Subjective listening effort and electrodermal activity in listening situations with reverberation and noise

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Disturbing factors like reverberation or ambient noise can obstruct speech recognition and raise the listening effort needed for communication in daily life. Situations with high listening effort are considered to incur an increased stress for the listener. The aim of this study was to assess listening effort in situations with background noise and reverberation. For this purpose, a subjective scaling of the listening effort, together with the electrodermal activity (EDA) as a measure of the autonomic stress reaction, was used. Ten young normal-hearing (NH) and 17 elderly hearing-impaired (HI) participants listened to sentences from the Oldenburg sentence test in stationary background noise and reverberation. Four listening situations were generated, an easy and a hard one for each of the two disturbing factors, which were related to each other by the Speech Transmission Index (STI). The results of the subjective scaling showed significant differences between the easy and the hard listening situations in both subject groups. However, various analyses of the EDA values indicate differences between the results of the groups. For the NH listeners, similar tendencies were observed both in the subjective results and the physiological EDA data. For the HI listeners, these effects in the EDA data were less pronounced.

INTRODUCTION

In this study, listening effort is regarded as the mental load needed to reach maximum speech recognition. Disturbing factors, such as reverberation or ambient noise, can obstruct speech recognition and increase listening effort. Situations with high listening effort are considered to imply an increased stress for the listener (Mackersie and Cones, 2011). When exposed to stress, the human body reacts with a change in many physiological parameters via the autonomic nervous system (Gramann and Schandry, 2009; Goldstein and Kopin, 2007). One of these physiological measures is the electrodermal activity (EDA), also known as skin conductance. The EDA describes the electrical conductance and potential changes of the skin (Schandry, 1989). It is influenced by the innervation of eccrine sweat

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glands, which are stimulated sympathetically (Critchley, 2002). The sympathetic nervous system is that part of the nervous system that stimulates the fight-or-flight response (Goldstein and Kopin, 2007) of the body. The goal of the experiment in the present study was to examine the relationship between the subjectively-rated listening effort and the physiological EDA measure in easy and in hard listening situations in the presence of noise and reverberation for young normal-hearing and elderly hearing-impaired participants.

METHODS

Participants

Ten NH and 17 HI subjects participated in the experiment. The age of the NH subjects was 19 to 28 (average: 23 yrs) and the HI subjects were 52 to 85 (average: 73 yrs). NH was defined as a hearing threshold of ≤ 20 dB HL at all audiometer frequencies in the range from 250 Hz to 8 kHz. The HI subjects exhibited a mild-to-moderate hearing loss of 23.1 to 53.1 dB HL (average of 0.5, 1, 2, and 4 kHz, PTA_4). All participants received a compensation (12 Euro/h) for their expenses. The experiment was approved by the ethics commission of the Carl von Ossietzky University in Oldenburg, Germany.

Stimuli and test conditions

The Oldenburg Sentence Test (OLSA, Wagener *et al.*, 1999), with 30 sentences per list, was used as speech signal. The speech stimuli were either mixed with speech-simulating stationary noise ("Olnoise") or convoluted with impulse responses of real rooms, to add reverberation. For both situations, noise and reverberation, an easy and a hard hearing condition were generated. Previous experiments by Rennies *et al.* (2014) and Schepker *et al.* (2015), using the same stimuli, showed a similar subjective listening-effort rating for NH and HI both for at SNRs of −6 dB and −2 dB (as hard conditions), as well as 6 dB and 10 dB SNR (as easy conditions). Therefore, these values were also chosen in the current study. The room impulse responses characterized by their reverberation time T_{60} were chosen to provide approx. the same Speech Transmission Index (STI, Houtgast and Steeneken, 1985; Schepker *et al.*, 2015), i.e., approx. 4 s (NH) and 2 s (HI) for the hard, and 0.5 s (NH) and 0.3 s (HI) for the easy condition. The level of the speech signals was adjusted to a sound pressure level (SPL) of 55 dB for the NH subjects and to the same individual subjective loudness in categorical units, using loudness scaling, for the HI subjects (Rennies *et al.*, 2013). This resulted in an average presentation level of 69 dB SPL (STD 4.7 dB) for the HI subjects.

