Using BEAR data to obtain reduced versions of the SSQ-12 and IOI-HA-7 questionnaires

TOBIAS PIECHOWIAK[1,*] AND DAVID ZAPALA[2]

[1] *GN Store Nord A/S, DK-2750 Ballerup, Denmark*

[2] *Mayo Clinic, Jacksonville, FL 32224, USA*

The Speech, Spatial and Qualities of Hearing scale (SSQ-12) and the International Outcome Inventory for Hearing Aids (IOI-HA-7) are questionnaires containing 12 and 7 items, respectively. They are designed to subjectively assess hearing ability and are complementary to behavioral measures. Both questionnaires have been applied across a range of clinical and clinical research-related contexts, for example for assessing outcomes of e.g., cochlear implants and hearing aids. However, due to time constraints neither of the questionnaires seem to be an inherent part of standard clinical quality control. The Better Hearing Rehabilitation (BEAR) database contains SSQ-12 and IOI-HA-7 scores of around 1600 subjects. Applying an Exploratory Factor Analysis (EFA) on the data from the 2nd visit allowed us to reduce the SSQ-12 to 5 questions and the IOI-HA to 3 remaining questions. The SSQ-5 explains 79 % of the variance in the SSQ-12 data while the IOI-HA-3 accounts for 70 % of the variance in the original IOI-HA-7. These new versions have the potential to be used more efficiently by shortening time and focusing on the items that are most effective to reflect individual benefit. Furthermore, the analysis seems to confirm the validity of such a reduction from similar findings in the literature that were done on different datasets.

INTRODUCTION

Our understanding of the many factors that may influence a person's auditory capacity has grown substantially over the past decades. We now recognize the importance of identifying and accounting for conditions such as depression, cognitive impairment, willingness to pursue audiological treatment, and overall health. In an effort to account for these factors, there is a growing pressure to deploy multiple questionnaires in the clinic waiting room. Validated questionnaires can be an efficient way to extract useful information in a busy clinic. However, answering long sets of questions can be taxing for the patient to complete and may adversely affect the patient experience. So there is a need to ask questions efficiently. The Speech, Spatial and Qualities of Hearing scale (Gatehouse and Noble, 2004) is a popular questionnaire tool that was designed for use as a complement to behavioral or experimental measures of hearing ability. The scale was intended to sample every day experiences related to speech understanding, auditory spatial perception and related abilities, and sound quality in a way that scores

*Corresponding author: tpiechowiak@gnresound.com

Proceedings of the International Symposium on Auditory and Audiological Research (Proc. ISAAR), Vol. 7: Auditory Learning in Biological and Artificial Systems, August 2019, Nyborg, Denmark. Edited by A. Kressner, J. Regev, J. C.-Dalsgaard, L. Tranebjærg, S. Santurette, and T. Dau. The Danavox Jubilee Foundation, 2019. ©The Authors. ISSN: 2596-5522.

could generalize across individuals and life situations. The original scale has 49 items and has been applied across a range of clinical and clinical research-related contexts (see Akeroyd *et al.*, 2014). For example, it has been used to assess the effects of age on the hearing ability in subjects with "normal" hearing (Banh *et al.*, 2012) and the effects of unilateral hearing loss (Olsen *et al.*, 2012). It has been used to compare the effects of one versus two cochlear implants (e.g., Laske *et al.*, 2009), one cochlear implant versus implant and contralateral linear frequency transposing hearing aid fitting (Hua *et al.*, 2012), and the effects of musical training on cochlear implant performance (Fuller *et al.*, 2012). There are shorter versions of the SSQ already available. Noble *et al.* (2013) proposed a 12-item version of the SSQ (the SSQ-12). Deemester *et al.* (2012) proposed a 5-item SSQ-5. Akeroyd *et al.* (2014) found four factors on the SSQ-49, three clear factors "speech understanding", "spatial perception", and "clarity" with a possible fourth factor named "effort".

