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Validation of the LittlEARS® Auditory Questionnaire in children with normal hearing

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ABSTRACT

Objectives: With more children receiving cochlear implants during infancy, there is a need for validated assessments of pre-verbal and early verbal auditory skills. The LittlEARS® Auditory Questionnaire is presented here as the first module of the LittlEARS® test battery. The LittlEARS® Auditory Questionnaire was developed and piloted to assess the auditory behaviour of normal hearing children and hearing impaired children who receive a cochlear implant or hearing aid prior to 24 months of age. This paper presents results from two studies: one validating the LittlEARS® Auditory Questionnaire on children with normal hearing who are German speaking and a second validating the norm curves found after adaptation and administration of the questionnaire to children with normal hearing in 15 different languages.

Methods: Scores from a group of 218 German and Austrian children with normal hearing between 5 days and 24 months of age were used to create a norm curve. The questionnaire was adapted from the German original into English and then 15 other languages to date. Regression curves were found based on parental responses from 3309 normal hearing infants and toddlers. Curves for each language were compared to the original German validation curve.

Results: The results of the first study were a norm curve which reflects the age-dependence of auditory behaviour, reliability and homogeneity as a measure of auditory behaviour, and calculations of expected

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and critical values as a function of age. Results of the second study show that the regression curves found for all the adapted languages are essentially equal to the German norm curve, as no statistically significant differences were found.

Conclusions: The LittlEARS® Auditory Questionnaire is a valid, language-independent tool for assessing the early auditory behaviour of infants and toddlers with normal hearing. The results of this study suggest that the LittlEARS® Auditory Questionnaire could also be very useful for documenting children's progress with their current amplification, providing evidence of the need for implantation, or highlighting the need for follow-up in other developmental areas.

1. Introduction

The widespread implementation of newborn hearing screening and subsequent earlier intervention with cochlear implants (CI) has necessitated more and better ways of assessing younger and younger children. With infants as young as 5 or 6 months old receiving a CI, there is a clear need for validated tools assessing auditory–verbal progress after implantation which are sensitive to the particular skill set of the pre-verbal child. Now more than ever, these tools are not only relevant to evidence-based practice in the area of cochlear implantation, but they are crucial to predicting timelines and expected outcomes with the individual in mind. Significant differences have been documented in the auditory–verbal growth of children implanted under the age of 4 versus under the age of 2 [1–6]. In fact, children implanted before the age of 2 reportedly now have the possibility of closing the gap between their own auditory–verbal skills and that of normal hearing peers [7]. In addition, support for very early implantation and for the existence of a "critical" or at least "sensitive" period for optimal auditory and verbal development [8] is growing and with it, the need for strong and valid measures. Knowing exactly how the skill set of each individual child compares to that of normal hearing peers would be useful in determining realistic goals and targets for therapy, not to mention counselling parents along those lines.

A good measure of auditory skill development must be validated if it is meant to inform evidence-based rehabilitation practice. It must be able to furnish pre-operative, post-operative and follow-up data. The availability of a variety of relevant and appropriate evaluations in several languages is essential for documenting the benefits of early implantation and aiding in the decision-making processes of families of newborns with hearing impairment worldwide.

The MED-EL LittlEARS® Auditory Questionnaire (LEAQ) [9,10] was designed as a continuation of the Evaluation of Auditory Responses to Speech (EARS) [11], a comprehensive test battery developed in 1996 by Allum-Mecklenburg to aid the evaluation and rehabilitation of CI recipients 3 years and older. The LEAQ was the first LittlEARS® module introduced and supplies a general picture of auditory behaviour and functioning for children under the age of 2. The 35 "yes/no" questions draw from speech-language research documenting the receptive, semantic, and expressive behaviours and milestones which normally constitute an infant or toddler's reactions to auditory stimuli in the natural environment. The LEAQ yields a total score (total of "yes" responses) which corresponds to expected values for a given age. In this way the LEAQ is intended to document general progress and age appropriateness of the auditory behaviours exhibited by the infant or toddler pre-operatively and after cochlear implantation. The LEAQ aims to provide valuable information to clinicians concerned with the progress of infants and toddlers with normal hearing or with infants who need general follow-up after newborn hearing screening [12].

To generate the relevant items for the questionnaire a thorough literature review and focus groups discussions, such as paediatric audiologists, psychologists, statisticians, and speech pathologists, were obtained. Further, the experience and results of existing developmental scales, such as: "Receptive – Expressive Emergent Language Test" [13], "Mac Arthur Communicative Development Inventories" [14], "ELFRA" [15], "The Rossetti Infant and Toddler Language Scale" [16], and "IT-MAIS" [17] were studied before creating the new questionnaire.

