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PERCEPTION OF INTENTIONAL PROSODY IN SENSORINEURAL HEARING LOSS

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Abstract

Social interactions require interpreting intentions and mental states, often conveyed via speech prosody. This study investigated the impact of sensorineural hearing loss and hearing aids on the perception of paralinguistic prosody conveying intentions. The performance and the confidence of adults with typical hearing and of experienced hearing aid users were evaluated in two classification tasks: 1) distinguishing between sincerity, sarcasm, teasing, or telling a white lie in audio and audio-video recordings of short dyadic exchanges, and 2) distinguishing whether audio recordings of grammatical questions convey genuine questions or indirect requests. Hearing aid users were tested unaided and aided. Linear mixed-effects modeling revealed that hearing loss decreased confidence, and that hearing aid use increased it. Hearing loss did not significantly decrease classification performance, at least not when accounting for age. Hearing aids only improved performance in the first classification task. Visual cues benefited both performance and confidence, and the benefit on confidence was strongest for participants with hearing loss unaided. These findings suggest that changes in confidence should be viewed as an important challenge of hearing loss and should be considered in rehabilitation strategies.

Keywords: *hearing loss, hearing aids, prosody, intentions, confidence*

1. Introduction

Human communication is more than the sharing of messages, it is also a social interaction during which conversational partners convey information about their mental states, such as their emotional state while delivering a message, their intention delivering it, or their stance towards the message or the situation and the people involved [1]. Conversational partners use speech prosody – the variations of the intonational, rhythmic, and tonal properties within an utterance [2] – as a vehicle to convey their intentions and mental states. In audiological research, the perception of affective prosody – the prosody carrying information about emotional states – has been a topic of particular interest in recent years [3], [4]. Adults with age-related hearing loss recognize emotions less accurately than those with typical hearing [5], [6], [7], [8], [9], and hearing aids do not seem to restore this ability [6], [7], [8], [10]. By contrast, the perception by this population of non-affective (linguistic and paralinguistic) prosody has received less attention [11], [12], [13], [14].

The present study adds to this line of research by focusing on paralinguistic speech prosody conveying intentions. Specifically, we report the results of two experimental tasks. The first task (**Section 3**) assessed the perception of social subtext during social exchanges, using the audio and audio-video recordings developed by [15] to test the ability to distinguish between sincerity, sarcasm, teasing, or telling a white lie. The second task (**Section 4**) assessed the perception of pragmatic intent, using audio recordings from [2] to test the ability to evaluate whether a grammatical question is actually meant as an indirect request. In addition to measuring performance, we collected participants' confidence ratings in their judgments. Audiological research on affective prosody perception has so far focused on performance, but we argue that listeners' subjective feelings about their accuracy, i.e. their confidence, might guide social interactions more immediately than performance alone. Also, if hearing loss were associated with lower confidence, it could potentially foster personal insecurity [16]. Finally, for the first task, the stimuli from [15] enabled us to investigate the interplay between hearing loss, hearing aid use, and the presence of visual cues. Human communication is multimodal, and information about

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speakers' emotional states, attitudes, or intentions is conveyed simultaneously through the auditory and the visual modalities [15], [17]. Hence, it is important to assess whether – and to which extent – visual information may compensate for prosody perception deficits in everyday communication.

1.1 Research questions

We addressed the following four research questions (RQ) (questions about the role of visual cues only apply to the investigation of social subtext in **Section 3**):

RQ1. Are listeners with hearing loss worse at distinguishing between intentions than their peers with typical hearing, and if so, is their performance improved with visual cues?

RQ2. Do hearing aids help with intention perception performance, and do they help more when visual cues are missing?

RQ3. Are listeners with hearing loss less confident when evaluating intentions than their peers with typical hearing, and if so, is their confidence improved with visual cues?

RQ4. Do hearing aids increase confidence, especially when visual cues are missing?

