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Cost-Effectiveness of Neonatal Hearing Screening Programs: A Micro-Simulation Modeling Analysis

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Objectives: Early detection of neonatal hearing impairment moderates the negative effects on speech and language development. Universal neonatal hearing screening protocols vary in tests used, timing of testing and the number of stages of screening. This study estimated the cost-effectiveness of various protocols in the preparation of implementation of neonatal hearing screening in Albania.

Design: A micro-simulation model was developed using input on demography, natural history of neonatal hearing impairment, screening characteristics and treatment. Parameter values were derived from a review of the literature and expert opinion. We simulated multiple protocols using otoacoustic emissions (OAE) and automated auditory brainstem response (aABR), varying the test type, timing and number of stages. Cost-effectiveness was analyzed over a life-time horizon.

Results: The two best protocols for well infants were OAE followed by aABR (i.e., two-stage OAE-aABR) testing in the maternity ward and single-aABR testing. Incremental cost-effectiveness ratios were €4181 and €78,077 per quality-adjusted life-year gained, respectively. Single-aABR screening led to more cases being detected compared to a two-stage screening program. However, it also resulted in higher referral rates, which increased the total costs of diagnostics. Multi-staged screening decreased referral rates but may increase the number of missed cases due to false-negative test results and nonattendance.

Conclusions: Only the 2-stage OAE-aABR (maternity ward) protocol was below the willingness-to-pay threshold of €10,413 for Albania, as suggested by the World Health Organization, and was found to be cost-effective. This study is among the few to assess neonatal hearing screening programs over a life-time horizon and the first to predict the cost-effectiveness of multiple screening scenarios.

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INTRODUCTION

About 32 million children worldwide experience disabling hearing impairment (WHO 2013).

Before the widespread implementation of hearing screening, permanent hearing impairment among infants typically went undetected until signs of the hearing impairment were evident to caregivers. Early detection of neonatal hearing impairment can lead to earlier interventions that improve language development (Pimperton et al. 2016; Yoshinaga-Itano et al. 2017). Studies have repeatedly shown that, by introducing universal neonatal hearing screening (UNHS), more infants with hearing impairment are referred for audiological assessment and at a younger age (Thompson et al. 2001; Wood et al. 2015). A United Kingdom controlled trial found that with UNHS, 62 more infants with hearing impairment per 100,000 were referred for audiological assessment before 6 months of age compared to the study cohort without UNHS (Wessex Universal Neonatal Hearing Screening Trial Group 1998).

UNHS has been implemented in the US and in many European countries, but screening protocols vary in the type of screening test used, the timing of testing, and the number of screening rounds (Arehart et al. 1998; Joint Committee on Infant Hearing guidelines 2007; Sloot et al. 2015). When a screening program is either in development or being evaluated, comparing the cost-effectiveness of various screening protocols is useful to support the decision-making processes. However, the evidence supporting UNHS as a cost-effective program is scarce. A recent systematic review by Sharma et al. (2019) updated the previous systematic reviews by Colgan et al. (2012) and Langer et al. (2012). They concluded that only a few publications included quality of life, estimates over the entire lifetime, or distinction of the severity of hearing impairment.

The design of UNHS protocols includes the test method(s), the location, and the number of rescreening stages. The screening tests used may be otoacoustic emissions (OAE), automated auditory brainstem response (aABR), or a combination of the two. A screening test may result in either "pass" or "refer." The first stage aims to screen all infants. In a one-stage protocol, infants that do not pass the screen will be referred for a full audiological diagnostic assessment. In a protocol with multiple stages, infants that do not pass initial screening are referred for a second (and possible third) stage for rescreening before referral for diagnostic assessment. Screening may take place in the

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maternity hospital before discharge or after discharge during an outpatient visit.

