Adjusting expectations: Hearing abilities in a population-based sample using an SSQ short form

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Self-reports of hearing (dis)abilities play an important role in hearing rehabilitation. Among the large variety of questionnaires, the Speech, Spatial, and Qualities of Hearing Scale (SSQ) has become an internationally used measure to assess hearing abilities in specified everyday listening situations using a visualized scale ranging from 0 to 10. Research mainly focused on adults with impaired hearing, whereas adults with "normal" hearing were hardly considered. However, the ratings of adults out of the general population could be of particular interest when it comes to the question of score benchmarks based on different definitions of "normal" hearing. In the cross-sectional, population-based study HÖRSTAT (n=1903) the German SSQ17 short form was used along with a standardized interview and comprehensive hearing examinations. As the SSQ score distributions are extremely negatively skewed, semiparametric quantile and expectile regression analysis was performed to examine the conditional score distribution and the effects of age, gender, globally reported hearing problems, hearing loss, and social status. Though no normative cut-off values can be established from empirical findings only, the distribution of "normal" hearing abilities might align the management of expectations during the process of hearing rehabilitation.

INTRODUCTION

Since the Speech, Spatial and Qualities of Hearing Scale (SSQ) showed "promise as an instrument for evaluating interventions of various kinds" in audiological rehabilitation (Gatehouse and Noble, 2004), various short forms were developed to foster it's usability. Research focused on hearing-impaired adults, whereas 'normal'-hearing adults were included for validation in non-English versions (e.g., Banh *et al.*, 2012; Deemester *et al.*, 2012; Moulin and Richard, 2016). Recruitment of the normal-hearing participants followed audiological criteria and university students often served as the young control group. But hearing ability established by means of a questionnaire is a cognitive construct, thus shaped, e.g., by performance expectations, habitat with diverse acoustical demands, second-party opinions, and comparisons.

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Therefore, variability sources and benchmark scores derived from socially homogeneous groups are as critical as sample size. Furthermore, the score distribution is often skewed, thus the report of mean and standard deviation and the use of parametric methods is misleading.

This article sets out three objectives: First, it attempts to derive a benchmark distribution for hearing abilities in the general population using SSQ items. Assuming that ability assessment refers to a cognitive construct, it secondly aims to identify non-audiological factors such as age, gender, and education which might influence SSQ ratings. Third and finally, an innovative statistical method will be presented that copes appropriately with non-normal distributions in order to achieve the previously stated objectives.

METHODS

SSQ17 questionnaire

In general, the SSQ items describe everyday situations and a listening task. The respondents rate how well they can fulfill the task using a visualized scale ranging from 0 (not at all / a lot of effort) to 10 (perfectly / no effort). The original SSQ presented by Gatehouse and Noble (2004) comprises 50 items assigned to three subscales. Table 1 lists the items included in the German SSQ17 short form (Kießling *et al.*, 2011).

Subscale	Pragmatic subscale	Item ref. SSQ50
Speech	Speech in noise (2), speech in speech (2), multiple speech-stream processing and switching (1)	1.4, 1.5, 1.7, 1.9, 1.10
Spatial	Localization (2), distance and movement (3)	2.5, 2.6, 2.7, 2.9, 2.12
Qualities	Sound quality and naturalness (3), segregation of sounds (1), identification of sound and objects (1)	3.3, 3.4, 3.8, 3.9, 3.10

Table 1: Items (number) in the SSQ17 according to the numbering in the original SSQ (Gatehouse and Noble, 2004) and the pragmatic subscale allocation proposed by Gatehouse and Akeroyd (2006).

SSQ17 cut the subscales down to 5 items each, complemented by the items understanding speech in quiet (1.2) and listening effort (3.18). The subjects received the questionnaire together with the HÖRSTAT invitation letter and were asked to return the completed SSQ17 during the examination appointment.