2. General methods

2.1 Participants

Nineteen adults with typical hearing (63.2 ± 7.1 years, 13 female) and 21 adults with permanent sensorineural hearing loss (71.9 ± 6.8 years, 11 female) participated in the study. The inclusion criteria were: native speaker of American English, 55 – 84 years of age, no history of neurogenic or psychological disorders, and self-reported typical hearing or sensorineural hearing loss with hearing aid experience (> 6 months). Participants with typical hearing had air-conduction audiometric thresholds better than 30 dB HL through 500 – 4000 Hz. Hearing aid users had pure-tone thresholds (average for both ears at 0.5, 1, 2, and 4kHz) between 21 and 63 dB HL (43 ± 13 dB HL). All participants passed the Mini Mental State Examination [18] with a score of 24 or better, indicating they were at low risk of cognitive impairment. All participants scored 10 or lower on the anxiety and depression subscales of the Hospital Anxiety and Depression Scale [19], indicating they were at low risk for anxiety or depression. There was one exception: a participant with typical hearing who did not complete the questionnaires due to a technical error. Participants were paid for their time on an hourly basis. All study procedures were completed with approval from Vanderbilt University Medical Center's Institutional Review Board (IRB# 230449).

2.2 Hearing aids

Hearing aid users were all fit with the same hearing aids for the duration of the study (Signia Pure Charge & Go IX behind-the-ear), with non-custom eartips and venting based on their own hearing aids. Using the same hearing aid brand and model reduces between-participant variability arising from differences in device characteristics and ensures they all are fitted according to the same protocol. Hearing aid features were set to default (adaptive directional microphones, moderate noise reduction, feedback reduction active, frequency lowering deactivated). Amplification was programmed to match the National Acoustics Laboratory Nonlinear 2 prescriptive targets [20] and verified using real-ear measurements with a 65-dB speech signal (Audioscan Verifit 1). Match to prescriptive target was within 5 dB through 4000 Hz in both ears.

2.3 Study design

Participants were recruited for a broader study investigating the effects of hearing aid use on the perception of affective prosody and paralinguistic prosody conveying intentions. This paper focuses on the latter; affective prosody results are reported in [21] and [22]. Participants provided informed consent, completed audiometric testing and questionnaires, and those with typical hearing completed the experimental tasks in a sound-attenuated booth. Participants with hearing loss were fit with research hearing aids, wore them for ~ 3 weeks to acclimatize, and then completed the experimental tasks, with and without the hearing aids in an order counterbalanced across participants.

2.4 Data analysis

For both tasks, unbiased hit rates [23] were computed for each crossing of intention and modality, for each participant, and used as a measure of performance. The unbiased hit rate is the product of the hit rate and of the differential accuracy. The latter quantifies the correct use of a response option and is calculated as the ratio of the true positives and of the sum of the true and false positives. Confidence ratings were not used trial-per-trial in the statistical analyses but averaged, for each participant, across trials of a given crossing of intention and modality, to perform statistical analyses on the same number of data samples for confidence ratings as for unbiased hit rates. Results were analyzed in R [24]. Linear mixed-effects regression models with robust standard errors were fit using *lme4* [25] and *clubSandwich* [26], and were diagnosed and compared using *performance* [27]. All models included random intercepts per participant. We evaluated **RQ1** and **RQ3** by fitting models on the data from typical hearing participants and from participants with hearing loss unaided, whereas for **RQ2** and **RQ4** we used the data from participants with hearing loss, unaided and aided. The reference levels for categorical factors were always: typical hearing for hearing loss, unaided for hearing aid use, auditory-only for modality, sincerity for intention in the first task, and question for intention in the second task. Additional model details are provided in the results sections.

3. Social Subtext – Sincerity vs. Sarcasm, Lies, and Teasing

3.1 Stimuli

Speech stimuli were taken from the Relational Inference in Social Communication corpus (RISC; [15]), which was obtained via request to its authors. The RISC consists of video vignettes depicting short question-response exchanges, in North American English, between pairs of actors, with the respondent being either sincere, sarcastic, teasing the asker, or telling a white lie. “Teasing” is also sometimes referred to as “positive sarcasm” or “jocularity”. “Sarcastic” in the present paper refers to “negative sarcasm” specifically. Sincere responses can be either “literal positive” (sincerely positive statements) or “literal negative” (sincerely negative statements). The RISC’s vignettes portray one of four types of social relationships between the communication partners: romantic couple, friends, colleagues, or boss/employee. About half of the vignettes have verbal context at the beginning that reveals the true state of mind of the responder. For the present study, only vignettes with no such verbal context were used as we wanted the participants to rely on hearing the intent, rather than relying on the context. The type of social relationship was not a variable of interest to us, so only vignettes portraying a relationship between colleagues or a boss/employee relationship were used, to minimize task performance variability linked to this variable.