It is not feasible to compare multiple screening protocols in a controlled trial, simply because of the expense and time required to recruit and follow-up an appropriately large study sample micro-simulation models, in which individuals lives are simulated, use data resources from multiple studies, which enable calculations of the life-time costs and effects of a variety of screening protocols. Local circumstances, such as health care infrastructure, screening participation, treatment opportunities, and costs, could all influence the effectiveness of a screening program. For example, if the test is performed when the infant is still in the maternity ward, the participation rates for the first hearing test are likely to be high. Long travel distances—especially in poorer, rural regions—could result in lower participation rates for follow-up screening tests and audiological assessments.

Part of the EUSCREEN project included implementation of UNHS in Albania. This study aimed to estimate the most cost-effective UNHS protocol. We developed a micro-simulation model. Then, we simulated multiple UNHS protocols for the example of Albania and calculated the most cost-effective protocol for the country. The model was built to analyze screening protocols for full term, well babies excluding those admitted to the neonatal intensive care unit.

MATERIALS AND METHODS

We developed a microsimulation model using the MIcrosimulation SCreening ANalysis framework to simulate the costs and effects of various UNHS programs. MIcrosimulation SCreening ANalysis is a microsimulation model developed for the evaluation of screening and has been used previously to estimate the harms, benefits, and cost-effectiveness of various cancer screening programs (de Kok et al. 2012; van Hees et al. 2014; Heijnsdijk et al. 2015; Sankatsing et al. 2015). In this model, the lives of 10 million individuals were simulated from birth to death in a situation without a NHS program. Next, the model simulates for the same population a situation in which a screening program identifies the hearing impairment. With this approach, the population health outcomes of various screening programs can be compared.

Figure 1 describes the first part of the model. Permanent hearing impairment can be congenital or acquired later on in life. Hearing impairment can worsen in the first years of life or it can progress from unilateral to bilateral. Directly after birth, the hearing impairment is undetected (pre-clinical states in Fig. 1). Without a screening program, this hearing impairment will be detected later in life, by the parents, caregivers, or teachers. The age of clinical detection depends on the age of onset and degree of hearing impairment (ref Fortnum). With a screening program,

