Speech related hearing aid benefit index derived from standardized self-reported questionnaire data

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Speech understanding in noisy environments has been the most desired hearing-aid (HA) benefit sought by HA users. This paper examines the possibility of developing a speech-related HA benefit index from the speech-related questions in the self-reported questionnaire data. One question from Health-Related Quality of Life (HRQoL) instrument 15D and nine questions from the Speech, Spatial and Qualities of Hearing Scale (SSQ) having a direct implication to speech were selected for the analysis. After applying weights relevant to 15D, a delta of base-line (prior to HA fitting) and follow-up (two months after the initial fitting) responses to the selected questions were determined. A principal component analysis (PCA) was performed on the scaled and centered delta values. The resultant principal component scores were used to derive the composite index indicative of speech-related HA benefit.

INTRODUCTION

The speech intelligibility in challenging environments is, according to Kochkin (2002), the most desired improvement in hearing-aid (HA) rehabilitation. Studies also suggest that conversation in the presence of noise was the listening situation rated as the lowest in satisfaction by HA users (Abrams and Kihm, 2015). The subjective improvement in hearing ability in challenging listening situations involving speech

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understanding reflected in the self-reported questionnaire responses can be used as an effective HA outcome measure, this is established in previous studies, including Cox (2009) and Lopez-Poveda (2017).

This study is part of an effort to identify potential sub-populations with low HA benefit in the population of 1,961 patients provided HA rehabilitation in two audiological departments at two university hospitals in Denmark, Wolff *et al.* (2017). The data analysed was collected as part of the Better hEAring Rehabilitation project (BEAR), a Danish national project envisioned to improve hearing rehabilitation through an evidence-based renewal of clinical practice. The purpose of the present study is to develop a speech-related HA benefit index to facilitate a single-dimension scale from the differently scaled self-reported questionnaires collected in the BEAR project.

METHOD

Only the questions with direct implication to speech understanding were considered for the analysis. Principal Component Analysis (PCA) was used to understand the underlying relationship between the selected questions. This approach is inspired by similar approaches in the field of socio-economic studies (Antony and Rao, 2007; Howe *et al.*, 2008; Chao and Wu, 2017). The resultant principal component (PC) scores and their contribution to explaining overall variance in the responses are used to calculate a composite index that can be an indicator of speech-related HA benefit.

Data

Data from the 1,961 patients registered in the centralized clinical database of the BEAR project are analyzed. The mean age of the patients was 67 years (ranging from 19 years to 100 years), with 72% first-time HA users and 28% experienced HA users. The records consisted of audiometric data (including air- and bone-conduction hearing thresholds, acoustic reflex, tympanometry, speech reception thresholds, and speech recognition scores), self-reported quality of life evaluation questionnaires (15D Sintonen and Pekurinen (1993) and a non-standardized health-related questionnaire, and Tinnitus Handicap Inventory (THI) Newman *et al.* (1996)), specific standard questionnaires to understand the hearing disabilities and HA outcome (Speech, Spatial and Qualities of Hearing Scale (SSQ) Gatehouse and Noble (2004), and International Outcome Inventory for HA (IOI-HA) Cox and Alexander (2002)), and HA data (HA type, fitting rationale, HA log time, and Real-Ear Measurements, REM).

Seventeen of the original SSQ questions were included, 12 of which are from the standard short form of SSQ49; the SSQ12, and five extra questions including one question from the speech domain, and four questions from the quality of hearing domain of the SSQ49. The SSQ questions were provided with a scale from 0 to 100 in the RedCap (Harris *et al.* (2019)) implementation, assuming that the responses divided by 10 would give the same scaling as in the standard SSQ from 0 to 10 (Lorentzen *et al.*, 2019). The responses were recorded online before the planned visit of the patients for the HA fitting, and before the scheduled follow-up visit (approximately two months after the initial fitting). For the present analysis, question 3 of the 15D, and the nine questions from the customized implementation of the SSQ that all had direct implication to speech understanding were included (See Tab. 1).