The International Outcome Inventory for Hearing Aids (Cox *et al.* (2000); referred to as IOI-HA-7) is a 7-item questionnaire outcome measure which is considered sufficiently general to apply to many different types of investigations carried out across the world and for many different applications. It was developed at a workshop on *Measuring Outcomes in Audiological Rehabilitation Using Hearing Aids* in Eriksholm in Denmark. The IOI-HA is not intended to replace existing outcome measures but to serve as a useful add-on to already existing measures in a research context. Similar to the SSQ it has been used as a standalone tool for quality assessment of hearing-aids and cochlear implants (Noble, 2002; Erixon and Rask-Andersen, 2015).

The Better-Hearing-Rehabilitation Project (BEAR) is a five year project whose purpose is to promote research in clinical audiology, particularly the development of new clinical methods for diagnosis and hearing-aid fitting. The overall goal is to come up with a new extended fitting procedure. One part of this project is to collect a relatively large database of general as well as auditory information about the subjects and their current fitting. This database contains information of around 2000 subjects including the scores from SSQ-12 and IOI-HA-7 for around 1600 subjects. Subjects had to fill out the SSQ at two occasions: inital fitting and a follow-up visit (2nd visit) two-to three month after the inital visit took place which allows for a direct rating of improvement. The IOI-HA was only rated at the 2nd visit. Based on this data in this work we investigated if and to what extend the SSQ-12 and IOI-HA-7 can be reduced further in order to speed up their use and if the structure of those reduced versions correspond to what has been found in earlier studies (Deemester *et al.* (2012) for the SSQ).

METHOD

Multivariate data are often viewed as multiple indirect measurements arising from an underlying source, which typically cannot be directly measured. Exploratory Factor Analysis is a classical technique developed in the statistical literature that aims to identify these latent sources. In this sense it is a dimensionality reduction technique.

The classical factor analysis model was developed by researchers in psychometrics, like Hastie *et al.* (2008).

With $q < p$, a factor analysis model has the form

$$\begin{aligned} X_1 &= a_{11}S_1 + ... + a_{1q}S_q + \varepsilon_1 \\ X_2 &= a_{21}S_1 + ... + a_{2q}S_q + \varepsilon_2 \\ &\vdots \\ X_p &= a_{p1}S_1 + ... + a_{qp}S_q + \varepsilon_p \end{aligned}$$

or in matrix notation

$$\mathbf{X} = \mathbf{AS} + \varepsilon \qquad \text{(Eq. 1)}$$

The parameters basically all reside in the covariance matrix

$$\sum = \mathbf{AA^T} + \mathbf{D}_\varepsilon \qquad \text{(Eq. 2)}$$

with $D_\varepsilon = diag[Var(\varepsilon_1),...,Var(\varepsilon_p)]$. A is a *pxq* matrix of *factor loadings* and the ε_j are uncorrelated zero-mean disturbances. The factor loadings are used to name and interpret the factors.The **singular value decomposition** (SVD) is a way to decompose quadratic and non-quadratic matrices into their singular-or eigenvalue representation from which the principal factors can be derived. The number of factors is determined by comparing the eigenvalues generated from a data matrix to the eigenvalues generated from a Monte-Carlo simulation created from a random data matrix of the same size and retains those with eigenvalues larger than zero. This is known as parallel analysis and the criteria as *Horn's criterium* for factor analysis (see Dinno , 2014, for an overview).

The analysis here was done with the R programming language (see R Core Team, 2017).

RESULTS AND DISCUSSION

The Exploratory Factor Analysis yields 5 factors for the SSQ-12 and 3 factors for the IOI-HA-7. They explain 79 and 70% of the cumulative variance, respectively. These are also the number of factors with eigenvalues larger than zero (see eigenvalues for SSQ analyis in Figure 1).

The following two figures (2 and 3) show the factor loadings for the individual SSQ and IOI-HA items, respectively. In the figures the factor loadings are stacked in order to see the entire dependency of each single item on the factors.

