Hearing support to reduce listening effort at work: an EEG study

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Abstract

A prolonged exposition to an acoustically challenging environment can cause cognitive fatigue. Service- and support centers are examples of work environments where this is particularly relevant. In several guidelines (E-VDI 2569:2016-02 and ISO 3382-3:2012-05), the focus is to avoid deleterious aftereffects of irrelevant speech by means of room acoustical interventions, such as shielding and zoning. In service- and support centers however it is furthermore important to ensure good speech quality for the agent to reduce listening effort. Technical assistance systems can improve speech intelligibility and alleviate listening effort. Hearing support tailored to the individual's hearing ability and listening preference, built into the telephone, is an example of such an assistance system. In the current study the effect of an individualized hearing support technology on listening effort was evaluated by means of recording an electroencephalogram (EEG). Via a simulated telephone connection participants listened to sentences in noise and answered questions regarding the content. In trials with hearing support, activity in the EEG-alpha frequency band (9-10 Hz) was reduced significantly, indicating a decrease in listening effort. The results suggest that an individualized hearing support offers a possibility to ease acoustically induced mental load and is a tool to improve the working conditions in service- and support centers.

Introduction

The aim of this study is to investigate the effect of a personalized hearing support system in acoustically challenging environments such as service- and support centers. This individualized hearing support is intended to improve speech understanding and listening comfort which in turn should reduce cognitive strain and listening effort [1].

A telecommunication work environment such as a service- and support center requires good speech comprehension to be able to process relevant information and to quickly enter and extract information to and from various databases. Particularly older adults with decreasing hearing function experience the required immediate and flexible customer support as challenging. Around 12-14 million people in Germany between ages 15-75 years have hearing impairments that require treatment. In the age group of 50 to 65 year old adults the ratio is 1 in 4 [2]. Implementing hearing support systems could be one approach to improve work environments to alleviate sensory-cognitive strain and prevent fatigue caused by prolonged compensatory effort expended to meet sensory demands [3].

Job performance of service- and support center agents are characterized by complex communication processes with a customer (relevant speech) and tuning out irrelevant speech from colleagues in parallel. In line with this, it became obvious that the tasks are cognitively challenging particularly for older employees and that the reductions in hearing function cause difficulties in understanding the customers and that the hearing deficits tax the limited cognitive resources [3,4]. Therefore service- and support centers are classified with the highest requirement class A towards room acoustical treatments (cf. E-VDI 2569:2016-02 [5]; ISO 3382-3:2012-05 [6]).

The model of limited cognitive resources fits the shared-resource hypothesis [7] which states that both sensory and cognitive processes access a common pool of (neural) resources. If due to sensory deficits more resources are needed for signal processing fewer resources are available for subsequent cognitive tasks or they need to be compensated for by investing extra effort. Neuroergonomic methods have the potential to measure changes in neurocognitive resources and thereby are suited, for example by recording electroencephalograms (EEG), to investigate indexes of cognitive strain at the workplace [8]. First studies show that changes in the alpha frequency band of the EEG signal could constitute neurophysiological markers of cognitive load and listening effort [9,10]. Employees in service and support centers are confronted with interfering background noise which reduces listening comfort and speech intelligibility and can increase listening effort [11]. Hearing support built-into a telephone offers the possibility that incoming calls can be adjusted to the individual hearing abilities and preferences of the user receiving the call. In this study an intuitive and easy to use listening support system [12] was evaluated in terms of its effect on listening effort.

The hearing support technology used in this study has been evaluated in a previous subjective evaluation project in which service and support employees rated the hearing support as useful and helpful in accomplishing the work load [4]. The goal of the current project is to provide physiological support for the effect of the hearing assistance in the telephone on listening effort by analyzing neurophysiological markers extracted from the EEG.

Materials & Methods

Participants:

A total of 13 participants (mean age = 57.5 years, SD = 5.0 years) were recruited for the study. They reported to be in good health, had no cognitive impairment (mean DemTect [13] score = 17.11 (0.93)) but an uncorrected mild hearing deficit (pure tone average (PTA) = 17.7 (8.9) dB HL).

