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Research Paper

Effects of attention on the speech reception threshold and pupil response of people with impaired and normal hearing

Thomas Koelewijn*, Niek J. Versfeld, Sophia E. Kramer

Section Ear & Hearing, Department of Otolaryngology-Head and Neck Surgery and Amsterdam Public Health Research Institute, VU University Medical Center, Amsterdam, The Netherlands

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A B S T R A C T

For people with hearing difficulties, following a conversation in a noisy environment requires substantial cognitive processing, which is often perceived as effortful. Recent studies with normal hearing (NH) listeners showed that the pupil dilation response, a measure of cognitive processing load, is affected by 'attention related' processes. How these processes affect the pupil dilation response for hearing impaired (HI) listeners remains unknown. Therefore, the current study investigated the effect of auditory attention on various pupil response parameters for 15 NH adults (median age 51 yrs.) and 15 adults with mild to moderate sensorineural hearing loss (median age 52 yrs.). Both groups listened to two different sentences presented simultaneously, one to each ear and partially masked by stationary noise. Participants had to repeat either both sentences or only one, for which they had to divide or focus attention, respectively. When repeating one sentence, the target sentence location (left or right) was either randomized or blocked across trials, which in the latter case allowed for a better spatial focus of attention. The speech-to-noise ratio was adjusted to yield about 50% sentences correct for each task and condition. NH participants had lower ('better') speech reception thresholds (SRT) than HI participants. The pupil measures showed no between-group effects, with the exception of a shorter peak latency for HI participants, which indicated a shorter processing time. Both groups showed higher SRTs and a larger pupil dilation response when two sentences were processed instead of one. Additionally, SRTs were higher and dilation responses were larger for both groups when the target location was randomized instead of fixed. We conclude that although HI participants could cope with less noise than the NH group, their ability to focus attention on a single talker, thereby improving SRTs and lowering cognitive processing load, was preserved. Shorter peak latencies could indicate that HI listeners adapt their listening strategy by not processing some information, which reduces processing time and thereby listening effort.

1. Introduction

Hearing loss can result in a degraded representation of the auditory scene, which makes it harder to differentiate target speech from competing sounds (Shinn-Cunningham and Best, 2008). By making more auditory information available through acoustic amplification (e.g. by using hearing aids), listening in complex situations may become easier. For instance, benefits of bilateral over unilateral hearing aid fittings have been shown for listening conditions that require spatial auditory attention (Noble and Gatehouse, 2009). Conversely, more auditory input leads to the necessity to process more information, which results in higher levels of listening effort, especially when there is uncertainty about the location of the speaker (Koelewijn et al., 2015, 2014a). One question is: how do audible binaural spatial cues affect listening effort during speech processing by people with sensorineural hearing loss?

Listening effort has recently been defined as 'the deliberate allocation of mental resources to overcome obstacles in goal pursuit when listening' (Pichora-Fuller et al., 2016). Based on the attention model of Kahneman (1973) and a recent modified version of it called the Framework for Understanding Effortful Listening (FUEL, Pichora-Fuller et al., 2016), one can argue that attention, manipulated for instance by means of task instructions, can affect the allocation of cognitive resources and thereby performance. The

* Corresponding author. VUmc – Ear & Hearing, De Boelelaan 1117, 1081 HV Amsterdam, The Netherlands.
E-mail address: t.koelewijn@vumc.nl (T. Koelewijn).

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availability of these resources is linked to levels of arousal of an individual. These levels of arousal can be measured as autonomic responses by means of pupillometry.

Recent studies (Koelewijn et al., 2015, 2014a) showed an effect of divided attention on the pupil dilation response for young normal hearing adults during processing of speech in noise. Consistent with FUEL it was shown that when participants were instructed to repeat two streams of masked speech instead of one, their performance dropped and their evoked pupil dilation response became larger (Koelewijn et al., 2014a). This is consistent with the idea that allocation of more resources (higher load) leads to larger pupil dilation (Just et al., 2003; Kahneman and Beatty, 1966). These pupillometry studies (Koelewijn et al., 2015, 2014a) were based on a design of Best et al. (2010), who showed that when normal hearing (NH) and hearing impaired (HI) participants were presented with two sentences in noise, one to each ear, performance dropped when both sentences had to be repeated instead of one. Apart from requiring a more favorable signal to noise ratio (SNR) than for the NH participants, the HI listeners' performance, when repeating one or two sentence over a range of fixed SNRs, was strikingly similar to that of the NH group.

Previous research (Kidd et al., 2005; Kitterick et al., 2010) showed that knowing *where* to listen has a positive effect on speech perception performance. Knowing where to listen also seems to reduce listening effort. When the location of the target speech was known, NH participant's pupil dilation response was significantly smaller than when the location was uncertain (Koelewijn et al., 2015). However, sensorineural hearing loss is known to affect binaural hearing (Moore, 1996) by affecting the ability to detect interaural time differences (ITD) and interaural level differences (ILD), both strong cues in spatial hearing in the horizontal plane. Additionally, binaural hearing is more strongly affected in people with an asymmetrical than with symmetrical loss, as is shown in studies using the Speech hearing, Spatial hearing and Qualities of hearing (SSQ) questionnaire (Gatehouse and Akeroyd, 2006; Noble and Gatehouse, 2004). Considering that sensorineural hearing loss has been shown to affect spatial hearing, it might also affect listening effort in spatially uncertain listening conditions.