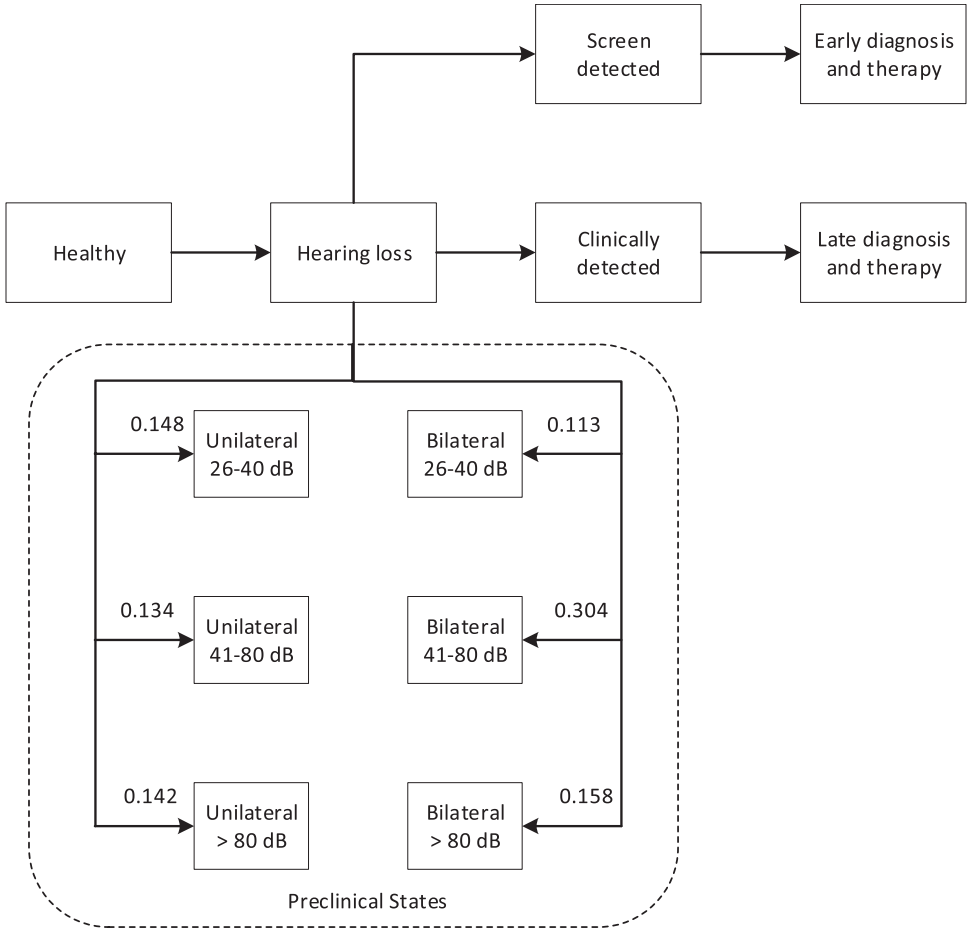

Fig. 1. General MISCAN-Hearing model structure including possible hearing impairment states. In the model, an infant can get hearing impairment at birth or at any time in life. The proportions unilateral and bilateral and level of severity are indicated in the figure. Also, progression to a more severe state or from unilateral to bilateral is possible (not shown in the figure). Hearing loss can be detected clinically (for example by parents' concerns), or by neonatal hearing screening. When hearing loss is detected by screening, the infants probably have a higher quality of life. MISCAN, MIcrosimulation SCreening Analysis.

the hearing impairment can be either detected or missed by the screening test. Detected hearing impairment can be left untreated (especially mild or unilateral hearing impairment) or treated with hearing aids or cochlear implantation. Depending on the severity of the hearing impairment and the effect of interventions, quality of life will be affected. Supplement I in Supplemental Digital Content 1, http://links.lww.com/TP/C32 provides more detailed information about the micro-simulation modeling techniques used for this analysis.

We defined a set of input parameters and selected their values based on data from the literature and multiple expert meetings. Next, we defined a general model for hearing screening. Finally, as an example, we altered several parameters to the circumstances within the context of Albanian health care. An overview of all input parameter values is provided in Table 1.

Natural History of Hearing Impairment

Permanent hearing impairment can be unilateral or bilateral, categorized into three levels of severity, based on the World Health Organization (2017) classification: mild hearing impairment (26 to 40 decibel [dB]), moderate and severe hearing impairment (41 to 80 dB), and profound hearing impairment (more than 80 dB). Input from multiple large cohort studies was used to model this natural history (Fortnum & Davis 1997; Cone-Wesson et al. 2000; Berninger & Westling 2011; Watkin & Baldwin 2011).

Accurate data on the onset and progression of hearing impairment are scarce (Fortnum et al. 2001; Barreira-Nielsen et al. 2016). Barreira-Nielsen et al. (2016) followed children identified with hearing impairment in the neonatal period until 4 years of age. Their results showed that 23% of the children had a deterioration of 20 dB within the 4 years period. In our model, we assumed that 10% of infants with mild hearing impairment will progress to moderate/severe and 10% of infants with moderate/severe hearing impairment will progress to profound across an average of 4 years. Similarly, we assumed that 10% of infants with unilateral hearing impairment will develop bilateral hearing impairment within an average of 4 years. Using these proportions as input parameters, the model estimated 22.7 per 10,000 neonates with unilateral or bilateral hearing impairment >25 dB at birth. At age 3, a total prevalence of 28.3 per 10,000 children was estimated. This increases to 37.6 per 10,000 children at age 9.

Health-Related Quality of Life

Health-related quality of life (HR-QoL) is described by using utility values, where the value zero corresponds to death and one corresponds to being perfectly healthy (Drummond et al. 2005). For the purpose of the model, utility values were derived from Barton et al. (2006), who used a version of the Health Utilities Index Mark 3 for children with bilateral hearing impairment greater than 40 dB. Utility values for bilateral hearing impairment 26 to 40 dB and unilateral hearing impairment greater than 40 dB were assumed to be 0.85 and no utility loss was assumed for unilateral mild hearing impairment (Table 1).

