Individual hearing aid benefit: Ecological momentary assessment of hearing abilities

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Questionnaires are often used to address the subjective perspective on hearing abilities in the course of hearing aid (HA) fitting. Weaknesses of this approach are, e.g., memory bias and possible mismatch of the pre-defined and individually experienced listening situations. Ecological momentary assessment (EMA) including in-situ surveys in real-life, could tackle these issues. We conducted an EMA study to examine how HA uptake changes the perception of everyday hearing abilities. In collaboration with local hearing aid acousticians, 16 first-time and follow-up HA wearers were recruited. They used the smartphone-based EMA system olMEGA for 3-4 full days before HA fitting and after HA acclimatization. This system allows for specifying situations and sound sources as well as for assessing hearing related dimensions like speech understanding and listening effort. Nine hundred thirty-three surveys out of a total of 1705 surveys related to speech listening events. Results showed a considerable individual variability regarding the type of reported events, the distribution and position of assessments. Overall, speech understanding improved by 1.1 scores and listening effort decreased by 1.3 scores on 7-point scales in post-intervention EMA compared to pre-intervention EMA.

INTRODUCTION

Questionnaires are widely used in hearing rehabilitation and research to capture the subjective perspective on hearing abilities. Apart from their advantages, the standardized inventories certainly do have weaknesses as well. Filled in retrospectively, the assessment might be biased by memory effects. Moreover, the pre-defined listening situations described in the questionnaires might not meet the real-life challenges experienced by the individual – neither in frequency nor in importance. Therefore, ecological momentary assessment (EMA), an in-situ survey including prompt and repeated assessments in real-life is increasingly used in audiological research (Holube *et al.*, under review). Galvez *et al.* (2012) were among the first who demonstrated the feasibility of EMA in elderly hearing aid users. They already claimed further studies to determine if EMA "can be used in the clinical setting with patients, both before and after receiving hearing aids." Against this

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background, we used an EMA approach in a field study with clients seeking hearing health care in order to trace the change of self-reported hearing abilities, particularly listening effort and speech understanding, associated with hearing aid uptake.

METHODS

Study design

The interventional field study was carried out from 2018 to 2019 in Oldenburg, Germany. Adults who were medically advised for hearing aid uptake conducted EMA surveys before being fitted with hearing aids ("pre" condition) and after hearing aid acclimatization ("post" condition). Along with the EMA surveys, the study protocol included various other measures not reported here such as comprehensive audiometric tests, questionnaires, interviews, and external assessment of communication behavior. The research design and procedures passed examination by the ethics commission of the Carl von Ossietzky University in Oldenburg. Written informed consent was obtained from all participants. Study participation was remunerated on an hourly basis for visits at the institute and blanket per day for EMA periods.

Participants

In collaboration with local hearing aid acousticians, 24 adults with a medical prescription for hearing aids were recruited. Seven participants cancelled hearing aid (HA) uptake during the fitting process and one participant left the study. In total, 16 adults (8 males, 8 females) aged 48 to 76 yrs (median 67 yrs) completed the study protocol, among them 13 first-time HA users and three follow-up users. HA choice and fitting were left to the participant and the HA acoustician, respectively, since they reflect decisions made in real-life professional care. The participants' hearing losses were mild to moderate and, except in participant no. 9, rather symmetric (Figure 1). HA acclimatization took 3.3 months on average (min. 0.7, max. 5.4).

EMA equipment and sampling

The participants used olMEGA, a smartphone-based EMA device. olMEGA provides an adaptive questionnaire app and allows for privacy-aware storage of acoustical feature data (Kowalk *et al.*, 2018). Every participant was instructed in the handling of the device for about 30 minutes and received an illustrated manual as well as the experimenter's phone number in case they needed support. Every participant used the EMA device for 3 to 4 days both before HA fitting and after HA acclimatization. Subject-initiated entries were possible at any time and a reminder was scheduled every 25 to 35 minutes.