Study sample

The data was derived from the cross-sectional study HÖRSTAT (2010–2012). This study was based on random samples stratified by age and gender from two medium-sized towns in Northwest Germany. The response was low in young age bands, but fairly high in the middle-aged and elderly adults from 40 to 79 years (30%), resulting in an overall response rate of 21%. At large, the study sample of 1,903 adults approximated both the national distribution by gender and age. The hearing examination included pure-tone audiometry in accordance to ISO 8253-1, the Goettingen sentence test in noise (Kollmeier and Wesselkamp, 1997), the German digit triplet test (Zokoll *et al.*, 2012), a standardized interview, and the SSQ17 questionnaire. The study design, test procedure and equipment are described in detail elsewhere (von Gablenz and Holube, 2016).

Valid data from pure-tone audiometry and the SSQ17 were inclusion criteria for this analysis leading to a sample of 1,836 adults (45% males) aged 18 to 97 years. Prevalence of hearing impairment was 16% defined as PTA4 > 25 dB HL in the better ear (PTA4: pure-tone average at 0.5, 1, 2, and 4 kHz). In total, 26% reported hearing difficulties in the standardized interview and 8% met the criterion for asymmetric hearing thresholds (interaural PTA4 difference > 10 dB). Social composition was somewhat biased towards highly educated strata if school attainment level is presumed to indicate social position. About 51% of the subjects received an advanced school education according to the traditional German educational system.

Statistical analysis

PTA4 in the better ear is used as a key parameter for the state of hearing to facilitate comparability of results, since Spearman correlation analysis showed equal to slightly better correlation coefficients between SSQ scores and better ear PTA4 ($r = -0.175$ to -0.418) than for the better ear speech reception thresholds (SRT) in the Goettingen sentence test in noise ($r = -0.170$ to -0.412). Correlation coefficients are only marginally higher if related to the worse ear PTA4 or SRT.

With regard to SSQ ratings, this analysis is based on the mean score by subject across all SSQ17 items (SSQ17) and the SSQ17 subscales. Missing values (2%) are dealt with multiple imputation through regression with error. Similarities between the subscales are used to fit generalized additive models for the imputation of one score with all remaining subscales in the predictor. The estimation of the models is then cycled and finally SSQ17 is recomputed.

Score distributions are negatively skewed for all subscales (and items). Skewness is −0.9 in the speech, −1.1 in the spatial and −1.8 in the qualities subscale. As the assumptions for parametric statistics are not met, this analysis refers to quantile regression (Koenker and Bassett, 1978), an approach on the verge of becoming a standard tool in modern regression analysis. While a simple mean regression attempts to describe the expectation of a response as a function of the covariates, the results of a quantile or expectile regression offer a much broader view. In principle, a dense set of expectiles or quantiles allows for an analysis of the complete conditional distribution of the response. This can lead to new insight into the dependency structure between the response and its covariates.

For the inclusion of nonlinear effects, an efficient semiparametric quantile regression (SPQR) is performed. Penalized splines divided into a parametric part and its random nonlinear deviations, smoothed with an additive penalty term, are used in a fast linear programming procedure. Computationally, regression quantiles with a LASSO penalty for random effects are obtained by minimizing an asymmetrically weighted absolute residuals criterion

$$\sum_{\{i=1\}}^{n} w_\tau\left(y_i, Z_i\beta_\tau\right)\left|y_i - X_i\alpha_\tau - B_i\gamma_\tau\right| + \lambda|\gamma_\tau| \qquad \text{(Eq. 1)}$$

with asymmetric weights

$$w_\tau(y, Z\beta) = \begin{cases} 1-\tau \text{ if } y < Z\beta \\ \tau \text{ if } y > Z\beta \end{cases}$$

a response y and a quantile-specific predictor $Z\beta_\tau$ consisting of the unpenalized effects $X\alpha_\tau$ and the penalised random part $B\,\gamma_\tau$ for each quantile level τ. This loss function can be subject to a linear program.