With the assumption that interventions were successful, we simulated an improvement in quality of life expressed by a higher utility value. For example, a child having bilateral hearing impairment between 41 and 80 dB and successfully treated with hearing aids and follow-up support, will have a utility of 0.85 instead of 0.66 for the rest of his/her lifetime.

TABLE 1. Input parameters and baseline values for MISCAN hearing screening model

Input parameter	Baseline value
Demography	Life table Albania (Eurostat, 2017)
Time before clinical detection	Average (s.d.) Weibull distribution
Unilateral	4 years (1)
Bilateral, 26–40 dB	3 years (1)
Bilateral, 41–80 dB	2 years (1)
Bilateral, >80 dB	1 year (0.5)
Test device	Sensitivity per test
OAE	0.95
aABR	0.97
Treatment by hearing impairment category	Probability
Unilateral 26–40 dB	0.5 no treatment
	0.5 family education
Unilateral 41–80 dB	0.3 no treatment
	0.6 family education
	0.1 hearing aid
Unilateral >80 dB	0.3 no treatment
	0.65 family education
	0.05 hearing aid
Bilateral 26–40 dB	0.35 no treatment
	0.35 family education
	0.3 hearing aid
Bilateral 41–80 dB	0.1 no treatment
	0.1 family education
	0.8 hearing aid
Bilateral >80 dB	0.05 no treatment
	0.05 family education
	0.9 hearing aid
Health-related quality of life by hearing impairment category	
Unilateral mild (26–40 dB)	1.0
Unilateral moderate, severe, profound (>40 dB)	0.85
Bilateral mild (26–40 dB)	0.85
Bilateral moderate, severe (41–80 dB)	0.661
Bilateral profound (>81 dB)	0.467
Average unit costs	EUROs
Invitation per child	1
OAE screening test	10
aABR screening test	20
Diagnostic consultation	60
Early family education (first year)	94
Hearing aid (per side)	110
Fitting hearing aids (per side)	290
Repair of hearing aids (yearly)	23
Extra costs due to late treatment (age 1–16)	EUROs
Unilateral >80 dB loss	500
Bilateral 41–80 dB loss	1000
Bilateral >80 dB loss	1500

aABR indicates automated auditory brainstem response; OAE, otoacoustic emissions.

Model Adjustments for Albania

Multiple screening protocols were defined with a variation in test method, age of the infant during testing, and the number of stages of screening. For each stage in each protocol, the test sensitivity, referral rate, and participation rates were defined (Table 2). We used screening test sensitivities of 97% for aABR and 95% for OAE for detecting hearing impairment >40 dB, based on the findings of a controlled trial study in the

TABLE 2. Screening protocols and attendance rates per screening stage for Albania

Screening protocol	Day of testing after birth (per screening stage)	Program sensitivity (100% attendance assumed)	Positive predictive value	Stage 1		Stage 2		Stage 3		Overall attendance
				Attend*	Refer**	Attend	Refer	Attend	Refer	
OAE OAE aABR	2 – 10 – 30	88%	17.7%	95%	10%	70%	30%	70%	30%	47%
OAE OAE aABR (maternity)	1 – 2 – 10	88%	8.9%	95%	20%	95%	30%	70%	30%	63%
OAE aABR	2 – 10	92%	6.1%	95%	10%	70%	30%	N/A	N/A	67%
OAE aABR (maternity)	2 – 2	92%	5.6%	95%	10%	95%	30%	N/A	N/A	90%
aABR aABR	2 – 10	94%	8.2%	95%	7%	70%	30%	N/A	N/A	67%
aABR	2	97%	2.5%	95%	7%	N/A	N/A	N/A	N/A	95%

Overview of all screening protocols tested in the model. All programs assume first-round testing at the maternity ward. Both programs labeled 'maternity' involve screening while still admitted to maternity ward for the first two stages.
Attend: Attendance rate; number of children attending specified screening stage, as a percentage of all children invited for that particular round. Refer**: Referral rates; number of children referred to next stage or diagnostic follow-up, as a percentage of all children screened in that particular stage.*
aABR indicates automated auditory brainstem response; OAE, otoacoustic emissions.

