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Publication date:
2019

Document Version
Publisher's PDF, also known as Version of record

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Introduction

The present work is inspired by the thought of having a single index to scale the hearing aid (HA) benefit from self-reported questionnaires. Previous studies have shown that speech understanding in noisy environments is one of the most desired improvements sought by hearing aid users [1, 2]. The perceived HA benefit thus can depend on the facilitation of everyday communication in challenging environments by the HA. This should also ideally reflect in self-reported questionnaires responses recorded in the BEAR project. Single index scale would facilitate the identification of a sub-population, if there exist, with a low-compensation benefit from the usage of hearing aid.

The self-reported questionnaire responses recorded during the follow-up visit 2 months after the initial fit, show a stronger correlation (Figure 1) of 15D question 3 related to speech understanding, to the 17 questions of SSQ, and three questions from IOI-HA (Question 3, 5, and 6), which were also part of the same survey (Figure 2). Further, a composite single value index created from speech-related questions (SRQ) that are part of the survey can be a good representation of the perceived hearing aid benefit.

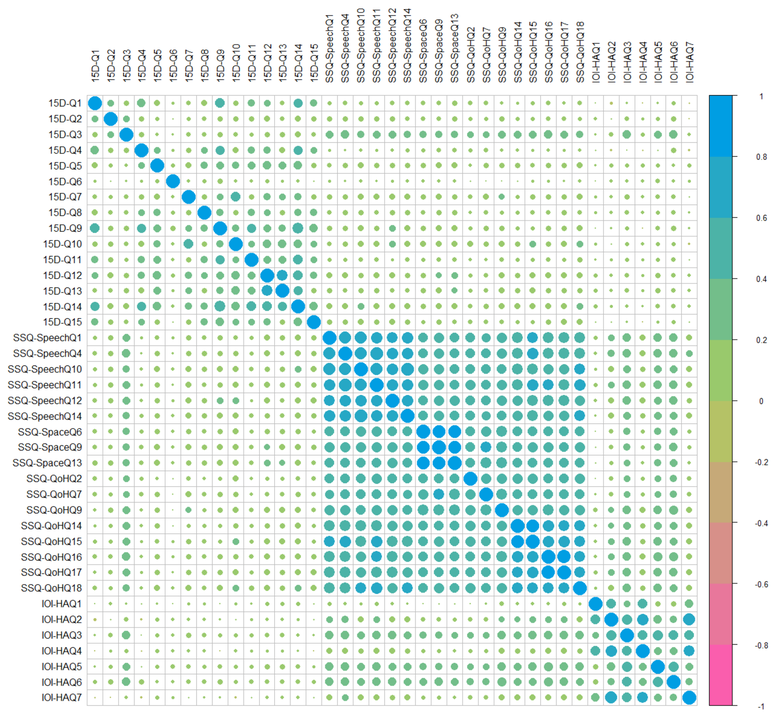

Figure 1. Correlation matrix for 15D, SSQ (17 questions) and IOI-HA recorded during the follow-up visit 2 months after the initial fitting of the hearing aid.

Methods

The principal component analysis is used as the basis to form a composite index related to speech understanding from the self-reported questionnaires. This approach is well established in constructing a composite socio-economic status index [3, 4].

Three sets of questions were selected for the study are:

- Speech Related Questions -Set 1: 15D-Question 3, IOI-HA (Question 3, 5, and 6), and SSQ Speech domain questions (Question 1, 4, 10, 11, and 12)
- Speech Related Questions -Set 2: 15D-Question 3, SSQ Speech domain questions (Question 1, 4, 10, 11, 12, and 14), SSQ Quality domain (Questions 14, 15, 16, 17)
- All questions of all three questionnaires (total 39 questions).

Only responses recorded from the follow-up visit (after 2 months of initial fit) were considered for the study.