RESULTS

In the general population, SSQ17 scores averaged by subject across all items are almost unchanged until the age of 50 years with 8.3 points at the median. They decline to 7.8 and 7.1 points at the age of 70 and 80 years, respectively. These results refer to a zero-model that simply regressed scores on age.

Figure 1, in contrast, shows not only SSQ17 scores as a function of age (dots), but also the score distribution from a quantile regression model that was controlled for self-reported hearing difficulties only (lines). Since these adults feel comfortable with their hearing in general, this distribution could reasonably be assumed to describe the benchmark for hearing abilities assessed using the SSQ17. The ability scores decrease with age. This decrease is somewhat more pronounced in the lower than in the upper half of the distribution. Intercept spans rounded 3 points from the 0.05 to the 0.95 quantile (5.9 to 9.0). The parametric regression coefficient, which accounts for hearing difficulties, is −1.4 at the median, that is, the median regression curve is shifted down by 1.4 points in adults reporting hearing difficulties. As expected, the effect of self-reported difficulties is greater in low scoring than in high scoring adults. The coefficients range from −2.0 at the lowest to −1.1 at the highest quantile.

Figure 2 shows the score distribution in the speech subscale as a function of PTA4 in the better ear (dots). The curves display a quantile regression model that controls the association of PTA4 and SSQ scores for age, gender, hearing difficulties, and asymmetric pure tone hearing. Thus, quantile curves refer to males with symmetric thresholds who did not report hearing difficulties as the reference distribution. The corresponding parametric regression coefficients that estimate the effect of age, female gender, asymmetric thresholds, and hearing difficulties are listed in Table 2 for selected quantiles 0.1, 0.5, and 0.9. This table also includes intercept and coefficients estimated in analogous regression models on the spatial and qualities subscale data, which are not graphically displayed.

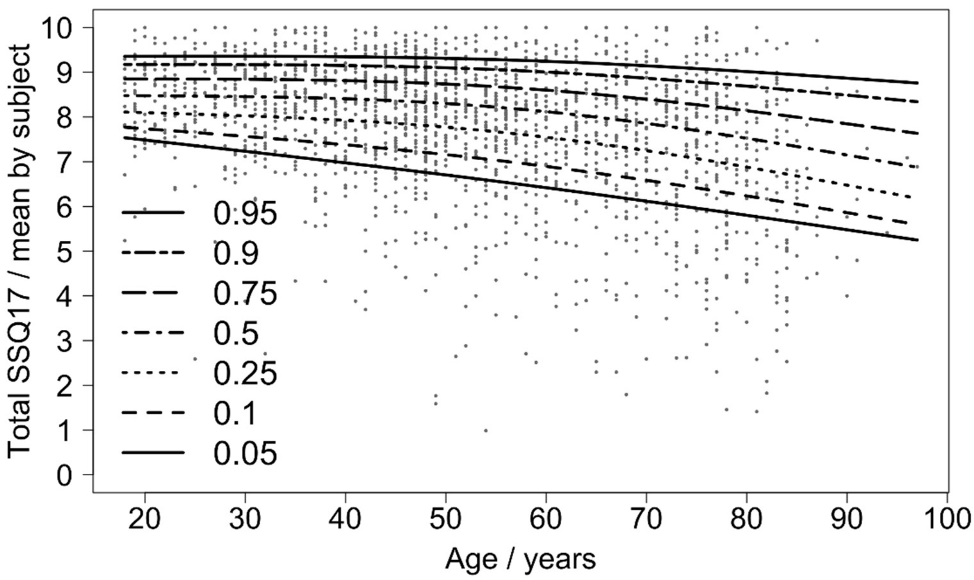

Fig. 1: SSQ17 scores averaged by subject across all items as a function of age (dots). Regression lines refer to adults without self-report of hearing difficulties.