United Kingdom (Kennedy et al. 2005), see Supplement I in Supplemental Digital Content 1, http://links.lww.com/TP/C32.

For the referral rate, we used 9.7% when screening was performed with OAE on day 2 (24 to 48 hours) after birth, based on a previous pilot study in Albania (Hatzopoulos et al. 2007). When OAE testing was performed within the first 24 hours after birth, we used a higher referral rate (20%), due to increased likelihood of fluid in the middle ear directly after birth (Hergils 2007). For testing with aABR on day 2, a referral rate of 7% was used (Hofmann et al. 2012).

Participation rates were estimated to be 95% for all inpatient screens. This was the case in all first stages and in some second stages, if performed while infants were still in the maternity ward. When second (and third) stages occur after hospital discharge, we estimated a 70% participation rate based on expert opinion from the members of the EUSCREEN study.

Treatment

For the example of Albania, each treatment intervention can include family education, sign language, speech therapy, and special education throughout childhood. The probability of each treatment type was based on the Bamford et al. (2007) report, updated with Albanian expert opinion. Currently, there is little opportunity for pediatric cochlear implantation in Albania. Although cochlear implantation may be adopted as usual care in the future, we assumed that all patients eligible for cochlear implantation were offered amplification via hearing aids. We estimated the probability of success (i.e., significant improvement of HR-QoL) to be 80% if infants were treated before their first birthday. The success rate declines linearly to 0% if initiated at age 6 years of age or older.

Costs of Screening and Treatment

The costs per screen were estimated based on the screening test device used, nurses' salary, and room rental. The costs for treatment were divided into costs for initial treatment (first year), costs for life-time usage of hearing aids, and additional costs for special education and early family intervention (Bamford et al. 2007). Infants treated with hearing aids were assumed to have their hearing aids replaced every 5 years on average for the rest of their lives. Most likely, each infant detected after the age of one would require extra investments on special education and early family intervention. These costs were obtained from local expert opinion and were included in the model for the ages of 1 to 16 years. Prices were converted from 2007 pound (£) to 2017 euro (€). Both direct and downstream health care costs were included (Table 1).

Cost-Effectiveness

For each protocol, the quality-adjusted life years (QALYs) gained were calculated by multiplying the increase in HR-QoL for each child by the remaining life-years based on the life expectancy for Albania. Next, the sum of all costs (screening, diagnosis, and treatment) and the sum of all QALYs were calculated for all 10 million infants in the micro-simulation. Cost-effectiveness was calculated by dividing the total net costs by the QALYs gained. We used a 3% discount rate for both costs and QALYs, that is, the costs and QALYs were valued 3% less each year to reflect uncertainty in the future, as is common practice in health economic studies. Cost-effectiveness was analyzed from a health care perspective, meaning that societal costs (e.g., travel costs for the parents) and benefits (e.g., increased work productivity later in life due to successful amplification with hearing aids in early childhood) were not included.

To compare the screening protocols, we determined the average cost-effectiveness ratio (ACER) and the incremental cost-effectiveness ratio (ICER). The ACER is calculated as the net costs per QALY gained compared with no screening. The ICER is calculated as the incremental net costs per incremental QALY gained compared with the previous cost-effective protocol.

One-way sensitivity analyses were performed by varying each selected parameter of the model individually. These additional model simulations aimed to evaluate the effect of specific parameters on the simulation results. The results of the sensitivity analyses can reflect variation across countries.

