilities and places staffed by other medical personnel. The ongoing nature of such a training program is an obstacle to successful treatment since it represents the most neglected part of the training.⁷² CHW-delivered interventions in the US to reduce heart disease have been shown to be effective in underserved communities, indicating that training programs have successfully been developed. The United States Agency for International Development (USAID) Health Care Improvement Project suggests that refresher training should happen every six months in order for CHWs to learn new skills, refine old ones, and make sure skills are being practiced correctly.⁷³

Currently in sub-Saharan Africa, training courses for CHWs are not sufficient to improve the quality of health in these countries.⁷⁴ Specifically in regards to hearing loss, its high prevalence in sub-Saharan Africa is in part due to a shortage of health workers, including audiologists, resources for the provision of hearing interventions, and a lack of support and rehabilitation programs.⁷⁵ A review on CHW training programs in LMIC highlighted that most training programs are in-person and do not capitalize on tools such as the Internet to increase participation and increase accessibility. As far as the implementation of the scale-up program in LMICs, one recommendation is that the program should have regularly scheduled check-ins with the CHWs every six months after implantation to ensure that the screening process is running smoothly. The recommendations regarding the implementation of a training program for CHWs are to strengthen

training and screening and assess the effectiveness of all stages of the design of the program. In addition to CHW training, there should be training for the supervisors, including health professionals and administrative staff, to ensure that supervisors can understand and advise CHWs of their effectiveness and progress. These supervisors are typically healthcare professionals who already are not equipped with the specific skills needed to manage a team of CHWs and lack the time to handle such tasks.⁷⁶ Perhaps more compensation for these health professionals would allow them to allocate valuable patient hours to supervise CHWs in their training. Additionally, there should be clear strategies for integrating CHWs into primary care teams at healthcare facilities.⁷⁶

Previous research has suggested that there could be some issues in integrating this intervention into the sub-Saharan African community.⁷⁶ Although there has been success in implementing a CHW training program for CHWs for cardiovascular disease in LMIC, there are issues of remuneration, a lack of respect from formally trained healthcare professionals, and a lack of clear career paths for CHWs that serve as obstacles for their integration into the health system framework in areas that could greatly benefit from them.⁷⁶ The same recent study has also found barriers where local health centers are concerned in terms of issues with training, effective supervision, the selection of CHWs to be trained, and compensation for CHWs.⁷⁶ There also exists a tension in LMICs similar to sub-Saharan Africa between primary care services to use CHWs and share their tasks.⁷⁶ An informational training for professional healthcare workers who oversee or have to share tasks with CHWs about their benefits and role in a cost-effective intervention for health conditions that disproportionately affect LMICs.

Since cost of screening, cost of CSOM, rAOM, pOME resolution rates, and cochlear implant device costs are the parameters that had the greatest effects on cost-effectiveness outcomes, policy that focuses on mitigating these parameters would be beneficial in ensuring that

the CHW scale-up intervention is maximizing cost-effectiveness. The other parameters in the SAs did not vary cost-effectiveness outcomes as much, indicating that allocating resources to these would not be the best use of time or money to focus on. All parameters had some effect on cost-effectiveness outcomes, however, and all were cost-effective because they were below the Nigerian WTP threshold of \$6,000/QALY. At base case, all parameters result in interventions that are less costly and more effective, hence the negative ICER values during sensitivity analysis.

Future research

In this analysis, the scale-up of a training program for CHWs was modeled by including parameters such as the probability of being identified and treated and having rAOM, pOME and CSOM resolve as a function of being screened. Future research should include what would happen with scale-up of each individual step of the screening process that was modeled (screening, identification, linkage to treatment, rAOM, pOME resolution and CSOM resolution) or the cost-effectiveness of using this same intervention at different ages, such as earlier in childhood or for adults. Additionally, the cost-effectiveness of other methods of treating OM could be explored. In this analysis, we only considered the most conservative treatment, which was the combination of aural toileting and topical antibiotics. There are other treatments for OM that were not modeled in the analysis, including oral antibiotics, like topical and non-topical quinolones. This would provide a better idea as to how effective the intervention in this analysis is in comparison.