Speech and language development research considers the perception of acoustic signals in babies to be one of the crucial aspects of their development. One of the general questions regarding pre-verbal auditory development is how babies behave in response to auditory stimuli? Northern and Downs [18] provide an overview of observable behavioural responses: reflexive, orienting and attentive. Additionally, the head turning behaviour was described as an orienting response with reference to the localization of a sound source. With continuing development, auditory behaviour can also be detected using visual reinforcement and conditional behavioural responses [19]. Infants clearly show preference to their mother's voice and are able to recognise rhymes and melodies as well as to use sentence prosody in order to discriminate words [20–22]. Newborns also show the ability to discriminate suprasegmental, prosodic features [23,24] and infants can discriminate phonetic components of a language [24,25]. Later on, infants are able to distinguish words from other acoustic stimuli and associate them with their conceptual representations [26,27]. Auditory skills obtained in the pre-verbal stages of development seem to be crucial for the communicative progress and have a significant value in child's further speech and language development.

The questionnaire format relies on parental observation; this format is justified, as infants and toddlers are often unwilling to participate in unfamiliar situations and are too young for standardized testing. According to Grimm and Doil, parent questionnaires have been shown to be "suitable and reliable screening tools with high validity" [15]. The LEAQ was designed with special attention to the quality requirements outlined by Grimm and Doil [15] and with efficiency in mind.

The purpose of the current study was (1) the validation of the LEAQ on children with normal hearing who are German speaking, as published in German by Weichbold et al. [28] and (2) the adaptation and validation of the LEAQ in 15 languages.

2. Study 1—development of the German version of the LEAQ

The LEAQ was initially developed in German, and both its theoretical background and validation statistics have been reported in German [28]. Because this version was the basis for the English version from which subsequent versions came, a brief report about its construction is given here.

2.1. Methods

2.1.1. Subjects

In a cross-sectional study 218 children aged between 5 days and 24 months were recruited from day nurseries in Innsbruck, Austria

Table 1
Parameters of the item analysis: index of difficulty, discriminatory power coefficient, selectivity index, correlation between age and score for the original German and Austrian group ($N = 218$) and the overall ($N = 3309$) sample.

Item nr.	Index of difficulty			Discriminatory power coefficient			Selectivity index			Correlation of age and total score		
	German	Overall	Diff.	German	Overall	Diff.	German	Overall	Diff.	German	Overall	Diff.
1	0.98	0.99	0.01	0.25	0.17	−0.08	0.93	0.91	−0.02	0.21	0.13	−0.08
2	0.98	0.97	−0.01	0.16	0.25	0.09	0.61	0.76	0.15	0.1	0.19	0.09
3	0.94	0.95	0.01	0.37	0.37	0.00	0.75	0.87	0.12	0.3	0.27	−0.03
4	0.93	0.95	0.02	0.37	0.44	0.07	0.72	1.00	0.30	0.26	0.31	0.05
5	0.85	0.89	0.04	0.51	0.44	−0.07	0.71	0.72	0.01	0.41	0.34	−0.07
6	0.84	0.88	0.04	0.59	0.51	−0.08	0.81	0.77	−0.04	0.47	0.41	−0.06
7	0.83	0.87	0.04	0.54	0.52	−0.02	0.73	0.77	0.04	0.44	0.41	−0.03
8	0.82	0.76	−0.06	0.24	0.26	0.02	0.32	0.31	−0.01	0.13	0.13	0.00
9	0.81	0.79	−0.02	0.66	0.42	−0.24	0.84	0.51	−0.33	0.52	0.35	−0.17
10	0.8	0.82	0.02	0.55	0.51	−0.04	0.69	0.67	−0.02	0.43	0.40	−0.03
11	0.78	0.86	0.08	0.58	0.53	−0.05	0.7	0.77	0.07	0.47	0.44	−0.03
12	0.74	0.78	0.04	0.76	0.72	−0.04	0.86	0.87	0.01	0.69	0.62	−0.07
13	0.74	0.78	0.04	0.73	0.63	−0.10	0.82	0.77	−0.05	0.59	0.52	−0.07
14	0.72	0.70	−0.02	0.29	0.42	0.13	0.32	0.46	0.14	0.33	0.27	−0.06
15	0.71	0.66	−0.05	0.76	0.73	−0.03	0.84	0.77	−0.07	0.67	0.63	−0.04
16	0.7	0.67	−0.03	0.75	0.77	0.02	0.82	0.82	0.00	0.66	0.68	0.02
17	0.69	0.59	−0.10	0.76	0.76	0.00	0.82	0.77	−0.05	0.64	0.69	0.05
18	0.64	0.63	−0.01	0.81	0.79	−0.02	0.84	0.82	−0.02	0.76	0.73	−0.03
19	0.63	0.56	−0.07	0.71	0.71	0.00	0.74	0.72	−0.02	0.63	0.61	−0.02
20	0.59	0.60	0.01	0.86	0.85	−0.01	0.88	0.87	−0.01	0.8	0.74	−0.06
21	0.55	0.56	0.01	0.75	0.76	0.01	0.76	0.77	0.01	0.65	0.67	0.02
22	0.52	0.54	0.02	0.87	0.87	0.00	0.87	0.87	0.00	0.81	0.79	−0.02
23	0.51	0.54	0.03	0.85	0.87	0.02	0.85	0.87	0.02	0.8	0.78	−0.02
24	0.5	0.49	−0.01	0.87	0.82	−0.05	0.87	0.82	−0.05	0.81	0.81	0.00
25	0.42	0.47	0.05	0.78	0.77	−0.01	0.79	0.77	−0.02	0.73	0.72	−0.01
26	0.42	0.43	0.01	0.81	0.81	0.00	0.82	0.82	0.00	0.79	0.74	−0.05
27	0.4	0.46	0.06	0.79	0.82	0.03	0.81	0.82	0.01	0.75	0.76	0.01
28	0.4	0.41	0.01	0.77	0.76	−0.01	0.79	0.77	−0.02	0.73	0.70	−0.03
29	0.39	0.35	−0.04	0.7	0.68	−0.02	0.72	0.72	0.00	0.64	0.62	−0.02
30	0.39	0.38	−0.01	0.8	0.74	−0.06	0.82	0.77	−0.05	0.77	0.71	−0.06
31	0.38	0.32	−0.06	0.72	0.67	−0.05	0.75	0.72	−0.03	0.7	0.60	−0.10
32	0.34	0.37	0.03	0.72	0.79	0.07	0.76	0.82	0.06	0.7	0.70	0.00
33	0.32	0.47	0.15	0.62	0.66	0.04	0.66	0.67	0.01	0.63	0.58	−0.05
34	0.27	0.30	0.03	0.65	0.65	0.00	0.73	0.72	−0.01	0.71	0.69	−0.02
35	0.25	0.23	−0.02	0.57	0.61	0.04	0.66	0.72	0.06	0.62	0.57	−0.05
Avg.	0.62	0.63	0.01	0.64	0.63	−0.01	0.75	0.76	0.00	0.58	0.55	−0.03
Min	0.25	0.23	−0.10	0.16	0.17	−0.24	0.32	0.31	−0.33	0.10	0.13	−0.17
Max	0.98	0.99	0.15	0.87	0.87	0.13	0.93	1.00	0.30	0.81	0.81	0.09