Participants in the present study performed the task on one of three lists of 48 vignettes chosen pseudo-randomly without repetition. Each list had a combination of six vignettes by four intentions by two modalities. In the auditory-visual modality, videos of the social exchange were displayed. In the auditory-only modality, the video components of the vignettes were covered by a black square. The order of the vignettes was blocked by modality within a list, and the order of the modalities was counterbalanced between participants. The six vignettes per intention and modality were always three “boss/employee” and three “colleagues” vignettes. The six “sincere” vignettes per modality were always three “literal negative” and three “literal positive” vignettes. Ten additional vignettes were selected for practice: five vignettes per modality, with one of each “sarcasm”, “teasing”, “white lie”, “literal negative”, and “literal positive”.

3.2 Task

The experimental task was implemented in PsychoPy [28]. Stimuli were presented in free field (one frontal loudspeaker) at an average of 60 dB SPL. Participants listened to the stimuli one at a time, categorized the stimulus (response alternatives: “be sincere”, “be sarcastic”, “joke around”, or “tell a white lie”), and rated their confidence in their category choice on a continuous scale (0–100, no numerical markings) labelled at the endpoints “Not at all” and “Extremely”. There was no time limit to answer. Participants had to click a button to move on to the next stimulus.

3.3 Results

Fig. 1 and Fig. 2 display box plots of the unbiased hit rates and of the confidence ratings, for each intention and group/condition. The final models for **RQ1** and **RQ2** included modality, intention, age, and either participant group (**RQ1**) or hearing aid use (**RQ2**) as fixed factors. Age was included because of the well-documented worsening of emotion classification performance with older age in adults [12], [29], [30], [31], and because an exploratory plot of the unbiased hit rates against age showed a trend for a negative association. The interactions between modality and participant group (**RQ1**) and between modality and hearing aid use (**RQ2**) were initially included but discarded from the final model because they were not significant and the AIC/BIC values were smaller without them.

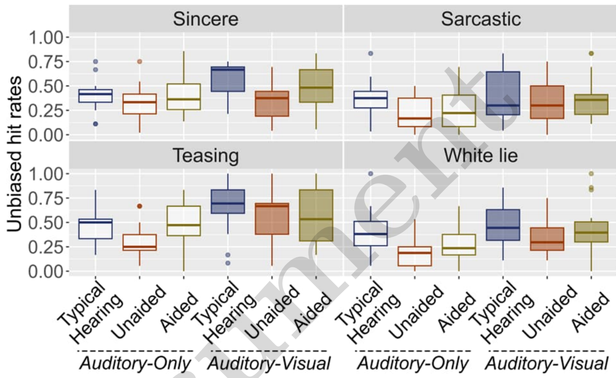

Figure 1. Box plots of unbiased hit rates as a function of intention (sincere, sarcastic, teasing, white lie), modality (auditory-only, auditory-visual), and group/condition (typical hearing, participants with hearing loss unaided, participants with hearing loss aided).

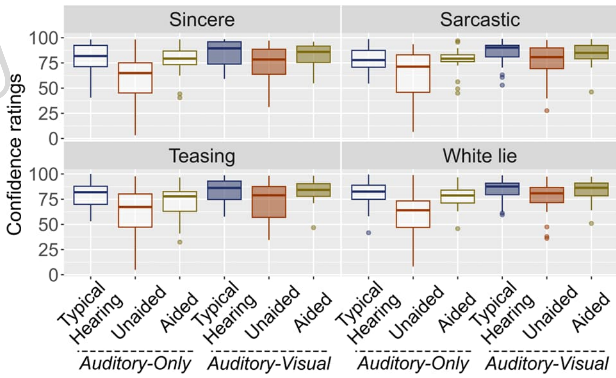

Figure 2. As Fig. 1, for confidence ratings.

The results (coefficients, confidence intervals and significant p-values) are displayed in Fig. 3. For **RQ1** (Fig. 3A), unaided participants with hearing loss did not perform significantly worse than participants with typical hearing. For **RQ2** (Fig. 3B), participants with hearing loss performed better when wearing study hearing aids than when unaided. In addition, visual cues improved performance, older age was associated with worse performance when the model included all the participants (Fig. 3A), and recognition of white lies and sarcasm was worse than sincerity, but recognition of teasing was better.