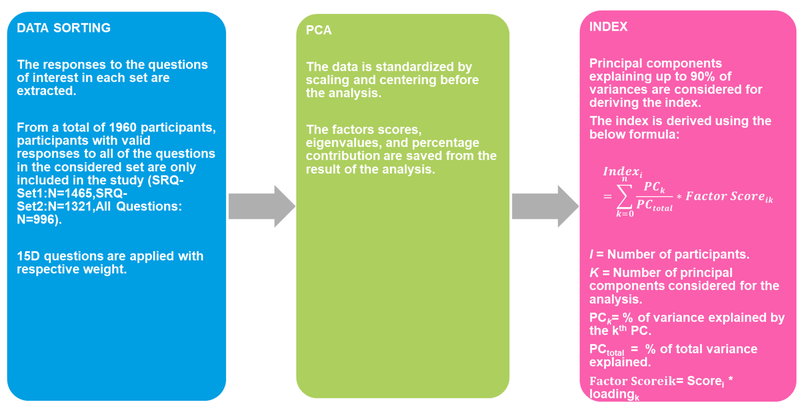

Figure 2. The data was sorted and weights for 15D were applied before performing PCA, and calculation of composite single value index.

Results

Questions	Speech Related Questions -Set 1						Speech Related Questions - Set2						All Questions																							
	PC1 53%	PC2 15%	PC3 8%	PC4 6%	PC5 5%	PC6 5%	PC1 62%	PC2 9%	PC3 8%	PC4 5%	PC5 4%	PC6 4%	PC1 30%	PC2 10%	PC3 8%	PC4 4%	PC5 3%	PC6 3%	PC7 3%	PC8 3%	PC9 2%	PC10 2%	PC11 2%	PC12 2%	PC13 2%	PC14 2%	PC15 2%	PC16 2%	PC17 2%	PC18 2%	PC19 1%	PC20 1%	PC21 1%	PC22 1%	PC23 1%	PC24 1%
15DQ1-Mobility:5 options ranging from walking normally to bed ridden.													0.38	6.94	0.01	1.24	9.61	3.35	3.48	0.06	0.46	5.61	0.41	0.28	1.93	4.17	12.06	0.04	33.80	0.73	1.66	4.08	0.03	0.00	1.98	0.01
15DQ2-Vision:5 options ranging from see normally to completely blind.													0.41	1.54	0.03	0.71	5.24	5.40	10.01	1.78	25.71	0.76	16.72	10.58	5.19	1.95	0.48	2.33	3.97	2.46	1.27	0.76	1.09	0.07	0.01	0.01
15DQ3-Hearing:5 options ranging from hear normally to completely deaf.	5.98	8.36	85.13	0.06	0.05	0.19	2.88	5.49	88.37	2.04	0.56	0.27	1.74	0.08	0.13	0.59	10.13	15.66	0.11	0.37	0.11	0.34	0.00	0.01	6.87	5.14	0.01	36.07	3.99	8.98	0.81	0.11	0.13	0.07	4.00	0.71
15DQ4-Breathing:5 options ranging from breathe normally to breathing difficulties at all times.													0.28	7.98	0.01	0.03	5.36	1.99	0.81	1.62	4.66	2.62	0.53	4.76	27.33	0.81	1.82	1.27	6.40	14.06	2.99	3.73	1.92	1.19	0.18	0.51
15DQ5-Sleeping:5 options ranging from sleeping normally to severe sleeplessness.													0.65	5.64	0.30	0.62	3.19	1.42	8.30	1.18	1.20	2.53	1.15	16.95	0.24	10.22	12.74	3.98	8.09	3.86	5.53	3.95	4.55	0.26	0.92	0.31
15DQ6-Eating:5 options ranging from eat normally to unable to eat all.													0.07	0.63	0.25	0.05	0.19	0.45	38.94	15.31	0.05	16.64	20.26	1.55	0.42	0.37	0.01	0.72	0.94	0.73	0.07	0.31	0.00	0.35	0.02	0.03
15DQ7-Speech:5 options ranging from speak normally to can only make myself understood by gestures.													0.74	3.20	0.06	1.01	3.93	4.20	2.70	25.04	12.01	1.77	0.30	1.75	0.01	0.71	0.10	0.15	1.67	1.12	20.84	3.35	7.56	0.49	0.01	2.32
15DQ8-Excretion:5 options ranging from my bladder and bowel work normally to no control over my bladder and/or bowel function.													0.51	4.01	0.21	0.27	0.82	2.75	5.17	0.73	1.80	44.49	4.06	1.60	7.27	6.35	0.14	0.06	10.69	0.00	0.02	4.02	1.62	0.01	1.19	0.00
15DQ9-Usual Activities:5 options ranging from perform my usual activities to unable to manage.													0.82	10.99	0.09	1.27	3.79	3.34	0.07	0.05	2.72	2.56	1.65	1.00	1.36	1.59	0.20	0.13	0.01	0.28	0.90	24.22	0.26	0.01	6.44	0.11