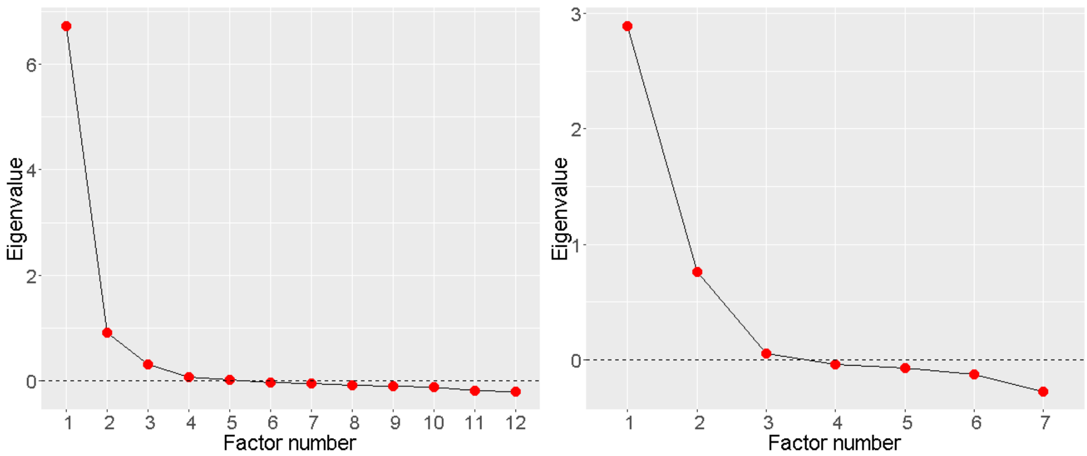

Fig. 1: Scree plot showing the eigenvalues of factors for the SSQ (left panel) and IOI data (right panel). The plot suggests retaining five factors for SSQ and three for IOI according to a parallel analysis which retains eigenvalues larger than zero.

When analysing the factor loadings on each SSQ-12 item one can see that *Factor 1* mainly loads on items relating to speech, while *Factor 2* loads on item relating to space. *Factor 3* loads mainly on sound item #2 which deals with the ability to separate different sound streams. *Factor 4* is clearly associated with listening effort since it correlates mainly with sound item #14. *Factor 5* on the other hand load equally on sound items #7 and #9. They deal with the clarity of everyday sounds and music but not necessarily involving multiple streams of sounds. They are somehow comparable to the findings from Akeroyd *et al.* (2014) who found four factors: *Speech Understanding, Spatial Perception, Clarity and Effort*. In general, good sound clarity means that the sound is as close to reality, or ”like-being-there”, as possible. In this sense, factors *Source Separation* and *Frequency Resolution* contribute to sound clarity. Thus, the findings from this study and those find by Akeroyd *et al.* (2014) do not contradict each other but point to the same factors contributing to the assessment of hearing aid qualities.

One could summarize the factor analysis by tagging each factor with a new label:

Factor labels for SSQ

- Factor 1: *Speech Understanding*
- Factor 2: *Spatial Perception*
- Factor 3: *Source Separation*
- Factor 4: *Listening Effort*
- Factor 5: *Frequency Resolution*

