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Sources of Variability of Speech, Spatial, and Qualities of Hearing Scale (SSQ) Scores in Normal-Hearing and Hearing-Impaired Populations.

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**Sources of Variability of Speech, Spatial, and Qualities of Hearing Scale (SSQ) Scores
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Key words: Self-Report Measure; Short Form; Hearing Disability; Hearing Loss; Spatial
Hearing; Speech; Speech, Spatial and Qualities of Hearing Scale.

Acronyms and abbreviations

SSQ: Speech, Spatial and Qualities of Hearing Scale

SSQ5: 5-item SSQ short form

SSQ12: 12-item SSQ short form

SSQ15: 15-item SSQ short form

Speech: Speech subscale of the SSQ

Spatial: Spatial hearing subscale of the SSQ

Qualities: Qualities of hearing subscale of the SSQ

HIS: Hearing-impaired subjects

NHS: Normal-hearing subjects

PTA: Pure-tone average (0.5, 1, 2 and 4 kHz)

SD: Standard deviation

NA: Non-applicable answers

Abstract

Objective: To identify and quantify sources of variability in scores on the Speech, Spatial, and Qualities of Hearing Scale (SSQ) and its short forms among normal-hearing and hearing-impaired subjects using a French-language version of the SSQ.

Design: Multi-regression analyses of SSQ scores were performed using age, gender, years of education, hearing loss, and hearing-loss asymmetry as predictors. Similar analyses were performed for each subscale (*Speech*, *Spatial* and *Qualities*), for several SSQ short forms and for differences in subscale scores.

Study sample: One hundred normal-hearing subjects (NHS) and 230 hearing-impaired subjects (HIS).

Results: Hearing loss in the better ear and hearing-loss asymmetry were the two main predictors of scores on the overall SSQ, the 3 main subscales and the SSQ short forms. The greatest difference between the NHS and HIS was observed for the *Speech* subscale, and the NHS showed scores well below the maximum of 10. An age effect was observed mostly on the *Speech* subscale items, and the number of years of education had a significant influence on several *Spatial* and *Qualities* subscales items.

Conclusion: Strong similarities between SSQ scores obtained across different populations and languages and between SSQ and short forms, underline their potential international use.

Introduction

Self-reported outcome measures are essential for the benefits of rehabilitation measures, taking into account not only a patient's impairment and medical diagnosis but the functional consequences of his/her impairment. The Speech, Hearing and Qualities of Hearing scale (SSQ) designed by Gatehouse & Noble (2004) is becoming one of the most widely used self-report measures for spatial hearing. The SSQ has recently begun to be used in several languages other than English e.g., Dutch (Demeester et al, 2012), Korean (Heo et al, 2013), German (Kiessling et al, 2011), and French (Moulin et al, 2015). Comparisons among the reported results obtained with different language versions have shown good agreement across several languages (Moulin et al, 2015), suggesting the potential use of the SSQ as an international standard (Arlinger, 2000).

Although the SSQ has the advantage of exploring some very specific aspects of hearing via 49 items organised in 3 main subscales and 10 pragmatic subscales (Gatehouse & Akeroyd, 2006), it has the inevitable disadvantage of its length (the complete scale is more than 1000 words long) and the substantial cognitive effort it requires. Indeed, using a French version of the SSQ (Moulin et al, 2015), we obtained a greater number of missing answers for the most difficult-to-read items (as determined via readability indexes), and the self-assessed time to complete the scale was more than 25 minutes for 25% of the hearing-impaired subjects, making the SSQ difficult to implement for routine clinical use or rapid assessment. To overcome this problem, several SSQ short forms have been suggested. Demeester et al (2012) devised a 5-item screening version (SSQ5) from a Dutch version of the SSQ; Kiessling et al, (2011) derived a 15-item short form (SSQ15) with 5 items per subscale from a German version of the SSQ; and Noble et al (2013) developed a 12-item version (SSQ12) based on their considerable multicentre experience with the SSQ UK Version and on a factor analysis (Noble et al, 2013). However, each of these short forms was independently designed using a different language version of the SSQ and only one (the SSQ5) has been tested to date on populations other than the hearing-impaired groups used when the forms were designed (Mertens et al, 2013) [c.f. the nine sins of short-form building described by Smith et al (2000)]. Consequently, comparisons among the SSQ and its 3 short forms using a French version of the SSQ (i.e., a language version different from the ones used to build the short forms) in normal-hearing subjects (NHS) and hearing-impaired subjects (HIS) could help ascertain the short forms' characteristics.

For any scale, one of the concerns is to identify items that are likely to have significant predictors other than the ones expected (Cox et al, 2000). For instance, hearing loss, the degree of asymmetry of hearing loss or age would be expected (and desired) predictors, whereas other confounds, such as gender or years of education, would be less welcome. In addition, to

overcome the potential problem of inter-subject variability in scoring perception (e.g., some subjects are more likely than others to assess their own difficulties as severe), the differences in scores between two subscales are considered: this comparison offers the potential advantage of exploring specific aspects of hearing disability.

Therefore, we systematically investigated the potential influence of several factors, including the number of years of education, on SSQ scores across all items, across the subscales, the differences in subscale scores and the different SSQ short forms.

