LAB MEASUREMENTS OF LISTENING EFFORT AND LISTENING-RELATED FATIGUE: STEPS TOWARDS HIGHER ECOLOGICAL VALIDITY

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ABSTRACT

When talking about listening related ecological validity one often refers to speech intelligibility measures in noisy situations. This presentation draws the focus on "Fatigue" and "Listening Effort". Both are important factors in daily life of hearing-impaired people. When we want to improve these factors in real life, we need good lab measures to quantify disabilities and relief from e.g. hearing devices. This talk presents results from two studies. In the first we simulated a typical acoustical day and compressed it in time to evaluate the effect of hearing aid usage on fatigue in the laboratory. We were able to show that hearing aid provision indeed helped to decrease listening effort and in the consequence listening related fatigue. In the second study, listening effort was measured for soft speech at different distances. This was conducted with headphones using virtual acoustics and loudspeakers in a real reverberant room. This comparison revealed that virtual acoustic was able to replicate results of the real setup and is a helpful tool to investigate ecologically relevant measures in hearing rehabilitation where large rooms are typically not available for measurements.

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1. INTRODUCTION

Keidser et al. described the term ecological validity' by "the degree to which findings reflect real-life hearing-related function, activity or participation" [1]. Ongoing research deals with how to investigate the "hearing related function" in real life. One approach is looking at the consequences of degraded perception and one example for such a consequence is often reported by hearing-impaired people: They feel tired at the end of their listening day [2]. Hearing impaired people need to invest higher listening effort (LE), which can lead to listening related fatigue (LRF). This link between LE and mental fatigue has been described in detail before [2,3]. Therefore, the goal of the first study presented in this contribution was to develop a lab measure with a high ecological validity to investigate whether hearing aids might help to reduce LRF.
Another question is what is "real life"? According to Wu et al. low Signal to Noise Ratios (SNR) are very rare [4]. They recorded every day listening situations for 20 hearing-impaired subjects for 5 to 6 weeks. They showed that very noisy situations with SNRs of below 0dB comprised only 7.5% of all listening situations. About 43% of all situations were described to be a "quiet" situation with a median SNR

of 10 dB SNR. This indicates that it is important to take quiet situations with high SNRs into account to increase the ecological validity. Appleton [5] also evaluated the importance of specific listening scenarios for hearing aid users and found that, e.g., understanding over distance is still a challenge for hearing-impaired people. The second study addresses LE of soft speech as a function of distance and compares results for virtual acoustics with results from a real setup.

2. FATIGUE STUDY

In Study 1 we investigated whether hearing aids help to reduce listening related fatigue in the lab using virtual acoustics. The approach combines realistic listening scenarios with subjective, physiological and behavioral measurement methods. Different tasks with different variants of acoustical scenes were arranged into a "Time Compressed Acoustic Day" (TCAD) [6]. Here we will present only the results dealing with subjective listening effort (LE) und listening related fatigue (LRF). More details can be found in Blümer et al. [7,8].

2.1 Methods

2.1.1 Subjects

20 experienced hearing aid users (10 female/10 male) with mild to moderate sensorineural hearing loss (mean BEHL 4F PTA = 32.4 ± 5.3dB HL) and mean age of 70,9 years (std. 6,1 years) participated in this study.

2.1.2 Hearing aids

Phonak Audéo M90-312 hearing aids with closed couplings (closed domes) programmed at default settings for the individual hearing losses.

2.1.3 Time Compressed Acoustic Day (TCAD)

A total of eight listening tests were conducted with a net measurement time of approximately 90 minutes. In addition, subjective ratings were queried before and after each test, and a non-acoustic concentration test was administered before and after the acoustic measurement sequence. Five different acoustical scenes were combined: Speech in noise (SiN), soft speech in quiet (SSiQ), speech from adjacent room (SaR), speech in TV (STV) and a multi talker scene (MTS) covering a broad range of typical daily life scenes. Virtual acoustic environments were implemented using TASCAR [9].

