Effects of Altered Intensity Feedback on Speech in Healthy Speakers

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Résumé

Cette étude a examiné le rôle de la rétroaction auditive dans la régulation de l'intensité de la parole chez les adultes en bonne santé. Dix participants ont effectué cinq tâches de production de la parole (voyelle, lecture de phrases avec/sans instructions d'ignorer la rétroaction, et conversation à une distance d'un/six mètres de l'interlocuteur) dans diverses conditions de rétroaction et d'intensité altérée (RIA). Les conditions RIA allaient de plus/moins 2,5, 5, 7,5, 10, 12,5 et 15dB SPL par rapport à la condition équivalente (0dB). Les valeurs d'intensité de la parole obtenues pour chacune des treize conditions RIA ont été soumises à une analyse de régression linéaire et les valeurs de pente et d'interception résultantes ont été comparées. La pente moyenne de la fonction RIA s'est avérée être significativement plus raide pour les tâches de conversation (-0,16) que pour les tâches de lecture (-0,07). Aucune différence de pente n'a été constatée pour la comparaison des tâches de lecture avec et sans instructions d'ignorer les rétroactions altérées ou pour la comparaison des conversations à une distance d'un et six mètres de l'interlocuteur. Il semble que les tâches de discours avec des exigences de communication plus importantes (c'est-à-dire la conversation) montrent des réponses compensatoires plus importantes à la RIA que les tâches avec des exigences de communication plus faibles (la lecture). Les résultats suggèrent que les demandes de la tâche de parole peuvent interagir avec le traitement de la rétroaction auditive pour influencer la régulation de l'intensité de la parole.

Mots clefs : perception, communication, parole, intensité de la parole, rétroaction auditive altérée, rétroaction auditive

Abstract

This study examined the role of auditory feedback in speech intensity regulation in healthy adults. Ten participants completed five speech production tasks (vowel, sentence reading with/without instructions to ignore feedback, and conversation at one/six meter interlocutor distances) under various altered intensity feedback (AIF) conditions. AIF conditions ranged from plus/minus 2.5, 5, 7.5, 10, 12.5, and 15dB SPL relative to the equivalent (0dB) condition. Speech intensity values obtained for each of the thirteen AIF conditions were submitted to a linear regression analysis and the resulting slope and intercept values were compared. The average slope for the AIF function was found to be significantly steeper for the conversation tasks (-.16) than for the reading tasks (-.07). No difference in slope was found for the comparison of the reading tasks with and without instructions to ignore altered feedback or for the comparison of conversations at one- and six-meter interlocutor distances. It appears that speech tasks with greater communicative demands (i.e. conversation) show larger compensatory responses to AIF than tasks with lower communicative demands (reading). Results suggest that demands of the speech task can interact with the processing of auditory feedback to influence the regulation of speech intensity

Keywords: perception, communication, speech, speech intensity, altered auditory feedback, auditory feedback

1 Introduction

The neurological system relies on a variety of factors to regulate and produce speech at an intensity that is appropriate for the communicative situation. Auditory processes, and physical processes are required [1, 2]. The importance of auditory processing for speech is evident during child development when acoustic input heavily influences the speech patterns of pre-lingual children [3-7]. Researchers suggest the low speech intelligibility of hearing-impaired speakers is a result of auditory signal perception impairment [8-10]. In addition, this is described in studies of post-lingually deafened individuals who present with abnormalities in the loudness, pitch, and rate of speech [11].

The use of auditory information in the ongoing control of speech production can be most effectively studied by altering the auditory feedback signal. If, during a speech movement, one experiences unexpected alterations of their sensory feedback (auditory, visual, proprioceptive) the speech-motor system should be able to recognize the incongruence from the motor plan and adjust or compensate accordingly. This adaptive process is thought to involve stored representations of the intended speech output based on previous experiences [12]. Perturbation studies involve altering auditory feedback and measuring responses to brief (~200-500ms) perturbations of the speech signal and existing literature describes this type of compensatory response by healthy speakers (pitch and formant structure perturbations) as an alteration in speech production in the opposite direction to the perturbation (although some studies have also shown following and null responses) [13-15]. Healthy participants

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similarly respond to brief unexpected intensity perturbations by compensating in the opposite direction to the feedback [16, 17].

Altered intensity feedback (AIF) (also referred to as "sidetone amplification" in previous literature [1, 18,19]) involves the presentation of one's own speech via headphones for the duration of the utterance (in contrast to the brief, typically 200-500ms, alteration in a perturbation paradigm). This type of manipulation causes the participant to continuously hear their speech intensity at an altered (increased or decreased) level. Similar to the perturbation findings, this causes a healthy speaker to adjust their speech intensity in the opposite direction to the alteration, as a presumed compensation response [1, 18-21]. The AIF paradigm enables evaluation of the AIF function or the relationship between changes in speech intensity that is perceived and subsequent changes in speech intensity that is produced. Slope of the AIF function has been observed to range between -.1 and -.15 with no background noise [1, 18] (See Figure 1 as example of the AIF slope function from Lane and Tranel (1969). Increased slope functions (-.4) have been observed when AIF is presented with background noise [1, 18]. When instructed to maintain a constant level of loudness (use the auditory feedback to make compensatory adjustments as needed to maintain a constant level), participants also show an increased (-.46) slope function compared to when no instructions are provided [19].