The Lancet Commission on Hearing Loss has also extended its analysis beyond focusing on just OM in Nigeria. Previous analyses have included a validation of DeciBHAL in the United States as well as international settings of Chile, India, and Nigeria. Past CEAs have included

over-the-counter hearing aids in the United States, vaccination scale-up in Chile, India, and Nigeria, and community-based hearing screening in India. Future analyses and unanswered questions include an investigation of yearly PCP screening in US adults, leisure exposure value in India, and child versus newborn screening in India. Extensions of these analyses could also be a focus of the Commission, changing parameters or the model structure slightly to accommodate different circumstances or interventions that could occur in the already published analyses. Specifically, with regard to Nigeria, the cost-effectiveness of various hearing interventions such as HAs and CIs has not been investigated, nor has the cost-effectiveness of surgical treatment for OM. All of these represent possible future applications of DeciBHAL in terms of CEAs.

CONCLUSION

This analysis shows that the scale-up of a training program for CHWs in Nigeria is a cost-effective method of mitigating otitis media. To have the most reduction in cases of rAOM, pOME, and CSOM, the parameters in the model that had the greatest effect on cost-effectiveness were resolution rates of rAOM, pOME and CSOM as well as the per-person annual cost of CSOM; these are what policymakers and clinicians should focus on. The other parameters were still cost-effective, although not as much as the resolution rates or cost of CSOM. The findings of this study can be applied to implementing the same training scale-up intervention in other LMICs or conducting other CEAs in Nigeria, in addition to future CEAs in other settings with other interventions to mitigate hearing loss.

Bibliography

1. Blake S Wilson DLT, Michael H Merson, Gerard M O'Donoghue. Global hearing health care: new findings and perspectives. *Lancet* 2017; **2**(10111): 2503-15.
2. Team W. World report on hearing, 2021.
3. Bolajoko O Olusanya KJN, James E Saunders. The global burden of disabling hearing impairment: a call to action *Bull World Health Organ* 2014; **1**(5): 367-73.
4. Ethan D Borre MMD, Austin Ayer, Gloria Zhang, Susan D Emmett, Debara L Tucci, Blake S Wilson, Kamaria Kaalund, Osondu Ogbuaji, Gillian D Sanders. Evidence gaps in economic analyses of hearing healthcare: A systematic review *EClinicalMedicine* 2021; **3**5(100872).