The adaptive questionnaire app provided staggered option menus to specify situations, activities, speech familiarity, sound sources, and target signals. Assessments were requested for various hearing dimensions and related items, such as sound localization, importance of good hearing, listening effort, loudness, pleasantness of sounds, disability, and speech understanding (in that order) using 7-point ordinal scales. One survey took approximately 1 to 1.5 min. Delimited by the first and the last survey of each day, the daily usage of the EMA device was 11 h on average.

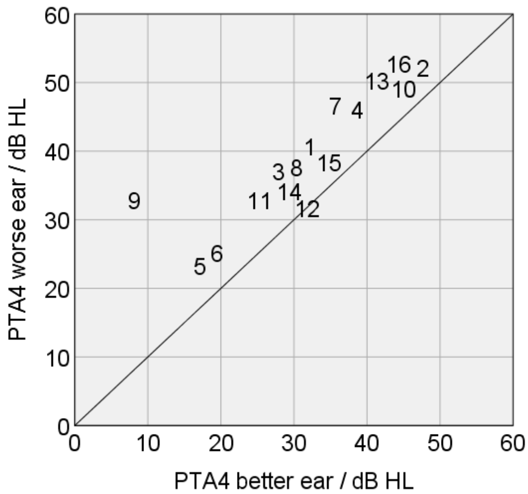

Fig. 1: Study participants' hearing loss at PTA (0.5, 1, 2, and 4 kHz) in the better and the worse ear. The numbers refer to the participants' randomized ID (alphanumeric strings) in ascending order for first-time HA users (no. 1 to 13) and follow-up HA users (no. 14 to 16).

Statistical analysis

To reduce the variety of listening and non-listening events, the participants' responses to the target sound sources were aggregated to five categories: Natural speech in quiet, natural speech in the presence of other sound sources, electro-acoustically presented speech (radio, TV, mobile or landline phone, loudspeaker), non-speech listening targets, and non-listening events. For further analysis, numerical values ranging from 1 to 7 were assigned to assessments given on the ordinal scales and the corresponding variables were treated as metric. Assessments given for speech listening events as dependent variables were regressed on condition as independent variable (pre versus post HA intervention) using a mixed model approach, though the distributional assumptions for linear regression were not fully met. Participants were included as fixed factor and intercepts as well as slopes were defined as random factors. Moreover, correlation coefficients were calculated. Pearson correlational analyses included the individual differences at the mean score in pre- and post-intervention EMA, days of HA acclimatization, and PTA in the better and worse ear. Spearmen's correlation coefficients were calculated to clarify the relationship of assessments for different dimensions of hearing abilities.

RESULTS

In total, 1705 EMA surveys were collected in the pre and post condition (mean 106, min. 48, max. 155 per participant). Of these 1705 surveys, 1109 related to listening events of any type. In total, 933 surveys related to speech listening events with assessment of speech understanding and listening effort.

Comparability of listening events

Before comparing pre- and post-intervention assessments, we examined whether the proportion of target sound types matched in pre and post EMA on the individual level. Figure 2 shows the high inter-subject variability regarding the events assessed. In many cases, the proportion of surveys in non-listening events is high, most probably due to reminder-initiated responses, whereas listening to speech in background noise or listening to electro-acoustically presented speech mostly account for a small fraction only. The match of target sound types in pre and post EMA was moderate ($r_{Spearman}$= 0.64).