RESULTS

Effects

About 23 infants (per 10,000 population) were expected to be born with hearing impairment. Table 3 shows the average number of infants participating and referred and the number of cases detected per 10,000 infants for each screening protocol. The 2-stage screening protocol, OAE-aABR (maternity), referred 271 infants for audiological diagnostic testing, to detect an average of 15.2 infants with hearing impairment. When the second stage of the same protocol (OAE-aABR) was performed at day 10 after birth, 200 infants were referred for diagnostic testing, which resulted in an average of 11.1 infants with

TABLE 3. Predicted number of participation, referrals, cases detected, and cost-effectiveness for various screening protocols for Albania per 10,000 children

	OAE aABR (maternity)	OAE aABR	OAE OAE aABR	OAE OAE aABR (maternity)	aABR	aABR aABR
Stage 1 participation	9500	9500	9500	9500	9500	9500
Stage 1 referrals[a]	950	950	950	1900	**665**	665
Stage 2 participation	903	665	665	1805	n/a	466
Stage 2 referrals[a]	**271**	**200**	200	542	n/a	**140**
Stage 3 participation	n/a	n/a	140	379	n/a	n/a
Stage 3 referrals[a]	n/a	n/a	**42**	**114**	n/a	n/a
Cases detected due to UNHS, age <6 months[b]	15.2	11.1	7.4	10.2	16.8	11.5
Bilateral >40 dB cases detected due to UNHS, age <6 months[c]	8.6	6.3	4.2	5.8	9.6	6.5
Discounting 3%						
Total extra costs (€)	€45,915	€61,976	€71,568	€74,874	€135,968	€147,067
Total QALYs gained	10.98	8.05	5.39	7.48	12.14	8.40
ACER[d] (€/QALYs)	€4182	€7700	€13,273	€10,013	€11,204	€17,511
ICER[e] (Δ€/ΔQALYs)	€4182	Inefficient	Inefficient	Inefficient	€78,077	Inefficient

[a]*Referrals from screening to diagnostic consultation in the bold cells.*
[b]*Predicted total cases of hearing impairment at birth: 22.7/10,000.*
[c]*Predicted total cases of bilateral hearing impairment >40 dB at birth: 10.4/10,000.*
[d]*ACER, average cost-effectiveness ratio: total costs/total QALYs gained compared with no NHS (rounded).*
[e]*ICER, incremental net costs per incremental QALY gained compared with the previous cost-effective protocol (rounded).*
aABR indicates automated auditory brainstem response; OAE, otoacoustic emissions; QALYs, quality-adjusted life year; UNHS, universal neonatal hearing screening.

hearing impairment detected. Here, fewer infants were detected due to lower participation at the second stage. If a multi-stage screening protocol is implemented, infants were lost to follow-up between test rounds and fewer infants were detected. For a single-stage aABR screening protocol with minimal lost to follow-up, a relatively high numbers (average of 16.8 infants) were detected. However, in this protocol, a large amount (665 infants) were referred for audiological diagnostics, which substantially increased the expense.

Cost-Effectiveness

Table 3 shows the total life-time costs, QALYs gained, ACER, and ICER for each screening protocol for a cohort of 10,000 children. OAE-aABR (maternity) was estimated to cost €45,915 for 11 QALYs gained compared to no screening program. This resulted in €4181 per QALY gained (ACER). The single-stage aABR protocol was estimated to cost €135,968 for 12.1 QALYs gained compared to no screening protocol. This resulted (rounded) in €11,204 per QALY gained (ACER).

Figure 2 provides another overview of the total life-time costs and QALYs gained for each screening protocol. The two protocols using only aABR were more expensive than the protocols using only OAE or a combination of OAE and aABR. The OAE-aABR (maternity) protocol and aABR protocol gained the most QALYs, but the differences between the protocols were very small (one QALY per 10,000 children).