and Solingen, Germany. Inclusion criteria were: age of 0–24 months, absence of known disabilities including hearing loss, and parents who were willing to participate in the study. There were 100 female children and 87 male children, with 31 cases where gender was not specified on the intake form. All parents signed informed consent.

2.1.2. Validation procedure

First, a list of 40 questions referring to the auditory behaviours of very young children was compiled and administered to the parents. The parents' answers were statistically analysed within the model of the classical test theory in order to identify questions which were not suitable for inclusion in the questionnaire and to evaluate the psychometric characteristics of the remaining ones.

The statistical analyses included item analysis and scale analysis. Item analysis focused on two statistics: the item facility index and the item discrimination index. Item facility is obtained by calculating the ratio of the number of respondents who give the "yes" response to the whole number of respondents (index of difficulty). Item discrimination is the correlation between an individual item and the total score of the questionnaire (discrimination coefficient). Once the values of the facility and discrimination indices were obtained, the selectivity index was calculated.

For the scale analysis, the correlation between the total score and the age of the children (Pearson's correlation coefficient), the internal consistency of the scale (Cronbach's alpha), the split-half reliability (Spearman–Brown split-half coefficient) and the predictive accuracy of the scale (Guttman's lambda) were determined. Additionally, influence of the child's gender and questionnaire administration type (interviewer versus self-administered) on the total score were assessed.

Standardized values for children with normal hearing were established using the total scores of the sample. A polynomial regression analysis with "age" as the independent variable and the "total score" as the dependent variable was applied to generate a norm curve with standardized values. The results of the regression analysis were also used to determine the confidence intervals in which the age-specific values are found with 95% probability. The lower band of the confidence interval was defined as the critical lower limit for children with normal hearing. Scores above this limit are considered to be consistent with normal, age-appropriate auditory development, while scores below this critical lower limit could raise concern.

2.2. Results

2.2.1. Correlation between age and item scores

To check the items' suitability for measuring the age-dependency of behaviour, their correlation with age was calculated. The correlation coefficients range from 0.10 to 0.81 (Table 1). About one third of the items show a strong positive correlation with age ($r \geq 0.7$), while only a few are weakly correlated ($r \leq 0.3$).

Table 2
Parameters of the scale analysis: correlation coefficient (r) between age and total score, Cronbach's alpha (α), split-half reliability (Spearman's Brown split-half coefficient), Guttman's lambda (λ) and gender independency (p-value) for each language and the overall sample [9].