5. Abdulazeez Ahmed AAA, Emmanuel Kolo. Diagnosis and management of otitis media with effusion in a tertiary hospital in Kano: a best practice implementation project. *JBIR Database of Systematic Reviews and Implementation Reports* 2018; **16**(10): 2050-63.
6. Hearing loss: an important global health concern. *Lancet* 2016; **387**(10036): 2351.
7. Lancet T. The Lancet. Hearing loss: time for sound action. *Lancet* 2017; **390**(10111): 2414.
8. LM Haile KK, PS Briant, et al. Hearing loss prevalence and years lived with disability, 1990-2019: findings from the Global Burden of Disease Study 2019 *Lancet North America Edition* 2021; **397**(10278): 996-1009.
9. K Graydon CW, H Miller, H Gunasekera. Global burden of hearing impairment and ear disease. *The Journal of Laryngology & Otology* 2018; **133**(1): 18-25.
10. Susan D Emmett HWF. Bilateral Hearing Loss is Associated with Decreased Nonverbal Intelligence in US Children Ages 6 to 16 Years. *Laryngoscope* 2014; **124**(9): 2176-81.
11. Bolajoko O Olusanya RJR, Agnete Parving. Reducing the burden of communication disorders in the developing world: an opportunity for the millennium development project. *JAMA* 2006; **296**(4): 441-4.
12. Kenneth Southall J-PG, Mary Beth Jennings. Stigma: a negative and a positive influence on help-seeking for adults with acquired hearing loss. *International Journal of Audiology* 2010; **49**(11): 804-14.
13. Debara Tucci MHM, Blake S Wilson. A summary of the literature on global hearing impairment: current status and priorities for action. *Otology & Neurotology* 2010; **31**(1): 31-41.
14. Preben Homøe KK, Janet R Casey, Roger A M J Damoiseaux, Thijs M A van Dongen, Hasantha Gunasekera, Ramon G Jensen, Ellen Kvestad, Peter S Morris, Heather M Weinreich. Panel 1: Epidemiology and Diagnosis. *Otolaryngology - Head and Neck Surgery* 2017; **156**: 1-21.
15. Gill Livingston AS, Vasiliki Orgeta, Sergi G Costafreda, Jonathan Huntley, David Ames, Clive Ballard, Sube Banerjee, Alistair Burns, Jiska Cohen-Mansfield, Claudia Cooper, Nick Fox, Laura N Gitlin, Robert Howard, Helen C Kales, Eric B Larson, Karen Ritchie, Kenneth Rockwood, Elizabeth L Sampson, Quincy Samus, Lon S Schneider, Geir Salbaek, Linda Teri, Naaheed Mukadam. Dementia prevention, intervention, and care. *Lancet* 2017; **390**(10113): 2673-734.
16. O.A. Afolabi JOF, H.K. Omokanye, F. Olatoke, T.O. Odi, M.J. Saka, R.K. Adaranijo. Socioeconomic challenges of chronic suppurative otitis media management in state tertiary health facility in Nigeria *Egyptian Journal of Ear, Nose, Throat and Allied Sciences* 2013; **15**: 17-22.
17. Ali Qureishi YL, Katherine Belfield, John P Birchall, Matjia Daniel. Update on otitis media - prevention and treatment *Infection and Drug Resistance* 2014; **7**: 15-24.
18. OA Afolabi AS, FE Ologe, C Nwabuisi, CC Nwawolo. Pattern of bacterial isolates in the middle ear discharge of patients with chronic suppurative otitis media in a tertiary hospital in North central Nigeria. *African Health Sciences* 2012; **12**(3): 362-5.
19. Morris P. Chronic suppurative otitis media. *BMJ Clinical Evidence* 2012; **2012**.
20. Yan Zhang MX, Jin Zhang, Lingxia Zeng, Yanfei Wang, Qing Yin Zheng. Risk factors for chronic and recurrent otitis media-a meta-analysis. *PLoS One* 2014; **9**(1).
21. BM Ahmad MK. Chronic suppurative otitis media in Gombe, Nigeria. *Nigerian Journal of Surgical Research* 2003; **5**(3).

22. Mahamood F Bhutta KH, Lee-Yee Chong, Jessica Daw, Anne GM Schilder, Martin J Burton, Christopher G Brennan-Jones Aural toilet (ear cleaning) for chronic suppurative otitis media. *Chochrane Library* 2020.
23. Medicine JH. Ear Infection (Otitis Media). 2023.
<https://www.hopkinsmedicine.org/health/conditions-and-diseases/otitis-media>.
24. Acuin J. Chronic suppurative otitis media. *BMJ Clinical Evidence* 2007; **2007**(0507).
25. Rehab Alwotayan KA. Otitis media: a review for the Family physician *Bulletin of the Kuwait Institute for Medical Specialization* 2003; **2**: 83-9.
26. V Rupa AJ, A Joseph. Chronic suppurative otitis media: prevalence and practices among rural South Indian children. *International Journal of Pediatric Otorhinolaryngology* 1999; **48**: 217-21.
27. M V Goycoolea MMH, C Ruah Otitis media: the pathogenesis approach. Definitions and terminology *Otolaryngologic Clinics of North America* 1991; **24**(4): 757-61.
28. Lucky Onotai AO. Chronic Suppurative Otitis Media in Nigerian Children: The Port Harcourt Experience *British Journal of Medicine and Medical Research* 2015; **7**(10): 833-8.
29. Lorenzo Monasta LR, Federico Marchetti, Marcella Montico, Liza Vecchi Brumatti, Alessandro Bavcar, Domenico Grasso, Chiara Barbiero, Giorgio Tamburlini. Burden of disease caused by otitis media: systematic review and global estimates. *PLoS One* 2012; **7**(4).
30. Gerard O'Donoghue DLT, Blake S Wilson The mounting burden of hearing loss worldwide: gearing up global collaboration. 2017.
<https://www.entandaudiologynews.com/features/audiology-features/post/the-mounting-burden-of-hearing-loss-worldwide-gearing-up-global-collaboration>.
31. Bradley McPherson SMS. Childhood hearing loss in sub-Saharan Africa: A review and recommendations. *International Journal of Pediatric Otorhinolaryngology* 1997; **40**(1): 1-18.
32. A Adoga TN, O Silas. Chronic suppurative otitis media: Socio-economic implications in a tertiary hospital in Northern Nigeria. *Pan African Medical Journal* 2010; **4**(1).
33. FT Orji BD. Observations on the Current Bacteriological Profile of Chronic Suppurative Otitis Media in South Eastern Nigeria. *Ann Med Health Sci Res* 2015; **5**(2): 124-8.
34. WHO. Global costs of unaddressed hearing loss and cost-effectiveness of interventions: a WHO report, 2017, 2017.
35. GC Ilechukwu CI, BC Ezeanolue, IJ Okoroafor, NC Ojinnaka, AC Ubesie, GO Emechebe, and J Eze. Ear-related problems among children attending the paediatric and otorhinolaryngology out-patients clinics of the University of Nigeria Teaching Hospital, Enugu. *African Health Sciences* 2016; **16**(2): 363-6.
36. Bank TW. GDP per capita (Current US\$) - Nigeria. 2023.
<https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?locations=NG>.
37. Ethan D Borre AA, Carolina Der, Titus Ibekwe, Susan D Emmett, Siddharth Dixit, Minahil Shahid, Bolajoko Olusanya, Suneela Garg, Mohini Johri, James E. Saunders, Debara L Tucci, Blake S Wilson, Osondu Ogbuoji, Gillian Sanders Schmidler. Validation of the decision model of hearing loss across the lifespan (DeciBHAL) in Chile, India, and Nigeria. *EClinicalMedicine* 2022; **00**(101502).
38. Kutz JW. Audiology Pure-Tone Testing. 2018.