Table 1 summarizes the paradigms within the different scenes. All paradigms were performed unaided and aided with hearing aids. Both conditions were measured at two different days, the order of unaided/aided was randomized across subjects.

Table 1. Description of the different listening tasks used in the TCAD.

Test	Description	Level of Sspeech (S) and Masker (M)
OLSBY (SiN)	Memory recall (auditory), reaction (visual)	S: SRT50% plus 4 dB N: Cafeteria at 67 dB SPL
OLERT1 (SSiQ)	Reaction on target words in running speech (auditory). First OLERT:	S: 62 dB SPL N diffuse: 59 dB SPL (breakfast scene)
OLERT2 (STV)	Reaction on target words in running speech (auditory).	S: 62 dB SPL N270: 59 dB SPL(in the aided condition a TV connector was used)
CCOLSA (MTS)	Word recognition of switching target talkers (auditory)	S: adaptive (initial 0 dB SNR) N: pup scene at 68 dB SPL
Attended Speaker (SaR)	Speech in speech, comprehension task (auditory)	S: 60 dB SPL N at 90°: radio traffic news at 53 dB SPL

2.1.4 Subjective rating of effort and fatigue

After each paradigm subjects were asked to rate how much they had to concentrate in the last task and how mentally exhausted they are, both on a scale from 0 (did not had to concentrate) to 10 (had to concentrate very hard) for the LE rating and from 0 (not exhausted) to 10 (very exhausted) for the LRF rating.

2.2 Results

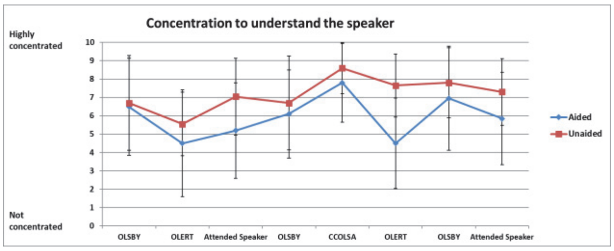

Figure 1. Rating of listening effort (how much did you have to concentrate to follow the speaker) for the different tasks (mean and standard deviations). Unaided ratings in red, aided ratings in blue.

Figure 1 shows the LE ratings after each of the 8 tasks. Significant differences between aided versus unaided conditions were observed for the second OLERT task (p=0.02) and the final Attended Speaker Task (p=0.02). A multivariate repeated measures GLM showed a main effect of hearing aid provision (F(1,16)=13,77, $p < 0.01$) and a main effect of task (F(7,16)=8,994, $p < 0.001$), as well as an interaction of hearing aid provision and task (F(7,112)=3,135, $p < 0.01$).

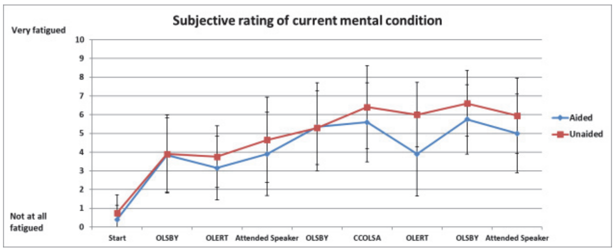

Figure 2. Rating of listening related fatigue ("How mentally exhausted or fatigued do you feel after the task?") for the different tasks (mean and standard deviations). Unaided ratings in red, aided ratings in blue.

In Figure 2 the fatigue ratings are shown after each of the tasks and at the beginning of the TCAD. The multivariate repeated measures GLM showed a main effect of hearing aid provision (F(1,16)=4,780, $p < 0.05$) and a main effect of task (F(8,128)=46,454, $p < 0.001$) as well as an interaction between hearing aid provision and task (F(7,128)=2,757, $p < 0.01$).

2.3 Discussion

The TCAD allows to investigate listening effort and as a consequence listening related fatigue in a lab setup with high ecological validity. The combination of different tasks into one "time compressed acoustic day" helps to overcome the monotonous character of other studies with a looped listening task as in Hornsby [10].
High subjective LE ratings were observed throughout the tasks with significant lower ratings in the aided condition. Fatigue ratings were seen to increase throughout the TCAD in both the unaided and aided conditions, with generally lower ratings in the latter (Figure 3).