Question ref.	Pragmatic sub-scale	Questions
15D3	Not applicable	Question 3 Hearing: 1. I can hear normally 2. I hear normal speech with little difficulty 3. I hear normal speech with considerable difficulty 4. I hear even loud voices poorly; I am almost deaf 5. I am completely deaf.
SSQ49-1.1	Speech in noise	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 what the person you're talking to says?
SSQ49-1.4	Speech in noise	You are in a group of about five people in a busy restaurant. You can see everyone else in the group. Can you follow the conversation?
SSQ49-1.10	Multiple speech streams	You are listening to someone talking to you, while at the same time trying to follow the news on TV. Can you follow what both people are saying?
SSQ49-1.11	Multiple speech streams	You are in conversation with one person in a room where there are many other people talking. Can you follow what the person you are talking to is saying?
SSQ49-1.12	Multiple speech streams	You are with a group and the conversation switches from one person to another. Can you easily follow the conversation without missing the start of what each new speaker is saying?
SSQ49-1.14	Multiple speech streams	You are listening to someone on the telephone and someone next to you starts talking. Can you follow what's being said by both speakers?
SSQ49-3.14	Listening effort	Do you have to concentrate very much when listening to someone or something?
SSQ49-3.15	Listening effort	Do you have to put in a lot of effort to hear what is being said in conversation with others?
SSQ49-3.16	Not applicable	When you are the driver in a car can you easily hear what someone is saying who is sitting alongside you?
SSQ49-3.17	Not applicable	When you are a passenger can you easily hear what the driver is saying sitting alongside you?

Table 1: Questions included in the defined set of questions for analysis, including pragmatic subscales according to Gatehouse and Akeroyd (2006).

Analysis

A total of $n = 1{,}148$ out of 1,961 patients had given valid responses to all ten questions of interest for the present analysis consisting of both first time and experienced HA users. The standardized weights for the Danish version of 15D according to Wittrup-Jensen and Pedersen (2008) were applied, and the delta values (difference between baseline before fitting and before follow-up visit) calculated for the 15D and the subset of the SSQ questions. The delta values were scaled and centred before PCA.

The PCs with eigenvalues higher than 1 were considered for determining the composite index. The derived principal component score of the respective PC was weighted with a ratio of the percentage contribution of the PC to the overall percentage of variance explained by all the considered PCs. The summation of the weighted component scores of all the PCs determined the composite index, as shown in Eq. 1. This approach is an adaptation of method described in Antony and Rao (2007).

$$Index_i = \sum_{k=1}^{n} [PC_k/PC_{total}] * ComponentScore_{ik} \qquad \text{(Eq. 1)}$$

where,

$$ComponentScore_{ik} = \sum_{j=1}^{n} Observation_{ji} * Loading_{kj} \qquad \text{(Eq. 2)}$$

- i - number of patients
- k - number of principal components considered
- j - number of questions considered
- PC_k - percentage of variance explained by the k^{th} principal component
- PC_{total} - overall percentage of variance explained by all k principal components
- $Observation_{ji}$ - Scaled and centred recorded response values for j^{th} question for i^{th} individual.
- $Loadings_{kj}$ - Rotated principal axis values for k^{th} component for j^{th} question.

RESULTS

The scree plot in Fig. 1 shows the percentage of variance in the data explained by each PC. The first two components are considered for further analysis with respect to the eigenvalues of these components (overall: 60.8%, PC1: 49.3%, and PC2: 11.5%). Even though only two components were considered for deriving the index, this choice was statistically verified by performing an Analysis of Variance (ANOVA) on the index derived by including one to six PCs. Including more than two components did not show any statistically significant change in the index. Tab. 2 shows the percentage contribution of each question towards the respective PC considered in the further analysis. It can be seen that PC1 is built by contributions from all SSQ questions included, whereas PC2 is clearly dominated by the two questions (SSQ-Q14 and SSQ-Q15) that relate to listening effort.

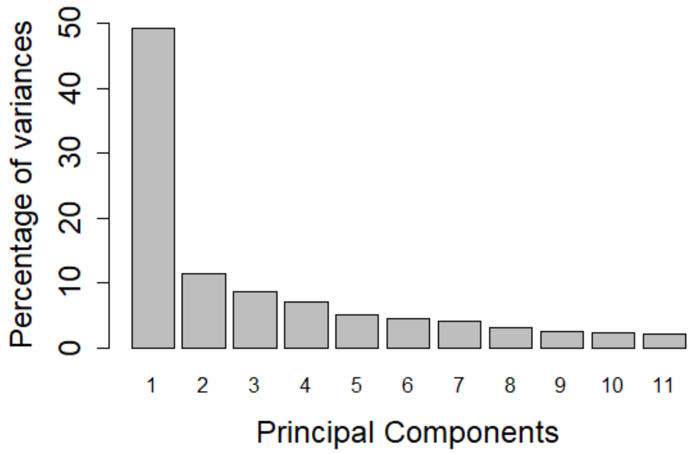

Fig. 1: Scree plot indicating percentage of variance explained by each principal component.