Country (Language)	Sample size (n)	Corr. age + total score[a]	Cronbach's alpha[b]	Split-half reliability[c]	Guttman's lambda[d]	Gender independency[e]
Belgium (Flemish)	142	0.93	0.96	0.96	0.93	0.22
Bulgaria (Bulgarian)	101	0.82	0.96	0.90	0.87	0.77
China (Mandarin)	157	0.84	0.95	0.91	0.88	0.53
Finland (Finnish)	364	0.91	0.96	0.95	0.93	0.74
France (French)	216	0.83	0.93	0.91	0.90	0.96
Germany/Austria (German)	218	0.91	0.96	0.88	0.93	0.16
Greece (Greek)	93	0.80	0.96	0.89	0.85	0.85
Poland (Polish)	325	0.90	0.95	0.95	0.93	0.54
Romania (Romanian)	88	0.80	0.96	0.89	0.85	0.32
Russia (Russian)	180	0.93	0.97	0.96	0.92	0.93
Serbia (Serbian)	183	0.86	0.97	0.92	0.89	0.50
Slovakia (Slovak)	592	0.92	0.96	0.95	0.89	na[f]
Slovenia (Slovenian)	366	0.92	0.96	0.96	0.93	0.23
Switzerland (German)	92	0.92	0.96	0.96	0.94	0.76
USA (English)	144	0.85	0.98	0.92	0.88	0.96
USA (Spanish)	48	0.93	0.95	0.96	0.94	na[f]
Overall	3309	0.89	0.96	0.94	0.92	0.22

[a] Pearson's correlation coefficient ranges from 0 to 1, where a value of 0.7 or higher shows a high correlation.
[b] A value of $\alpha > 0.7$ is considered desirable.
[c] Spearman's Brown split-half coefficient ranges from 0 to 1, where a value of 0.7 or higher shows a high precision.
[d] Guttman's lambda ranges from 0 to 1, where a value of 0.3 or higher is required to show strong predictability.
[e] A p-value of less than 0.05 indicates a significant difference in total scores between male and female.
[f] Information not available.

Items with a low coefficient (items 1–4, 8 and 14) have limited meaning for the child's age-dependent auditory response. Nevertheless, they were included in the questionnaire for practical reasons (see below).

2.2.2. Item analysis

To assess the items' suitability for inclusion in the questionnaire, the index of difficulty, the discrimination index and the selectivity index were calculated for each item (Table 1). The index of difficulty represents the ratio of the number of "yes" responses to the total number of responses. A high value means that an item is "easy" (i.e., that almost all parents gave a "yes" response), while a low value indicates that an item is "difficult". In the study, the indices range from 0.25 to 0.98. Although items with indices >0.90 do not contribute greatly to the selectivity of the questionnaire, four were still included. The reason for this was a practical one: to avoid causing concern or frustration in parents of very young children (with normal hearing or hearing impairment) who have marked one or several "no" responses. In other words, by including these "easy" questions, it was our hope that parents would at least be able to mark some positive responses. In the questionnaire, the items are presented in order of difficulty, starting with the easiest items.

The discrimination index indicates the correlation of an item with the total score. A high correlation coefficient means that the item has a considerable impact on the total score and clearly differentiates between good and poor performers. Most of the coefficients in this study are greater than $r = 0.5$, a value which is considered to indicate good discriminatory power. Items with a lower coefficient (items 1–4, 8 and 14) have limited meaning for assessing a child's age-dependent auditory response.

Because the difficulty index and the discrimination index are related to each other, the two indices must be considered together when evaluating the suitability of an item. For this purpose, the selectivity index, which combines the two indices and provides a measure of "combined" suitability, was calculated. Only items with selectivity indices greater than 0.3 were rated as suitable for inclusion in the questionnaire. This resulted in the exclusion of five items from the original 40-item list.

2.2.3. Scale analysis

Parameters and results of the scale analysis are shown in Table 2.

(a) Correlation between age and (total) score.

The correlation between age and total score was calculated to obtain information about the ability of the questionnaire to measure age-dependent auditory behaviour. With a correlation coefficient of $r = 0.91$, the correlation was found to be very high. Thus, the older the child, the higher the child's expected score.

(b) Internal consistency of the scale.

Internal consistency is the unidimensionality of a scale, i.e., its suitability to assess exactly one construct. A measure of internal consistency is Cronbach's alpha (α) which will generally increase when the correlations between the items increase. A value of $\alpha = 0.96$ was found, which indicates very high internal consistency.

(c) Split-half reliability.

The Spearman-Brown split-half coefficient was calculated to estimate the full test reliability of the questionnaire based on split-half reliability measures. The coefficient was found to be $r = 0.88$, which indicates good reliability.

(d) Predictive accuracy of the scale.

The predictive accuracy of the scale was calculated using Guttman's lambda (λ). It determines the accuracy with which the dependent variable (here: total score) can be predicted from the independent variable (age). The values of Guttman's lambda can range from 0 to 1, where values of $\lambda > 0.3$ are considered to show sufficient predictability. The value found was $\lambda = 0.93$, which indicates very high predictability.