Materials and Methods

1. General procedure

As the data collection protocol has been detailed in a companion paper (Moulin et al, 2015), it will be only briefly summarised here. The SSQ data were collected using a French translation of the SSQ (cf. the details of the translation procedure in the companion paper) with 100 young NHS, aged between 18 and 27 years old [mean age = 20.8 years, (SD = 2.2); mean number of years of formal education = 16.7, (SD = 1.7); mean PTA on the worse ear = 8.7 dB HL (SD = 3.6); mean PTA of the better ear = 1.1 dB HL (SD= 4.5)] and 230 HIS from an ENT department, amongst which 216 completed the SSQ with less than 10 missing (or non applicable) responses [average age = 54.2 (SD = 17); number of educational years = 12.4 (SD = 4.3); better ear PTA = 26 dB HL (SD = 15) with 15.2 dB (SD = 23.3) of asymmetry]. The better ear average PTA increased significantly with the worse ear average PTA, with $r = 0.48$ ($p < 0.0001$). The questionnaire was explained to each HIS by the clinician, and the HIS were invited to complete the questionnaire at home, note the time they needed to complete the questionnaire and return the questionnaire by post. Pure-tone audiometric data were collected for all subjects and pure-tone averages (PTA) were calculated across the thresholds at 500, 1000, 2000 and 4000 Hz for each ear.

2. Statistics and data analysis

2.1. Scores

The scores were calculated for subjects who showed fewer than 10 missing (or non-applicable) responses on the SSQ, which resulted in a population of 98 NHS and 216 HIS. For each subject, the average score was calculated across the 49 SSQ items, for each of the main subscales (*Speech* (#1.1 to #1.14), *Spatial* (#2.1 to #2.17) and *Qualities* (#3.1 to #3.19, without #3.15, which pertains to only hearing-aid wearers) and for the 10 pragmatic subscales (*Speech in quiet* (#1.2 & #1.3), *Speech in noise* (#1.1 and #1.4 to #1.6), *Speech in speech contexts* (#1.7 to #1.9 and #1.11), *Multiple speech stream processing and switching* (#1.10, #1.12 and #1.14), *Localisation* (#2.1 to #2.6), *Distance and movement* (#2.7 to #2.13, #2.15 and #2.16), *Sound quality and naturalness* (#3.8 to #3.12), *Identification of sounds and objects* (#3.4 to #3.7 and #3.13), *Segregation of sounds* (#3.1 to #3.3), and *Listening efforts* (#3.14, #3.18 and #3.19) defined by Gatehouse & Akeroyd (2006).

In addition, scores were calculated for the different SSQ short forms available in the literature: the SSQ5 (#1.8; #2.3 and 2.9; #3.9 and #3.14; Demeester et al, 2012), the SSQ12 (#1.1, #1.4

and #1.10-1.12; #2.6, #2.9 and #2.13; #3.2, #3.7, #3.9 and #3.14; Noble et al, 2013) and the SSQ15 (#1.4-1.5, #1.7, #1.9-1.10; #2.5-2.7, #2.9, #2.12; #3.3-3.4, #3.8-3.10, Kiessling et al, 2011).

For each subject, difference scores were obtained for the 3 main subscales (*Speech - Spatial; Qualities - Spatial and Qualities - Speech*), and the difference in scores between the highest-scoring pragmatic subscales (for both NHS and HIS), the *Speech in quiet (SiQ)* subscale, and the lowest-scoring pragmatic subscales for the NHS group (*Distance and movement, DistMov*) and the HIS group (*Localisation, Loc*) were obtained (*SiQ - Loc* and *SiQ - DistMov*).

2.2. Statistical procedures

As the data were non-Gaussian, especially for the NHS, non-parametric tests such as the Mann-Whitney test, Wilcoxon rank-sum tests and Friedman's ANOVA were used to compare the NHS and HIS scores, including their scores on the SSQ subscales. A correlation analysis was performed between HIS SSQ scores (and subscale scores) and gender, age, years of education, hearing loss and hearing-loss asymmetry. Only the 216 HIS were included in this correlation analysis for 2 reasons: 1) Although not all of the variables were Gaussian according to the Shapiro-Wilk test, the skewness and kurtosis of the scores were reasonable in the HIS. 2) The NHS had a significantly higher average number of years of education than the HIS. Therefore, including the NHS in the regression analysis would reinforce the influence of the number of years of education that would tend to be associated with a normal PTA. Each regression model was checked with bootstrap analysis using the "boot" R package with 10000 bootstrap replicates, including calculation of non-parametric bootstrap 95% confidence intervals using the adjusted bootstrap percentile method (Field et al, 2012). Differences between correlation coefficients were tested using Fisher's z score (Steiger, 1980). A false discovery rate approach was chosen for multicomparisons (Benjamini & Hochberg, 1995; Asendorpf et al, 2013; Glickman et al, 2014). All of the exact p-values are specified, and the p-corrected value for significance is 0.01. All statistical analyses were performed using the R statistical package version 3.1.0 (2014-04-10).

Results

1. SSQ scores

1.1. Comparison between subscales and short forms

The average SSQ score across HIS was 6.6 (SD = 2.0), and the subscales differed significantly from one another (F-ANOVA, Chi-squared = 116, $p < 0.0001$): the *Speech* subscale showed the lowest score (5.9, SD = 2.3), and the *Qualities* subscale showed the highest score (7.2, SD = 1.9). The pattern obtained in NHS was quite different: they had a significantly lower score on the *Spatial* subscale than on the other two subscales (fig. 1). The SSQ12 scores were significantly lower than the scores for the other forms, and there were no significant differences among the SSQ5, SSQ15 or SSQ scores (fig. 1). The SSQ12 scores were significantly lower than the SSQ scores (paired Wilcoxon, $z = 6.8$, $p < 0.00001$ for NHS; Wilcoxon, $z > 4.1$, $p < 0.0001$ for HIS) and the SSQ5 and SSQ15 scores, but there were no significant differences among the SSQ and the other 2 short forms (SSQ5 and SSQ15) or between the SSQ5 and the SSQ15.