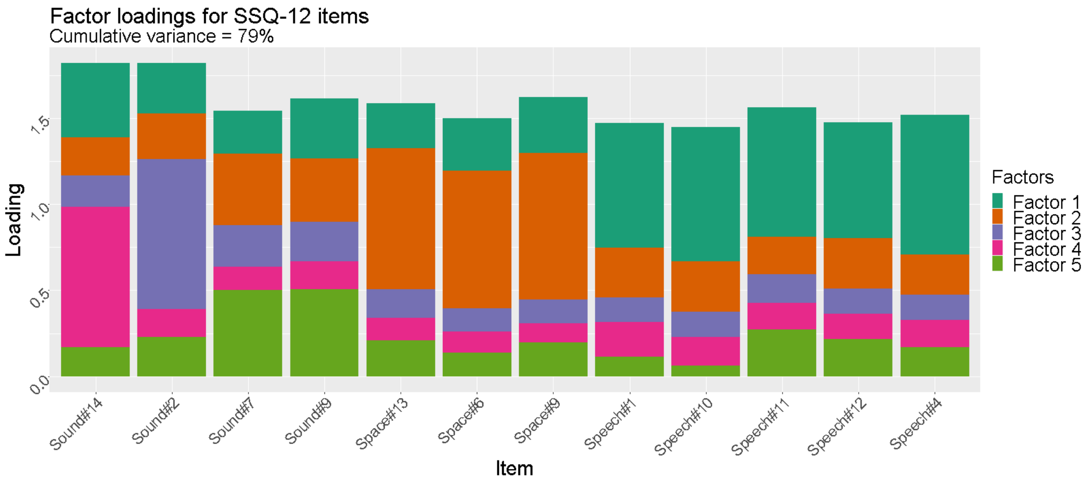

Fig. 2: Results of the factor analyis for the SSQ-12. **Horn's criterium** suggests five remaining factors as seen in Figure 1. These five factors show high correlation with speech understanding, spatial perception, source separation, listening effort, and frequency resolution. See text for details.

Factor labels for IOI-HA

- Factor 1: *Benefits with Hearing Aids*
- Factor 2: *Residual Difficulties with Hearing Aids*
- Factor 3: *Usage*

How do we come up with the items for a potential five item SSQ-5 and three item IOI-HA-3?

In this study, we simply choose those items from the original questionnaires which show the highest correlation (which are the loadings) with the respective factors. Based on this approach we propose the following SSQ-5 and IOI-HA-3:

SSQ-5

- #1: *You are talking with one other person and there is a TV on in the same room. Without turning the TV down, can you follow the conversation?*
- #2: *Can you tell from the sound which direction a bus or truck is moving, e.g., from your left to your right or right to left?*
- #3: *When you hear more than one sound at a time, do you have the impression that it seems like a single jumbled sound?*

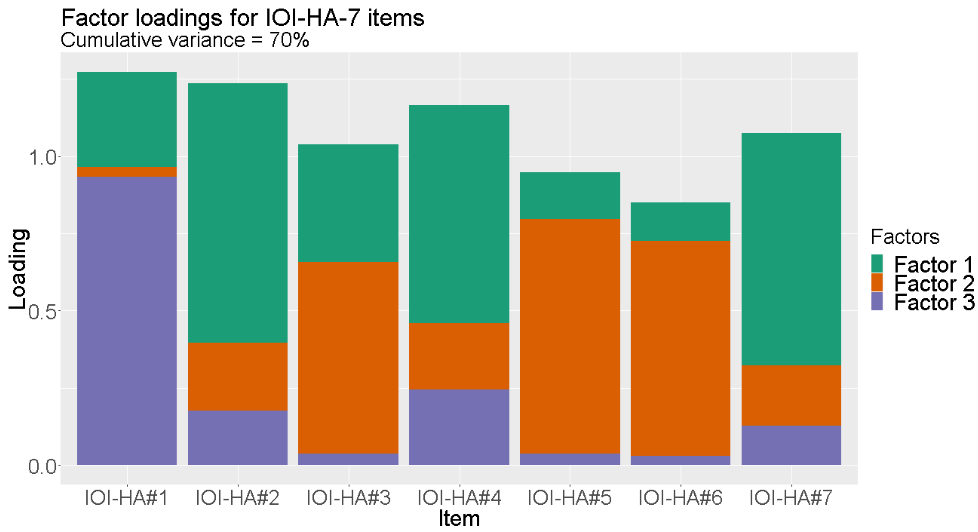

Fig. 3: Results of the factor analyis for the IOI-HA-7. **Horn's criterium** suggests three remaining factors. These three factors show high correlation with speech understanding, spatial perception, source separation, listening effort, and frequency resolution. See text for details.

