Speech intelligibility in dual task with hearing aids and adaptive digital wireless microphone technology

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Remote microphones (RMs) have been developed to support hearing aid users to understand distant talkers. A drawback of these systems is the deteriorated speech intelligibility in the near-field, as the hearing aids need to be in omnidirectional mode in combination with these RMs. This has changed with the introduction of a new hearing-aid technology developed specifically to support the user in the near-field when using a RM, by enabling directional microphones of the hearing aid. To verify the performance of this novel system, speech intelligibility tests were conducted using a dual-task paradigm. *Primary task:* Sentences of the female Oldenburg Matrix Test were presented continuously. The task of the subject was to mark the recognized name on a tablet. *Secondary task:* A speech recognition test with meaningful sentences (Göttinger Sentence Test, male voice) was carried out with the task to repeat the sentences. The primary-task stimuli were presented from a loudspeaker in the far-field and the secondary-task stimuli from a loudspeaker in the near-field (and vice versa), within a surrounding loudspeaker array playing restaurant noise. Results of 15 hearing-impaired subjects showed that the directional hearing-aid microphone delivered superior performance compared to the omni microphone. Benefits of the RM were confirmed for both primary and secondary tasks. For a higher ecological validity, the data were analyzed considering both tasks simultaneously. This analysis showed a positive effect of the directional hearing aid microphone.

INTRODUCTION

One of the most common problems that individuals with hearing loss face is to follow conversations in complex listening environments. Listening is often difficult when there is excessive background noise, reverberation, and large distances between the target signal and the individual with a hearing loss. This is also seen when the hearing loss is at least partly compensated by hearing aids. In order to overcome these three main factors, individuals with hearing loss require a better signal-to-noise (SNR) ratio than those with normal hearing (Baquis, 2014).

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To address this need, modern hearing aids (HAs) include directional microphones that have been shown to increase speech understanding in noise (Dillon, 2012).

While directional microphones provide measureable benefit, they have their limitations. For example, a 4-5 dB SNR benefit can be achieved with directional microphones, but up to 25 dB SNR (depending on degree of hearing loss) may be needed to help individuals with hearing loss (Baquis, 2014). Additionally, directional microphones are primarily effective when used in the near-field, approximately 1.5 meters from the target signal (Kim and Kim, 2014).

Individuals who need additional SNR improvement beyond the potential of directional microphones may therefore consider utilizing remote microphones (RMs). Using RMs, the distance between the target signal and the microphone and thus the amount of background noise and reverberation can be significantly reduced. RMs are intended for far-field use and have historically been realized using frequency modulation (FM) transmission, where the FM radio transmitter is coupled with a microphone that the talker wears. The microphone signal is directly transmitted to the listener's hearing aid or cochlear implant via a (miniature) radio receiver using direct audio input or telecoil. These systems have shown significant benefit for both hearing-aid users (Anderson and Goldstein, 2004) and cochlear-implant users (Wolfe *et al.*, 2012). Traditional FM systems were generally configured as either fixed analog or adaptive analog systems.

Digital adaptive wireless systems are able to provide higher SNR improvements than traditional analogue FM systems, resulting in significantly better speech intelligibility of up to 35% in (high-level) noise (Wolfe *et al.*, 2013; Thibodeau, 2014). Therefore, the hearing-aid industry started to develop digital transmission systems described as adaptive digital wireless microphone technology. The present study investigates the benefit of an adaptive digital wireless technology ("Phonak Roger") for hearing aid users in adverse listening environments.

Historically, digital hearing-aid technology utilized two analog to digital converters forcing a single microphone mode (omni-directional) when using a RM. This led to a decrease in speech intelligibility in noise in the near field when speech was simultaneously presented to the RM and transmitted to the hearing aid.

In order to solve this problem, Phonak introduces a new solution/technology utilizing three analog-to-digital converters in the input stage of the hearing device, allowing for directional microphone settings to be used in conjunction with RMs.

Several studies have examined the use of RMs in combination with omni-directional hearing-aid microphones versus directional hearing-aid microphones in children either with static or with adaptive behavior. In a recent study Jones and Rakita (2016) used Phonak Sky V hearing aids. Speech was either presented from a loudspeaker simulating a peer talker *or* from a second loudspeaker simulating a class mate from behind *but not* a simultaneous presentation of both talkers. They found that children performed better on speech recognition tests in noise when using Roger plus hearing aid in directional microphone mode compared to Roger plus hearing aid in omni-directional mode by up to 25%.