(e) Influence of gender on total score.

In an effort to analyse whether male and female children show different auditory development, the total scores of boys and girls were statistically compared. In addition, we investigated whether different types of questionnaire administration would influence results. One group of parents received the questionnaire with written instructions and was asked to fill it out on their own (self-administered). The other group sat with a professional who read the questions

aloud to them and marked their answers on the questionnaire form (interviewer-administered). The statistical analysis (ANOVA) showed that neither gender nor administration type had a significant influence on the total scores.

2.2.4. Generation of a norm curve

To establish a norm curve for the development of auditory behaviour of children between 0 and 2 years of age, a regression analysis with "age" as independent variable and "total score" as dependent variable was carried out. Calculations were performed by applying the least squares method. Several regression models, including linear, exponential, power, and logarithmic were explored. The best model, explaining 86% of the total variance, was a second order polynomial regression with the regression equation: $y = -0.038x^2 + 2.22x + 2.07$; where x = age and y = total score ($F = 672$, $df = 215$, $p < 0.001$). From this equation, expected values of age-dependent total scores were calculated for each age group. These scores were established as "standard scores" or "normative scores". In addition, the residual values (expected minus observed scores) were used to determine the 95% confidence interval of the scores in each age group. Fig. 1 shows a scatter plot of the raw data, the norm curve generated from them, and the lower band of the 95% confidence interval.

3. Study 2—adaptation and validation of the LEAQ

3.1. Methods

After validation of the German version of the questionnaire on a sample of 218 children with normal hearing, the LEAQ was adapted into English (see procedure below). From this English version it was and is still being adapted into a number of languages. In each case, validation of the LEAQ in each individual language is encouraged. This paper will report on the validation of LEAQ in 15 languages.

3.1.1. Subjects

3309 children with normal hearing from 16 different countries were involved in the study. A minimum of 48 children per language were involved. Table 2 shows an overview of how many children were included in the study and from which country and language. Parents were recruited in each country from early intervention centres, children's care centres, paediatric centres and clinics with neonatal services. The questionnaires were either posted or given out to parents by a professional. The study was designed and conducted according to Declaration of Helsinki (1996) and MED-DEV 2.12.2 guidelines for conducting Post-Market Studies. Where required, country specific ethical clearance was obtained.

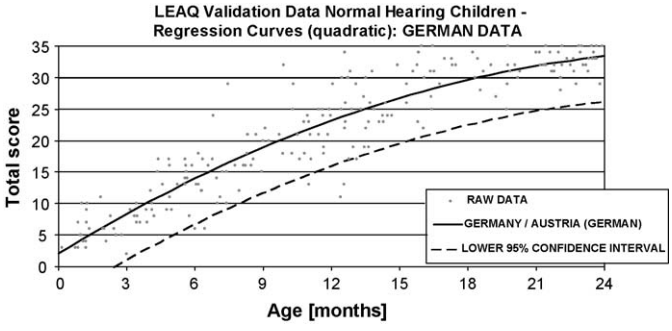

Fig. 1. Regression curve (quadratic) with age as the independent and total score as the dependent variables. Raw data, standardized expected values (norm curve) and standardized minimum values (lower 95% confidence interval) of age-specific auditory behaviour for the original German and Austrian sample.

15 "validation groups" were included in the study, not including the original German validation group from Austria and Germany. For most validation groups, the written language version of the questionnaire was different from German. For Switzerland, the original language version (German) was used. Two language versions were validated for the United States: American English and American Spanish. Throughout this paper each validation group will be referred to as a "language".

3.1.2. Adaptation and validation procedure

The stages involved in this process were (a) translation, (b) validation of the translated English and versions, (c) analyses of equivalence between versions, and (d) development and validation of an overall norm curve.

(a) The methods of translation and "back translation" were used for the first stage of the adaptation process. It was carried out by translators who were specialists in the field of audiology or speech-language pathology and experienced in translation. First, the LEAQ was directly translated from English (or the German original, depending on availability of translators in English) into a target language by Translator A (for each language). A second translator (Translator B for each language) then translated Translator A's version back into English (or German), which is why this is called "back translation". In this way, the English (German) translations from Translator B were compared to the English (German) document originally used by Translator A. If there were discrepancies between these two English (German) versions, they were discussed and settled so that the translated version was (1) as accurate and true to the original as possible while still being culturally appropriate and (2) measuring the same behaviours as the original version intended. In some cases, translations were also discussed with parents to ensure that "parent friendly" language was used.

(b) After completing the adaptation process, the LEAQ was given to a sample of parents of children with normal hearing. Data were used to determine whether scores obtained from the sample were valid and reliable. The same validation procedure used for the initial validation on the German speaking sample and described above was applied. In this way, a norm-reference curve was obtained for each language.