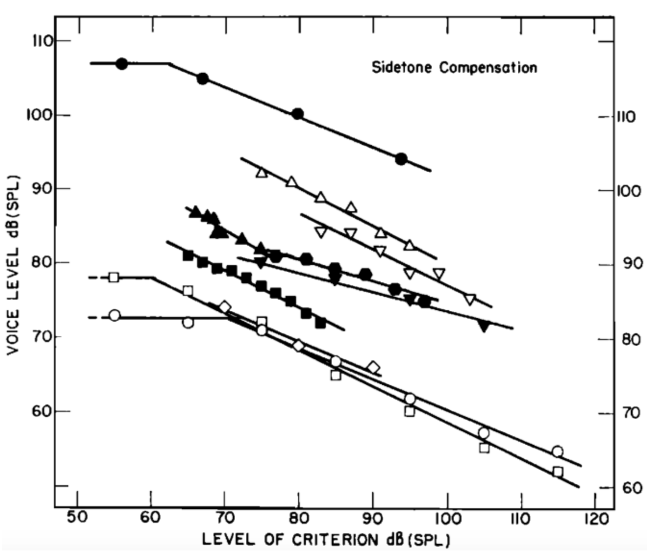

Figure 1: Sample graph depicting the AIF function. Reprinted from Regulation of Voice Communication by Sensory Dynamics, by Lane, Tranel, and Sisson, 1969, retrieved from The Journal of the Acoustical Society of America, 47 (1969) [21].

1.1 Speech task

Average speech intensity can be obtained across a vowel, sentence, and across a breath group or utterance within speech. Quasi-speech tasks include those that do not necessarily represent natural speech (e.g. vowel prolongation and reading). Junqua, Finckle, and Field [22] found speech intensity increased more in background noise (Lombard effect [23]) during conversational speech than in a reading task. Thus, the nature of the speech task appears to have an influence on the regulation of speech intensity. The effect of speech task on speech intensity regulation is also exemplified by the work of Patel and colleagues [24]. These researchers suggest it is possible that healthy participants may regulate speech intensity (during perturbed feedback) only in speaking contexts requiring a specific linguistic goal, specifically relating to emphatic stress in a sentence. However, it is possible that suprasegmental (intensity regulation across a sentence) and segmental aspects of speech (related to the production of specific vowels or consonants) may be controlled by different mechanisms for which auditory feedback plays different roles [25]. It is unclear if the role of auditory feedback for speech intensity differs depending on the nature of the speech task. Fletcher, Raff, and Parmley [26] and Noll [27] found reduced slope values (within background noise conditions) during monosyllable (-.25) and passage readings (-.3) respectively, suggestive of a possible attenuation of the AIF effect in conditions lacking a communicative goal. To our knowledge, previous studies have not examined the role of auditory feedback for speech intensity across tasks with differing communicative intent using AIF.

1.2 Distance conditions

In typical conversational settings, the speaker must monitor the environment and their own speech intensity levels in order to compensate for such factors as the distance of the intended listener [23, 28]. In order to do these things, the speaker must have some sort of sensorimotor monitoring process in place to maintain appropriate intensity of speech. The talker-to-listener distance, or interlocutor distance, can cause a speaker to increase their speech intensity with increasing distance [29, 30]. Previous studies have explored the importance of speaking context for speech intensity regulation, with findings consistent with incremental increases in intensity corresponding to increasing interlocutor distances [31-34]. The role of auditory feedback for speech intensity regulation within this naturalistic context is yet to be explored and it is hypothesized that increased interlocuter distance will be associated with an increased slope of the AIF function.

1.3 Directed attention

Of additional interest is the question of what role the speaker's level of attention to auditory feedback plays in the regulation of speech intensity. Specifically, if a speaker's attention is directed to their auditory feedback, will the impact of altered feedback be increased or reduced. To our knowledge, only two studies have explored this condition. Siegel and Pick [1] found a similar slope of the function of AIF when participants were instructed to ignore the altered feedback in background noise (.15). Lane, Catania and Stevens [19] however, found a reduced slope when participants were asked to ignore altered feedback while producing a vowel (ah). Thus, the ability to maintain a constant intensity of speech while ignoring auditory feedback remains poorly understood.

2 Methods

2.1 Participants

Ten healthy female adults (aged 19-32 years) served as participants. All participants passed a bilateral 25 dB HL hearing screening at .25, .5, 1, 2 and 4 kHz. Participants spoke English as their primary language and had no history of speech, hearing or neurological impairments. The current study was approved by the Non-medical Research Ethics Board at Western University, London, Ontario, Canada. Informed consent was obtained from all participants.