Stimuli and experimental design:

The Oldenburg sentence test (OLdenburger SAtztest (OLSA, [14]) contains grammatically correct but predominantly non-sense sentences consisting of five words (name, verb, number, adjective, object). The sentences are not predictable, as for each of the five parts of the sentence 10 possible words exist to fill that respective slot.

In one of the conditions participants adjusted sound level and sound pattern to their individual preference by using a two dimensional user interface [12]. This intuitive and easy-to-use interface allows adjustment of sound level on the Y-axis and timbre on the X-axis. This individually preferred sound adjustment was made in background noise as well as in quiet (i.e. no background noise) as reference level. In the other condition no hearing support was activated and the speech level was set to 65 dB SPL. The OLSA sentences were presented via open headphones (Sennheiser HD-650).

The International Speech Test Signal (ISTS [15]) background noise was presented via a loudspeaker in front of the participant (0°) at a distance of 1m. For the duration of the experiment the noise level remained constant at 55 dB SPL. The ISTS is based on recordings of natural speech by six female speakers who read the story “The North Wind and the Sun (George Fyler Townsend)” in their native language (American English, Arabic, Chinese, German, Spanish). Due to the segmentation and mixing of the six separate recordings, the speech signal is unintelligible, yet maintains the temporal and spectral structure of a female speaker.

Each condition consisted of 10 blocks of three OLSA sentences each. The task of the participants was to remember the content of the three sentences. After each block (i.e. after every third sentence) participants were asked to recall the names, the numbers or the objects they heard. Which of the three parts was probed was randomized and not known to the subjects a priori. Participants could choose by mouse click from 10 different possible answers per sentence. Before the start of the experimental session participants were given the opportunity to practice the task. There were two conditions:

- A_ISTS: individually adjusted listening preference (A) in ISTS noise (55 dB SPL)
- B_ISTS: no individually adjusted listening preference (B – baseline) in ISTS noise (55 dB); speech signal was presented at 65 dB SPL

The sequence of the conditions was balanced across participants. One OLSA sentence lasts about two seconds. Between each sentence a break of one second was introduced. Background noise played continuously until the questions appeared on the screen. There was no time restriction on answering the questions. After every condition the participants were asked to rate the experienced level of effort during the last condition. A categorical scale from 1 = effortless to 13 = extremely effortful was used [16]. The total duration per condition lasted between 5-7 minutes.

EEG recordings:

A wireless EEG system (mBrainTrain, Belgrad, Serbia) was used to record a continuous EEG signal from 24 Ag/AgCl electrodes mounted in an elastic cap (EasyCap, Herrsching) and arranged according to the international 10-20 system [17]. EEG data was recorded using the software Lab Streaming Layer [18] while participants listened to the OLSA sentences and answered the corresponding questions. The EEG data were collected with a 500 Hz sampling rate and an online low-pass filter of 250 Hz. Impedances were kept below 10 – 15 kΩ. Offline EEG data were processed and analyzed using EEGLab v.13 [19]. Data were re-referenced to linked mastoids filtered by a 0.1 – 30 Hz bandpass filter. EEG and EOG artefacts were identified and removed applying an independent component analysis.

The continuous EEG was divided into 8-second intervals starting with the onset of the first sentence of the OLSA sentence triplet. This interval was preceded by a 1.5 second baseline interval. To extract time-frequency data or event-related spectral perturbations (ERSP), epoched trial data were convoluted with dynamic Morlet wavelets (3 cycles width at lowest frequency to 50 cycles width at highest), and the power spectra were estimated from 3 Hz to 250 Hz steps and for the entire duration of the epoch including the pre-stimulus baseline interval. For each participant ERSP values were computed and averaged for each condition. ERSP data were analyzed using Bonferroni-corrected permutation t-tests (2-sided, 1000 permutations) with a statistical significance level of $p = .05$ (EEGLab v.13). We restricted the analyses of ERSP data to the spectrum from 3 to 25 Hz. As outlined previously, this frequency band has been associated with listening effort and cognitive load in parietal brain areas [9,10]. To reduce the number of statistical tests we restricted our statistical permutation tests of ERSP data a-priori to the parietal electrode sites P3, Pz, P4.