Measurement procedure

To minimize any muscle activities due to body movements, the participants were located in a relaxed position on a couch in a sound-isolated test booth and wore headphones (Sennheiser HD650). The experiment started with a relaxation time of approx. 10 min, followed by two training lists with the OLSA. Then, the first of the four randomly-presented test conditions, started by a recovery time of approx. 5 min and was followed by one test list of the OLSA during which the participants repeated the words they recognized. After each test list, the participants were interviewed and asked to subjectively rate their listening effort. Subsequently, the next test condition started with another recovery time of about 5 min. During the whole duration of the experiment, including test and recovery phases, the EDA was recorded as amplitude in μS using Nexus 10-MKII via electrodes and using a low, constant current on the middle phalanx of the index finger and the middle finger of the non-dominant hand.

Subjective listening effort was rated using a categorical scale showing seven labeled categories and six intermediate steps (Luts *et al.*, 2010). Effort scale categorical units (ESCU) were assigned to the categories. They were labeled from no effort (German “mühelos”; 1 ESCU), very little effort (“sehr wenig anstrengend”; 3 ESCU), little effort (“wenig anstrengend”; 5 ESCU), moderate effort (“mittelgradig anstrengend”; 7 ESCU), considerable effort (“deutlich anstrengend”; 9 ESCU), very much effort (“sehr anstrengend”; 11 ESCU), to extreme effort (“extrem anstrengend”; 13 ESCU). The values in ESCU were not visible to the subjects.

RESULTS

Subjective rating

The results of the subjective listening effort scaling obtained with the NH and HI subjects in each of the four conditions are shown in Fig. 1. For both subject groups, significant differences between the conditions were observed (Friedman test p<0.001 for NH and SH). Post-hoc Wilcoxon tests revealed significant differences between easy and hard conditions in noise and in reverberation (noise: p=0.005 for NH and p<0.001 for SH; reverberation: p<0.001 for NH and p=0.005 for SH). The ratings for the easy noise and the easy reverberation condition were similar in both subject groups, but the two hard conditions were significantly different in both groups (p=0.010 for NH and p=0.002 for SH). The hard conditions required a higher listening effort in reverberation than noise.

EDA

An example of the time course of the EDA during the whole experiment for one subject is given in Fig. 2. The EDA typically decreases during the recovery phases between the different conditions. At the beginning of each test list, the EDA typically showed an onset followed by a decay during its duration, but also exhibited several maxima and minima during other test lists. During the interview and the listening-effort rating directly after each test list, the EDA showed high amplitudes and substantial variations that are mainly based on motor activities of the body during this phase.