Apparatus and acoustic measures

Participants were seated in an audiometric booth for the duration of the study. Participants were provided with a standard set of audiometric headphones (Telephonics 51OCO17-1) and headset microphone (AKG C520) attached to a preamplifier (M-Audio preamp USB), audiometer (GSI-10, model 1710), and desktop computer. The microphone was placed 6 cm from the midline of the participant's mouth. Calibration of the microphone was obtained with a sound level meter placed 15 cm (6 inches) from the participant's mouth while they produced three short (< 5sec) 'ah' sounds at 70 dBA SPL. The recording module in the Praat software [35] was used to digitize the speech samples at 44.1 kHz and 16 bits. During speech tasks, the audiometer was used to alter the intensity of the participant's speech. The headphone output was calibrated (made equivalent) to the input microphone using speech noise produced by the audiometer and an audio speaker placed 6 cm from the headset microphone. The calibration of the output of the headphones was accomplished with an earphone coupler (Bruel & Kjaer, type 4152) attached to a sound level meter (Bruel & Kjaer, type 2203). For the measurement of speech intensity in all conditions and tasks, the recorded speech audio files were analyzed off-line using the acoustic intensity measurement module in the Praat program [35]. The root mean squared (RMS) intensity contour method was used to obtain the average intensity for each utterance. Average speech intensity across 2-3 second segments of speech were used for this analysis, with long pauses (>500ms) removed.

2.2 Procedures

Participants were prompted by the experimenter to complete speech-related tasks in the following sequence: produce 1) a prolonged vowel sound (ah) in a comfortable speaking loudness, 2) engage in conversation with the experimenter at a close distance (1 meter), 3) engage in conversation a second time with the experimenter at a far distance (6 meters), 4) read sentences printed on paper, and 5) read sentences printed on paper while attempting to maintain their habitual speech intensity and ignore the AIF. A detailed description of each of the above tasks is presented in section 2.3.1. The order of tasks was selected to minimize the potential influence of some of the tasks on subsequent tasks. For example, the task involving the instruction to "ignore the altered feedback" was always given last because of concerns that it might influence attention strategies used in subsequent conditions. Throughout each of the speech-related tasks listed above (1-5), the participants received randomly presented AIF related to their own speech. The random AIF conditions included 2 repetitions of the following 13 conditions; 2.5, 5, 7.5, 10, 12.5, and 15dB reductions in the feedback intensity and 0, 2.5, 5, 7.5, 10, 12.5, and 15dB increases in the feedback intensity. These conditions were selected because previous AIF literature focused primarily on 10dB increments and pilot data suggested that speech production responses are evident (participants were noted to produce speech responses in the opposite direction to the alteration) with smaller increments. Participants were naïve to the altered feedback conditions. AIF was initiated following instructions for each task, just prior to participant speech production and was terminated once the participant completed the requested task.

Speech tasks and conditions

Vowel Prolongation. Participants were required to produce a sustained phonation of "ah" in a comfortable speaking voice for approximately 3 seconds for each of the AIF conditions.

Conversation. Participants were requested to discuss familiar topics with the experimenter for about 5-10 utterances per altered feedback condition. Topics included family, hobbies, occupational experiences, interests, and recent vacations. The first conversational task was performed with the listener-experimenter at an interlocutor distance of 1 meter (near). The second conversational task occurred at an interlocutor distance of 6 meters (far).

Sentence Readings. Sentences included two randomly selected items from the Sentence Intelligibility Test (SIT) [36] as well as the sentence, "She saw patty buy two poppies". Participants first read aloud the sentences with no specific instruction regarding speech loudness except to "read these sentences to me". Following this task, they read aloud the sentences with the instruction to maintain a constant comfortable voice and try to ignore the altered feedback presented through the headphones.

2.3 Statistical analysis

Each participant's average speech intensity obtained for each of the 13 levels of AIF was analyzed using linear regression (value of altered feedback versus value of resulting speech intensity). The slope and zero intercept values, obtained from the participants' linear regressions during each of the 5 speech tasks, were submitted to six separate repeated measures analyses of variances (followed by post-hoc analyses and Bonferroni correction for multiple comparisons) in order to examine for differences in the mean slope and the mean intercept across 1) the three speech tasks (conversation at a near distance, vowel, reading with no instructions); 2) the two distance conditions (conversation at a near distance and conversation at a far distance); and 3) directed attention conditions (reading with no instruction and reading with instruction to ignore altered feedback). R2 values (coefficient of determination) from each participant's regression slopes were averaged and mean R2 are provided in Table I.

Table 1: Average Altered Intensity Feedback (AIF) slope, zero intercept, and R2 values for the five speech tasks/conditions with standard deviations in parentheses.