The correlations between the different short forms and the SSQ49 were very high (fig. 2), with the smallest $r^2 = 0.90$ for the SSQ5. Following Noble et al (2013), we fitted power functions linking each short-form to the SSQ given the general equations

$$SSQ_{short} = 10 * (SSQ_{49}/10)^b$$

$$SSQ_{49} = 10 * (SSQ_{short}/10)^c$$

The values of b and c were (with non-parametric bootstrap 95% confidence intervals, calculated using the adjusted bootstrap percentile method and 10000 replicates, reported in brackets):

$$SSQ_{15}: b = 1.05 [1.032, 1.068], c = 0.95 [0.930, 0.963]$$

$$SSQ_{12}: b = 1.20 [1.173, 1.225], c = 0.83 [0.810, 0.847]$$

$$SSQ_5: b = 1.03 [0.991, 1.068], c = 0.95 [0.915, 0.984]$$

The confidence intervals for b and c for SSQ 5 overlap 1.0 so the SSQ5:SSQ49 relationship is essentially linear. The SSQ15 confidence intervals almost reach 1.0. The SSQ12 confidence intervals are further from 1.0 so the SSQ12:SSQ49 relationship is significantly non-linear. Noble et al (2013) found b and c values of 1.25 and 0.80, which are close but do lie slightly outside our intervals (Fig. 2).

1.2. Influence of hearing loss

The average score for the SSQ and the 3 subscales decreased with increasing hearing loss, and the *Speech* scores decreased more rapidly with increasing hearing loss than the *Qualities* scores did. A significant difference was observed between scores obtained by the young NHS and the HIS with a better-ear PTA < 15 dB HL (fig. 3). A linear regression (NHS+HIS) showed a decrease of 0.7 points on the total SSQ per 10-dB increase in PTA in the better ear (equation 1), that is substantially greater than the decrease of 0.43 points/10 dB reported by Akeroyd et al. (2014). The greater dependency of the *Speech* subscale score on hearing loss was confirmed by the greater slope (0.9 points per 10 dB) versus the lower gradients (0.6 points per 10-dB HL) for the *Spatial* and *Qualities* subscales (equations 2 to 4). Equations 1 to 7 show the dependency of the SSQ scores on hearing loss, where HL represents the hearing loss in dB HL (PTA for the better ear), *SSQSubscale* represents the score from 0 to 10, *r* represents the Pearson correlation coefficient and non-parametric bootstrap confidence intervals are specified in brackets for the slope (*s*) and the intercept (*I*) respectively.

$$\text{SSQ} = -0.069 * \text{HL} + 8.60 \quad r = 0.65; s = [-0.078, -0.059]; I = [8.38, 8.80] \quad (1)$$

$$\text{SSQSpeech} = -0.088 * \text{HL} + 8.49 \quad r = 0.7; s = [-0.098, -0.077]; I = [8.28, 8.72] \quad (2)$$

$$\text{SSQSpatial} = -0.060 * \text{HL} + 8.22 \quad r = 0.51; s = [-0.073, -0.048]; I = [7.93, 8.48] \quad (3)$$

$$\text{SSQQualities} = -0.061 * \text{HL} + 9.02 \quad r = 0.60; s = [-0.072, -0.050]; I = [8.81, 9.23] \quad (4)$$

All short forms showed greater slopes, especially the SSQ12 (0.75 point per 10 dB) :

$$\text{SSQ5} = -0.069 * \text{HL} + 8.56 \quad (r = 0.63) s = [-0.0796, -0.0589]; I = [8.327, 8.772] \quad (5)$$

$$\text{SSQ12} = -0.075 * \text{HL} + 8.33 \quad (r = 0.65) s = [-0.0850, -0.0643]; I = [8.087, 8.556] \quad (6)$$

$$\text{SSQ15} = -0.072 * \text{HL} + 8.59 \quad (r = 0.64) s = [-0.0820, -0.0612]; I = [8.368, 8.810] \quad (7)$$

2. The influence of hearing-impaired subjects' characteristics on their scores

The average score for each item of the SSQ and for each subscale (table 1) decreased significantly with increasing hearing loss, with a minimum correlation of -0.20. The lowest correlations were observed for items #3.11 to #3.13 ($|r| < 0.30$). The correlation between the total SSQ score and the better ear PTA was -0.56 (table 1). The influence of age on SSQ score

was significantly greater for the *Speech* subscale than for the two other subscales ($Z > 2.8$, $p < 0.005$), whereas the correlation between hearing-loss asymmetry and the *Spatial* subscale was significantly stronger than the correlation between hearing-loss asymmetry and each of the two other subscales ($Z > 3.4$, $p < 0.001$).

Similar results were obtained for the pragmatic subscales, with a strong age effect on *SIN* & *SiSCont* and a strong hearing-loss asymmetry correlation with the *Localisation* and *DistMov* subscales. The scores increased significantly with the number of years of education and decreased with increasing age for almost all subscales, but the number of years of education decreased significantly with increasing age, perhaps reinforcing the age effect (table 1).

This correlational analysis allowed us to choose the potential predictors of SSQ scores in a stepwise multi-regression analysis that offers a way to compare the relative influence of each predictor using the beta coefficients. The following explanatory variables were chosen: age, PTA for the better ear, number of years of education, hearing-loss asymmetry and gender. The beta coefficients allowed us to compare the relative influence of each statistically significant predictor on the SSQ scores. However, only two predictors were found to be significant, namely better-ear PTA and hearing-loss asymmetry. Table 2 presents the results. Forty percent of the SSQ scores' variance was explained by the better-ear PTA (beta = -0.63) and hearing-loss asymmetry (beta = -0.25) and hearing-loss asymmetry predicts the variance of the *Spatial* subscale more strongly than it predicts the variance of the other subscales.