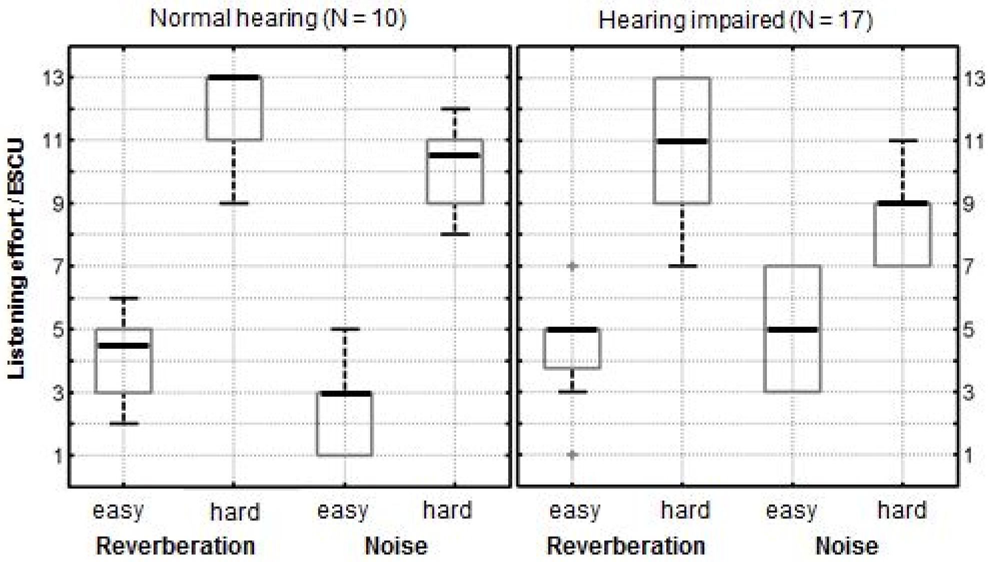

Fig. 1: Results of subjective listening effort ratings for normal-hearing (left) and hearing-impaired subjects (right) in the easy and hard reverberant and noise condition.

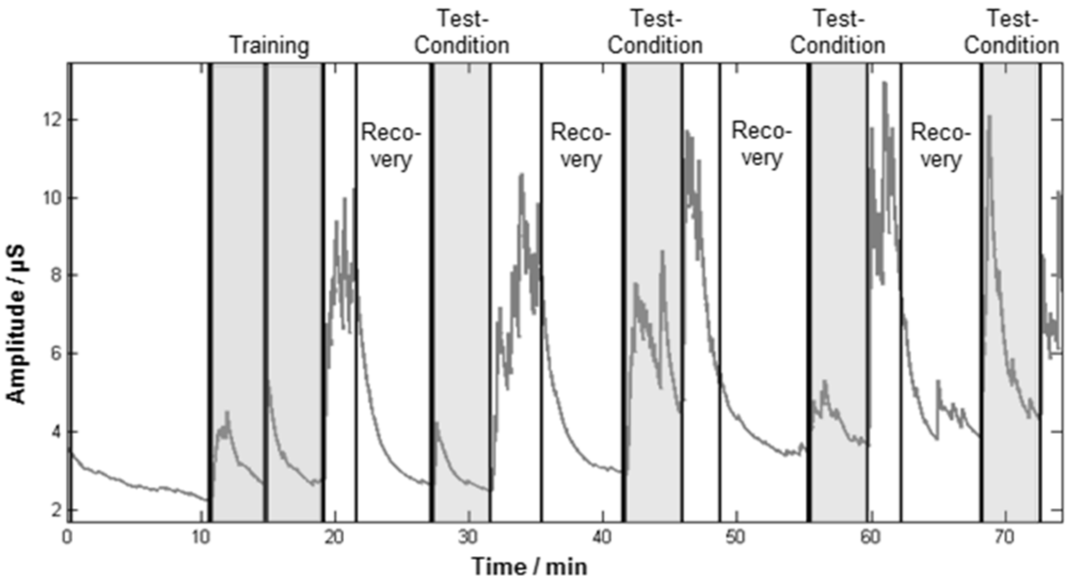

Fig. 2: Example of the time course of the EDA for one subject. The first grey area indicates the two training lists whereas the other four grey areas indicate the four test lists with different test conditions.

The EDA amplitudes during the test lists were compared across the four test conditions in terms of their averaged *z*-values (Mackersie and Cones, 2011; Mackersie *et al.*, 2015) and their relative peak rate. For the *z*-values, the average EDA amplitude during the last second before the start of each test list was regarded as the baseline for each subject and each condition. This baseline was subtracted from the EDA amplitudes averaged over the whole duration of the following test list, respectively. The results for each subject and each test condition were converted to *z*-values by subtracting the average of all subjects and test conditions and dividing by the respective standard deviation. The results in Fig. 3 show for NH subjects (left panel) the same tendency as for the subjective ratings, but non-significant differences (Friedman test, p=0.073). For HI subjects (right panel), the same tendency was observed for reverberation only, but not for the noise conditions (Friedman test, p=0.153).