Previous research showed the performance of RM with omni versus directional hearing aid microphones in either near-field or far-field target signals. However, it has not been investigated yet what happens when the target signal switches between the near field and far field. It is not uncommon for a listener to change their auditory focus in a given situation. For example, during a wedding reception the listener would like to listen to both, the official speech and comments from the people next to him/her. The present study aims to reproduce this type of adverse listening environment where the target signal changes from being close to the hearing aid wearer to being further away.

To that end, a dual-task paradigm was employed, which consists of two parallel speech intelligibility tasks and was developed to assess the interaction of target signals in near field and far field for hearing aid users with RMs.

METHODS

Subjects

Fifteen experienced hearing aid users with a severe sensorineural hearing loss (mean 4HFA (Roeser, 1996) of the better ear was 62.8 dB HL with a standard deviation of 6.1 dB HL) took part in the study. All subjects were inexperienced users of RM technologies. Subject ages ranged from 63 to 83 years with a mean age of 72 years (4 female, 11 male).

Hearing devices and test conditions

All subjects were bilaterally fitted with Phonak Naída V90 SP hearing aids (HAs). The initial setting was based on the subjects' audiograms and the fitting rule "Adaptive Phonak Digital" (Latzel 2013). The default acoustical coupling suggested by the fitting software Phonak Target 4.1 was selected. Fine tuning of the hearing aids (without RM) was allowed during an acclimatization period. The final settings were verified using real ear measurements.

During the laboratory measurement the subjects additionally received a RM ("Phonak Roger Pen") that was connected to the hearing aids ("Phonak Naída V90 SP") via receivers ("Phonak Roger 18").

Three different hearing aid conditions were defined:

P1: RM plus Hearing aids in omni-directional microphone setting
P2: RM plus Hearing aids in directional microphone setting
P3: Hearing aids alone without RM, binaural microphone setting ("StereoZoom")

Dual-task paradigm

In the primary task, sentences from the Oldenburg Sentence Test, spoken by a female speaker (OLSA, Wagener *et al.*, 2014), where presented continuously at a constant SNR. The subjects were asked to identify the name within each sentence from a list of 10 alternatives presented via a tablet PC.

A secondary task was performed simultaneously using the Göttingen Sentence Test presented via a male talker (GÖSA, Kollmeier and Wesselkamp, 1997) at a selected constant SNR. The subject was instructed to repeat all recognizable words. Based on word scoring, speech intelligibility in percent was determined.

Both tasks were simultaneously performed in a diffuse cafeteria noise scenario (L_{eq}=62 dB SPL, measured at the position where the RM was placed right in front of the far-field loudspeaker and at the position of the subject (see Fig. 1).

There were two set-up conditions:

(1) The primary task was presented in the far field from a loudspeaker at a distance of 6.4 m. The secondary task was presented from a loudspeaker in the near field (1.4 m).
(2) The primary task was presented from a loudspeaker in the near field (1.4 m) and the secondary task from a loudspeaker in the far field (6.4 m).

The presentation level of the primary task was kept constant at 65 dB SPL for the the primary task in the near field and at 70 dB SPL in the far field. These presentation levels assured audibility of the OLSA sentences for all subjects.

The loudspeaker set up is illustrated in Fig. 1.

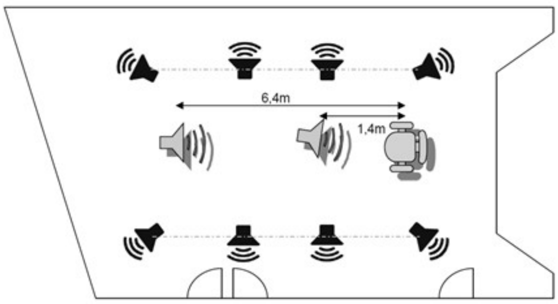

Fig. 1: Schematic display of the set-up used for the dual-task paradigm.