The different short forms yielded results similar to those of the SSQ, with 36% to 37% of the variance for the three short forms explained by two predictors (fig. 4). The 3 subscales of the SSQ15 yielded results similar to those of the 3 main subscales, with better-ear PTA and hearing-loss asymmetry as significant predictors. The exception was the SSQ15 *Qualities* subscale, which showed a third predictor that had a reasonable, though formally insignificant, influence: the number of years of education, with $0.01 < p < 0.05$. However, the number of years of education was the main predictor (beta = -0.26, $p < 0.0003$), along with better-ear PTA (beta = 0.24, $p < 0.0007$), of the time required to complete the SSQ; together, these factors explained 21% of the variance ($F(3, 200) = 18$, $p < 0.0001$). The time required to complete the SSQ increased when the patient had fewer years of education and a greater hearing loss and when it was the first questionnaire completed.

The 10 pragmatic subscales analysis showed the same patterns (fig. 4): both better-ear PTA and (to a lesser degree) hearing-loss asymmetry were predictors for all subscales, and they explained between 19% (*Qualities*) and 39% (*Localisation*) of the variance. As expected, the subscale *Localisation* was more strongly affected by hearing-loss asymmetry than the other subscales

were (with $\beta = -0.41$ for asymmetry). However, 2 of the 10 pragmatic subscales showed different associations: *Segregation of sounds* (#3.1 to #3.3) was significantly predicted by the number of years of education ($\beta = 0.18$, $p < 0.008$), as was the *IdSounds* pragmatic subscale to a lesser degree ($\beta = 0.13$, $p < 0.04$). A tendency ($p < 0.02$) for a decrease in *Speech in speech contexts* scores with increasing age was obtained.

The multi-regression analysis using the same initial 5 predictors revealed that the only significant predictor of (*Qualities – Spatial*), (*SiQ – Loc*) and (*SiQ - DistMov*) was hearing-loss asymmetry, which explained 6% to 11.2% of the variance ($p < 0.0002$). (*Speech - Spatial*) was predicted by hearing-loss asymmetry ($\beta = 0.29$) and gender ($\beta = 0.16$, $p < 0.02$), which explained 11.3% of variance, with increased (*Speech - Spatial*) values for women and with increasing hearing-loss asymmetry. For (*Qualities - Speech*), age was the only significant predictor; it explained 7.1% of variance ($p < 0.00008$), and the (*Qualities-Speech*) values increased with increasing age.

Multi-regression analyses were performed for each of the 49 separate items using the same 5 predictors that were used for the SSQ and its subscales (fig. 5). Only the predictors that survived a bootstrap check and had a p-value < 0.01 were retained. Across the 49 items, the percentage of variance explained ranged from 7.5% (#3.12) to 35% (#1.7 & #2.3), with a median of 23%. More than 16% of the variance was explained for all of the items aside from 3 items from the *Qualities* subscale (#3.11, #3.12 and #3.13). The beta coefficients associated with each significant predictor are displayed for each item (fig. 5). Most of the scores were predicted by only better-ear PTA and hearing-loss asymmetry; however, 7 items (#1.9, #2.14, #2.15, #2.16, #3.1, #3.2 and #3.8) depended significantly on the number of years of education, with an increasing score with more years of education, and several items on the *Qualities* subscale showed tendency toward this association (#3.3 to #3.5 and #3.7, $0.01 < p < 0.05$). Several items from the *Speech* subscale (#1.4, #1.6) showed a tendency toward an age effect ($0.01 < p < 0.05$), with decreasing scores with increasing age and #1.7 showed a significant effect. Isolated age effects that showed increasing scores with increasing age were obtained for #2.14 and #3.1. An isolated gender effect ($p < 0.03$) in which women gave lower scores was obtained for #2.13; however, this effect did not survive p threshold correction. Most items on the *Spatial* subscale were strongly predicted by hearing-loss asymmetry.

Discussion

As expected, SSQ scores decreased with increased hearing loss in the better ear by, on average, 0.69 points per 10 dB of hearing loss. This association is substantially greater than the 0.43 points per 10 dB HL reported by Akeroyd et al (2014) for their whole dataset. However, when only the unaided HIS were selected among Akeroyd et al.'s subjects, the rate increased to 0.53 points per 10 dB HL. In addition, our population consisted almost entirely of unaided HIS whose hearing loss was slightly greater than that of Akeroyd's group (23 dB HL versus 21 dB HL) and a group of NHS: there is a substantial difference (approximately 1 point) between the scores of our young NHS and those of our HIS with less than 15 dB HL PTA, suggesting that age and/or hearing-loss asymmetry could account for some proportion of the SSQ variability independent of hearing loss in the better ear.

The different short forms showed an association between scores and hearing loss that was either similar to that of the SSQ (in the case of the SSQ5) or a steeper decrease (in the case of both the SSQ15 and SSQ12). The SSQ12 showed the steepest slope (0.75 points per 10 dB HL), as Noble et al (2013) noted previously. This finding was confirmed by the slightly greater difference between NHS and HIS scores obtained on the SSQ12, although both groups scored slightly lower score on the SSQ12 than on the other forms.

Of the 3 main subscales, the Speech subscale showed the greatest decrease in score associated with hearing loss (almost 0.9 points per 10-dB HL) and the greatest difference between the NHS and HIS, suggesting an influence of age. The influence of age on the SSQ has been carefully addressed by Banh et al (2012), who did not observe any correlation between SSQ scores and hearing thresholds in their young NHS (which agrees with our results) but did observe a few weak correlations between a Words-in-Noise test and Speech subscale scores in an older group. The significant influence of age as a predictor was observed for items on the *Speech* subscale, especially #1.7, one of the items for which Banh et al (2012) reported a large age effect (a difference of 1.7). Five of the 7 items that showed an age effect in Banh et al (2012)'s data were from the *Speech* subscale. Age was the only significant predictor of the (*Speech - Qualities*) differential score and was one of the predictor for the *Speech in speech contexts* pragmatic subscale (that includes #1.7). The decrease in the (*Speech - Qualities*) values with increasing age suggests a greater variation in speech with age than in qualities with age, a result that was confirmed by the significantly higher correlation observed between *Speech* and age ($r = -0.38$) than between *Qualities* and age ($r = -0.24$). Consequently, age seems to have a specific effect on *Speech* subscale scores.