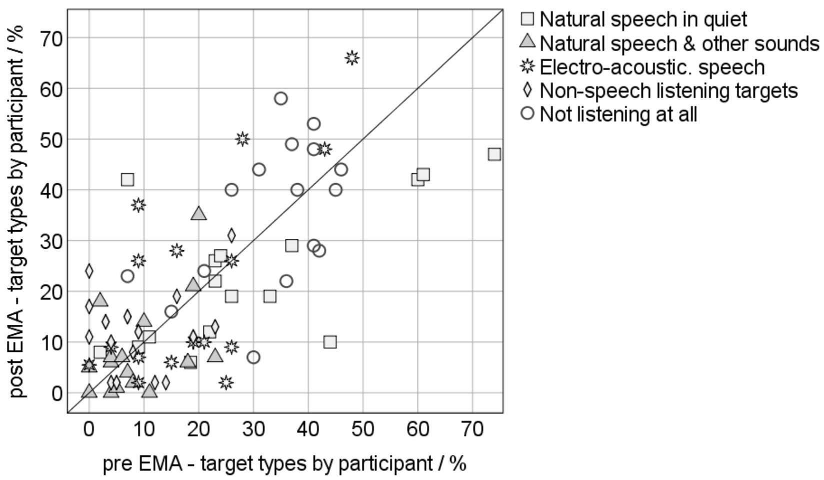

Fig. 2: Percent target types by participant in pre and post EMA.

Listening effort in pre and post EMA surveys

Individual assessments of listening effort in pre and post condition are shown in Figure 3 for three first-time users separately for three types of speech listening events. Note that these examples are randomly chosen out of the 13 first-time HA users.

As can be seen already from these few examples, the type of events, the position and distribution of assessments have different patterns. Participants 1 and 3 almost exclusively reported quiet environments when listening to natural speech, whereas participant 2 predominantly reported other sounds along with natural speech. Some participants used the entire scale, others only a quite narrow scale section for assessments. In this respect, EMA of HA first-time and follow-up users did not indicate any systematic difference. Correlational analyses showed that mean and standard deviation of listening effort assessments do not significantly relate to the degree of better or worse ear hearing loss neither in pre nor in post EMA. Absolute $r_{Pearson}$ estimates ranged from 0.04 to 0.28. In the post-intervention EMA, assessments of speech understanding and listening effort showed ceiling effects and variance was mostly lower than in pre-intervention EMA.

In general, assessments of listening effort and speech understanding are highly correlated ($r_{Spearman}$=0.78) and both are similarly high correlated to self-reported disability and the ability of sound localization with correlation coefficients ranging between 0.73 and 0.81.

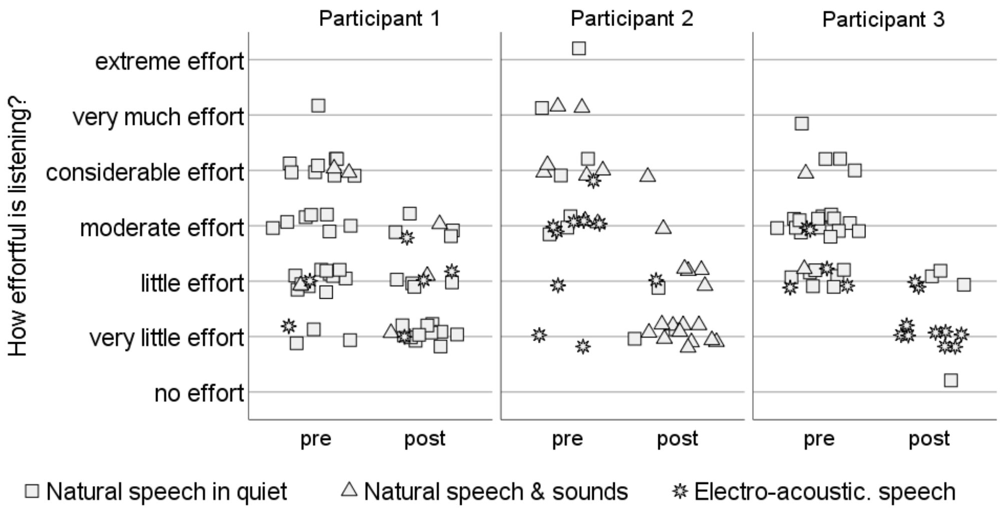

Fig. 3: Individual assessments of listening effort from pre- and post-intervention EMA. Data jittered for display.