For **RQ3**, the final model included modality, intention, and participant group as fixed factors. The results are displayed in Fig. 4A. Participants with hearing loss gave lower confidence ratings than participants with typical hearing in the auditory-only modality, but this difference between groups was reduced in the auditory-visual modality, as visual cues improved confidence to a greater extent for participants with hearing loss than for participants with typical hearing (positive interaction). For **RQ4**, the final model included modality, intention, and hearing aid use as fixed factors. The results are displayed in Fig. 4B. Participants with hearing loss gave higher confidence ratings when aided than when unaided in the auditory-only modality, but this hearing aid benefit was reduced in the auditory-visual modality (negative interaction), meaning that hearing aids increased confidence especially when visual cues were absent. Still, re-fitting the regression model with "auditory-visual" as the reference level for modality showed that the hearing aid benefit was also significant in the auditory-visual modality ($beta = 7.7$, $p < 0.01$, CI = [2.5 12.9]).

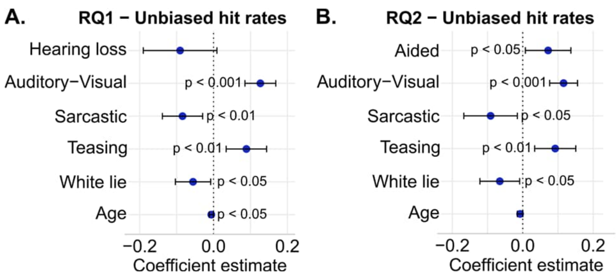

Figure 3. Forest plots of coefficient estimates, 95% confidence intervals, and p-values when significant (at an alpha of 0.05) for the final regression models. The model in **A** was fitted on the data from typical hearing participants and participants with hearing loss when unaided (N = 40). The model in **B** was fitted on the data from participants with hearing loss (N = 21), when unaided and aided.

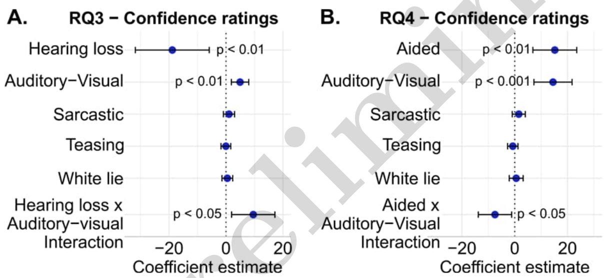

Figure 4. As Fig. 3, for confidence ratings.

4. Pragmatic Intent – Genuine Questions vs. Indirect Requests

4.1 Participants

Three participants with typical hearing and two with hearing loss could not complete this task due to technical problems, resulting in 16 participants with typical hearing (61.7 ± 6.5 years, 12 female) and 19 with hearing loss (71.9 ± 7.1 years, 10 female), two of which chose to only complete the task when aided.

4.2 Stimuli

Speech stimuli were taken from [2], which created a set of 12 audio sentences (six yes/no questions and six statements, in North American English) that are inherently ambiguous and have been recorded by 18 speakers with the intention of either being literal or of conveying an indirect request. The corpus and the behavioral data were downloaded from GitHub: https://github.com/seantrott/pros_scaled. Because overall performance on this task was only slightly above chance in [2], we selected the four sentences that elicited the best discrimination of the two intentions, i.e. the four sentences associated with the largest differences between the rate of request interpretations when intended as requests and when intended as non-requests. These four sentences were all yes/no questions ("Can you open that window?", "Can you close that door?", "Can you lift that box?", and "Can you say that in Spanish?": see Fig. 5 in [2]). Then, for the four questions retained, we used the behavioral data from [2] to calculate, for each of the 18 speakers, the mean difference between the rate of request interpretations when recordings were intended as requests and when they were not, and we discarded four speakers that were associated with a negative or null difference. Finally, we used the 14 remaining speakers to build three lists of six speakers that were, on average, associated with the same difference between the rate of request interpretations when recordings were intended as requests and when they were not (a difference of 26–27%, in the data from [2], when averaged over the four questions retained). Participants in the present study performed the task on one of three lists, which each had 48 recordings (four questions by six speakers by two intentions). One additional list was made for practice (eight recordings: four questions by two intentions, recorded by one of the non-retained speakers).

4.3 Task

This second experimental task was implemented in the same way as the first one, except that the response alternatives were "yes" or "no", in answer to the question (displayed on screen) "is this person making a request?".

4.4 Results

Fig. 5 displays box plots of the unbiased hit rates and of the confidence ratings, for the two intentions (asking a question or making a request) in each group/condition. Performance was generally low, although significantly different from chance in all six conditions (one-sided t-tests; $ps < 0.05$; chance Hu = 0.25). There were no significant effects of hearing loss or hearing aid use on performance (Fig. 5A; all $ps > 0.05$, linear mixed-effects modelling). Hence, answers to **RQ1** and **RQ2** were negative.