3. SOFT SPEECH STUDY

As less then 20% of all acoustic situations are noisy or very noisy [4], quiet situations play an important role in everyday life.
In Study 2, we investigated the effect of soft speech at different distances on listening effort. Due to the covid-19 pandemic, personal contact with subjects was prohibited. However, instead of inviting the subjects to our lab, we performed the study in the living rooms of the subjects. Therefore, we had to simulate the distance listening with virtual acoustics (study part one). After the covid-19 pandemic we invited subjects to replicate the study in a real room (study part two). This allowed us to compare a real setup with virtual acoustics.

3.1 Methods

3.1.1 Subjects

Study part one (virtual acoustics)
A total of 20 subjects participated in the study (10 male and 10 female, mean age 71.3y ±9.4y). All subjects were experienced with hearing aids for at least 2 years. Mean PTA: 50.9 dB HL (±5.3dB HL).

Study part two (real room)
Altogether 22 subjects experienced with hearing aids participated in this study (14 male and 8 female, mean age 74,1y ±7,3y). Mean PTA: 54,4 dB HL (±7dB HL).

3.1.2 Hearing aids

Phonak Audéo P90-R hearing aids were fitted to the individual hearing losses with all adaptive features set to off. The Soft Speech Enhancer (SSE) feature was set to "off" in one program and to "max" in the other program. The SSE was developed by Phonak to detect soft speech and provide suitable gain in situations with soft speech. All hearing aids were fitted with closed couplings (SlimTips).

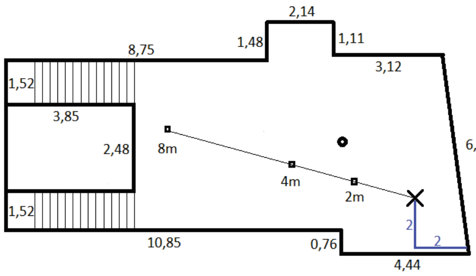

Figure 3.: Illustration of the real room, i.e., the foyer of the House of Hearing, Oldenburg, with a T60 reverberation time of 850ms. The numbers represent the length of the wall sections in meters.

Figure 4.: Picture of the 16 loudspeakers setup, with the artificial head (KEMAR) in the middle.

3.1.3 Study part one, virtual acoustics

To create a good virtual scene for the evaluation of soft speech at different distances, room impulse responses were recorded using a 1st order Ambisonics microphone for different distances in a real room (see figure 4). These room impulse responses were used in a TASCAR system with 16 loudspeakers (see figure 5) to create a scene in which OLSA sentences were presented from the front and had to be heard at the virtual distances of 1m, 2m, 4m and 8m.

The hearing aids were placed on the artificial head (KEMAR) in the middle of the loudspeaker circle. The individual fittings of the subjects were used to record the hearing aid outcomes. 3 Sentences from the Oldenburg Sentence test (OLSA) [11] were recorded for the virtual distance of 1m, 2m, 4m and 8m (see Table 2 for the levels at the corresponding distances).

These recordings were individually copied to the tablet in the "Remote Hearing Lab" (described below) and the subjects were able to listen to them at home via headphones. On a scale of no effort to extreme effort the subjects had to rate the subjective listening effort when they listened to the OLSA sentences [12]. Recordings were made with eight conditions: with Soft Speech Enhancer ON and OFF and for the different distances (randomized, each distance was presented four times).

The "Remote Hearing Lab" consists of a calibrated hardware setup in a case containing a tablet computer with Long-Term Evolution (LTE) Internet connection, audio hardware (audio interface with connected headphones Sennheiser HD 600, speaker Genelec 8010, microphone) and a hearing instrument fitting module (Noahlink Wireless).
The tablet is remotely controlled via internet. During the appointment the investigator can always communicate with the test person via video call. Special operating instructions help to set up the hardware at home, e.g. for a speech test or hearing aid fitting.