Speech Task	AIF-related Slope Values (*SD*)	AIF-related Intercept Values (*SD*)	R^2 values (SD)
Vowel production	-0.11 (0.03)	70.20 (4.24)	.52 (0.20)
Reading sentences (no instruction)	-0.07 (0.02)	67.07 (3.35)	.46 (0.12)
Reading sentences (instruction to ignore altered feedback)	-0.04 (0.04)	65.59 (2.11)	.23 (0.23)
Conversation near (1 meter interlocutor distance)	-0.16 (0.07)	66.28 (3.36)	.53 (0.22)
Conversation far (6 meters interlocutor distance)	-0.17 (0.05)	69.04 (3.04)	.67 (0.16)

3 Results

All participants responded to the AIF by producing speech intensity opposing the alteration. This finding was consistent across speech tasks. Results for speech intensity production are presented as linear regression slope values for all speech tasks in the boxplot in Figure 2

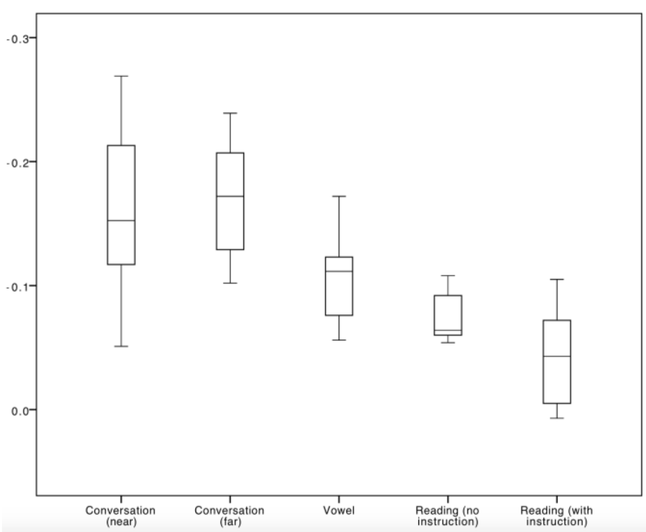

Figure 2: Average slope values for all tasks.

3.1 Slope

Speech tasks

Results for the RM-ANOVA indicated violation of sphericity (p>.05) and there was a significant effect of speech task on the AIF-related slope value using the Greenhouse-Geisser correction [F (1.28,11.52) = 14.311, p < .05]. Pairwise comparisons between the three speech tasks revealed a significantly reduced slope (flatter) for the reading task (M = -0.07, SD = 0.02) compared to the conversation task (M = -.16, SD = 0.07; p < .05). Individual and group mean results presented as linear regression slope functions for the speech tasks are depicted in Figure 3.

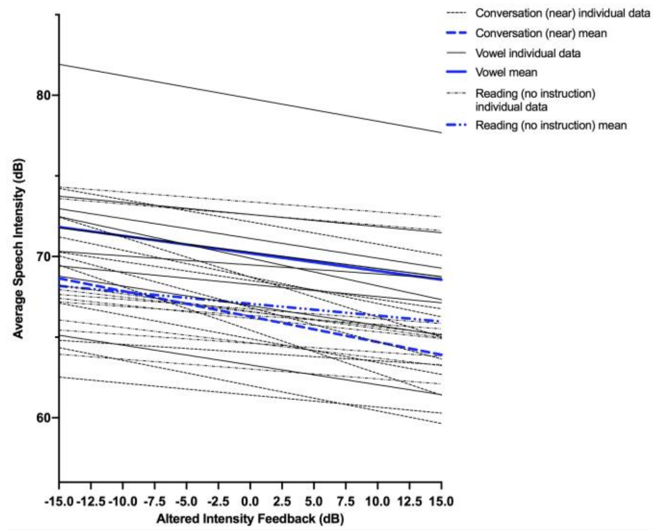

Figure 3: Individual and group regression slopes for the Speech Tasks (conversation near distance, vowel, reading no instruction).

Distance conditions

Results for the RM-ANOVA indicated there was no significant difference in the slope values for the conversation at an interlocutor distance of one meter versus six meters [F (1,9) = .32, p = .59]. Results for the distance conditions are depicted in Figure 4.

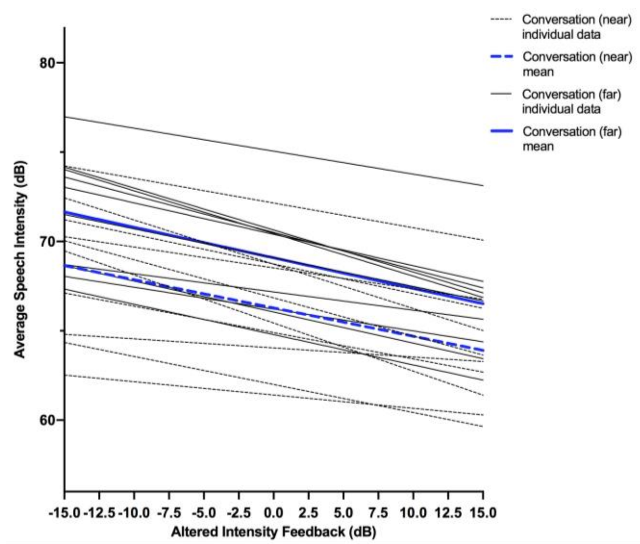

Figure 4: Individual and group regression slopes for the Distance Tasks (conversation at a near and conversation at a far distance).

Directed attention

Results for the RM-ANOVA indicated there was no significant difference in the slope values for the reading without instruction task versus reading with instruction task

[F (1,9) = 4.20, p = .07). Results for the reading conditions are depicted in Figure 5.