The current study uses the pupil response to speech-in-noise processing as an objective measure of listening effort. During processing of an auditory event, both the mean pupil dilation (MPD) and peak pupil dilation (PPD) are known to be sensitive indices of cognitive processing load (listening effort). Peak latency, the time from stimulus onset to PPD (Zekveld et al., 2011), is an indicator of the speed of cognitive processing (e.g., Hyönä et al., 1995). Hence, a shorter latency may indicate faster cognitive processing. Peak latency is also affected by the amount of processed information (Koelewijn et al., 2015), with less information leading to shorter latencies. Additionally, the baseline pupil size prior to the pupil response provides information about an individual's anticipation of resource allocation for the task at hand (e.g., Aston-Jones and Cohen, 2005).

Effects of divided attention on the pupil dilation response and thereby listening effort have been found for young normally hearing adults during processing of speech in noise (Koelewijn et al., 2014a). It is not known, however, how attentional processes affect the pupil response of HI listeners. The aim of the current study was to explore how spatial manipulations of auditory attention would affect listening effort for adults with hearing loss. The question addressed was whether people with symmetrical mild to moderate hearing loss are able to effectively use spatial auditory cues to enhance speech perception and to lower their listening effort. More specifically, does dividing attention over two talkers instead of focusing on one and knowing the location of the target speech have an effect on performance and the pupil responses for HI participants? We additionally aimed to compare these findings with those obtained for NH listeners.

The PPD previously observed for NH listeners (Koelewijn et al., 2015, 2014a) was closely tied to the amount of attentional resources required and how effectively these could be deployed during speech processing in adverse listening conditions. Based on previous research we hypothesized that the HI group would require an overall increase in SNRs compared to the NH group (e.g., Festen and Plomp, 1990) to reach the same level of intelligibility in all listening conditions. Consistent with Best et al. (2010), it was hypothesized that both groups would require an increase in the SNR on dual-target task compared to the single-target task. Between tasks, consistent with previous results for NH participants (Koelewijn et al., 2015, 2014a), we expected both the NH and HI participants to show a larger PPD in the dual-target task than in the single-target task because of increased processing demands (Pichora-Fuller et al., 2016). Additionally, it was hypothesized that focusing attention on a location would enable listeners to filter out irrelevant information, which in turn would reduce processing load. This should lead to a smaller PPD and a decrease in SNR, as shown previously (Koelewijn et al., 2015). Finally, given that spatial hearing is affected by mild to moderate sensorineural hearing loss, it was hypothesized that, a difference between the HI and the NH group in the effect of location uncertainty (on SNR and PPD) would be observed.

2. Methods

2.1. Participants

Fifteen NH adults (2 males, 13 females, age between 33 and 66 yrs., median age 51 yrs.) and fifteen HI adults (4 males, 11 females, age between 34 and 72 yrs., median age 52 yrs.), recruited at the VU University Medical Centre, participated in the study. The sample size of this study was based on the outcomes of two previous studies (Koelewijn et al., 2015, 2014a). NH was defined as pure-tone thresholds less than or equal to 20 dB HL over the octave frequencies 0.25–4 kHz. A single 25 dB HL dip at one of these frequencies in one ear was allowed. NH participant's pure-tone hearing thresholds averaged over both ears and over the octave frequencies 1–4 kHz (three-frequency pure-tone average), ranged from 1.7 to 13.3 dB (dB) hearing level (HL) (mean = 8.1 dB HL, standard deviation (SD) = 3.3 dB). HI participants had a three-frequency pure-tone average, averaged over the two ears, ranging from 30.8 to 62.5 dB HL (mean = 47.2 dB HL, SD = 9.6 dB). The differences between the three-frequency pure-tone average of the better and poorer ears for the HI participants ranged from 0 to 5 dB, so all had symmetrical hearing loss. Mean audiograms for the better and poorer ears for both groups are shown in Fig. 1. All participants in the HI group had an air-bone gap less than or equal to 10 dB, in one (the better) ear at 1 and 2 kHz, indicating sensorineural hearing loss. Participants in both groups had no history of neurological diseases and reported normal or corrected-to-normal vision. They were native Dutch speakers and provided written informed consent in accordance with the Ethics Committee of the VU University Medical Center, Amsterdam.

2.2. Tasks and materials

Participants were presented with two different everyday Dutch sentences (Versfeld et al., 2000), one to each ear, simultaneously via headphones. An example sentence is ‘Hij maakte de brief snel open’, which means ‘He quickly opened the letter’. One sentence was spoken by a female talker (S1) and the other by a male talker (S2). Each sentence was masked by stationary noise (see below),