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About cognitive outcome measures at ecological signal-to-noise ratios and cognitive-driven hearing aid signal processing

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Abstract

Purpose: To discuss two questions concerning how hearing aids interact with hearing and cognition.

Can signal processing in hearing aids improve memory? Can attention be used for top-down control of hearing aids?

Method: Memory recall test of heard sentences at signal-to-noise ratios adjusted to 95% correct speech recognition with and without binary mask noise reduction. A short literature review on recent findings on new brain imaging techniques showing potential for hearing aid control.

Conclusion: Two experiments indicate that it is possible to show improved memory with an experimental noise reduction algorithm at ecological signal-to-noise ratios and that it is possible to replicate these findings in a new language. The literature indicates that attention-controlled hearing aids may be developed in the future.

Keywords:

Cognition, working memory hearing aids, outcome measures, electroencephalography, EEG, hearing aid control, attention

Cognitive Hearing Science is an emerging field of interdisciplinary research that concerns the interactions between human hearing and cognition (Arlinger, Lunner, Lyxell, & Pichora-Fuller, 2009). There has been an increase in research investigating how hearing aids can support cognition and hearing and how hearing aids might be controlled by cognition. This paper discusses two questions concerning how hearing aids interact with hearing and cognition.

- Can signal processing in hearing aids improve memory?
- Can attention be used for top-down control of hearing aids?

Can hearing aids improve memory?

Working memory is important for online language processing in a dialogue. We use it to store, inhibit or ignore irrelevant information and to perform selected tasks. Working memory is our method of keeping track while taking turns or following the gist of a dialogue. The Ease of Language Understanding (ELU) model (Rönnberg, 2003; Rönnberg, Rudner, Foo, & Lunner, 2008; Rönnberg et al., 2013) describes the role of working memory capacity in sound and speech processing and attempts to explain empirical findings concerning these relationships, including the effects of hearing impairment on memory.

In a recent study by Smeds, Wolters, and Rung (in press), hearing aid users' signal-to-noise ratios (SNRs) in daily life were found to span a fairly large range, typically with a positive SNR (approximately +5 dB to + 10 dB). It is not useful to measure percent correct performance for speech in this SNR range since performance is close to 100% correct. Furthermore, noise reduction schemes in

hearing aids are usually most effective at positive signal-to-noise ratios. Therefore, if one would like to assess outcome of noise reduction schemes at ecological signal-to-noise ratios, testing at positive signal-to-noise ratios is necessary. However, most conventional speech-in-noise tests are insensitive at those high signal-to-noise ratios because of ceiling effects. Nevertheless, performing at 100% does not mean that the listening effort of the user should be overlooked. Even at high speech performance levels, other factors, such as changes in working memory load, might reveal differences due to the effects of hearing aids on the ease of listening. Such effects could influence how many words heard in a conversation are remembered.

Recall after successful aided listening and the effects of hearing aid signal processing on recall have been investigated by Ng, Rudner, Lunner, Pedersen, and Rönnberg (2013) as well as by Ng, Rudner, Lunner, and Rönnberg (2014). Ng and her colleagues introduced a memory recall method that was inspired by Sarampalis, Kalluri, Edwards, and Hafter (2009) and Pichora-Fuller (2006). The method involved having to recall the last word from each of seven consecutively presented Hearing In Noise Test (HINT) sentences. Ng et al. (2014) used multi-talker babble noise because it is a typical of background sound encountered in daily life. The memory recall test assesses both memory and word recognition accuracy. The latter measure is conducted using pre-calibrated individualized SNR settings to achieve approximately 95% correct performance (close to ceiling performance). Therefore, any improvement in ease of listening due to hearing aid signal processing would not be revealed by improvements in word recognition accuracy but rather to improvements in recall.