To answer **RQ3** and **RQ4**, we fitted linear mixed-effects regression models to the confidence ratings, with intention, age, and either group (for **RQ3**: typical hearing / unaided) or hearing aid use (for **RQ4**: unaided / aided). Age was included as a fixed factor because an exploratory plot of the unbiased hit rates against age showed a trend for a positive association. The results are displayed in Fig. 6A (**RQ3**) and 6B (**RQ4**). Participants with hearing loss gave lower confidence ratings than participants with typical hearing, and participants with hearing loss gave higher confidence ratings when aided than when unaided.

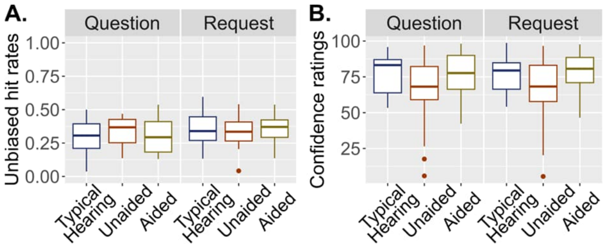

Figure 5. Box plots of unbiased hit rates and confidence ratings in the second task, as a function of intention (asking a question, making a request) and group/condition (typical hearing, participants with hearing loss unaided, participants with hearing loss aided).

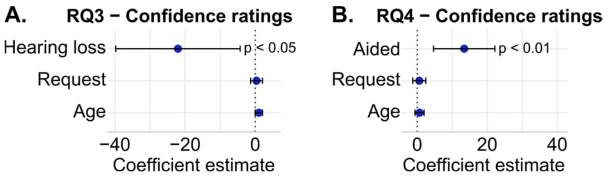

Figure 6. As Fig. 3, for confidence ratings in the second task. N = 33 in **A** and 19 (including 2 providing data only in the aided condition) in **B**.

5. Discussion

Our primary objective was to evaluate the impact of sensorineural hearing loss and hearing aid use on the perception of paralinguistic prosody conveying intentions and pragmatic intent. We observed a dissociation between performance and confidence: participants with hearing loss did not perform worse than their peers with typical hearing, but they were less confident. Meanwhile, hearing aid use was found to improve confidence and, for social subtext only, performance.

The lack of statistical effects of hearing loss on performance is at odds with audiological research on affective prosody [5], [6], [7], [8], [9], which suggests that the perception of intentional prosody might be less impacted by sensorineural hearing loss than affective prosody. This lack of effect on performance is also at odds with [11], which found a detrimental effect of hearing loss on the perception of social and pragmatic intentions. However, the stimuli in [11] were short (2 seconds) and filtered to be unintelligible: the greater information richness in our stimuli might have attenuated the difference in difficulty between groups. Our result also seems at odds with [14], which found a detrimental effect of hearing loss on irony recognition in stories, but this might be explained by an age difference not accounted for in their statistical analysis. It is worth noting that, if we refit the model in Fig. 3A without including age as a factor, the effect of hearing loss becomes significant (*beta* = -0.14, p < 0.01, CI = [-0.06 -0.23]). Finally, hearing aid use improving performance in the social subtext task is consistent with [14] finding that it improves irony recognition in stories.

The observation that hearing aid use improves confidence is – to our knowledge – a new result for the perception of intentional prosody, and complements similar observations we made for affective prosody [21], [22]. Studying the impacts of hearing loss and of hearing aid use on confidence is clinically relevant because confidence is arguably what guides social behavior in real-time interactions. More research is warranted to assess these impacts on listeners' metacognitive abilities, on their real-life behavior (e.g., decisions to withdraw from conversations), and on their well-being.

Finally, for the perception of social subtext, we observed that the addition of visual cues improved performance, to a similar extent for listeners with hearing loss and their peers with typical hearing, which is consistent with [11], and independently from hearing aid use. Again, the pattern of results for confidence is a bit different: the addition of visual cues improved confidence, but it did more so for listeners with hearing loss than for their peers with typical hearing, and it did more so when testing unaided than when using hearing aids. These differences between the impact on performance and the impact on confidence point to a need for more research to be carried on confidence, to better understand how hearing loss affects confidence in daily social exchanges, and to evaluate whether hearing rehabilitation strategies focused on confidence could play a role in improving hearing care.

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