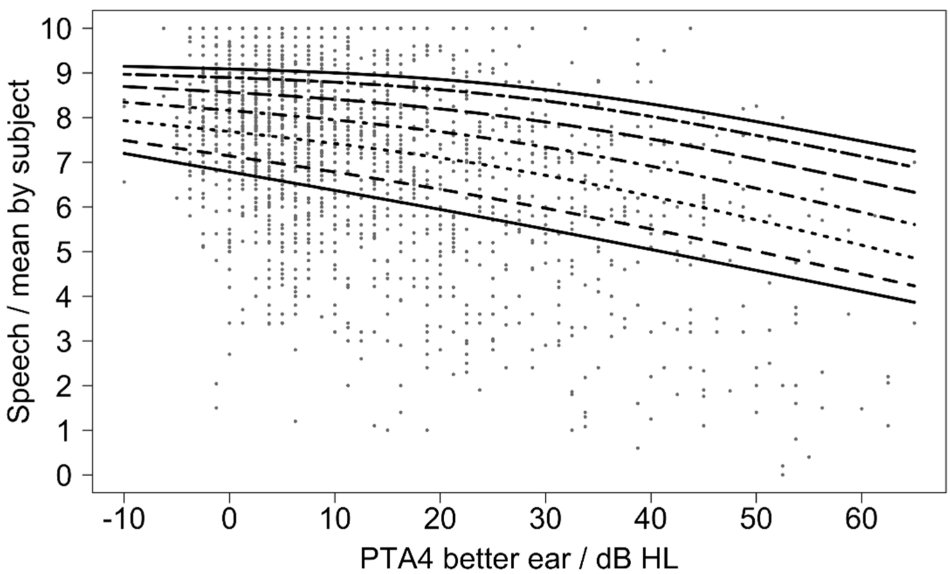

Fig. 2: Mean speech subscale SSQ17 scores by PTA4 in the better ear (dots). Regression curves refer to males with symmetric hearing thresholds without self-report of hearing difficulties.

Ability ratings are highest in the qualities subscale and lowest in the speech subscale. Age does not affect ability ratings either in high or in low scoring adults in these models. This is generally the case (models not shown) if PTA4 is controlled for. Asymmetric hearing and self-reported global hearing difficulties, in contrast, are significant factors in all subscales, with mostly higher effects in the distribution's bottom half. Self-report of hearing difficulties strongly influences the speech subscale, with only small differences between the quantiles. The corresponding coefficients are higher than in the other subscales and range from −1.5 to −1.3. Asymmetric PTA4 is the most influential factor in the spatial subscale, with coefficients between −1.1 and −0.4. Gender significantly affects the ratings on spatial items across all quantiles, though the effect is particularly strong in the bottom half. Females rate their abilities lower than males, with a maximum estimate of −0.9 points at the 0.05 quantile and −0.4 points at the median. In the speech and the qualities subscales, however, high scoring females rate their abilities slightly higher than males. Though significance is partly confirmed, gender has hardly a substantial impact because the estimated coefficients are rather small (≤ |0.2|). Extended models further revealed that high education is significantly associated with higher scores, particularly in the spatial and qualities subscales. The corresponding coefficients indicate 0.2 to 0.6 points at most quantiles.

