Summary
Pupillometry as a window onto listening effort: interactions between hearing impairment, hearing aid technologies and task difficulty during speech recognition

Currently available knowledge can only partly explain the relationship between a listeners' hearing ability, cognitive skills, speech recognition and the pupil dilation during speech recognition. Current evidence is limited to a restricted range of listening conditions and not yet confirmed for hearing-impaired listeners. The aim of this dissertation was to investigate the impact of hearing impairment and hearing aid technologies on speech recognition and listening effort. Four scientific studies were performed.

In the field of hearing and listening effort research, the number of methods to assess listening effort is constantly increasing but emerging evidence is not consistent. A systematic review of the existing evidence was first performed to determine the current state of knowledge regarding the effect of hearing impairment and hearing aid amplification on listening effort. The results indicated that listening effort can be larger for hearing impairment listeners as compared to listeners with normal hearing. People that are hard of hearing may perceive a degraded auditory input signal. Processing and understanding such a signal is assumed to affect the amount of task-evoked effort, depending on the listening situation. However, it is still not clear how hearing-impaired listeners allocate the amount of effort they spend across listening conditions. Our results from the systematic literature review did not indicate clear scientific evidence supporting reduced listening effort due to hearing aid amplification. In daily-life communication situations, signal to noise ratios may vary from very low to very high and involve different types of background maskers such as interfering speech or more stationary noise. It is still unknown whether the pupil response during speech recognition differs between hearing-impaired and normal-hearing listeners and in which listening conditions those differences occur. The second study had an experimental design. We aimed to better understand in which listening conditions hearing-impaired listeners invest more effort relative to normal-hearing listeners, and in which conditions the allocated effort might be lower. The impact of stimulus-related factors and hearing impairment on listening effort was investigated in a group of hearing-impaired and age-matched normal-hearing listeners. A broad range of signal-to-noise ratios was tested for a stationary and a single-talker masker corresponding to sentence recognition performance varying from 0% to 100% correct, including everyday life listening conditions. For both masker types, the results suggest an interactive effect between a listeners' hearing ability and the signal-to-noise ratio of the auditory stimuli on the pupil response during listening. Different patterns of pupil responses were found across signal-to-noise ratios between listener groups. Normal-hearing listeners showed maximum pupil responses across a small, pronounced range of signal-to-noise ratios for the stationary and the single-talker masker. Good hearing abilities may allow them to be adaptive in their allocation of effort across speech-to-noise rations. Hearing-impaired listeners showed maximum pupil responses across a wide range of positive speech-to-noise ratios. Both groups of listeners invested most effort, as indicated by the pupil responses, around 50% correct performance levels.

Previous research in the domain of speech perception and listening effort suggests that the pupil response, examined during speech recognition, sensitively reflects the influence of individual cognitive abilities. However, it is still not clear how associations between cognitive abilities, such as working memory capacity, and speech recognition may differ between normal-hearing and hearing-impaired listeners. In Chapter 4, we assessed whether
differences in the pupil response and sentence recognition performance could be explained by the listener’s cognitive abilities. For the same groups of hearing-impaired and normal-hearing listeners, working memory capacity and inhibition of interfering information and linguistic closure were examined. Our results show that normal-hearing and hearing-impaired listeners with better cognitive abilities have better speech recognition performance and larger pupil responses. Better cognitive abilities might allow the listeners to expend more cognitive resources on task performance in difficult conditions.

Hearing aids are designed to improve the audibility of sounds and facilitate better speech intelligibility in quiet and in noisy environments. Hearing aid users often report that communication in noisy environments is very tiring and effortful. Recent evidence indicates that effort can be reduced with noise reduction processing in hearing aids. However, current evidence is only available for a very limited range of listening conditions. It still remains unclear how hearing aid users invest listening effort across a broader range of listening conditions and how effortful listening relates to speech recognition performance. The purpose of a second experimental study (Chapter 5) was to examine whether a noise reduction scheme in hearing aids can reduce the effort for hearing-impaired listeners during speech recognition. Speech recognition performance and the pupil response were measured for a group of experienced hearing aid users wearing commercial hearing aids. A large range of SNRs for a stationary noise masker and a 4-talker masker was tested when the noise reduction processing was either active or inactive. For both masker types, we found a beneficial effect of the noise reduction scheme on sentence recognition performance and listening effort. The sentence recognition performance function was overall shifted towards negative (more difficult) SNRs. The corresponding pupil response was reduced at high SNRs, indicating decreased listening effort when speech recognition is proportional to everyday life listening environments for the hearing-impaired. Increased pupil responses at very difficult SNRs indicate that listeners were engaged in difficult listening conditions that would be impossible to follow without hearing aids.

The unique contribution of this thesis is the remarkably comprehensive dataset on speech recognition performance and the corresponding pupil dilation across a broad range of SNRs, including SNRs that reflect everyday life listening conditions. The results suggest that the allocation of listening effort depends on the relationship between the difficulty of the listening condition and the listeners hearing ability. Commercial noise reduction processing in hearing aids can allow hearing-impaired listeners to regain access to noisy listening conditions, which might be too difficult and too frustrating to participate in without hearing aids. Our results show in addition that noise reduction processing can reduce listening effort required during speech recognition in a stationary and a 4-talker masker. Our results for the 4-talker masker suggest that some aspects of listening effort may be reduced by the noise reduction processing, independent of the signal-to-noise ratio.