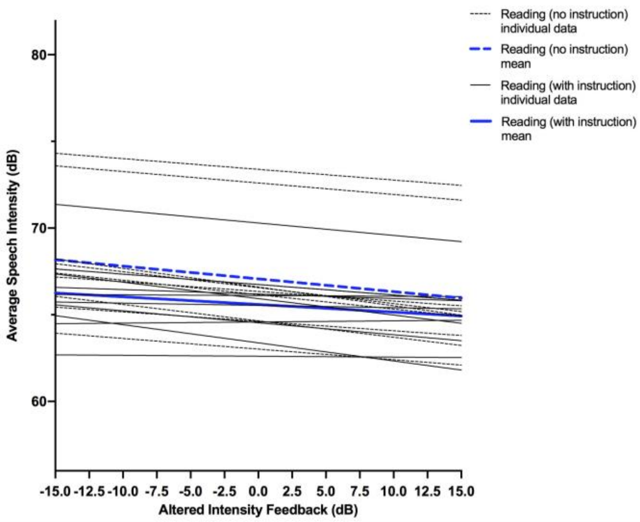

Figure 5: Individual and group regression slopes for the Directed Attention Tasks (reading with and without instruction).

3.2 Zero intercept

Speech tasks

RM-ANOVA analysis found a significant effect of speech task on the AIF-related intercept value [F (2,18) = 9.49, p < .05]. Pairwise comparisons between the three speech tasks revealed a lower intercept for the conversation at a near distance task (M = 66.28, SD = 3.36 dB) compared to the vowel task (M = 70.20, SD = 4.24 dB; p < .05). The zero intercept results from all tasks and conditions is depicted in Figure 6.

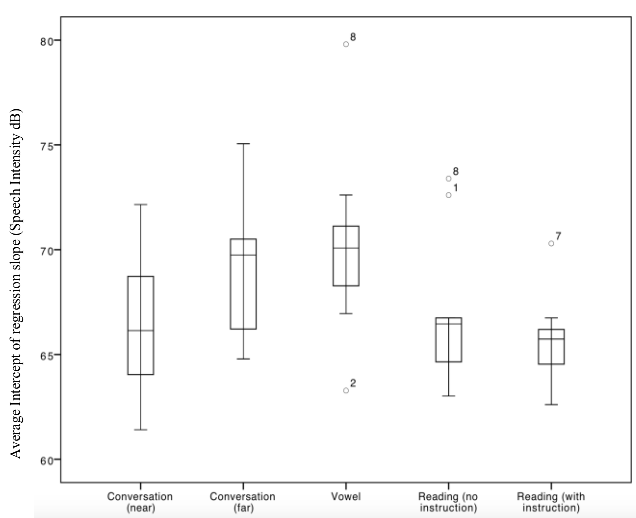

Figure 6: Average intercept for all tasks.

Distance conditions

RM-ANOVA analysis found a significant effect of speaking distance on the AIF-related intercept value [F (1,9) = 78.90, p < .001] related to an increased intercept in the conversation far task (M = 69.04, SD = 3.04 dB) compared to the conversation near task (M = 66.28, SD = 3.36 dB).

Directed attention

Results for the RM-ANOVA indicated that although slightly increased, there was no significant difference in the intercept values for the reading without instruction and the reading with instruction to ignore altered feedback task [F (1,9) = 1.23, p = .30).

4 Discussion

The goal of the present study was to determine the role of AIF on speech intensity regulation in the context of several speech tasks and conditions. Overall, participants in the current study modified their speech intensity in a compensatory manner (opposing direction) based on the auditory feedback intensity presented. This finding is consistent with previous literature [1, 18-21], and confirms that auditory feedback plays a role in the regulation of speech intensity. A novel aspect of the current study was the finding that that the speech task and speech condition can affect the compensatory response to AIF. We found a reduced slope of the altered feedback function with the reading task compared to the conversation task. Possible explanations for this finding are discussed in "Speech tasks" below. These results are consistent with and also extend the findings of previous research [26, 27] as the present study found these results to be maintained in no-noise conditions.

The average intercept of the regression function when producing a vowel was greater compared to speaking in conversation. One previous study found a similar increase in speech intensity for vowel production tasks compared to sentence reading and speaking extemporaneously [37].

The present study explored the impact of AIF in different speaking conditions (i.e. different interlocutor distances). Consistent with previous literature [29, 30] we found an increase in speech intensity with increasing interlocutor distance. However, the current study expands on these findings as the increase in speech intensity with increased interlocutor distance was observed in the context of AIF. In contrast, we did not find a difference in average slope across the different interlocutor distances, which presents opportunities for future research.

Previous research has identified gender-related differences in speech intensity such that men produce higher speech intensity in both reading and vowel prolongations [37] and Healey and colleagues [31] found that women produce larger increases in intensity across interlocutor distances. The current study was limited to female participants and therefore generalizations are cautioned.

Another speaking condition that should be considered in the AIF context is speaking in background noise, as speakers regulate their speech intensity in noise so as to maintain an adequate speech-to-noise ratio [38]. Previous work by Lane and Tranel [38] and Siegel and Pick [1] suggest that the addition of background noise to altered feedback conditions intensifies the response of the AIF effect. Future studies should explore the role of auditory feedback for speech intensity regulation in the context of background noise while completing a variety of speech tasks.