As expected, hearing-loss asymmetry was the second strongest predictor of SSQ scores (accounting for an additional 9% of variance after better-ear PTA). Its predictive value was especially strong for the spatial subscale, for which hearing-loss asymmetry accounted for an additional 14% of variance. An item-by-item analysis found that the beta coefficients for hearing-loss asymmetry were lower than -0.20 for almost all of the Spatial items, whereas the beta coefficients were greater than -0.20 for the items on the other subscales. Hearing-loss asymmetry was the most important predictor for items #2.6 and #2.7. In contrast, #2.14 and #2.16 were not significantly predicted by hearing-loss asymmetry, but were predicted by the number of years of education (as was #2.15). The lack of a significant correlation with hearing-loss asymmetry for those two items was previously noted by Gatehouse & Noble (2004) in their initial 153-patient sample. The factor analysis reported in Moulin et al. (2015) shows that communalities were at their lowest for #2.14 “*Do the sounds of things you are able to hear seem to be inside your head rather than out there in the world?*”, #2.15 “*Do the sounds of people or things you hear, but cannot see at first, turn out to be closer than expected when you do see them?*” and to #2.16 “*Do the sounds of people or things.... turn out to be further ...*” (for both the French and English SSQ versions). Those items also had a high number of missing responses and readability difficulties, suggesting that they presented greater cognitive difficulty than the other items.

One result showed a gender effect on one *Spatial* item (#2.13 “*Can you tell from the sound whether a bus or truck is coming towards you or going away?*”), which showed a lower score for women. Gender was a significant predictor of the (*Speech - Spatial*) index, for which women had higher values. A detailed inspection of the multi-regression analysis of the *Speech* and *Spatial* subscales suggests that the *Spatial* scores tended to be lower for women and the *Speech* scores tended to be higher. Perhaps the *Spatial* items are somewhat more difficult for women because of gender-linked differences in visuo-spatial ability (Voyer et al, 1995).

Hearing-loss asymmetry was a significant and larger predictor (beta lower than -0.20) for #3.14, #3.16 and #3.17, items that were previously noted in the factor analysis for their loadings on the speech factor rather than on the qualities factor (Moulin et al., 2015). Indeed, those items relate to speech-in-noise situations in which binaural cues are particularly important.

Several *Qualities* subscale item scores were dependent on the number of years of education, an association that was confirmed by the “*SegSounds*” and “*IdSounds*” pragmatic subscale scores, which increased significantly with increasing years of education. It is also possible that this influence was favoured by our use of self-report rather than interview mode for the SSQ. Indeed, Singh & Pichora-Füller (2010) have shown the importance of interviewers’ clarification of contexts. The self-report mode does not provide the potential help from an interviewer and

could increase the influence that general knowledge and number of years of education have on an individual's responses. This association can reflect both a degree of difficulty with the wording of some questions, difficulties imagining the situations depicted, and/or perhaps tiredness on the part of the subjects as these questions are the last of the 49 items. The dependence on the number of years of education was significant for the time needed for complete the SSQ (the time required increased with fewer years of education), but, reassuringly, it did not affect the SSQ scores or the SSQ *Qualities* subscale score. However, it did affect the SSQ15 *Qualities* subscale, a result that underscores the need to carefully select the items for inclusion in short forms and the need for both a data-driven approach and external validation in short-form building, as recommended by Widaman et al. (2011) and Stanton et al. (2002).

Differential scores between subscales could be valuable for assessing specific aspects of hearing disability, such those linked to hearing-loss asymmetry; several indices were significantly dependent on hearing-loss asymmetry independently of hearing loss. In addition, difference scores for several subscales within the same patient help decrease the inter-subject variability in absolute scores that results from patients' individual perception of self-evaluations. Hence, differential scores, such as (*Qualities – Spatial*), (*SiQ – Loc*) and (*SiQ-DistMov*) could be more sensitive to the modifications and benefits brought by hearing aids, especially in cases of asymmetric hearing loss (House et al, 2010), than absolute scores would be. Care must be taken to avoid a floor effect: i.e., if all the subscales scores are close to zero, then the differential scores would be artificially close to zero; however, that is more a general statistical problem, and data transformation could overcome this to a certain degree.

All short forms were predicted in a similar manner by hearing loss and hearing-loss asymmetry, without any other significant predictor. The good correlation between the SSQ and the SSQ5 obtained here for unaided HIS is in agreement with the good correlation obtained by Mertens et al (2013) for cochlear implant patients. SSQ12 showed a steeper variation of scores with better-ear PTA and a less-linear relationship with the SSQ49 compared with all of the other short forms, a difference previous noted by Noble et al (2013). The SSQ15 has the potential to retain the information available from the 3 main subscales of the full SSQ, but it includes a somewhat unwanted predictor for the *Qualities* subscale (the number of years of education). Indeed, several authors (Stanton, 2002; Widaman et al, 2011) suggest that external criteria, such as correlations with external factors, are the most important aspects of short-form validity. Hence, choosing the items that are most sensitive to hearing-loss asymmetry for the *Spatial* subscale and the items with a high score (and low variability) for NHS would increase the differential scores between subscales and the differences between NHS and HIS groups, providing greater sensitivity to hearing-loss asymmetry and hearing loss with a shorter assessment than the full SSQ requires. However, several results in several languages and for

several populations would have to be taken into account to develop an internationally valid short form (Arlinger, 2000).