15DQ10-Mental Function:5 options ranging from think clearly and logically to I am permanently confused and disoriented													0.85	5.45	0.00	0.33	10.06	4.17	3.05	9.98	4.79	0.07	0.36	1.59	0.81	0.33	0.39	0.39	0.29	5.33	23.71	4.21	5.97	2.09	1.18	0.22
15DQ11-Discomfort and Symptoms:5 options ranging from no physical discomfort to unbearable physical discomfort.													0.44	8.22	0.36	0.16	0.02	0.43	3.08	3.55	0.25	0.20	1.54	3.14	26.70	2.23	28.09	1.70	0.03	2.93	0.20	6.13	1.64	0.14	0.03	0.12
15DQ12-Depression:5 options ranging from do not feel depressed to feel extremely depressed													0.96	8.84	0.49	0.92	6.52	3.73	0.14	1.81	5.89	1.03	0.00	4.66	0.95	0.37	2.25	0.34	2.50	0.03	3.91	2.46	3.06	0.93	0.09	0.09
15DQ13-Distress:5 options ranging from do not feel stressed to feel extremely stressed													0.73	6.58	0.55	3.05	9.94	7.41	0.15	3.97	4.82	2.62	1.72	3.50	1.62	2.78	0.87	0.11	1.36	0.10	0.33	0.06	0.51	1.32	0.22	1.21
15DQ14-Viatlity:5 options ranging from feel healthy and energetic to feel extremely weary													1.06	13.17	0.28	0.37	0.09	0.48	0.45	2.09	0.12	0.77	0.47	0.47	0.01	0.03	0.75	0.99	1.49	0.37	0.09	10.53	6.72	0.27	1.59	0.09
15DQ15-Sexual Activity:5 options ranging from no adverse effect on sexual activity to sexual activity impossible.													0.59	5.68	0.01	2.64	0.54	1.71	3.02	0.35	0.36	10.68	2.38	38.13	1.27	1.22	2.27	0.02	9.02	0.58	2.09	8.49	3.17	0.24	2.22	0.00
IOI-HAQ1:Think about how much you used your present hearing aid(s) over the past two weeks. On an average day, how many hours did you use the hearing aid(s)?													0.17	0.06	11.27	1.06	1.22	1.96	7.78	0.08	1.18	0.63	8.31	0.99	8.60	5.08	21.93	4.30	2.00	8.60	3.76	0.78	1.40	1.21	0.61	0.24
IOI-HAQ2:Think about situation where you most wanted to hear better, before you got your present hearing aid(s). Over the past two weeks, how much has the hearing aid helped in that situation.													0.94	1.17	19.84	0.32	0.38	3.30	0.21	0.08	0.02	0.00	0.06	0.01	0.30	0.10	0.74	2.40	0.64	0.47	1.52	0.34	0.00	0.00	0.74	0.81
IOI-HAQ3:Think again about the situation where you most wanted to hear better. When you use your present hearing aid(s), how much difficulty do you STILL have in that situation?	7.94	17.73	5.04	53.09	14.06	1.76							2.20	0.70	9.49	0.00	1.92	3.03	0.47	0.21	0.30	0.59	1.32	0.61	0.80	0.70	1.17	1.91	0.61	0.39	0.06	0.86	1.13	9.46	29.67	7.52
IOI-HAQ4:Consider everything, do you think your present hearing aid(s) is worth the trouble?													0.68	0.89	19.13	0.69	0.11	1.78	0.73	0.32	0.00	0.01	0.16	0.54	0.23	0.29	0.03	0.11	0.05	0.50	0.44	0.36	4.46	2.75	0.22	0.23