In Figure 2, the efficiency frontier is the line that connects the cost-effective screening protocols. All protocols that fall beneath this line are inefficient. For example, implementing a three-stage screening protocol would cost more than a two-stage protocol and would also result in fewer QALYs gained. After excluding the inefficient protocols, only two protocols remained: OAE-aABR (maternity) and aABR. ICERs were calculated by dividing the difference in net costs by the differences in QALYs gained. The cheapest protocol was OAE-aABR (maternity). When comparing a situation without NHS to OAE-aABR (maternity), the resulting ICER was (rounded) €4181 per QALY gained (€45,915/11.0-0). When comparing OAE-aABR (maternity) to aABR, the resulting ICER (rounded) was €78,077 per QALY gained ([135,968 to 45,915]/[12.1 to 11.0]).

Sensitivity Analyses

One-way sensitivity analyses were performed for input parameters on the distribution of severity categories of hearing loss; the age of clinical detection; screening participation rates; costs of diagnosis and quality of life. Sensitivity analyses showed that the two-stage OAE-aABR (maternity) screening protocol using different assumptions was still preferred overall other protocols tested in the model (Supplement II in Supplemental Digital Content 1, http://links.lww.com/TP/C32).

DISCUSSION

The model revealed substantial differences in number of infants detected by screening and cost-effectiveness between

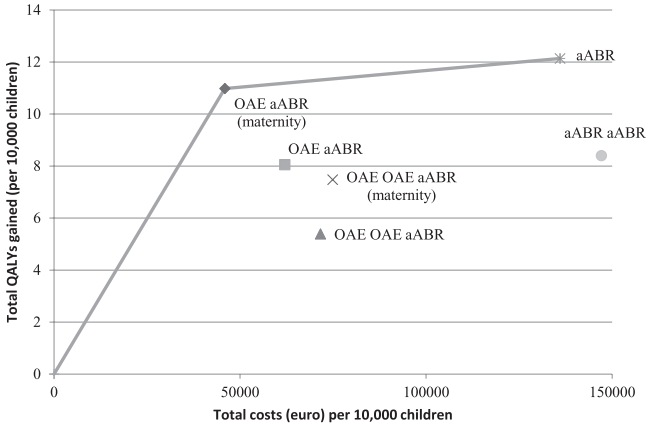

Fig. 2. The total costs and total QALYs gained for each strategy for Albania (at 3% discount rate). QALYs indicates quality-adjusted life year.

different screening methods. Overall, performing a multistage screening program will decrease the number of refers to diagnostic assessment. A two-stage OAE-aABR protocol resulted in over four times as many referrals for diagnostic testing compared to the three-stage OAE-OAE-aABR protocol. Many extra referrals will lead to unnecessary health care costs and is a burden for infants and their caregivers. Contrary, performing multiple screening stages may lead to an increased number of missed cases of hearing impairment in each screening stage, either caused by infants that don't attend the next stage of the protocol or by having false negative test results.

Another example of a choice in the screening program is about the day of screening. Ensuring all tests are performed while the infant is still in the maternity ward will increase the uptake and may lead to fewer cases lost in between stages. However, performing the first screening test too soon after birth will increase the number of false-positive tests due to the high likelihood of fluid in the middle ear directly after birth. Differences in health care system structure and child health care utilization between countries have to be taken into consideration when designing the most optimal screening program.

The willingness-to-pay threshold is a benchmark for health care policymakers to practically apply cost-effectiveness analyses to their decision-making processes. A new health care intervention can be considered cost-effective if the ICER between the new and current intervention is no more than three times the gross domestic product per capita (World Health Organization 2016). For Albania, the willingness-to-pay threshold is € 10,413 (3 times €3471) per QALY gained (World Bank Group 2017). Only the two-stage OAE-aABR (maternity) protocol (ICER = €4181) fell under the willingness-to-pay threshold for Albania. Therefore, the two-stage OAE-aABR (maternity) protocol is the cost-effective protocol for this country. Sensitivity analyses showed our model predictions are robust. The cost-effective ratio of this protocol remained below the Albanian willingness-to-pay threshold when we assumed an increasing age of clinical detection (ICER €2371) or a decreasing screening participation rate (ICER €6071). However, the cost-effectiveness ratio of the OAE-aABR (maternity) protocol exceeded the willingness-to-pay threshold when we assumed that the distribution of the prevalence of hearing impairment was shifted towards milder hearing losses (ICER €12,159) or when we assumed that effects of early hearing impairment identification on quality of life were smaller (ICER €24,895).