- #4: *Do you have to concentrate very much when listening to someone or something?*
- #5: *Do everyday sounds that you can hear easily seem clear to you (not blurred)?*

IOI-HA-3

- #1: *Think about the situation where you most wanted to hear better, before you got your present hearing aid. Over the past two weeks, how much has the hearing aid helped in that situation?*
- #2: *Over the past two weeks, with your present aids, how much have your hearing difficulties affected things you can do?*
- #3: *Think about how much you used your present hearing aids over the past two weeks. On an average day, how many hours did you use it?*

Finally, in order to compare the original SSQ-12 with the newly obtained SSQ-5, individual SSQ-12 scores as well as IOI-HA-7 with the obtained IOI-HA-3 original data is plotted against transformed scores with a power function linking the two for the SSQ and the IOI-HA. (left-and right panel Figure 4).

Regarding the SSQ both a power function line and a 1:1 line are also shown in red and black color, respectively. There is close agreement between the two versions of the

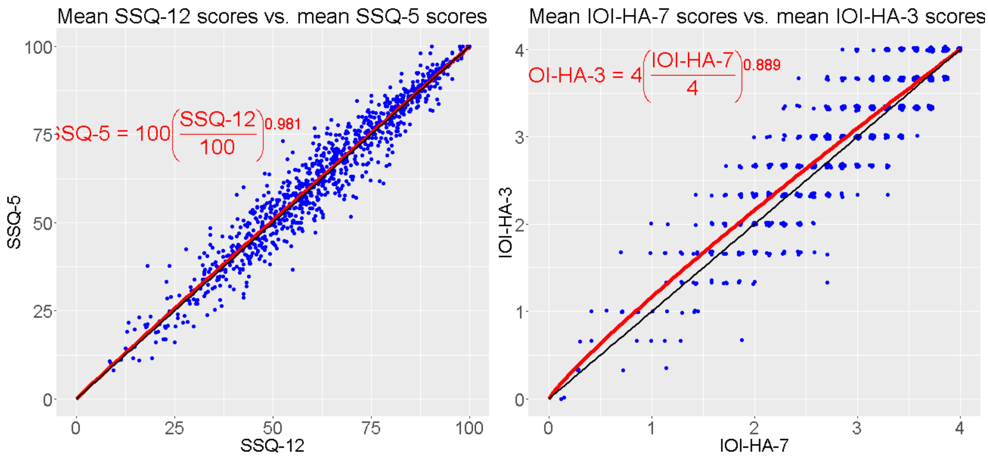

Fig. 4: Left: Individual SSQ-5 scores plotted against SSQ-12 scores. The red line indicates the best fit to a power function given by the equation in the top left corner while the black line shows an 1:1 relationship. They indicate an almost linear relationship between the scales. Right: Individual IOI-HA-3 scores plotted against IOI-HA-7 scores. The red line indicates the best fit to a power function given by the equation in the top left corner while the black line shows a 1:1 relationship

scale the small exponent indicating an almost linear relationship and no bias visible which is indicated by the proximity of the two lines.

For the IOI-HA, the lines indicate two things: (a) a modestly higher IOI-HA-3 average score compared to the IOI-HA-7 due the points lying above the 1:1 line and (b) a slightly steeper slope for the IOI-HA-7 relative to IOI-HA-3 which indicates a higher sensitivity between low-and high scores for the longer IOI-HA-7.

In general, it can be concluded from the current study that it is possible to further reduce the existing SSQ-12 and IOI-HA-7 questionnaires without critical loss of explanatory power (79% and 70% cumulative variance explained). This is in line with findings from other studies (see e.g., Akeroyd *et al.*, 2014; Deemester *et al.*, 2012; Moulin *et al.*, 2019) whose suggestion in reduction of size is similar to our findings. Shorter and more concise questionnaire likely lower the threshold of use of both from a clinician's standpoint and also from the subjects' point of view in the sense that the remaining questions are more precise and contrast more from each other.