Training

To avoid training effects a training of the dual task was performed during each session prior to the measurements. During the training, the test hearing aids were used without RM (target signals only in near-field). Additionally, the speech presentation level for the secondary task (GÖSA) was determined individually and was used for all measurement conditions for said subject for far- and near-field presentation. The constant presentation level of the secondary task was individually determined from the GÖSA SRT result, measured adaptively, plus 3 dB. This resulted in GÖSA speech presentation levels ranging from 59 to 71.3 dB SPL across subjects.

After the training, the dual-task measurements were performed in the three hearing-aid conditions and two set-up conditions described above.

RESULTS AND DISCUSSION

Dual-task paradigm: Single performance

The left panel of Fig. 2 shows the results of the primary task in terms of the percentage of correctly identified names. The hearing aid conditions are called P1 to P3 and the set-up conditions are indicated by the loudspeaker that the primary-task stimuli were presented from: “far” or “near”. An ANOVA of repeated measures revealed a significant main effect of hearing aid condition in the far-field [$F(4,14) = 66.606$, $p < 0,001$] and the post-hoc analysis showed a significant advantage of RM ($p < 0.001$) after Bonferroni correction (bfc.). This indicates that both programs (P1, P2) with RM active provided better performance than the HA alone (P3). This confirms earlier findings (Anderson and Goldstein, 2004; Wolfe *et al.*, 2012). In the near field, P1 and P2 showed no statistically significant differences with regard to primary-task performance. This finding does not suggest an advantage of P2 (directional microphone mode of HA) over P1 (omnidirectional microphone mode of HA) in both near-field and far-field conditions.

In the right panel of Figure 2 the results of the secondary task are illustrated in terms of percentage of correctly identified GÖSA words . The notation is similar to the left panel of Figure 2, except for “far” and “near” denoting the loudspeaker that the secondary-task stimuli were presented from. An ANOVA of repeated measures revealed a significant main effect of hearing-aid condition in the near-field [$F(4,14) = 189.408$, $p < 0,001$] and the post-hoc analysis showed a significant disadvantage of RM in the near-field ($p < 0.001$, bfc.). This indicates that the input from the RM was overlapping with the input of the HA microphone, resulting in poorer performance in the near-field. Without the RM, less interfering information was apparently provided to the listener in the near-field task. Results show P3 to markedly outperform the other hearing aid conditions regarding speech intelligibility in a noisy environment in the near-field. Furthermore, these results support the binaural beamformer (StereoZoom) which was active in P3, providing excellent performance in a noisy environment in the near-field (also noted by Appleton & König, 2014). Additionally, the post-hoc analysis revealed a significant advantage of the directional microphone (P2) over the omni-directional microphone (P1) in the near field ($p<0.05$, bfc.). In the far-field, no statistically significant difference between P1 and P2 was found, and therefore a general conclusion could not be established for the secondary task. This leads us to conclude that only the analysis of the common performance (primary and secondary task) is able to reflect the benefit of the different test conditions in near-field and far-field.

Dual-task paradigm: Common performance

The motivation of this study was to determine speech perception performance in a listening situation where the target signal changes from being close to the hearing-aid wearer to being further away. Dual-task costs were determined in order to calculate the common performance of both tasks within the dual-task paradigm.