39. Regan C Manayan OHL-L, Alison Packer, Kathryn Tribulski, Audrey Winans, Mark A Vecchiotti, Andrew R Scott Ambient noise limits efficacy of smartphone-based screening for hearing loss in children at risk. *American Journal of Otolaryngology* 2022; **43**(1).
40. Acuin J. Chronic suppurative otitis media: burden of illness and management options: WHO, 2004.
41. Lee F-S ML, Dubno JR, Mills JH. Longitudinal study of pure-tone thresholds in older persons *Ear Hear* 2005; **26**(1): 1-11.
42. RM Rosenfeld KD. Natural history of untreated otitis media. *Laryngoscope* 2003; **113**(10): 1645-57.
43. Rosenfeld RM SJ, Schwartz SR. Clinical practice guideline: otitis media with effusion (update). *Otolaryngol-Head Neck Surg* 2016; **154**(1_suppl): S1-S41.
44. Avnstorp MB HP, Bjerregaard P, Jensen RG Chronic suppurative otitis media, middle ear pathology and corresponding hearing loss in a cohort of Greenlandic children. *Int J Pediatr Otorhinolaryngol* 2016; **83**: 148-53.
45. Aarhaus L TK, Kvestad E, Engdahl B. Childhood otitis media: a cohort study with 30-year follow-up of hearing (the HUNT study). *Ear Hear* 2015; **36**(3): 302.
46. Adedeji TO TJ, Sogebi OA, Daniel AD. Management challenges of congenital & early onset childhood hearing loss in a sub-Saharan African country. *International Journal of Pediatric Otorhinolaryngology* 2015; **79**(10): 1625-9.
47. Ogunkeyede S AS, Daniel A, Adeyemo A. Burden of hearing loss in Subsaharan Africa: snapshot from an ENT clinic in Nigeria. *Heighpubs Otolaryngol Rhinol* 2019; **3**(1): 1-5.
48. Takahashi G MC, Beamer S, et al. Subjective measures of hearing aid benefit and satisfaction in the NIDCD/VA follow-up study *J Am Acad Audiol* 2007; **18**(4): 323-49.
49. Simpson AN, Matthews LJ, Cassarly C, Dubno JR. Time From Hearing Aid Candidacy to Hearing Aid Adoption: A Longitudinal Cohort Study. *Ear Hear* 2019; **40**(3): 468-76.
50. Chien W, Lin FR. Prevalence of hearing aid use among older adults in the United States. *Archives of Internal Medicine* 2012; **172**(3): 292-3.
51. Takahashi G, Martinez CD, Beamer S, et al. Subjective measures of hearing aid benefit and satisfaction in the NIDCD/VA follow-up study. *Journal of the American Academy of Audiology* 2007; **18**(4): 323-49.
52. Kochkin S, Beck DL, Christensen LA, et al. MarkeTrak VIII: The impact of the hearing healthcare professional on hearing aid user success. *Hearing Review* 2010; **17**(4): 12-34.
53. American Cochlear Implant Alliance. Cochlear Implants. Accessed 21 May 2021 at <https://www.acialliance.org/page/CochlearImplant>.
54. Goman AM, Lin FR. Prevalence of hearing loss by severity in the United States. *American Journal of Public Health* 2016; **106**(10): 1820-2.
55. Van Naarden K, Decouflé P, Caldwell K. Prevalence and characteristics of children with serious hearing impairment in metropolitan Atlanta, 1991–1993. *Pediatrics* 1999; **103**(3): 570-5.
56. Homans NC, Metselaar RM, Dingemanse JG, et al. Prevalence of age-related hearing loss, including sex differences, in older adults in a large cohort study. *The Laryngoscope* 2017; **127**(3): 725-30.
57. Cruickshanks KJ, Wiley TL, Tweed TS, et al. Prevalence of hearing loss in older adults in Beaver Dam, Wisconsin: The epidemiology of hearing loss study. *American journal of epidemiology* 1998; **148**(9): 879-86.