IOI-HAQ5:Over the past two weeks, with your present hearing aid(s), how much have your hearing difficulties affected the things you can do?	7.57	24.02	5.85	0.23	61.62	0.59							2.18	0.33	4.41	0.01	3.16	11.66	4.39	0.12	1.11	0.02	0.77	1.00	0.04	0.58	0.08	12.39	0.71	0.01	4.92	5.20	3.59	14.45	1.52	5.12
IOI-HAQ6:Over the past two weeks, with your present hearing aid(s), how much do you think other people were bothered by your hearing diffculties?	7.54	20.89	3.47	44.31	22.81	0.00							2.35	0.12	3.01	0.04	10.80	7.90	1.39	0.01	1.73	0.04	2.55	0.21	0.00	0.62	1.62	9.90	0.64	1.25	0.61	4.26	0.99	29.81	1.15	1.40
IOI-HAQ7:Considering everything, how much has your present hearing aid(s) changed your enjoyment of life?													0.73	1.08	17.41	0.31	0.09	5.12	0.03	0.06	0.01	0.24	0.75	0.01	0.66	0.80	4.69	2.62	0.93	1.20	1.46	1.02	0.63	0.41	9.98	0.69
SSQ-SpeechQ1: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?	14.01	5.75	0.06	1.52	0.16	24.54	9.93	3.98	0.10	0.08	9.53	26.63	5.11	0.66	0.21	3.58	0.08	0.14	0.00	0.47	2.84	0.18	1.13	0.34	0.40	0.02	0.38	0.13	0.00	0.07	1.08	0.28	2.75	0.88	1.62	0.74
SSQ-SpeechQ4: 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?	15.39	5.28	0.06	0.04	0.09	0.05	10.79	4.29	0.11	0.09	9.35	9.67	5.40	0.81	0.11	4.24	0.04	0.11	0.01	0.81	2.24	0.00	1.85	0.00	0.25	0.00	0.04	0.00	0.47	0.95	0.51	0.21	0.05	0.82	0.60	3.80
SSQ-SpeechQ10: Can you tell from the sound which direction a bus or truck is moving, for example, from your left to your right or right to left?	13.80	8.69	0.39	0.12	0.26	12.50	10.19	13.01	0.04	0.07	16.60	0.09	5.27	0.29	0.61	4.38	0.51	1.42	0.07	3.27	2.70	0.09	4.10	0.04	0.13	0.03	0.99	0.12	0.07	0.03	0.09	0.01	1.25	0.28	2.57	0.64
SSQ-SpeechQ11: Can you tell from the sound of their voice or footsteps which direction a person is moving, for example, from your left to your right or right to left?	14.68	5.38	0.00	0.58	0.01	2.42	10.26	4.69	0.08	0.69	14.34	9.48	5.53	0.66	0.24	3.08	0.35	0.05	0.24	0.76	1.50	0.05	1.06	0.01	0.09	0.05	0.02	0.04	0.00	2.32	0.13	0.05	0.67	0.10	1.34	0.08
SSQ-SpeechQ12: Can you tell from their voice or footsteps whether the person is coming towards you or going away?	13.08	3.91	0.00	0.04	0.94	57.94	9.33	2.78	0.35	2.78	32.22	22.45	4.96	0.29	0.39	1.91	0.01	0.03	0.25	2.43	0.66	0.05	0.73	0.19	0.86	1.15	0.63	0.54	0.15	0.74	0.43	0.47	12.71	3.02	7.43	0.97
SSQ-SpeechQ14: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?							9.17	13.33	0.12	0.05	12.36	29.53	4.89	0.27	0.61	3.38	0.38	1.33	0.03	3.05	1.18	0.66	3.81	0.02	0.44	0.01	0.59	0.15	0.02	1.38	0.31	0.36	0.36	0.75	2.54	5.06