Another goal of the present study was to examine the effect of instructions related to focus of attention on the AIF response functions. No difference was found between the reading task with instructions to ignore the altered feedback and the reading task without these instructions. Although there was a reduced slope in the reading task with instruction to ignore feedback, this did not reach significance. Siegel & Pick [1] found a similar slope of the function when asked to read sentences in background noise with and without instructions to ignore altered feedback. However, we found this in the absence of background noise suggesting the robustness of this finding.

Speech tasks

Results from the current study suggest that when producing a quasi-speech task, such as reading sentences, use of auditory feedback differs compared to when producing more naturalistic speech such as speaking in conversation. It is proposed that this may be related to two important influences: the complexity of the task, and differences in the communicative demands. With regard to complexity, the motor skill required and the attention/cognitive demands are considered distinct based on whether the speaker is executing a speech or quasi-speech task [39, 40]. Specifically, the complexity of the speech task relates to the degree of automaticity. Sentence reading tasks are considered to be more automatic and reduced in complexity compared to less automatic conversation tasks [41, 42]. For example, the speakers' loudness, pitch, articulation, vocal quality, and prosodic patterns may be engaged in order to be better understood during a conversational task. In addition, despite word-level complexity being comparative across these tasks, word selection is a process that only occurs during spontaneous conversational speaking tasks. Finally, additional processing of cues such as listener understanding and communication breakdown monitoring may be occurring during conversation tasks (when speaker and listener are engaged in turn-taking), however reading tasks may not engage these types of cognitive/attentional monitoring-type behaviours. It has been suggested that more automatic skeleto-motor movements are less impacted by distorted feedback than non-automatic movements [43]. This is an important consideration in the context of current theories of sensorimotor feedback and feedforward mechanisms, which posit that altered feedback, such as that created when speaking in background noise (Lombard effect) influences speech production in a seemingly rapid and involuntary manner [44, 45]. This has led to speech regulation mechanisms conceptualized as involving sensorimotor feedback loops that alter and update feedforward models of the intended speech output [44, 45]. A reduced slope during the reading task in the current study is suggestive of a relatively reduced impact of altered feedback. It is plausible that when executing a less complex and thus more automatic speech task, we require less input from ongoing sensory monitoring processes (sensorimotor feedback) because our speech intensity regulation system (internal model) considers speech intensity outputs from these tasks more reliable. In contrast, spontaneous speech may be considered comparatively increased in complexity, as this requires an internally generated motor plan, which is initiated and executed with the additional requirements of continuous self-monitoring during the movement.

Complexity of speech and quasi-speech tasks are also reflected in differences in underlying neuroanatomical patterns of control [40; refer to 39 for a review]. For example, unilateral left motor cortex lateralization has been observed in some imaging studies during speech tasks versus bilateral activation during non-speech oral tasks [46]. There is some evidence to suggest that altered feedback (frequency shifted) is associated with increased activity in the right hemisphere compared to unaltered feedback [47]. One possible hypothesis is that the right hemispheric activation during altered feedback requires complex integration processing of both hemispheres during conversational tasks, which typically only require unilateral pathways in unaltered feedback. Therefore, the sensorimotor integration of speech may involve distinct pathways and it is possible that fundamental differences in complexity of the neural control of speech during AIF may explain the relative slope differences found in the current study between speech and quasi-speech reading task. However, it is important to note that although the vowel task is typically considered a quasi-speech task, the current study did not find a significant difference between the vowel task and the conversation task. The differences between different quasi-speech tasks and the neural control of speech intensity during AIF across speech tasks requires further research.

Observed slope differences may be associated with differences in the communicative demands of the speech tasks. When a speaker is attempting to communicate a message, there is motivation and attention directed towards producing and maintaining adequate speech intensity to avoid reductions in speech intelligibility or communicative errors. Healthy speakers prioritize intelligibility, as evidenced by modifications of the speech signal when intelligibility is at risk of being compromised. One such modification is increasing speech intensity when speaking in noisy conditions despite this modification requiring a perceived increase in effort [23, 48, 49].

Related to motivational goals of communicating, previous literature suggests that certain tasks may prompt the speaker to maximize communication efficiency [50]. As such, with a presumed communication goal of increased intelligibility while speaking to a listener, we should expect a higher loudness-to-efficiency ratio, compared to a lower efficiency-to-loudness ratio during reading; when the goal that a listener perceive accurate information is comparatively reduced. Subsequently, to accomplish this goal, the speaker presumably relies on increased attention when in conversation. The net effect of increased motivation and attention, results in larger compensatory responses to altered feedback in conversation. In the current study, participants displayed larger compensatory responses to the AIF for the speech tasks with greater communicative demands (i.e. conversation) than speech tasks with lower communicative demands (reading sentences), consistent with the communication demands hypothesis. This potentially important effect of the communicative demands on the response to altered feedback may be relatively independent of other factors or demands that typically produce large changes in speech intensity (i.e. interlocutor distance).