58. Davis A, Smith FM, Stephens D, Gianopolous I. Acceptability, benefit, and costs of early screening for hearing disability: a study of potential screening tests and models. *Health Technol Assess* 2007; **11**(42): 1-294.
59. Kaur P, CS, Kannapiran P, Teo W-S, Ling CNW, Welchen CW, et al. Cost-utility analyses of hearing aid device for older adults in the community: a delayed start study. *BMC Health Serv Res* 2020; **20**(1): 1-11.
60. Borre ED, KK, Frisco N, Zhang G, Ayer A, Kelly-Hendrick M, Reed SD, Emmett SD, Francis HW, Tucci DL, Wilson BW, Kosinski A, Ogbuaji O, Sanders Schmidler GD. The impact of hearing loss and its treatment on health-related quality of life utility: a systematic review and meta-analyses. *Under rev.*
61. Grutters JP, JM, van der Horst F, Verschuure H, Dreschler WA, Anteunis LJ. Choosing between measures: comparison of EQ-5D, HU12 and HU13 in persons with hearing complaints. *Qual Life Res* 2007; **16**(8): 1439-49.
62. Semenov YR, YS, Seshamani M, Wang N-Y, Tobey EA, Eisenberg LS, et al. Age-dependent cost utility of pediatric cochlear implantation. *Ear Hear* 2013; **34**(4): 402-12.
63. Baltussen Rob AV, Priya Monica, Achamma Balraj,, Anand Job GNAJ. Costs and health effects of screening and delivery of hearing aids in Tamil Nadu, India: an observational study. *BMC Public Health* 2009; **9**(135): 1-7.
64. Kochkin S, BD, Christensen LA, et al. MarkeTra VIII: the impact of the hearing healthcare professional on hearing aid user success. *Hear Rev* 2010; **17**(4): 12-34.
65. Emmet SD, TD, Smith M, et al. GDP matters: cost effectiveness of cochlear implantation and deaf education in Sub-Saharan Africa. *Otol Neurotol* 2015; **36**(8): 1357-65.
66. Thorbjorn Lundberg LB, DJ, De We Swanepoel, Claude Laurent. Diagnostic accuracy of a general practitioner with video-otoscopy collected by a health care facilitator compared to traditional otoscopy. *International Journal of Pediatric Otorhinolaryngology* 2023; **99**: 49-53.
67. Rob Balutssen AS. Cost effectiveness of strategies to combat vision and hearing loss in sub-Saharan Africa and South East Asia: mathematical modelling study. *BMJ* 2012; **344**(e615).
68. Ethan D. Borre JRD, Evan R. Meyers, Susan D. Emmett, Juliessa M. Pavon, Howard W. Francis, Osondu Ogbuaji, Gillian D. Sanders Schmidler. Model-Projected Cost-Effectiveness of Adult Hearing Screening in the USA. *J Gen Intern Med* 2022.
69. Christopher McCabe MP, Isaac Awotwe, Andrew Sutton, Peter Hall. One-Way Sensitivity Analysis for Probabilistic Cost-Effectiveness Analysis: Conditional Expected Incremental Net Benefit. *Pharmacoeconomics* 2019; **38**(2): 135-41.
70. Claudia C. Dobler GHG, Zhen Wang, M. Hassan Murad. Users' Guide to Medical Decision Analysis. *Mayo Clinic Proceedings* 2021; **96**(8): 2205-17.
71. Sonia Ahmed LEC, Janelle Wagnild, Nasima Akhter, Scarlett Sturridge, Andrew Clarke, Pari Chowdhary, Diana Mukami, Adetayo Kasim & Kate Hampshire. Community health workers and health equity in low- and middle-income countries: systematic review and recommendations for policy and practice. *International Journal for Equity in Health* 2022; **21**(49).
72. Li VC GP, Dorfman S. A global review of training of community health workers, 1983-84. *Int Q Community Health Educ* 2006; **27**: 181-218.