SSQ-SpaceQ6: You are outside. A dog barks loudly. Can you tell immediately where it is, without having to look?													4.09	0.13	2.03	15.05	1.54	0.78	0.11	0.41	1.44	0.15	0.27	0.25	0.36	2.74	0.55	1.03	0.02	4.28	0.10	0.02	0.19	0.60	0.03	1.93
SSQ-SpaceQ9: Can you tell how far away a bus or a truck is, from the sound?													4.64	0.03	2.14	14.78	1.53	0.96	0.04	0.34	1.04	0.15	0.21	0.57	0.13	1.02	0.47	0.37	0.02	2.00	0.03	0.01	0.26	0.07	0.00	0.13
SSQ-SpaceQ13: Can you tell from the sound whether a bus or truck is coming towards you or going away?													4.28	0.01	2.21	17.06	1.28	0.61	0.02	0.02	1.59	0.06	0.00	0.45	0.17	1.01	0.18	0.65	0.46	1.76	0.25	0.01	0.02	0.28	0.08	0.19
SSQ-QoHQ2: When you hear more than one sound at a time, do you have the impression that it seems like a single jumbled sound?													3.46	0.46	1.24	0.75	0.00	0.72	1.69	0.11	3.42	1.66	0.56	0.94	0.07	25.54	1.42	0.37	0.08	4.67	5.66	3.52	3.32	1.49	1.59	11.47
SSQ-QoHQ7: When you listen to music, can you make out which instruments are playing?													3.51	0.14	1.49	6.18	0.14	1.26	1.33	0.14	2.48	0.00	0.29	0.70	0.26	5.62	2.00	1.31	0.26	9.68	2.32	2.70	0.65	3.30	0.04	32.71
SSQ-QoHQ9: Do everyday sounds that you can hear easily seem clear to you (not blurred)?													4.55	0.24	0.13	4.62	0.16	0.41	0.78	0.66	0.73	0.02	0.23	0.09	0.29	0.93	0.01	2.26	2.89	10.70	0.46	1.44	0.43	0.44	1.37	6.52
SSQ-QoHQ14: Do you have to concentrate very much when listening to someone or something?							9.02	9.88	4.61	32.01	0.00	1.61	4.61	0.80	0.31	1.34	2.29	0.01	0.13	5.79	1.26	0.38	2.90	1.66	0.25	0.73	0.17	4.44	1.29	3.42	0.45	0.22	11.39	2.17	6.74	0.40
SSQ-QoHQ15: Do you have to put in a lot of effort to hear what is being said in conversation with others?							9.91	8.49	4.06	21.13	1.18	0.16	5.16	0.75	0.35	1.50	2.20	0.13	0.07	3.59	0.86	0.20	3.62	0.97	0.13	0.31	0.07	3.49	3.53	2.88	0.48	0.01	6.02	1.94	3.14	0.41
SSQ-QoHQ16: When you are the driver in a car can you easily hear what someone is saying who is sitting alongside you?							9.52	15.83	0.76	18.83	2.69	0.11	5.17	0.51	0.14	0.95	0.13	0.31	0.42	5.01	2.49	0.73	6.28	0.11	1.09	7.13	0.00	1.13	0.11	0.70	3.63	0.01	4.48	0.02	2.57	0.00
SSQ-QoHQ17: When you are a passenger can you easily hear what the driver is saying sitting alongside you?							9.01	18.25	1.39	22.23	1.18	0.00	4.98	0.47	0.11	0.82	0.64	0.30	0.14	4.29	2.48	1.29	7.24	0.28	0.86	7.09	0.06	1.37	0.49	0.23	5.76	0.09	4.96	0.12	2.59	0.02
SSQ-QoHQ18: Can you easily ignore other sounds when trying to listen to something?													4.90	0.17	0.36	0.68	1.61	0.19	0.19	0.07	1.78	0.11	0.22	0.04	1.60	0.17	0.00	0.65	0.30	0.20	1.11	1.36	0.05	18.19	1.77	13.17