The content of the message may play a role in intensity adjustments. This includes communicative intent and emotional content; high emotional content may involve different neural control processes (direct corticobulbar pathways) [51] and produce wide ranges of speech loudness, which may not exist in emotionally neutral conversation. Methods to control for conversational or monologue content were employed in the current study. Conversation was elicited in the most natural manner possible, and therefore at times the topic shifted from the initial questions. Instances of noticeably high emotionally laden utterances during which the participant was visibly upset, were excluded from analysis (e.g. discussions that naturally progressed to death of a loved one). In these rare instances, additional samples of speech for that altered intensity feedback condition were elicited and were used to replace the emotionally laden utterances. Conversation included in all analysis were limited to emotionally neutral discussions such as describing a most recent vacation. However, it is possible that despite these precautions, some conversational samples may have involved high emotion content without the experimenter being aware. Future studies should consider using supplemental questions to verify emotional content of conversation.

Distance conditions

Talker-to-listener distance, or interlocutor distance explores a speaking condition that requires regulation of intensity based on multiple sensory processes. These include visual processing (e.g. depth perception) and auditory processing (e.g. self-produced speech as well as externally generated speech from the conversational partner). To our knowledge, the current study is the first to explore the relationship between interlocutor distance conditions and AIF. The results confirm that a similar slope function is observed during a conversation task regardless of interlocutor distance. Based on the communicative demands hypothesis, an increased slope function was expected with increasing distance between speaker and listener, since this would require improved monitoring of speech intensity regulation for avoidance of reduced intelligibility. The current results suggest that perhaps there is a ceiling beyond which increased attention towards sensorimotor feedback fails to alter the response. It is possible that the increased intercept (overall increase in speech intensity) in the far interlocutor distance condition provided adequate maintenance of speech intelligibility thereby rendering any further adjustments to the slope response unnecessary. The results also strengthen the evidence that the nature of the speech task plays an important role in intensity-related auditory-motor performance.

Directed attention

Overall, the data suggests that during the conditions of the present study, healthy speakers have difficulty ignoring the altered auditory feedback signal when given this explicit instruction. In other words, it appears that auditory feedback mechanisms were quite robust and the speakers appeared to be unable to use alternate mechanisms to control the level of their compensation. This finding should be interpreted with caution as we found a reduced R2 in this task suggesting a possible non-linear pattern in the equation. This is possible if the ability to ignore the altered feedback signal is related to the direction of the alteration, for example if it is easier to ignore the altered feedback when the feedback is in the negative direction than in the positive direction. Perhaps speakers are more sensitive to increased loudness as this relates to discomfort which may be more difficult to ignore compared to reduced loudness which may not be related to discomfort and is therefore easier to ignore. is also possible that the lower R2 may be related to increased intra subject variability, such that there were trial-to trial differences in the participant's ability to ignore the altered feedback.

The ability to direct attention towards and away from the intensity feedback of one's own voice, as well as the act to suppress the AIF compensation response requires further examination as inconsistencies appear in the literature. Lane and colleagues [19] found a reduced slope when instructed to ignore auditory feedback. It is important to note that in the current study, the slope in the reading task (with no instructions) was low, and therefore the non-significant difference when reading with instruction to ignore feedback is related to a possible floor effect. In the Lane and colleagues study [19], the non-ignore task had a much higher slope of -0.46 in the context of a sustained vowel, providing further support for this possible rationale. Future studies should examine the ignore feedback condition in the context of speech tasks with higher slope values, such as vowel prolongation or conversation tasks.

Related to this, evidence from previous studies by Scheerer and colleagues [52] and Tumber and colleagues [53] suggest that attention plays an important role in speech during altered feedback (note these were frequency perturbations) such that reduced compensations to distorted feedback were observed when subjects' attentional load was divided (speech combined with a visual distraction dual task). The "ignore altered feedback" condition in the current study may be creating a similar dual task manipulation such that the participants were required to read sentences while directing attention to the sound of their voice. This division of attention may have attenuated the response to the altered feedback in this condition, however this requires further examination in future studies.

5 Conclusion

The results of the present study confirm that auditory feedback about intensity plays an important role in the regulation of speech intensity in healthy speakers. Specifically, we found the role of auditory information for intensity regulation to be particularly important during specific speech tasks requiring complex processing and explicit communication goals. We found an increased response (steeper function) across a range of AIF levels in speaking conditions that require a clear communicative function such as having a conversation with a communication partner. This increased response function contrasted with the reduced response function observed in speech tasks without a communicative function (when reading sentences). These results suggest that the communication goal or the demands of the speech task may interact with auditory feedback to significantly influence the regulation of speech intensity. Although the use of auditory feedback for speech intensity regulation may be salient and in the current study healthy speakers had difficulty ignoring the altered auditory feedback when explicitly asked to do so, future studies are required to examine this finding in more detail. The current study aimed to provide a starting point from which to understand the effects of auditory feedback in healthy speakers however, future studies would benefit from examination of AIF during a range of speaking tasks in a larger sample size. Additional directions for future research include comparison to healthy older adults, as some researchers have suggested heightened sensitivity to sensory feedback in this cohort [54] as well as neurologically impaired populations with specific deficits related to speech loudness control. The current study was limited to native English-speakers and generalization to other populations is to be avoided.