(c) It was necessary to determine whether standardized scores obtained from the questionnaire were comparable across language groups. For example, an important question would be: would the distribution of scores obtained in the original German and Austrian validation be comparable to normal scores obtained in other languages? This was determined by carrying out correlations between standardised values of different language validations using Pearson's correlation coefficients.

(d) Finally, data from all children were used to establish an overall norm curve. The same validation process that was used for the initial German and Austrian validation was also employed here.

3.1.3. Software

SPSS for Windows 12.0-16.0 software (Chicago, IL, http://www.spss.com) and Microsoft® Office Excel 2003 were used for all analyses and graphs.

3.1.4. Missing data

Missing data were not imputed; only full data sets were used for analyses, except in cases where questions were intentionally left blank due to the LEAQ instructions. Specifically, parents were instructed to mark a "no" response if (1) they had never observed the behaviour in question and (2) if they were not sure if they had

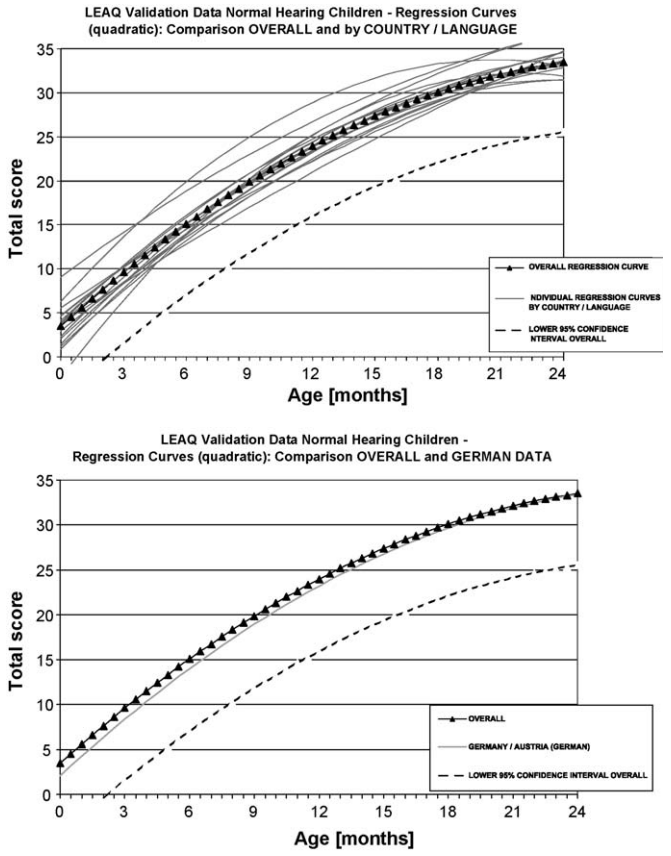

Fig. 2. Regression curves (quadratic) with age as independent and total score as dependent variables. (a) Standardized expected values (norm curves) of age-specific auditory behaviour for each language and the overall sample. (b) Standardized expected values (norm curves) of age-specific auditory behaviour for the German and Austrian versus the overall sample.

observed the behaviour in question. In cases where parents had 6 consecutive "no" responses, parent were instructed to stop completing the questionnaire and leave the remainder of the questions blank. This is because the items in the questionnaire were sorted on the "index of difficulty" of the original German and Austrian version (see Table 1). It was proven that stopping after 6 "no" responses did not result in a significantly different score from the score that would have been obtained from completion of all 35 questions of the LEAQ.

Table 3
Regression curve estimation quadratic with total score [total score = $a + b_1 \times$ age $- b_1(age)^2$] as dependent variable and Age as independent variable.

Sample	Regression equation ($y = a + b_1x - b_1x^2$)
OVERALL sample	$y = 3.470 + 2.163x - 0.038x^2$
Bulgaria	$y = 5.560 + 1.604x - 0.018x^2$
Belgium	$y = 3.673 + 1.666x - 0.016x^2$
Slovakia	$y = 4.143 + 2.147x - 0.033x^2$
USA (English)	$y = 2.308 + 2.402x - 0.047x^2$
Romania	$y = 2.538 + 1.919x - 0.031x^2$
France	$y = 0.879 + 2.461x - 0.049x^2$
Serbia	$y = 1.458 + 2.463x - 0.046x^2$
Finland	$y = 4.586 + 1.947x - 0.029x^2$
Slovenia	$y = 3.762 + 2.075x - 0.033x^2$
Germany/Austria	$y = 2.066 + 2.217x - 0.038x^2$
Russia	$y = -2.354 + 3.156x - 0.072x^2$
China	$y = 1.211 + 2.23x - 0.038x^2$
USA (Spanish)	$y = 9.084 + 1.779x - 0.026x^2$
Switzerland	$y = 4.687 + 1.921x - 0.030x^2$
Poland	$y = 2.917 + 1.952x - 0.028x^2$
Greece	$y = 6.272 + 2.653x - 0.064x^2$