Table 2. Mean presentation levels in the virtual and the real measurement setups for different distances of the target speech.

Distance	**Virtual setup** Level in dB SPL	**Real setup** Level in dB SPL
1m	55.2	--
2m	52.6	50.9
4m	51.2	49.1
8m	50.8	49.5

3.1.4 Study part two, real room

For this setup the same foyer at the House of Hearing in Oldenburg was used as real room (see figure 3). To save some time in the whole experiment, the measurement at 1m was skipped compared to the virtual setup. Subjects were asked to rate the subjective listening effort for sentences presented from a distance of 2m, 4m and 8m. To ensure a good working level, an adaptive speech test in quiet at a distance of 4m was performed to measure the level at which 50% of the words were understood (SRT50%). The SRT50 plus 10dB was used for the individual working level at 4m. Technical measurements of the level at the place of the subject (marked with the cross in figure 4) the level is 1.8dB higher when presenting at 2m and 0.4 dB higher for 8m distance.
Table 2 shows the levels that were used for the virtual setup and the mean presentation levels in the real setup for the different distances.

3.2 Results

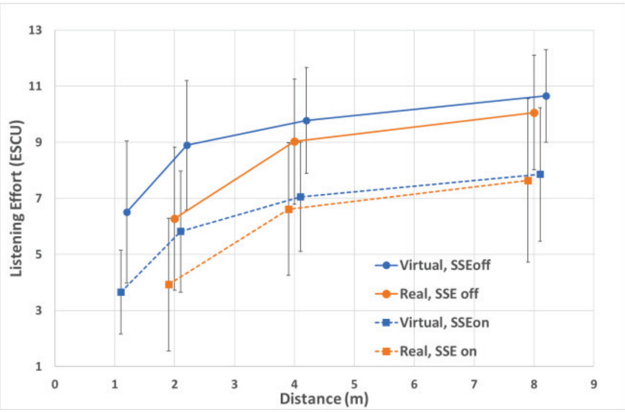

Figure 5. Results of the listening effort ratings **in the virtual setup (blue curves)** for different simulated distances and **in the real setup (orange curves)** for different real distances. Measurements with Soft Speech Enhancer (SSE) off with solid lines, with SSE on with dotted lines. Bars show the standard deviations.

Figure 5 shows the results of the subjective listening effort ratings in quiet for the different distances of 1m, 2m, 4m and 8m **in the virtual setup and** for ratings in the **real setup** for the different distances of 2m, 4m and 8m**.**

In the **virtual setup** the effort increases with distance: From 1m to 8m the effort is increasing by more then 4 scale units (TTEST, p<0.01). SSE on clearly reduces the subjective effort compared to SSE off by more then 2 scale units. A repeated measures ANOVA determined that mean performance levels showed a statistically significant difference between SSE_{ON} and SSE_{OFF} ($F(3, 72) = 16{,}327$, $p < .001$).
Comparable to the ratings in the virtual setup, the subjective listening effort is increasing with distance also in the **real setup** (TTEST, p<0.01). The SSE feature decreases the effort by more then 2 scale units. TTest including a Bonferroni correction was used for the statistical analysis and showed significant effect for all distances (p<0.001).

3.3 Discussion

The differences in LE ratings between both study parts are shown in figure 5. The biggest difference is that in the real setup no ratings were performed at 1m distance. This might explain the differences for the 2m ratings. For longer distances at 4m and 8m the ratings are comparable. The difference between the conditions SSE on and off is the same for both setups, virtual acoustic and real room.
Table 2 shows that the presentation levels were comparable in both study parts. Interestingly, the level does not decrease anymore from 4 to 8m. This is because the level of the reverberation is higher than the direct sound at these distances. But as the Direct-To-Reverberant Ratio decreases, LE increases further from 4 to 8m. This was the case in both study parts: in the virtual acoustic setup and in the study with the real setup. We were able to show that it is indeed possible to reveal effects with soft speech at different distances using virtual acoustics.

4. ACKNOWLEDGMENTS

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