Finally, the AIF paradigm is distinct from perturbation paradigms since brief perturbation shifts in the speech signal may involve involuntary processes. This is in contrast to AIF which may be under more voluntary control as the auditory alterations may be more perceptible to the speaker. Related to this, the current study did not examine possible sensorimotor adaptation processes, which is typically examined in the context of auditory perturbations. Adaptation is defined as involving “after-effects” such that the change in behaviour (compensation to altered perturbation) is continued after the altered feedback is removed (reducing or increasing the following response) [12, 55-58]. The current study did not examine potential after-effects of AIF, and instead the analyzed speech samples were selected from the mid-sections of vowel and utterance productions. It is presumed that if adaptation processes were occurring in the current study, an unpredictable pattern of findings across altered feedback conditions (non-linear function) may have been observed. However, in the current study, a steep slope of the function in the conversation task was observed, which means that following a change in the altered feedback condition, there was a predictable and stable pattern. Still, the dynamic adaptation processes that may be occurring in AIF is an interesting area of future research. Further directions for future research include examination of the distinction between AIF and perturbation experimental paradigms and the theoretical underpinnings.

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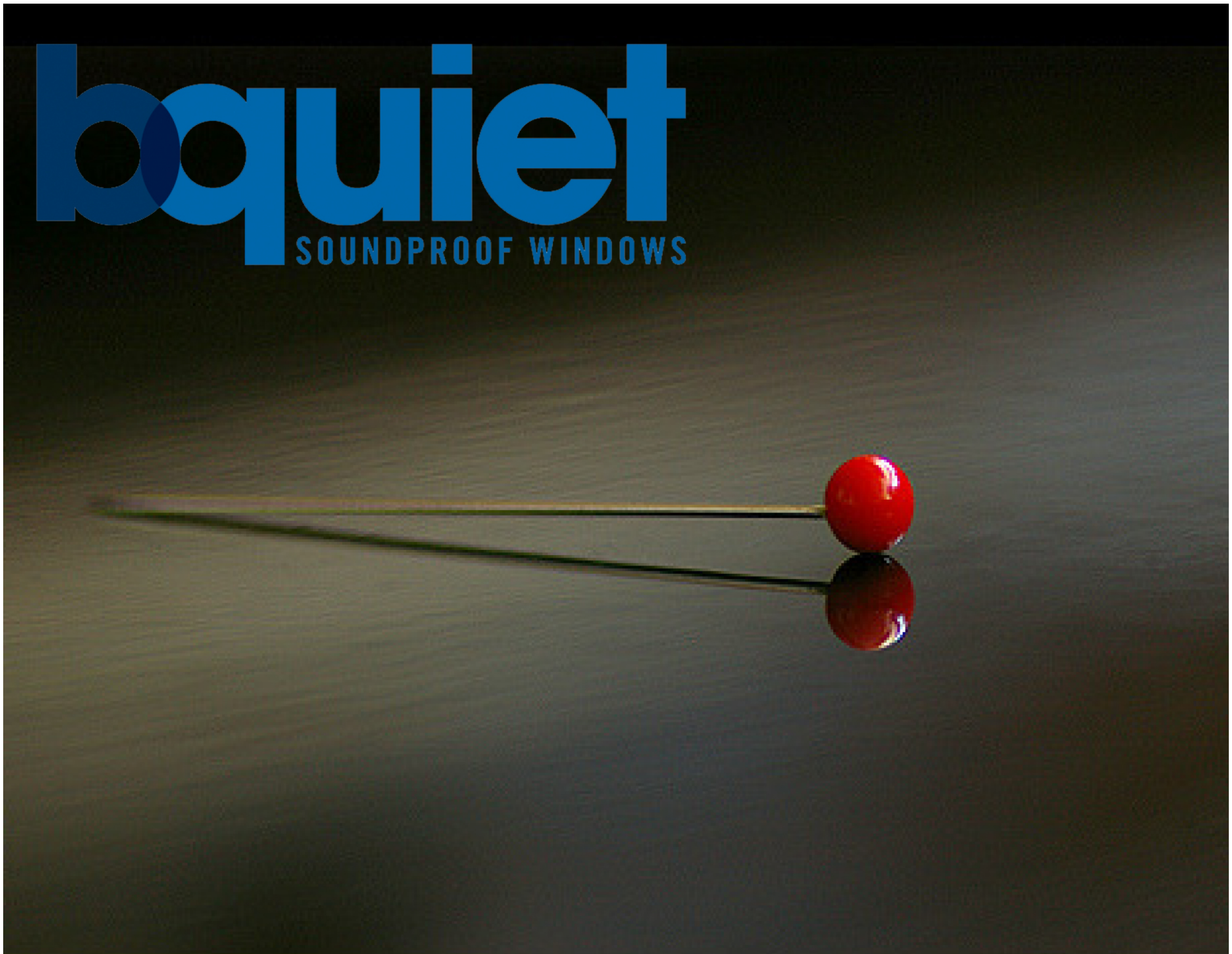

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