73. Wanduru P TM, Tuhebwe D. The performance of community health workers in the management of multiple childhood infectious diseases in Lira, northern Uganda - a mixed methods cross-sectional study. *Glob Health Action* 2016; **9**(33194).
74. Leslie HH GA, Nsona H. Training and supervision did not meaningfully improve quality of care for pregnant women or sick children in Sub-Saharan Africa. *Health Aff* 2016; **35**: 1716-24.
75. Wakisa Mulwafu HK, Asgaut Viste, and Frederik K Goplen. Feasibility and acceptability of training community health workers in ear and hearing care in Malawi: a cluster randomised controlled trial. *BMJ Open* 2017; **7**(10).
76. Abrahams-Gessel S CD, Gaziano TA, Levitt NS, and Puoane T. Challenges Facing Successful Scaling Up of Effective Screening for Cardiovascular Disease by Community Health Workers in Mexico and South Africa: Policy Implications. *Health Sys Policy Res* 2016; **3**(26).

APPENDIX

Appendix 1. Model internal validation

Below are samples of trace files for patients that go through the model. The first, Patient 3, represents a patient who did not acquire SNHL that enters the screening tree and is screened,

identified, treated, and their rAOM, pOME resolves, sending them to a no hearing loss health state. The second, Patient 4, represents a patient who did have SNHL and entered the OM screening tree, also getting screened, identified, treated, and their rAOM, pOME resolved, sending them back to a SNHL health state.

Patient 3: At 1 year of age, this patient randomly acquired rAOM. They survived another year, and in that year, did not progress to CSOM; in the same year, the OM did not resolve, rendering them in the remain OME health state. Again, within the same year, they did not acquire SNHL and were screened for OM. After screening, they were identified, treated, and their rAOM, pOME resolved, sending them to the no hearing loss health state.

1. Patient acquires rAOM

```
random walk to / rAOM / Rand(0,1) = 0.9138255514935184
```

```
jump to / No Hearing loss
```

```
termination condition / Markov Base / thread 0 / _strategy 1 / _trial 1 / _stage 2
```

```
_stage=100
```

```
_stage = 2
```

```
_stage=100 = 0.0
```

```
Incremental Reward (Payoff 2) / rAOM, pOME / thread 0 / _strategy 1 / _trial 1 / _stage 2
```

```
uModSNHL
```

```
uModSNHL = 0.65-uDecrementAll
```

```
uDecrementAll = 0
```

```
uModSNHL = 0.65
```

```
uModSNHL = 0.65
```

2. Patient does not progress to CSOM

random walk to / Survive / Rand(0,1) = 0.8349508377339111

probability / Progression to CSOM / thread 0 / _strategy 1 / _trial 1 / _stage 2
Probability (Node450)

probability / Progression to CSOM / thread 0 / _strategy 1 / _trial 1 / _stage 2
tCSOM_Inc_Given_rAOMPOME[tr_age_current]
tr_age_current = 2
tcsom_inc_given_raompome[] = 0.10507943
tCSOM_Inc_Given_rAOMPOME[tr_age_current] = 0.10507943
Probability (Node450) = 0.10507943

random walk to / No progression / Rand(0,1) = 0.6880975953974057

probability / Resolution / thread 0 / _strategy 1 / _trial 1 / _stage 2
Probability (Node465)