Individual Benefit

Most but not all participants assessed real-life listening being less effortful with (new) HA than before the intervention. Figure 4 shows the mean assessment of listening effort in pre and post EMA separately for all study participants and regardless of the type of speech listening event. As expected, individuals differ with regard to HA benefit in terms of absolute change in mean assessment, with follow-up users having overall less benefit than first-time users. HA benefit, however, is uncorrelated to both degree of hearing loss and duration of HA acclimatization. Absolute $r_{Pearson}$ estimates range from 0.16 to 0.35 and failed statistical significance.

A linear mixed regression model was established to estimate the impact of the HA intervention on various hearing dimensions and related items. Table 1 reports intercept and beta coefficients with bootstrapped 95%-confidence intervals for listening effort, speech understanding, and the pleasantness of sounds for both all speech listening events combined and separately for types of speech targets. HA intervention showed a significant effect on these hearing dimensions (p = 0.001, 2-tailed). Beta estimates indicate that listening effort decreased by 1.3 scores and speech understanding improved by 1.1 scores in the post-intervention EMA compared to the pre-intervention EMA. Estimates of speech understanding are almost the same for all speech target types, whereas the effect on listening effort was largest for natural speech in the presence of other sounds and smallest for electro-acoustically presented speech. Significant effects were stated also for localization of sounds and self-reported disability. Somewhat surprisingly, the pleasantness of sounds was also better assessed in post EMA than in pre EMA. Self-rated loudness and the importance of good hearing did not materially change (beta estimates ≤ 0.09).

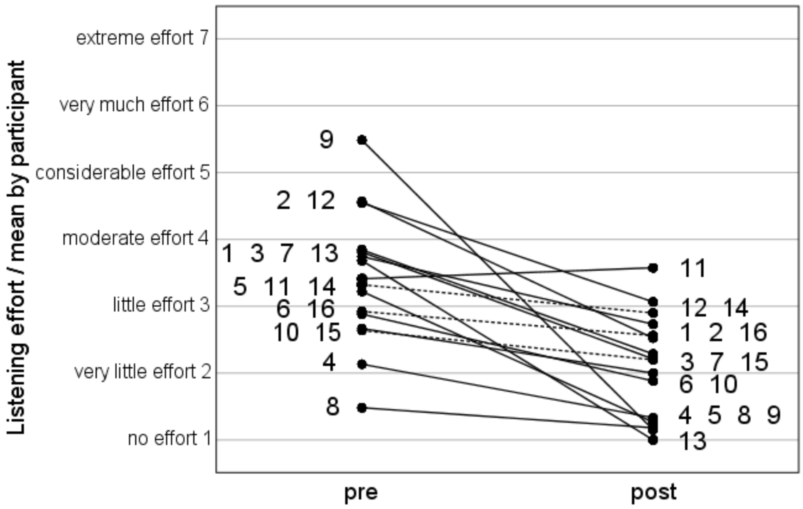

Fig. 4: Assessment of listening effort averaged by participant for all speech listening events in pre- and post-intervention EMA. Results are shown for first-time HA users (solid lines) and follow-up HA users (dashed lines).

Covariance parameters estimated in the mixed models reported in Table 1 confirmed that slopes as well as intercepts differed significantly between the participants. Moreover, the covariance of slopes and intercepts was negative in every one of the models indicating that higher pre-interventional assessments result in smaller intervention benefit.