REFERENCES

Akeroyd, M. A., Guy, F. H., Harrison, D. L., and Suller, S. L. (**2014**). "A factor analysis of the SSQ (Speech, Spatial, and Qualities of Hearing Scale).," Int. J. Audiol., **53**(2), 101-114

Banh, J., Singh, G., and Pichora-Fuller, M. K. (**2012**). "Age affects reponses on the Speech, Spatial and Qualities of Hearing scale (SSQ) by adults with minimal audiometric loss.," J. Am. Acad. Audiol., **23**, 81-91.

Cox, R., Hyde, M., Gatehouse, S., Noble, W., Dillon, H., Bentler, R., Stephens, D., Arlinger, S., Beck, L., Wilkerson, D., Kramer, S., Kricos, P., Gagne, J., Bess, F., and Hallberg, L. (**2000**). "Optimal outcome measures, research priorities, and international cooperation," Ear Hear., **21**, 106S-115S.

Deemester, K., Topsakal,V., Hendrickx, J-J, Fransen, E., Van Laer, L., and Van Camp, G. (**2012**). "Hearing disability measured by the Speech, Spatial, and Qualities of Hearing scale in clinically normal-hearing and hearing-impaired middle-aged persons, and disability screening by means of a reduced SSQ (the SSQ5)," Ear Hear., **33**, 615-626.

Dinno, A. (**2014**). "Gently Clarifying the Application of Horn's Parallel Analysis to Principal Component Analysis Versus Factor Analysis," unpublished, `https://alexisdinno.com/Software/files/PA_for_PCA_vs_FA.pdf`

Erixon, E., and Rask-Andersen, H. (**2015**). "Hearing and Patient Satisfaction Among 19 Patients Who Received Implants Intended for Hybrid Hearing: A Two-Year Follow-Up," Ear Hear., **36**, 271-8.

Fuller, C., Free, R., Maat, B., and Başkent, D. (**2012**). "Musical background not associated with self-perceived hearing performance or speech perception in postlingual cochlear-implant users.," J. Acoust. Soc. Am., **132**, 1009-1016.

Gatehouse, S., and Noble, W. (**2004**). "The Speech, Spatial and Qualities of Hearing scale (SSQ)," Int. J. Audiol., **43**, 85-99.

Hastie, T., Tibshirani, R., and Friedman, J. (**2008**). "Elements of Statistical Learning," Springer Series in Statistics.

Hua H., Johansson B., Jönsson R., and Magnusson, L. (**2012**). "Cochlear implant combined with a linear frequency transposing hearing aid.," J. Am. Acad. Audiol., **23**, 722-732.

Laske R. D., Veraguth D., Dillier N., Binkert A., Holzmann D., and Huber, A. M. (**2009**). "Subjective and objective results after bilateral cochlear implantation in adults.," Otol. Neurotol., **30**, 313-318.

Moulin, A., Vergne, J., Gallego, S. and Micheyl, C. (**2019**). "A new speech, spatial, and qualities of hearing scale short-form: factor, cluster, and comparative analyses," Ear Hear., **40**(4), 938-950.

Noble, W. (**2002**). "Extending the IOI to significant others and to non-hearing-aid-based interventions," Int. J. Audiol., **41**, 27-9.

Noble, W., Jensen N. S., Naylor G., Bhullar N., and Akeroyd, M. A. (**2013**). "A short form of the Speech, Spatial and Qualities of Hearing scale suitable for clinical use: The SSQ12," Int. J. Audiol., **52**, 409-412.

Olsen S. O., Hernvig L. H., and Nielsen, L. H. (**2012**). "Self-reported hearing performance among subjects with unilateral sensorineural hearing loss.," Audiol. Med., **10**, 83-92.

The R Core Team. (**2017**). "R: A Language and Environment for Statistical Computing," R Foundation for Statistical Computing, Vienna Austria.