Technical setup:

To present and to adjust the stimuli two separate PCs were used. The OLSA sentences were generated by means of a custom measurement software tool (MATLAB v.12.5) and presented via an external soundcard (cf. Figure 1, orange box). To simulate a realistic telephone scenario the signals were sent to a telephone and transmitted to an asterisk telephone system over a VoIP connection. The signal output occurred through a commercial IP telephone (Snom 821). Within the asterisk system the individual sound preference adjustment took place. Both the user interface as well as the software telephone, which received the telephone connection and presented the processed signals via headphones, were implemented on the second PC.

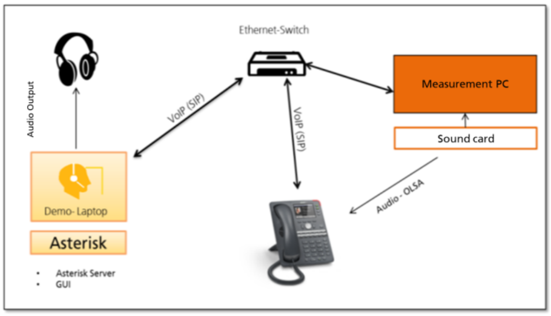

Figure 1: Illustration of the technical setup.

Results

Listening preference setting:

For the individualized adjustment of listening preference (cf. Figure 2) the level of the speech signal did not significantly increase relative to the baseline condition at which the speech level was fixed at 65 dB SPL ($p = .41$).

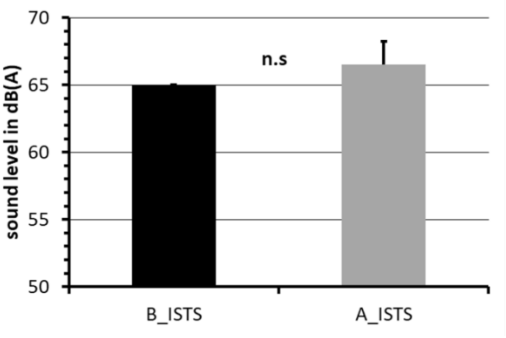

Figure 2: Average signal intensity for baseline (B_ISTS) and after adjustment of individual listening preference (A_ISTS) in ISTS noise; n.s. = not significant at $\alpha = .05$.

Subjective effort rating:

Figure 3 displays subjective ratings of experienced effort. In ISTS noise the individualized hearing support lowers the experienced effort significantly ($p < .01$) relative to the ISTS baseline condition (B_ISTS).

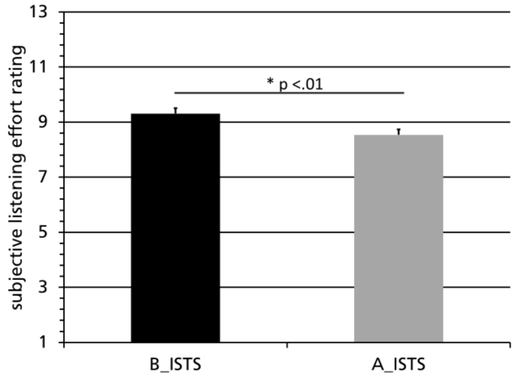

Figure 3: Averages and standard errors of subjective effort for baseline (B_ISTS) and after adjustment of individual listening preference (A_ISTS) in ISTS noise.

Accuracy:

The response accuracy did not show any statistically significant differences between the conditions (Figure 4).

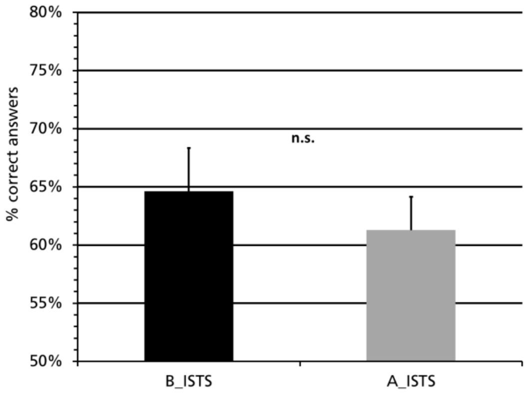

Figure 4: Averages and standard errors of response accuracy (% correct answers) for baseline (B_ISTS) and after adjustment of individual listening preference (A_ISTS) in ISTS noise; n.s. = not significant at $\alpha = .05$.