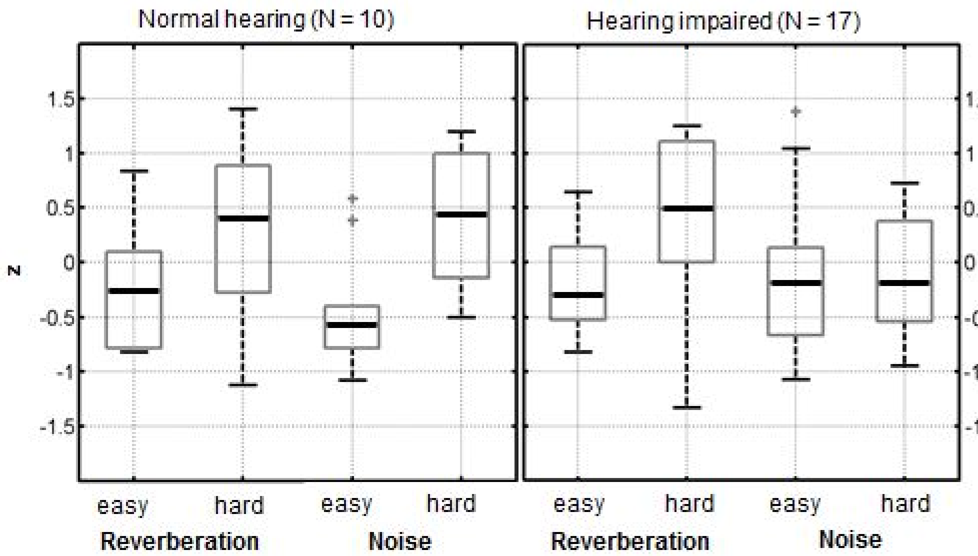

Fig. 3: Results of the *z*-values of the EDA for normal-hearing (left) and hearing-impaired subjects (right) in the easy and hard reverberant and noise condition.

The second measure, the relative peak rate, indicating the sympathetical level of excitation (Bruns and Praun, 2002), was calculated by counting the peaks of the EDA within the last three minutes of every recovery phase and within each test phase and dividing it by the duration of the respective recording periods. The relative peak rate of each test condition was given by the individual difference of the fluctuations/min in the test phase and in the previous recovery phase. Figure 4 shows the results for both groups. For the NH subjects (left panel), the results for the four test conditions were significantly different (Friedman test, p=0.008). However, a post-hoc Wilcoxon paired comparison test with Bonferroni correction did not show a significant difference. For the HI subjects, no significant differences were found between the test conditions.

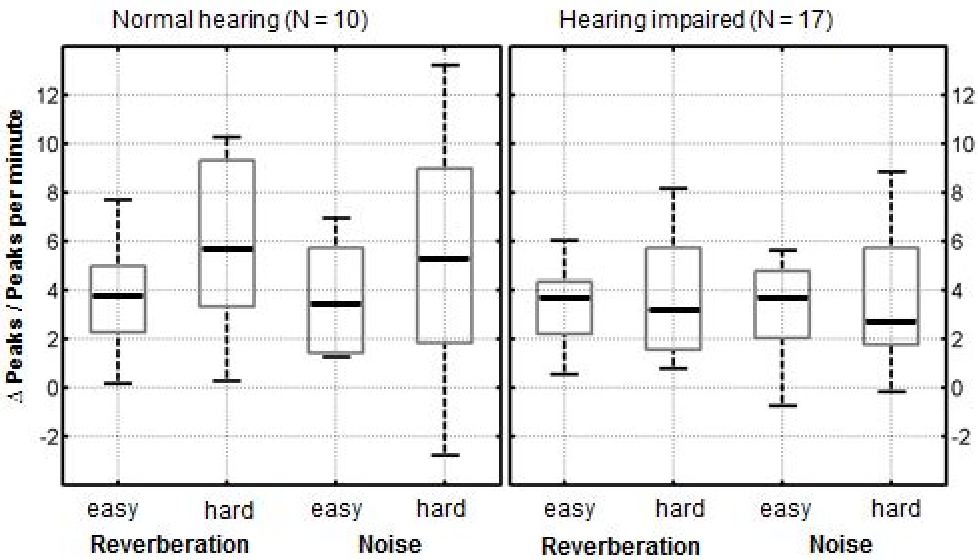

Fig. 4: Results of relative peak rate of the EDA for normal-hearing (left) and hearing-impaired subjects (right) in the easy and hard reverberant and noise condition.