To our knowledge, our model is the first that compared multiple hearing screening protocols where most studies compared only two to three screening programs (Keren et al. 2002; Grill et al. 2005; Burke et al. 2012; Colgan et al. 2012). Keren et al. (2002) concluded that UNHS could be cost-saving under the assumption that early detection substantially decreases future costs and productivity losses. Burke et al. (2012) concluded that costs of screening and baseline prevalence are the most influential factors in the cost-effectiveness of hearing screening protocols.

The model predictions in this study assessed quality-adjusted life-years over a lifetime horizon, which facilitates comparison between cost-effectiveness studies and interpreting results for decision-makers (Sanders et al. 2016). In contrast, most other studies estimated only the effects in the first years of life or reported on costs per case screened/detected, making it difficult to compare with other health interventions. Furthermore, the natural history component of our model was populated using multiple large cohort-studies, providing more certainty for the data used as model input. Finally, this model includes both unilateral and bilateral hearing impairment as well as mild hearing impairment.

There are some limitations to emphasize. First, our model incorporates hearing screening for well babies only. Infants admitted to the neonatal intensive care unit are often screened with a separate protocol due to the increased prevalence of auditory neuropathy. Second, we performed an economic evaluation from a health care perspective. We excluded societal costs such as loss of income by the caregivers when traveling for screening and treatment appointments. This was, however, our conscious decision. Scarcity of evidence on life-time productivity losses (e.g., income) due to hearing impairment would increase uncertainty regarding model outcomes. Thirdly, the exact relationship between the severity of neonatal hearing impairment, timeliness of early intervention and HR-QoL is unclear. A systematic review (41 studies) and meta-analysis (included 4 out of the 41 studies) found that HR-QoL was generally lower for children with hearing impairment compared to their normally hearing peers, but not all included studies supported that conclusion (Roland et al. 2016). However, to compare UNHS with other health care interventions, it is necessary to calculate costs per QALY gained. We aimed to cover the uncertainty of the utility values by imposing higher utilities (compared to baseline analysis) for hearing impairment in the sensitivity analysis.

Several assumptions had to be made for the model input. The participation rate, referral rate, sensitivity, specificity, and prevalence may turn out differently from our estimates. For example, true prevalence of hearing impairment in children is often unknown and varies between countries (Wilson et al. 2017; Bussé, 2020). Also, differences in socioeconomic background of the target population may lead to different health care utilization (Andersen 1995). Citizens of rural areas may experience difficulties in access to care caused by longer travel times for screening and follow-up diagnostics. Furthermore, referral rates are highly variable and have been shown to depend on the training of staff conducting the screening, the day of testing, the type of test used, and the referral criteria (unilateral/bilateral, hearing impairment threshold) (Vohr et al. 2001). Referral rates have been shown to be high in the first years of screening implementation and decrease as experience increases among the screeners (De Ceulaer et al. 2001; Wood et al. 2015). More accurate parameter values for the specified Albanian setting will become available after the first few years of implementation.

CONCLUSION

We developed a model that evaluated costs and effects of multiple UNHS protocols for well infants over a life-time horizon. The model estimations for Albania supported that a two-stage screening protocol (OAE-aABR maternity) was cost-effective for implementation. Because our model is readily adjustable, future possibilities for model development can include predictions for other countries and settings. This may be useful to decision-makers when designing the most optimal screening program for their country.

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working groups, critically revised the manuscript, and approved the final manuscript as submitted. A.G., HL.J.H., and H.J.d.K. conceptualized and designed the study, analyzed and interpreted the data in multiple organized expert working groups, critically revised the manuscript, and approved the final manuscript as submitted. F.S. conceptualized and designed the study, critically revised the manuscript, and approved the final manuscript as submitted. All authors agree to be accountable for all aspects of the work.

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