Conclusion

This work identified and quantified different sources of variability in the scores of the Speech, Spatial, and Qualities of Hearing Scale (SSQ) when used in a self-report mode. These sources included expected factors, such as hearing loss and hearing-loss asymmetry, and less-desirable factors, such as gender or the number of years of education. The use of differential scores among the 3 main subscales could provide more specific information; for instance, the *Speech - Qualities* scores showed a dependence on only hearing-loss asymmetry, and the *Speech - Spatial* scores showed a significant correlation with age only. Furthermore, the NHS group's score of substantially below the maximum of 10 needs to be taken into account when interpreting the scores of hearing-impaired individuals; in particular, the *Speech* subscale showed much greater differences between young NHS and HIS than the two other subscales. The many similarities among several language versions and the results obtained here and in Moulin et al. (2015) strongly favour the use of the SSQ as an international standard. However, the similarities (and dissimilarities, for some items) across languages and the unwanted predictors found for some SSQ items could be used to refine the SSQ and to build short forms using the multi-step, data-driven approach recommended in the international literature, which aims to retain the specificity of the 3 SSQ main subscales and reinforce the contrasts between HIS and NHS while reducing the length of the full SSQ, which can be quite taxing for some patients.

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Figure legends

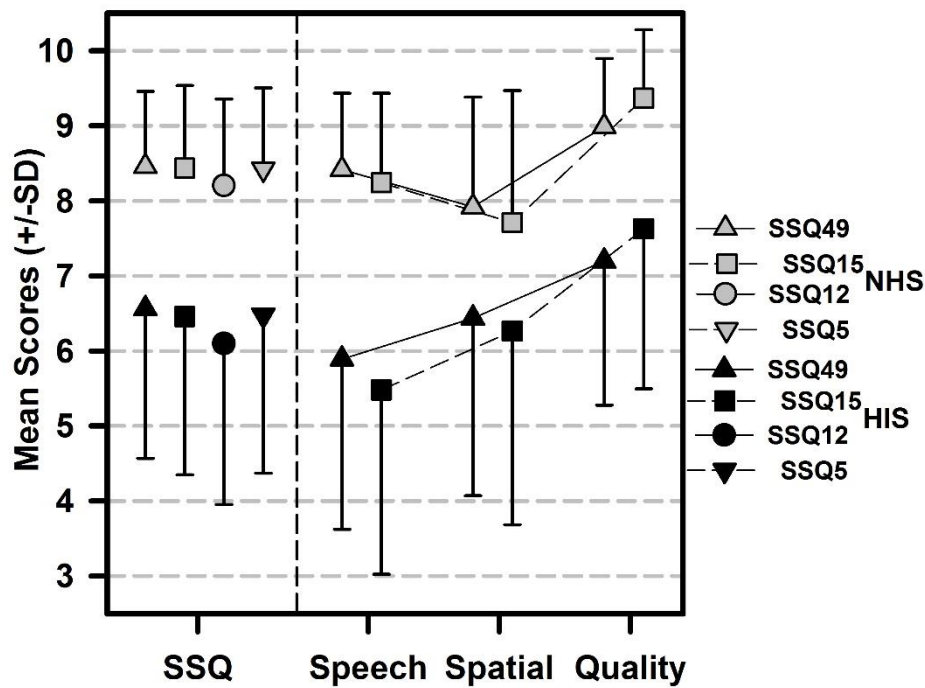


Fig. 1: Comparison of the mean scores (+/- standard deviation) for the full SSQ (up-triangles) and the different short forms (down-triangles for the SSQ5, dots for the SSQ12 and squares for the SSQ15), for the entire scale and for each of the main subscales (*Speech*, *Spatial* and *Qualities*). The scores were obtained for a normal-hearing population (NHS, n = 98; grey symbols) and a hearing-impaired population (HIS, n = 216; black symbols).

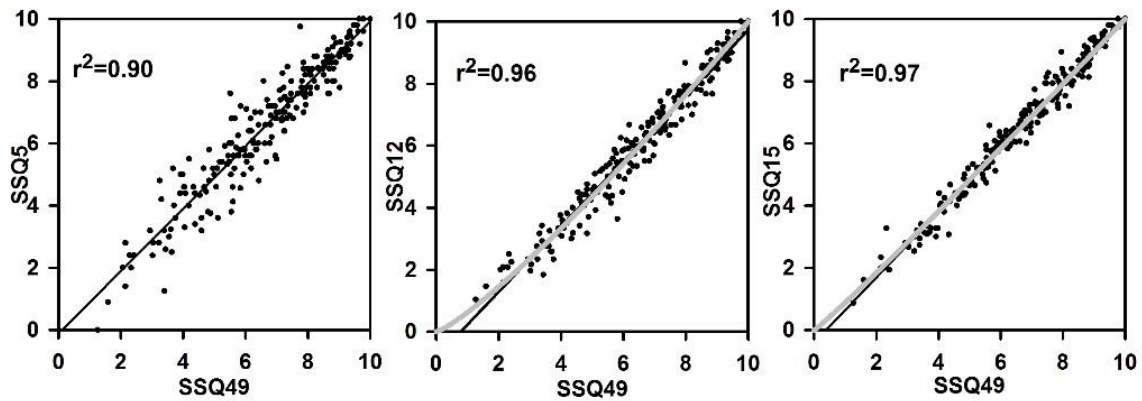


Fig. 2. Scatter plots of the scores obtained for each short form as a function of the full SSQ score (SSQ5 in fig. a, SSQ12 in fig. b, SSQ15 in fig. c). Linear regressions are represented by black lines, whereas power functions are represented by a grey line (for the SSQ12 and the SSQ15). The power function is not represented for the SSQ5 because no difference was visible with the linear regression. The percentage of explained variance (r^2) is reported for each figure.