EEG data:

The analysis of ERSP data indicated a significantly higher activity in the alpha frequency band (9 – 10 Hz) in the B_ISTS (no hearing support) compared to the A_ISTS condition (with acoustic hearing support). This difference is present for the entire time window and is most salient at electrode site Pz (cf. Figure 5).

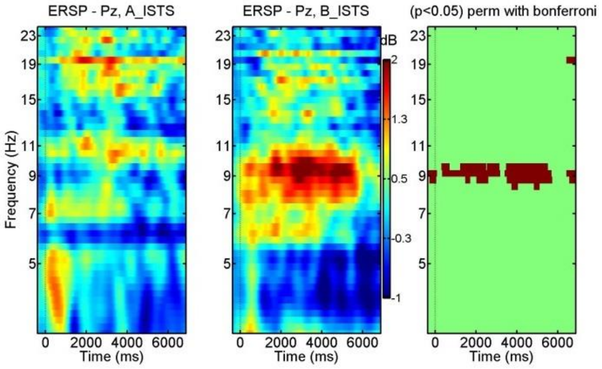

Figure 5: ERSP at electrode Pz during A_ISTS (left) and B_ISTS (center); right panel: significant differences (red area; $p < .05$) in the EEG alpha frequency band (9-10 Hz).

Discussion

The aim of the study was to use EEG to evaluate the effect of a hearing support system on neurophysiological markers of listening effort. Participants listened to spoken sentences in noise and answered questions regarding their content. The behavioral data (percent correct response) do not indicate a clear benefit linked to hearing support with respect to cognitive performance (cf. Figure 4).

A possible explanation for the lack of differences could be due to compensatory factors. Due to the suboptimal listening environment in conditions without hearing support (B_ISTS), participants had to put in more effort to compensate for or prevent poor behavioral performance. To achieve the same level of performance in suboptimal hearing conditions more effort had to be invested. Support for this interpretation comes from both the subjective ratings (cf. Figure 3) of effort as well as the EEG data. The analysis of EEG data (cf. Figure 5) reveals a higher activity in the alpha frequency band when no hearing support was activated (B_ISTS) relative to conditions with hearing support (A_ISTS). These results are in line with other studies that report changes in listening effort based on neurophysiological measures [9,10]. It is important to point out that the observed (behavioral and EEG-based) effects are not a result of different speech playback levels (and hence improved SNRs in the fixed-noise scenario), because the playback level did not differ between baseline and hearing-support condition. It is likely that the SNR of 10 dB was already high enough for the participants to easily follow the target talker and that, hence, no further increase in speech level was selected even though this would have been possible with the hearing-support system.

Conclusion:

In this study we were able to show how objective neuroergonomic measurement tools can be employed to evaluate the benefit of hearing support algorithms in a telephone system. The results indicate that an individual adjustment of listening preference yields a reduction in listening effort. We were able to show this with subjective data of experienced effort. Also, objective electrophysiological data show reductions in EEG parameters that have been linked to parameters indicative of listening effort, namely activity in the alpha frequency band. Due to an increasingly growing proportion of older employees individually tailored hearing support at the workplace is of special importance [4]. The technology investigated in this project provides an important step towards the realization of implementing individualized hearing support for employees in service and support centers. Such a technology increases comfort and by improving the signal quality it also alleviates cognitive effort and prevents cognitive fatigue due to prolonged effort [3].

From a methodological point of view the results of this study support EEG as a suitable method to address neuroergonomic issues such as cognitive load and listening effort. A particularly valuable asset, as was also shown in the current study, is that effects can be visualized independently of behavioral effects. Due to this added value it is feasible to detect compensatory mechanisms on a physiological level that otherwise might remain hidden.

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