3.2. Results

3.2.1. Scale analysis of language-specific data

Results of the scale analysis of every different language are shown in Table 2. A high correlation between age and score was found for every single language as well as for the overall sample. The coefficients lie between 0.80 and 0.93. Internal consistency, calculated using Cronbach's alpha, is similar to the German study. In every sample as well as in the overall sample, Cronbach's alpha has a value greater than 0.7 (range: 0.93–0.98), meaning that the internal consistency is very good. The Spearman's split-half coefficient ranges between 0.88 and 0.96 in all samples. This indicates a high measuring accuracy. The same is also valid for the predictive accuracy of the scale, which is measured by Guttman's lambda. Values of Guttman's lambda lie between 0.85 and 0.94. There were no differences between total test scores of boys and girls in any of the samples ($p > 0.05$).

3.2.2. Comparability across languages and countries

A norm curve was calculated separately for every country and language as well as for the overall sample (Fig. 2a). The aims of the establishment of norm curves were to have language-specific norms on the one hand and to show language independency of the outcomes on the other hand. Every norm curve was correlated to the data from the original German and Austrian sample and the overall sample (Fig. 2b). Pearson's correlation coefficients are in general very high. They range between 0.988 and 1.000. This implies very good comparability of all language-specific norm data, i.e., the German and Austrian curve and the overall norm curve.

3.2.3. Item analysis and standardized values of all data

Finally, data of all subjects who have participated in the study were subjected to an item analysis. As was done for the German and Austrian sample, the index of difficulty, the discriminatory power coefficient and the selectivity index were calculated for each item to assess the suitability of the items (Table 1). The indices of difficulty range from 0.23 to 0.99. Results are very similar to the German and Austrian sample. On average, there was only a difference of 0.01 between the 2 samples. The discriminatory power coefficients in the overall sample range between 0.17 and 0.87. On average, coefficients were 0.01 lower than the coefficients in the German speaking sample. The same applies to the selectivity index. They range between 0.31 and 1.02, and on average they are the same as in the German speaking sample. The regression equation for the overall sample is (Table 3): $y \equiv -0.038x^2 + 2.163x + 3.470$.

Standardized expected and minimum values are shown in Table 4. They are also very similar to the original German and Austrian standardized values.

4. Discussion

The results of this two part study confirm that the LEAQ is a relevant, language-independent tool which may be used internationally for assessing the age-related auditory behaviours of children. The LEAQ has been in use for several years, which implies that clinicians have placed their trust in its results. Though Weichbold et al. [28] were able to provide information on the LEAQ's reliability in a German and Austrian sample, this study provides further results on psychometric measures of the tool's validity in 15 different languages.

While Study 1 results did show that a few questions had a low correlation with age and a low discriminatory power (questions 1–4, 8 and 14), these questions were judged to be valuable to the LEAQ as a whole and were therefore kept. Questions 1–4 are as

Table 4
Standardized expected values and standardized minimum values (lower 95% confidence interval) of age-specific auditory behaviour for the German and Austrian versus the overall sample.

Age (months)	Expected value	Minimum value (lower limit of 95% confidence interval)	Age (months)	Expected value	Minimum value (lower limit of 95% confidence interval)
German and Austrian sample					
0 to <1	3	0	12 to <13	24	17
1 to <2	5	0	13 to <14	25	19
2 to <3	7	1	14 to <15	26	20
3 to <4	9	3	15 to <16	27	21
4 to <5	11	5	16 to <17	28	22
5 to <6	13	7	17 to <18	29	23
6 to <7	15	8	18 to <19	30	24
7 to <8	17	10	19 to <20	31	24
8 to <9	18	12	20 to <21	32	25
9 to <10	20	13	21 to <22	32	26
10 to <11	21	15	22 to <23	33	26
11 to <12	23	16	23 to <24	33	27
Overall sample					
0 to <1	5	0	12 to <13	25	17
1 to <2	7	0	13 to <14	26	18
2 to <3	9	1	14 to <15	27	19
3 to <4	11	3	15 to <16	28	20
4 to <5	12	4	16 to <17	29	21
5 to <6	14	6	17 to <18	30	22
6 to <7	16	8	18 to <19	31	23
7 to <8	18	10	19 to <20	31	23
8 to <9	19	11	20 to <21	32	24
9 to <10	21	13	21 to <22	32	25
10 to <11	22	14	22 to <23	33	25
11 to <12	23	15	23 to <24	33	25

follows: (1) ''Does your child respond to a familiar voice?'', (2) ''Does your child listen to somebody speaking?'', (3) ''When somebody is speaking, does your child turn his/her head towards the speaker?'', and (4) ''Is your child interested in toys producing sounds or music?''. These 4 items include auditory behaviours that are present in the first 1–2 months of typical child development. As the items have been sorted based on the difficulty index (Study 1), they are listed as items 1–4. This low level of difficulty for items 1–4 is confirmed in all other languages studied, as they are also almost always answered with a ''yes'' response.