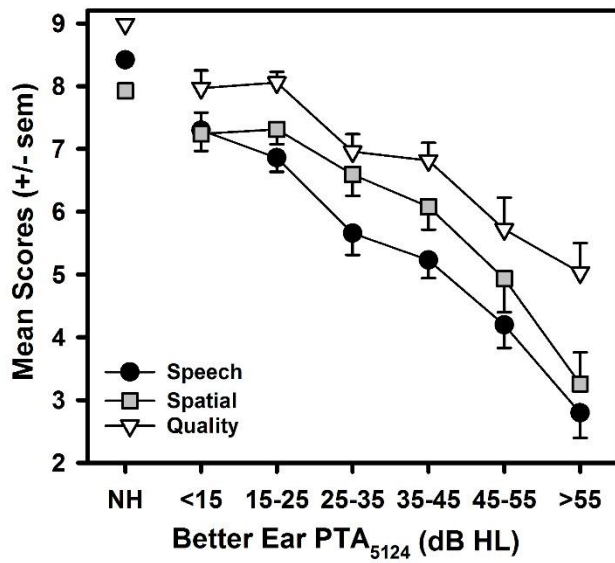


Fig. 3: Mean scores (+/- sem) for the SSQ (black dots-dotted line) and the 3 subscales (black dots for the *Speech* subscale, grey squares for the *Spatial* subscale and white triangles for the *Qualities* subscale) for the young normally hearing subjects (NHS) and the hearing-impaired subjects (HIS), grouped by the average pure-tone hearing threshold (PTA) (500 Hz, 1, 2 and 4 kHz) of their better ear.

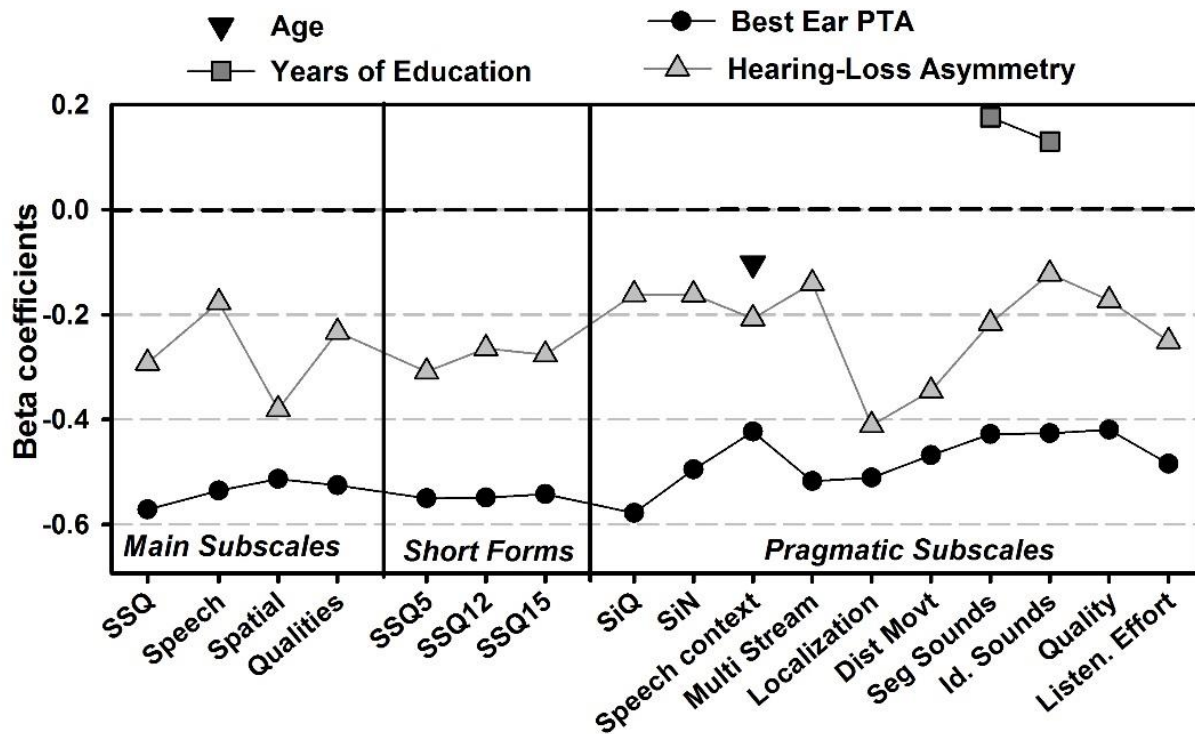


Fig. 4. Multi-regression analysis results for each SSQ main subscale (Speech Spatial and Qualities), short forms and 10 pragmatic subscales, with 4 predictors (age in black triangles, years of education in grey squares, hearing-loss asymmetry in grey triangles and better-ear PTA in black dots). The beta coefficients representing the relative influence of each statistically significant predictor are given for each subscale. The analyses were performed on 216 hearing-impaired subjects, and each regression model was checked by bootstrap analysis.