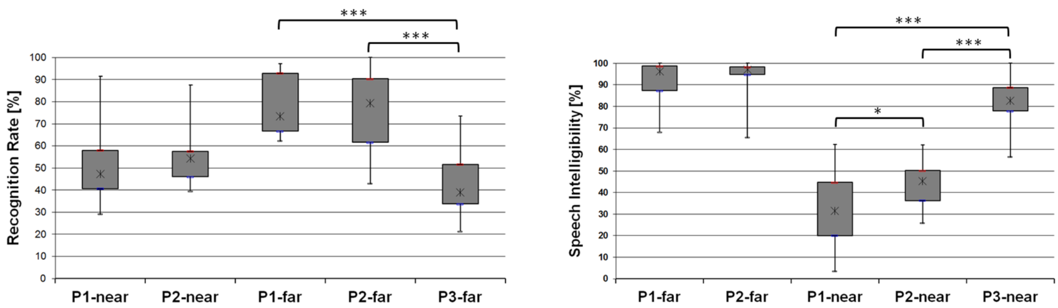

Fig. 2: *Left panel:* Recognition rate of names in continuous OLSA sentences (primary task) for hearing aid conditions P1, P2 and P3. Near: primary task was presented in the near-field; Far: primary task was presented in the far-field. *Right panel:* Speech intelligibility of GÖSA sentences (secondary task) for the hearing aid conditions P1, P2 and P3. Near: secondary task was presented in the near-field; Far: secondary task was presented in the far-field. Values are displayed as boxplots with median, minimum, maximum, 25th and 75th percentiles. *: Denotes statistically significant difference ($p<0.05$) ***: Denotes statistically significant differences ($p<0.001$). *Note:* P3 was not measured in the set-up condition 2, as from an ethical point of view it was not justifiable to conduct the secondary task from far-field as it would end up in a speech perception of about 0%. So the P3 hearing aid condition is only shown for the primary task in far-field and secondary task in near-field.

The main concept of dual-task costs is to measure the change of performance of the primary task due to the additional cognitive load of the secondary task (and vice versa). Most likely the performance of each task drops when performing both tasks at the same time compared to the case when every task is carried out alone. In the following, dual-task costs are calculated using the “probit” (probability units) transformation according to Oberauer *et al.* (2004): The differences in speech recognition (in percent correct) for doing every task in the single condition (data not shown here) compared to the dual task condition (Fig. 2) are calculated and expressed as the corresponding z-scores of a standard normal distribution. The probit values for both tasks are summed up afterwards to account for the common performance change on the primary and secondary task.

The dual-task costs are visualized in Fig. 3. A 2x2 factorial ANOVA of repeated measures revealed a significant main effect of hearing-aid condition [$F(1,14) = 56.282$, $p < 0{,}000$] and of set-up condition [$F(1,14) = 4.6153$, $p = 0{,}49$]. No statistically significant effect of the interaction of hearing aid condition & set-up condition could be found. *Hearing aid condition:* This result indicates that the directional microphone increases speech intelligibility regardless of whether the talker is near or far. It shows that the directional microphone not only improves speech perception in the near field but also for a distant speaker transmitted to the hearing aid via RM. In this case, the directional microphone acts as an additional means of noise suppression. *Set-up condition:* The results indicate that the different levels of difficulty for the tasks are influenced by the source position. When transmitting GÖSA speech material via RM to the HA, the performance is much better than when it is received with the microphones of the HA (see also Fig. 2, right panel). This may be due to the default mixing factor at the input stage of the HA, which is set to 10 dB amplification of the RM signal versus the HA microphone signal due to regulations for using a remote microphone/hearing aid system in school (Johnson *et al.*, 2011). The missing interaction effect for both hearing aid condition and set-up condition supports the extra benefit provided by the directional microphone regardless of where both tasks are presented from. P2 (directional microphones) showed to be beneficial both in the far-field and the near-field in terms of common performance.

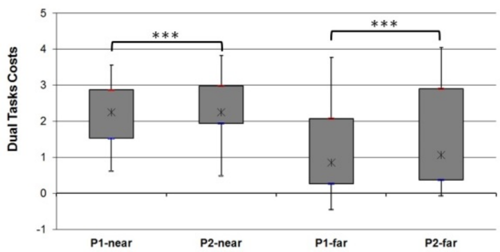

Fig. 3: Dual-task costs in probit (probability units) for hearing-aid conditions P1 and P2. Near: primary task was presented in the near field; Far: primary task was presented in the far-field. Values are displayed as boxplots with median, minimum, maximum, 25th and 75th percentiles (higher values represent better performance, thus less dual-task costs). ***: Denotes statistically significant difference ($p < 0.001$).

CONCLUSIONS

The described dual-task paradigm is an effective tool for testing the interaction of simultaneous input signals both in near field and in far field when using a hearing-aid in combination with a remote microphone. The set-up that has been used in this experiment is: (1) able to identify the advantages and disadvantages of a remote microphone/hearing-aid combination. The results confirm that the novel system (hearing aid with directional microphone in connection with a remote microphone) provides better common speech understanding in near and far-field. It can be expected that this set up could be optimized in terms of the mixing factor (amplification of RM input versus HA microphone input), particularly when used as a hearing solution for adults; (2) sensitive to differences between omnidirectional and directional microphone settings.

When analysing data of a dual task it is necessary to consider the common performance of both tasks. Calculating the "costs" of how much the performance of each single task drops when executing both tasks simultaneously has been shown to be a suitable way to derive the common performance.

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