From the component score, the loading, and the percentage contribution of the respective PC, the speech-related benefit index is derived using Eq. 1, see Fig. 2. The negative index refers to the particular individual having negative correlation to the dominant PCs.

DISCUSSION

A composite index related to speech benefit using a HA is derived from selected self-reported questionnaire data. The PCA reveals a first component dominated by the questions in SSQ, with slightly higher loads on questions 4, 10, and 11. These represent three different pragmatic sub-scales; speech in noise, multiple speech streams, and speech in speech, respectively. The second component is loaded significantly by the listening effort dimension.

It is hypothesized that the composite index proposed is indicative for the speech-related HA benefit of a given individual. Negative values in Fig. 2 would then indicate a low benefit of the HA in the functional domain of speech understanding. This is valid as the negative index represents a negative correlation of the responses to the PCs considered. However, a margin could be applied to account for the false positives (misclassified low benefit users). Although the index is not normally distributed, as a rough estimator we can consider one standard deviation length as the error margin. Thus, negative indices below -1.9, which is one standard deviation length away from

Question	PC 1	PC 2
15D3	1.47	1.07
SSQ49-1.1	**10.09**	2.83
SSQ49-1.4	**11.64**	4.51
SSQ49-1.10	**11.43**	**9.81**
SSQ49-1.11	**10.77**	5.47
SSQ49-1.12	**9.48**	3.40
SSQ49-1.14	**9.57**	**10.71**
SSQ49-3.14	7.62	**22.05**
SSQ49-3.15	8.53	**21.96**
SSQ49-3.16	**9.91**	8.71
SSQ49-3.17	**9.46**	9.47

Table 2: Percentage of variance accounted for each question by each principal component.

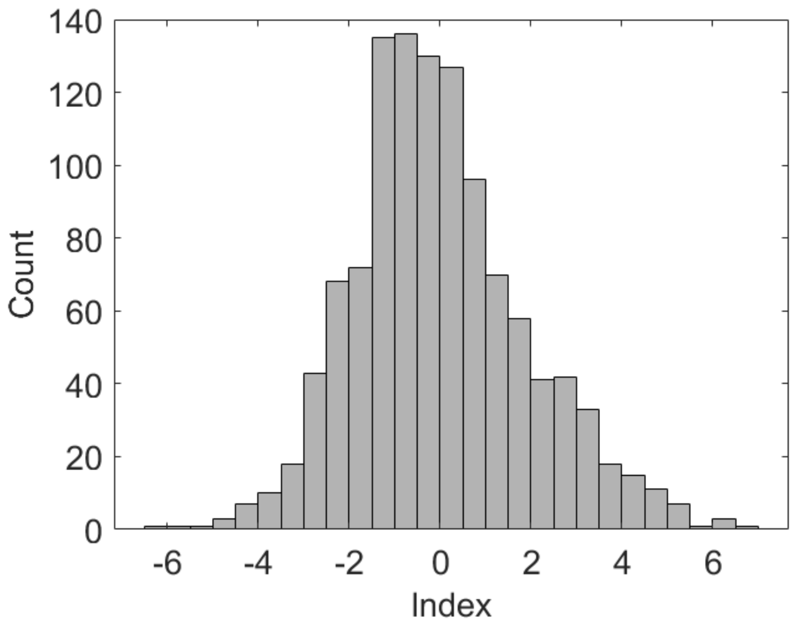

Fig. 2: Histogram showing the distribution of the derived speech-related benefit index, using Eq. 1.

the mean (which is -7e^{-12} and thus close to zero) could be an indicator of low benefit, and indices higher than $+1.9$ could represent the desired benefit, then 164 out of 1,148 patients in the present population have negative benefit (indices between -1.9, and -6). This accounts for a total of 14% of the patients included. Many studies have associated non-regular usage of the HA to lower benefit (Kochkin, 2007; Dillon *et al.*, 1999). The trend in the percentage of patients with non-regular HA usage found in these studies is similar to the percentage of patients with low benefit in the current study. This suggests further investigation of the HA usage of the patients identified as low-benefit users. The absolute criteria of one standard deviation length as error margin also have to be statistically validated.

CONCLUSIONS

A composite index has been derived based on the available self-reported questionnaire data relating to speech understanding. Considering the population studied, an individual having a negative speech-related benefit index less than -1.9 could be a potential low-benefit HA user.

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