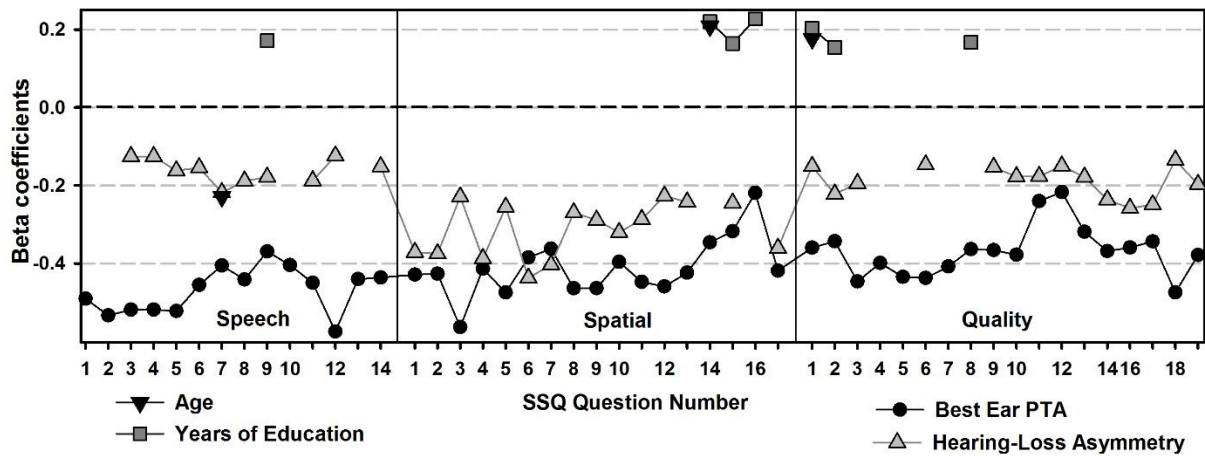


Fig. 5. Multi-regression analysis results for each SSQ item, with the same 4 predictors as fig. 4 (age in black triangles, years of education in grey squares, hearing-loss asymmetry in grey triangles and better-ear PTA in black dots). The beta coefficients representing the relative influence of each statistically significant predictor are given for each item. For instance, #1.1 had only better-ear PTA as a predictor, whereas #3.8 had better-ear PTA and years of education as predictors. The analyses were performed on 216 hearing-impaired subjects, and each regression model was checked by bootstrap analysis.

Tables

Table 1

Pearson correlations (r) with r >0.17: p<0.01		Age (years)	Years of education	Worse Ear PTA	Better Ear PTA	Ear Asymmetry	
Age		1.00	-0.38	0.34	0.55	0.02	
Years of Education		-0.38	1.00	-0.24	-0.41	-0.01	
SSQ							
	Total	-0.32	0.31	-0.52	-0.56	-0.23	
Main subscales	Speech	-0.38	0.30	-0.43	-0.57	-0.12	
	Spatial	-0.26	0.27	-0.56	-0.47	-0.33	
	Qualities	-0.25	0.27	-0.44	-0.49	-0.18	
Pragmatic Subscales (Gate- house & Akeroyd, 2006)	Speech	SiQ	-0.31	0.25	-0.41	-0.56	-0.10
		SiN	-0.37	0.26	-0.40	-0.54	-0.11
		SiSCont	-0.37	0.29	-0.43	-0.49	-0.16
		MultStream	-0.32	0.30	-0.38	-0.54	-0.08
	Spatial	Loc	-0.26	0.21	-0.57	-0.45	-0.36
		DisMOV	-0.27	0.29	-0.52	-0.45	-0.30
	Qualities	SegSnd	-0.20	0.32	-0.39	-0.41	-0.17
		IdSnd	-0.31	0.32	-0.34	-0.48	-0.08
		Qlty	-0.14	0.24	-0.32	-0.37	-0.13
		Effort	-0.19	0.13	-0.41	-0.40	-0.20

Table 1. Pearson correlation coefficients were calculated between several hearing-impaired subjects' variables (age, number of years of education, hearing threshold of the worse ear and the better ear and hearing-loss asymmetry) and SSQ subscales. Statistically significant correlations at a p level < 0.01 (n = 216) are noted in bold, and the greatest correlation coefficients are in the shaded cells. The correlation coefficients were compared using Fisher's z score (two-tailed), with significant differences marked as a bold line (p < 0.005) and a dotted line (p < 0.05).

Table 2

Variables	Predictors	r ²	beta	se beta	b	seb	t	F(1,214)	p
SSQ Score	step 1	31						95	<0.0000001
	Intercept				8.64	0.24	35.8		
	Better Ear PTA		-0.56	0.06	-0.07	0.01	-9.8		
	step 2	40						28	
	Intercept				8.82	0.13	68.0		
	Better Ear PTA		-0.63	0.04	-0.07	0.00	-15.2		
	Hearing-Loss Asymmetry		-0.25	0.04	-0.02	0.00	-5.9		
Speech subscale	step 1	33						105	<0.0000001
	Intercept				8.34	0.27	30.9		
	Better Ear PTA		-0.57	0.06	-0.09	0.01	-10.2		
	step 2	36						60	
	Intercept				8.69	0.28	30.5		
	Better Ear PTA		-0.59	0.06	-0.09	0.01	-10.8		
	Hearing-Loss Asymmetry		-0.18	0.06	-0.02	0.01	-3.3		
Spatial Subscale	step 1	22						61	<0.0000001
	Intercept				8.53	0.30	28.1		
	Better Ear PTA		-0.47	0.06	-0.07	0.01	-7.8		
	step 2	36						61	
	Intercept				9.31	0.30	31.4		
	Better Ear PTA		-0.51	0.05	-0.08	0.01	-9.3		
	Hearing-Loss Asymmetry		-0.38	0.05	-0.04	0.01	-7.0		
Quality Subscale	step 1	24						67	<0.0000001
	Intercept				8.96	0.24	36.8		
	Better Ear PTA		-0.49	0.06	-0.06	0.01	-8.2		
	step 2	29						44	
	Intercept				9.35	0.25	36.8		
	Better Ear PTA		-0.51	0.06	-0.07	0.01	-8.9		
	Hearing-Loss Asymmetry		-0.23	0.06	-0.02	0.00	-4.0		

Table 2. Stepwise multi-regression analysis of the SSQ score (and the 3 main SSQ subscales) with 2 predictor variables - better-ear PTA and hearing-loss asymmetry - for 216 hearing-impaired subjects. The size of the effect (r^2), the exact p values and the additional variance accounted for by the introduction of each new predictor are reported. The beta coefficients allow comparisons of the relative influence of each statistically significant predictor on the SSQ scores.