Two experiments were conducted using identical procedures to test memory in different languages (Ng et al., 2014; Lunner et al., in prep). One experiment tested 26 native Swedish speaking participants

using the Swedish HINT speech corpus (Hällgren, Larsby, & Arlinger, 2006) and the other tested 25 native Danish speaking participants using the Danish HINT speech corpus (Nielsen & Dau, 2011). It is good science to replicate findings. The Danish experiment was designed to replicate the Swedish experiment, but in new language, and at a different lab. The hypothesis was that the memory test was insensitive to a change from one Scandinavian language to another. The participants in both experiments had moderate symmetrical sensorineural hearing loss and had used well-fitted hearing aids for more than a year. In both experiments, tests were conducted using experimental linear hearing aids with individually shaped frequency responses to assure audibility of the speech material up to 6.5 kHz. With this experimental hearing aid, the SNR (using a four-talker babble background) was individually adjusted to achieve 95% correctly recognized sentence-final HINT words. Two settings of the experimental hearing aid were contrasted: a setting with a binary mask noise reduction (NR) processing algorithm (Boldt, Kjems, Pedersen, Lunner, & Wang, 2008) and a control setting without NR (no additional processing, NoP, in addition to the linear processing used in both conditions) The 7-item memory test was repeated 5 times in each setting, with the NR and NoP settings tested in counterbalanced order. The results of both experiments revealed an improvement in recall of approximately 10% for the experimental NR setting compared to the linear reference setting. This difference was statistically significant for both experiments ($t(25) > 4.2, p < .01$; ($t(24) > 4.1, p < .01$)). The average of the individual SNRs for 95% correct word recognition were 7.5 dB (SD = 1.9) for the Swedish material and 9.6 dB (SD = 2.3) for the Danish material. Thus, the results were obtained in the range of the SNRs observed in the ecological conditions reported by Smeds et al. (in press).

In summary, these two experiments indicate that it is possible to show improved memory with an experimental NR algorithm at ecological SNRs and that it is possible to replicate these findings in a different language.

Can attention be used for top-down control of hearing aids?

In a given listening situation, the mental/cognitive state of the listener may depend on the demands associated with the cognitive task (e.g., single task versus dual task, time of the day, fatigue, or dividing attention). Hearing aids include automatic control to regulate signal processing schemes, such as noise reduction and beam-forming/directional microphones, where the automatic control is devised from the acoustic environment. When controlling a hearing aid for a listener whose mental state may vary depending on task demands, it may not be sufficient to merely measure acoustics; it might be necessary to monitor cognitive parameters and adjust hearing aid settings accordingly (i.e., cognition-driven hearing aids). Such new technological developments could incorporate physiological monitoring with pupillometry or ‘brain-imaging’ technologies like the electroencephalogram (EEG).

Mesgarani and Chang (2012) have presented a particularly interesting dataset. These authors used multi-electrode surface recordings from the auditory cortex. The recordings demonstrate that the normal-hearing brain’s can modulate the cortical manifestation of the speech envelope for two competing talkers, with the attended speech source represented at the auditory cortex level as if it had been extracted by an attentional filter. It was possible to classify (with a high degree of certainty) the attended speech source based on the cortical recordings. The phenomenon that the brain seems to be able to weigh the neural input to enhance the attended source and to attenuate non-attended sources has

been termed attention modulation. Subsequently, the classification of the “attended talker” has been corroborated with conventional electroencephalography by O’Sullivan et al. (2014). Attention modulation through EEG or magnetoencephalography (MEG) has recently received much interest based on promising preliminary results (Luo & Poeppel 2010; Ding & Simon 2012; Choi, Rajaram, Varghese, & Shinn-Cunningham, 2013). However, at present, for hearing-impaired persons the degree to which attention modulation abilities can be classified from EEG is unknown (Shinn-Cunningham & Best, 2008).

If individuals with impaired hearing have preserved attention modulation abilities, then researchers may soon determine how to use them in future hearing aids. One line of research could be to design a hearing aid system that can be mentally (cognitively) steered to allow more “natural communication” for the listener. In addition to linear models, it might be possible to devise non-linear machine-learning algorithms that decode the brain signals picked up by EEG electrodes. These algorithms could be used to extract the “attended talker” signals and match them to acoustic sources in the environment. In turn, the “attended talker” signals could be used to steer an acoustic beam former towards the targeted speaker or sound source.

Such developments may be a forerunner to broader applications of cognitive brain imaging to decipher and exploit human intentions and expectations in prosthetic sensory systems, particularly given the increased availability, miniaturization, and affordability of EEG recording setups in scientific research and medical diagnostics.

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