DISCUSSION

This study used EMA to trace the change of hearing abilities and related dimensions in real-world environments associated with hearing aid uptake. Particular emphasis was put on the assessment of listening effort and speech understanding before hearing aid uptake and after hearing aid acclimatization. At large, self-report for both hearing dimensions was found to be shifted towards improvement after HA acclimatization, presumably indicating HA benefit. This was shown on the individual level, exemplarily also for different types of speech listening events, and with effect estimates based on a mixed model approach. It was further shown that pre-interventional assessments and HA benefit were connected and that both were not significantly related to the degree of hearing loss and the duration of the acclimatization period. Note that three participants were follow-up HA users and 10 out of 13 HA first-time users had mild hearing loss, partly retaining pure-tone hearing abilities not considered as “impaired“ according to the WHO criterion for hearing impairment (better ear PTA > 25 dB HL). For this reason, ceiling effects were to be assumed not only in post-, but also in pre-interventional assessments while larger intervention effects would be expected in participants with a more pronounced and previously unaided hearing loss. In the present study sample, the mixed model estimate established an overall improvement by 1 to 1.6 categories on the 7-point scales for listening effort and speech understanding. Given the heterogeneity of the study sample, these results must be interpreted with caution since the sample size does not support including further covariates in the model to control, e.g., for the degree and type of hearing loss, socio-demographics, first- and follow-up HA use. However, estimates based only the data of twelve HA first-users with symmetric hearing loss (excluding the data of participant no. 9 due to pronounced asymmetric hearing), were very similar to the estimates derived in the total sample (95%-CI widely overlap). Timmer *et al.* (2018) also researched the effect of HA rehabilitation using EMA in 10 elderly subjects with mild hearing impairment in unaided and aided conditions. In contrast to the present study, the subjects were fitted with HA as part of the study and had prior experience with the EMA method. Using different item wording and scales, Timmer *et al.* also found significant improvements in the aided condition compared to the unaided baseline condition, though somewhat stronger for speech understanding (beta = 0.9) than listening effort (beta = 0.7).

Dimension	**Intercept**	**Beta**	**[95% CI]**
How effortful is listening?			
All speech listening events	3.4	-1.3	[-1.4, -1.2]
Natural speech in quiet	3.5	-1.4	[-1.6, -1.1]
Natural speech & sounds	3.8	-1.6	[-1.9, -1.1]
Electro-acoustic. speech	3.1	-1.1	[-1.3, -0.9]
How good or bad do you understand?			
All speech listening events	4.6	1.1	[1.0, 1.2]
Natural speech in quiet	4.6	1.1	[0.9, 1.2]
Natural speech & sounds	4.3	1.2	[0.7, 1.7]
Electro-acoustic. speech	4.7	1.0	[0.8, 1.2]
How pleasant are the sounds?	4.5	0.5	[0.2, 0.7]

Table 1: Effect of HA intervention estimated in a mixed model regression analysis. Assessments of speech listening events regressed on condition (pre versus post intervention). Scale orientation: nothing at all (1), no effort (1), very unpleasant (1).

More importantly, the results of this study emphasize the between-subjects variability with regard to the types of situations that were assessed as well as with regard to the assessment patterns. Providing snapshots of real-life hearing, EMA has pinpointed the diversity of listening experiences. Since individualization is crucial in hearing health care, EMA has been found to be a suitable method for specifying individual challenges and issues. Thus, the main strength of this field study was to demonstrate that EMA can be incorporated in the process of HA fitting with elderly adults completely naïve towards hearing studies and the respective tests and questionnaires. Participants were normal clients of HA acousticians, initially not prepared to take part in any study of this kind. They received feedback of their EMA results and shared them with their HA acoustician. By this means, EMA has the potential to encourage, guide and substantiate the dialogue in the clinical practice, especially when clients are reserved or unable to find the appropriate terms to describe their experiences. However, there are limitations to this study. The main limitation is that carry-over effects are not controlled in the AB design used in this study. Thus, the robustness of effects is not confirmed. An ABA-design including a withdrawal of HA as reported by Timmer *et al.* (2018) was not viable due to ethical reasons. In this context, the positive HA intervention effect on the pleasantness of sounds should be examined more closely. The order of items in the EMA survey might impact the assessments. It is unclear, for example, whether the assessments of listening effort and speech understanding are unchanged if either one or the other is assessed first. Additionally, it is still an open question whether the participants were able to keep the concepts of the hearing dimensions, particularly listening effort and speech understanding, separated and consciously present. These issues cannot be settled based on the data from this study, but certainly merit further attention.

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