probability / Resolution / thread 0 / _strategy 1 / _trial 1 / _stage 2
prAOMPOMEResolution
prAOMPOMEResolution = 1/4
prAOMPOMEResolution = 0.25
prAOMPOMEResolution = 0.25
Probability (Node465) = 0.25

random walk to / Remain OME / Rand(0,1) = 0.14135900445779762

3. Patient enters screening tree and goes to no HL

random walk to / Screen / $\text{Rand}(0,1) = 0.38147026635274994$

probability / Identified / thread 0 / _strategy 1 / _trial 1 / _stage 2
Probability (Node509)

probability / Identified / thread 0 / _strategy 1 / _trial 1 / _stage 2
pIdentifiedFromScreen
pIdentifiedFromScreen = 0.985
pIdentifiedFromScreen = 0.985
Probability (Node509) = 0.985

random walk to / Identified / $\text{Rand}(0,1) = 0.9188139545542221$

probability / Treated / thread 0 / _strategy 1 / _trial 1 / _stage 2
Probability (Node511)

probability / Treated / thread 0 / _strategy 1 / _trial 1 / _stage 2
pTreatmentFromScreening
pTreatmentFromScreening = 0.5
pTreatmentFromScreening = 0.5
Probability (Node511) = 0.5

random walk to / Treated / $\text{Rand}(0,1) = 0.20088765309212908$

probability / Resolution / thread 0 / _strategy 1 / _trial 1 / _stage 2
Probability (Node513)

probability / Resolution / thread 0 / _strategy 1 / _trial 1 / _stage 2
prAOMPOMEScreeningResolution
prAOMPOMEScreeningResolution = 0.484
prAOMPOMEScreeningResolution = 0.484
Probability (Node513) = 0.484

4. Patient goes to no hearing loss

```
Incremental Reward (Payoff 2) / No Hearing loss / thread 0 / _strategy 1 / _trial 1 / _stage 3  
0.84  
0.84 = 0.84
```

```
Incremental Reward (Payoff 1) / No Hearing loss / thread 0 / _strategy 1 / _trial 1 / _stage 3  
cScreenNoHLTOTAL  
  cScreenNoHLTOTAL = 0  
cScreenNoHLTOTAL = 0.0
```

```
tracker modification / No Hearing loss / thread 0 / _strategy 1 / _trial 1 / _stage 3  
if(tBorn=0;AgeStart+_stage;_stage-_trial)  
  tborn = 0  
  AgeStart = 0  
  _stage = 3  
if(tBorn=0;AgeStart+_stage;_stage-_trial) = 3.0  
{T} tr_age_current = 3
```

Patient 4: the patient had previously acquired SNHL at age 1. They receive non-surgical treatment in the same year which then is persistent for more than one year. They do not progress to CSOM and enter the screening tree, where they are screened, identified, treated, and then enter a logic node where it is recognized that they previously had SNHL and they return to a state of having SNHL with no treatment.

random walk to / Screen / Rand(0,1) = 0.521522883912903

probability / Identified / thread 0 / _strategy 1 / _trial 1 / _stage 4
Probability (Node509)

probability / Identified / thread 0 / _strategy 1 / _trial 1 / _stage 4
pIdentifiedFromScreen
pIdentifiedFromScreen = 0.985
pIdentifiedFromScreen = 0.985
Probability (Node509) = 0.985

random walk to / Identified / Rand(0,1) = 0.60610151142024

probability / Treated / thread 0 / _strategy 1 / _trial 1 / _stage 4
Probability (Node511)

probability / Treated / thread 0 / _strategy 1 / _trial 1 / _stage 4
pTreatmentFromScreening
pTreatmentFromScreening = 0.5
pTreatmentFromScreening = 0.5
Probability (Node511) = 0.5

random walk to / Treated / Rand(0,1) = 0.4440834427820713

logic node / No pre-existing SNHL / thread 0 / _strategy 1 / _trial 1 / _stage 4
tr_SNHL=0
tr_snhl = 1
tr_SNHL=0 = 0.0

logic node / Pre-existing SNHL / thread 0 / _strategy 1 / _trial 1 / _stage 4
tr_SNHL=1
tr_snhl = 1
tr_SNHL=1 = 1.0

random walk to / Pre-existing SNHL / Rand(0,1) = 0.4659456174042881

jump to / rAOM, pOME

1. The patient acquires SNHL at age 1. They acquire AOM at age 3, which progresses to OME which is then persistent for over a year.