The results of the EDA in *z*-values and in relative peak rate for all participants were compared to the subjective listening effort rating in ESCU (see Fig. 5). Besides the large scatter with very different EDA values for the same ESCU, Spearman's rank correlation revealed a low but significant correlation of *r*=0.337 for the *z*-values but no significant correlation for the relative peak rate.

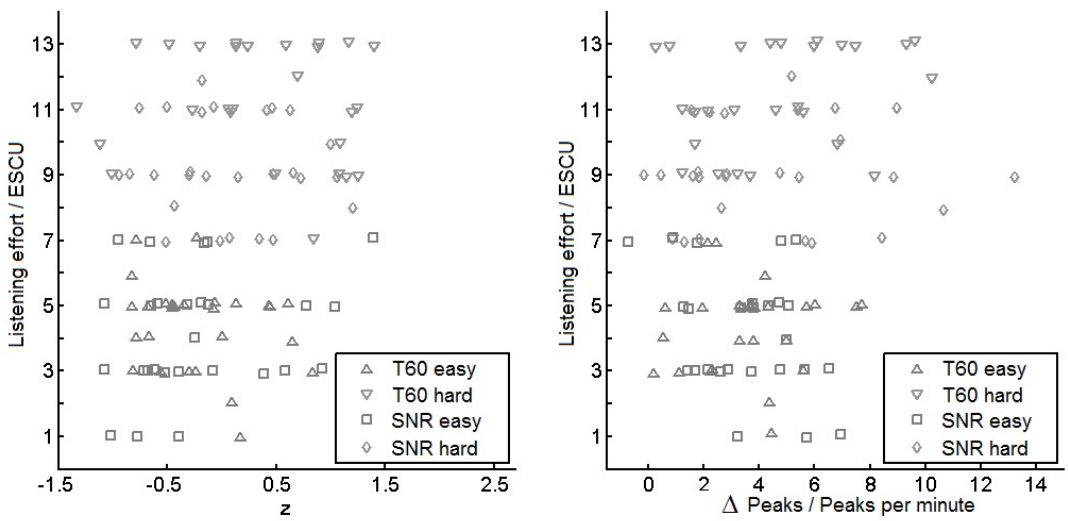

Fig. 5: Scatter plots of subjective listening effort in ESCU and EDA in *z*-values (left) and in relative peak rate (right) for all four test conditions.

DISCUSSION AND CONCLUSIONS

The subjective ratings of listening effort distinguish very well between the easy and the hard test conditions for both subject groups. Nevertheless, the differences between the test conditions are less pronounced in the older HI subjects compared to the younger NH subjects. This might be related to the older age of the HI subjects compared to the NH subjects and their respective listening experience in hard conditions (see, e.g., Larsby *et al.*, 2005). In contrast to the subjective ratings, both analysis methods of the EDA show a large scatter of the results as well as small or absent differences between the four test conditions and between the subject groups. Nevertheless, the results for the NH subjects indicate the same tendencies in the EDA data as in the subjective ratings where, for the HI subjects, differences in the EDA were observed only for some of the test conditions. Even though the test conditions were selected to manifest very different subjective listening efforts, differences in the EDA were difficult to demonstrate, especially for the group of HI subjects. One reason might be that the HI subjects perceived less stress in the hard conditions due to their experience with listening difficulties in everyday life. In addition, the lab situation without any interfering factors might cause less stress than usual listening experiences, as expressed at least by one subject. Another reason might be the older age of the HI subjects, which is frequently accompanied by skin alterations and therefore possible problems in recording the EDA. The lack of stress is also supported by the very weak relationship between subjective ratings and EDA recordings for all test conditions and participants. The EDA does not seem to be directly related to the subjective ratings, but might, in addition, be influenced by other so far unknown factors. The precise mechanism in skin conductance variations, and therefore also the applicability of the EDA in the lab, remains to be explained.

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