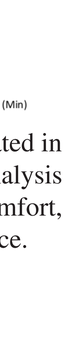

Figure 3. The table shows PCA results for the three sets of questionnaires. The percentage contribution of each principal component (PC) is indicated in the second row of the header. The values in the fields below each PC are the percentage contribution of each question to that respective PC. From analysis of all questions, it can be seen 1) PC1 is clearly linked to speech understanding (SSQ answers), 2) PC2 is related to mental well-being (stress, discomfort, depression), 3) PC3 is most strongly related to hearing benefit (IOI-HA), whereas 4) PC4 may represent spatial dimensions of the hearing experience.

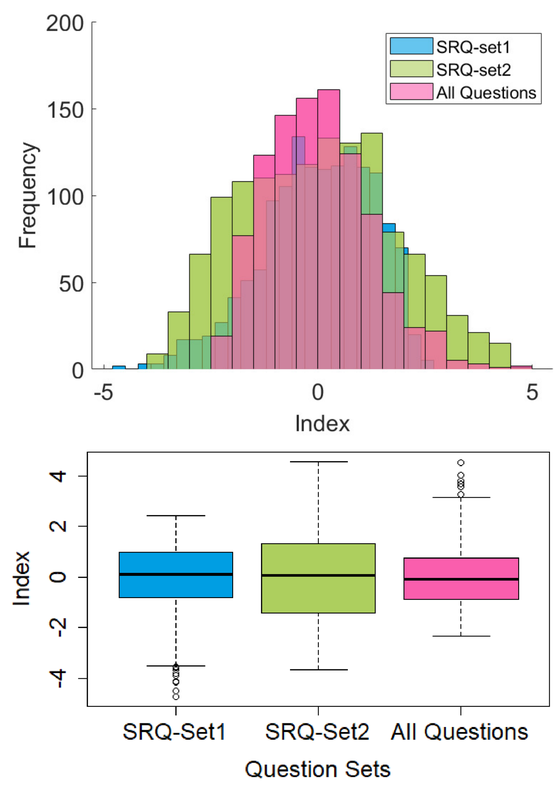

Figure 4. Top: The plot shows the histogram of the derived index from all three sets of questions. Bottom: The box plot with the median of the derived index and error bars showing the 95% confidence intervals. It can be seen that the median in all cases is close to the same level. An ANOVA showed no significant difference between the three sets of questions.

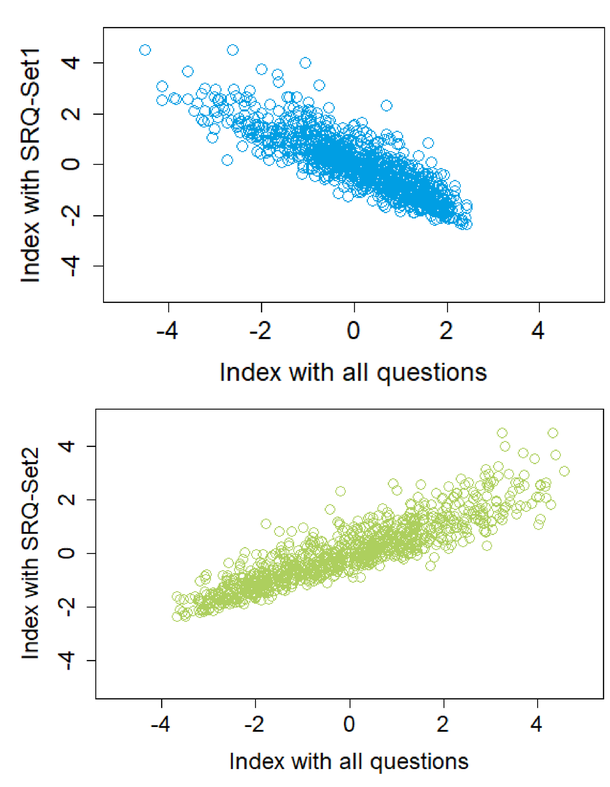

Figure 5. Top: The index derived from SRQSet1 plotted against the index derived using all 39 questions. The plot shows negative covariance (covariance coefficient: -1.31). Bottom: The index derived from SRQSet2 plotted against the index derived using all 39 questions. The plot shows positive covariance (covariance coefficient: 1.92).

Discussion

The results establish the relation of speech in the perceived benefit. The positive covariance of the index derived from speech specific questions to all questions supports this hypothesis.

The derived composite index can thus be used to define the sub-population with low compensation benefit from a speech-related function point of view. A negative index can be an indication of low aided benefit.

Further, the index can be regressed with other outcomes like aided speech intelligibility, compression parameters, word-recognition scores, and hearing aid usage time for having a stronger understanding of underlying factors defining low compensation benefit.

Conclusion

The results suggest that the composite single value speech-related benefit index using PCA can indicate the perceived benefit of hearing aid use.

The speech-related questions, the SRQ-set2, can be representative of overall benefit with a positive covariance to the index based on all questions included in the present study.

This approach can be extended using other powerful multivariate statistical tools like partial least square (PLS) method can open up more possibilities in predicting aided benefit using only audiometric and demographic variables.

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Presented at the International Symposium On Auditory And Audiological Research 2019

Acknowledgement

Collaboration and support by Innovation Fund Denmark (Grand Solutions 5164-00011B), Oticon, GN Resound, Widex and other partners (University of Southern Denmark, Aalborg University, the Technical University of Denmark, Force, and Aalborg, Odense and Copenhagen University Hospitals) is sincerely acknowledged. The authors would also like to thank Palle Rye and Michal Fereczkowski for their valuable inputs and critical comments.