Questions 8 and 14 are (8) ''Does your child stop crying when you speak to him/her without him/her seeing you?'' and (14) ''When your child is sad or moody, can he/she be calmed down or influenced by music?'' The findings of low correlation with age and low discriminatory power for these two questions may mean that the behavioural responses being assessed by these are more dependent on the individual child (e.g., habits or personality) than on age or auditory skills. More specifically, questions 8 and 14 may not relate to or reflect typical behaviour in families. Instead of trying to calm a child auditorily only (i.e., through voice or music alone), parents would be more likely to come close to the child and touch the child while giving auditory support. These visual and tactile components of communication would then be likely to contribute to making the child calm. Thus, the ''auditory-only'' condition which questions 8 and 14 ask about is probably not realistic for most situations or families.

Furthermore, question 14 is one of only a few questions on the LEAQ which does not include (next to it) an example of the behaviour being asked about. Perhaps some examples like ''child stops crying and listens'' or ''child cries more quietly'' may be helpful to parents in answering this question. It was decided, though, to keep question 14 because it queries an important topic: music. Even though reactions to music often depend on experience and personal tastes, it was determined that music is an aspect of everyday living that should be polled.

If nothing else, a ''no'' response to question 14 could encourage communication between the clinician and the caregiver about home practice with music. Though we decided to keep questions 8 and 14, further data would be needed in order to determine their value or if their value could be influenced by providing more examples (question 14) or rewording these questions.

The finding that the LEAQ is gender independent is interesting because there has been a fair amount of research documenting a higher (within-family) incidence of language disorders in male children than in female children [29–32]. Though the LEAQ is primarily concerned with early auditory behaviours, some questions do involve emerging expressive and receptive language skills. The age group the LEAQ assesses may simply be too young for such differences to have fully emerged or the sample size may not be large enough to provide insight into this question. There is some evidence that these genetic (and environmental) differences in language development may be more evident in late toddlerhood (around or after 2 years of age) [33], which our results of gender independency would tend to support.

The results of Study 1 showed that the original German and Austrian LEAQ is an appropriate tool for measuring age-related auditory behaviours, as it was found to have good age-dependency, internal consistency, reliability, predictive accuracy, and no influence of gender. Scale analysis revealed an excellent correlation between age and total score, which makes the LEAQ a potentially useful tool for long term follow-up testing (up to 2 years) after early implantation. Accuracy of the scale is also supported by high correlations. Given all of these strong correlations, the LEAQ could also be a powerful tool for: documenting a child's progress with his current amplification, providing evidence of the need for implantation, or highlighting the need for follow-up in other developmental areas.

Study 2 yielded very good results on psychometric measures for the language-adapted versions of the questionnaires. These showed high internal consistency, measuring accuracy, predictive accuracy, and no differences for gender. The original aim of Study 2,

establishing language-independent norm curves for each language that could be correlated to the original German and Austrian curve, was achieved. In comparing the results of the German and Austrian version versus the overall results of all the languages (Table 2), it is apparent that some of the numbers differ quite a bit, especially in the Selectivity Index category. This was not particularly concerning for us because the other groups involved were probably not as highly selected, meaning they were quite possibly more diverse, than the German and Austrian group. Given the probable homogeneity of the German and Austrian group, we can accept the scores of the overall group since these more closely resemble real life populations.

One way to improve this study would be to have an equal number of children from each language as well as an equal number of children at each age interval within the samples. As it is now, we see that the language curves (Fig. 2) are very similar, but there are a few curves which stand out slightly. The differences between these curves are not statistically significant.

Our results from 3309 children (Study 1 and Study 2) establish the LEAQ as not only accurate, gender independent, and age dependent, but also language independent. The LEAQ is a statistically validated tool currently available for quick and easy assessment of auditory development in children with normal hearing. Future research should focus on validating the LEAQ in a group of children using hearing instruments. Once validated for this group, the LEAQ could be more widely established as a valid tool for use with infants and toddlers with normal hearing who need follow-up after newborn screening [12] or with those who have already received very early amplification or implantation.

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Appendix A

Examples of items used in the LittlEARS® Auditory Questionnaire

	Auditory Response	Answer		Example
1.	Does your child respond to a familiar voice?	□ yes	□ no	Smiles; looks towards source; talks animatedly
10.	Does your child "recognize" acoustic rituals?	□ yes	□ no	Musical box by bed; lullaby; water running into the tub
14.	When your child is sad or moody, can he/she be calmed down or influenced by music?	□ yes	□ no	
23.	Does your child understand simple questions?	□ yes	□ no	"Where is your tummy?"; "Where is daddy?"
29.	Does your child correctly repeat a sequence of short and long syllables you have said?	□ yes	□ no	"La-la-laaa..."
34.	Does your child follow complex commands?	□ yes	□ no	"Take your shoes off and come here."

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