tracker modification / SNHL only, no tx / thread 0 / _strategy 1 / _trial 1 / _stage 1
1
1 = 1.0
{T} tr_snhl = 1

2. The patient acquires AOM at age 3 which turns into OME persisting for more than three months.

```
random walk to / OME?3 months / Rand(0,1) = 0.596388397877195
```

```
tracker modification / OME?3 months / thread 0 / _strategy 1 / _trial 1 / _stage 3  
tr_OME3moCumInc+1  
tr_ome3mocuminc = 0  
tr_OME3moCumInc+1 = 1.0  
{T} tr_ome3mocuminc = 1
```

```
probability / sugical treatment / thread 0 / _strategy 1 / _trial 1 / _stage 3  
Probability (Node367)
```

```
probability / sugical treatment / thread 0 / _strategy 1 / _trial 1 / _stage 3  
pOMEsurgery  
pOMEsurgery = 0  
pOMEsurgery = 0.0  
Probability (Node367) = 0.0
```

```
random walk to / non-surgical treatment / Rand(0,1) = 0.3709850768491125
```

```
probability / Resolution / thread 0 / _strategy 1 / _trial 1 / _stage 3  
Probability (Node371)
```

```
probability / Resolution / thread 0 / _strategy 1 / _trial 1 / _stage 3  
pOMEResolve1year  
pOMEResolve1year = 0.705  
pOMEResolve1year = 0.705  
Probability (Node371) = 0.705
```

```
random walk to / Persistence ?1 year / Rand(0,1) = 0.9893631946736395
```

- The patient does not progress to CSOM and enters the screening tree; they are screened, identified, treated, and are returned to the pre-existing SNHL health state

```

probability / Treated / thread 0 / _strategy 1 / _trial 1 / _stage 4
pTreatmentFromScreening
  pTreatmentFromScreening = 0.5
pTreatmentFromScreening = 0.5
Probability (Node511) = 0.5

random walk to / Treated / Rand(0,1) = 0.4440834427820713

logic node / No pre-existing SNHL / thread 0 / _strategy 1 / _trial 1 / _stage 4
tr_SNHL=0
  tr_snhl = 1
tr_SNHL=0 = 0.0

logic node / Pre-existing SNHL / thread 0 / _strategy 1 / _trial 1 / _stage 4
tr_SNHL=1
  tr_snhl = 1
tr_SNHL=1 = 1.0

random walk to / Pre-existing SNHL / Rand(0,1) = 0.4659456174042881

jump to / rAOM, pOME

termination condition / Markov Base / thread 0 / _strategy 1 / _trial 1 / _stage 5
_stage=100
  _stage = 5
_stage=100 = 0.0

Incremental Reward (Payoff 2) / SNHL only, no tx / thread 0 / _strategy 1 / _trial 1 / _stage 5
if(tr_HLDb <= 34; uSNHLMild;0) + if(tr_HLDb > 34 & tr_HLDb <= 49; uMildModSNHL;0) + if(tr_HLDb > 49 & tr_HLDb <= 64; uModSNHL;0) + if(tr_HLDb > 64 & tr_HLDb
<= 79; uModSevSNHL;0) + if(tr_HLDb > 79 & tr_HLDb <= 94; USevSNHL;0) + if(tr_HLDb > 94; uProfoundSNHL;0)
  tr_hldb = 0
  uSNHLMild = 0.713-uDecrementAll
  uDecrementAll = 0
  uSNHLMild = 0.713
  tr_hldb = 0
  tr_hldb = 0
  tr_hldb = 0
  tr_hldb = 0
  tr_hldb = 0
  if(tr_HLDb <= 34; uSNHLMild;0) + if(tr_HLDb > 34 & tr_HLDb <= 49; uMildModSNHL;0) + if(tr_HLDb > 49 & tr_HLDb <= 64; uModSNHL;0) + if(tr_HLDb > 64 & tr_HLDb
<= 79; uModSevSNHL;0) + if(tr_HLDb > 79 & tr_HLDb <= 94; USevSNHL;0) + if(tr_HLDb > 94; uProfoundSNHL;0) = 0.713

```