		0.1	sd	0.5	sd	0.9	sd
Speech	Intercept	**4.73**	0.41	**6.14**	0.48	**8.04**	0.69
	Age / year	**-0.01**	0.01	**-0.00**	0.00	**0.00**	0.00
	Female gender	**-0.06**	0.11	**0.10**	0.08	**0.15**	0.07
	Asymmetric PTA4 *	**-0.83**	0.19	**-0.77**	0.18	**-0.56**	0.17
	Hearing difficulties *	**-1.46**	0.14	**-1.51**	0.11	**-1.39**	0.10
Spatial	Intercept	**5.03**	0.46	**6.55**	0.31	**7.89**	0.27
	Age / year	**0.00**	0.01	**0.00**	0.00	**0.00**	0.00
	Female gender *	**-0.80**	0.13	**-0.44**	0.08	**-0.25**	0.07
	Asymmetric PTA4 *	**-1.05**	0.26	**-0.76**	0.11	**-0.54**	0.19
	Hearing difficulties *	**-0.89**	0.18	**-0.75**	0.20	**-0.56**	0.10
Qualities	Intercept	**5.58**	0.44	**7.58**	1.23	**8.89**	0.67
	Age / year	**-0.00**	0.00	**-0.00**	0.00	**-0.00**	0.00
	Female gender	**0.00**	0.10	**0.16**	0.06	**0.14**	0.04
	Asymmetric PTA4 *	**-0.83**	0.17	**-0.39**	0.17	**-0.18**	0.14
	Hearing difficulties *	**-1.03**	0.30	**-0.73**	0.09	**-0.47**	0.07

Table 2: Parametric effects on the speech, spatial and qualities subscales of SSQ17. Regression coefficients for the 0.1, 0.5, and 0.9 quantile and standard deviation (sd). Coefficients greater than 1.96 sd are considered to be significant.

DISCUSSION

Adults who do not complain about hearing and mostly do not meet the criterion of hearing impairment rate their hearing abilities in the SSQ17 well below the scale maximum. Basically, this was already known from earlier research (e.g., Moulin and Richard, 2016; Demeester *et al.,* 2012; Banh *et al.*, 2012). The question was, rather, to estimate a reference using a population-based sample. Comparing results from different SSQ studies calls for some reservations. Whereas test administration seems not to affect scores on the SSQ systematically (Singh and Pichora-Fuller, 2010), language translation and item selection are always an issue, aggravated by different analytical approaches. This applies in particular for comparisons between the benchmark distributions derived from the general population using quantile regression to benchmark scores defined as the arithmetic mean from tailored study samples. Nevertheless, our results point towards lower benchmark score levels in young adults than reported earlier, e.g., by Demeester *et al.*, 2012; Banh *et al.*, 2012.

Chronological age does not influence ability ratings if audibility operationalized by PTA4 and interaural symmetry is controlled for. This finding is along the same lines as Agus *et al.* (2009) who did not observe a correlation between age and items addressing speech in speech and multistream listening situations, but contrasts with Banh *et al.* (2012), who established a combined effect of age and hearing impairment.

As expected, the association of SSQ ratings and pure-tone hearing is most affected by globally reported hearing difficulties. Agus *et al*. (2009) also distinguished by the self-report of hearing difficulties in their analysis. They found a group difference of 1.4 points for speech items on average which is well in line with our estimations (−1.5 to −1.4 points). Our results show, in addition, that the impact of self-reported difficulties is roughly halved for the spatial and qualities subscale.

To our knowledge, the effect of gender on spatial items was not reported for other studies though Moulin and Richard (2016) observed a possibly related trend for the differential score between the speech and spatial subscale. This effect cannot be traced back to audiological criteria from the present state of the analysis. Additionally, the impact of educational level on SSQ scores seems to be under-researched so far. Moulin and Richard (2016) reported an effect for selected items mainly in the qualities subscale, whereas our results suggest a considerably broader impact. Overall, the effect of gender, education and, in general terms, social position seem relevant enough to merit attention.

SUMMARY AND OUTLOOK

Quantile regression analysis gives an appropriate display of hearing abilities in the general population that makes a description of a benchmark distribution possible. Though de facto observations do not bear any normative power for methodological reasons, they facilitate orientation in the rehabilitation process. Furthermore, social factors influence ability ratings. This finding is only partly addressed in earlier studies. Age, however, shows no effect if audibility is controlled for. The next steps will be to extended the analysis towards item and pragmatic subscale level and to include other factors that potentially influence the SSQ ability rating. Further, two-way interaction terms reflecting potential dependencies between the covariates and the cut-off for disability will be examined and discussed for this population-based sample.

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