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Speech Amplification Device Usage in Hypophonia: Spontaneous Speech Intelligibility

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ABSTRACT

Purpose: The primary purpose of this study was to evaluate the effect of three different types of speech amplification devices on spontaneous speech intelligibility of people with hypophonia secondary to Parkinson's disease or parkinsonism.
Method: Twenty-one individuals with hypophonia described pictures aloud to their primary communication partner in four device and two noise conditions. Device conditions included no device, a portable wired speech amplifier, a wireless stationary amplifier, and a one-way personal communication system. Noise conditions included quiet and 65-dB multitalker background noise. Speech intelligibility was evaluated from the perspective of two listener groups, familiar communication partners and naive listeners, as a function of device type and noise.
Results: Overall, all three devices were associated with improved intelligibility, especially in noise and for longer utterances for both listener groups. Intelligibility was highest for the personal communication system and lowest for the portable wired amplifier. These results for spontaneous speech patterned similarly to those for read sentences reported for these same talkers and listeners in Knowles et al. (2020).
Conclusions: Speech amplification devices demonstrate measurable improvements in intelligibility of spontaneous speech in individuals with hypophonia. Findings add to a growing body of evidence of the potential effectiveness of speech amplification as a management tool for hypophonia.
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Hypophonia, characterized by reduced vocal loudness, is an early and common symptom of Parkinson's disease (PD; Adams & Dykstra, 2009; Kempler & Van Lancker, 2002). This condition manifests as a reduction in speech intensity of 2–5 dB SPL compared to neurologically healthy elderly individuals, resulting in a perceived loudness decrease of approximately 40% (Adams & Dykstra, 2009; Fox & Ramig, 1997). The decrease in loudness may stem from a sensorimotor deficit that affects self-perceived volume (Adams & Dykstra, 2009; Clark et al., 2014; Ho et al., 2000) and decreased vocal fold adduction force, leading to inadequate subglottal pressure (Duffy, 2019). Additionally, changes to speech breathing in PD suggest that the rigidity of respiratory muscles and overall muscle stiffness may further hinder the ability to generate adequate breath support, exacerbating vocal loudness difficulties (Huber et al., 2003; Huber & Darling, 2011; Reyes et al., 2020; Solomon & Hixon, 1993).

The vocal characteristics of hypophonia, which is estimated to be present in more than half of all people with PD (Logemann et al., 1978), is one set of symptoms in a broader cluster of speech symptoms in PD known as hypokinetic dysarthria (Darley et al., 1969b). Additional speech features of hypokinetic dysarthria include rate abnormalities, repeated phonemes, monopitch and monoloudness, and articulatory imprecision (Darley et al., 1969a). Hypokinetic dysarthria and hypophonia are also present in atypical

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Parkinsonism conditions, such as progressive supranuclear palsy and multiple system atrophy (MSA). While many of the communication challenges in atypical and idiopathic Parkinsonism, hereafter referred to as PD(+), are similar, speech features do tend to differ in systematic ways as well (Huh et al., 2015; Kowalska-Taczanowska et al., 2020; Rusz et al., 2015). For instance, people with atypical Parkinsonism often experience more severe speech symptoms consistent with mixed dysarthria, characterized by a combination of hypokinetic, ataxic, and/or spastic features (Kowalska-Taczanowska et al., 2020; Rusz et al., 2015; Sachin et al., 2008).

Speech and voice challenges can significantly impact the quality of life for individuals with PD(+). Communication difficulties, altered self-perception, and challenges in compensating for speech deficiencies, particularly loudness, often lead to social withdrawal, reduced quality of life (Miller et al., 2006), and lower levels of communicative participation (Dykstra et al., 2015; McAuliffe et al., 2017). The gold standard approach for managing hypophonia is intensive behavioral speech therapy targeting vocal loudness (Behrman et al., 2020; Ramig et al., 2004). While this behavioral approach is beneficial for many individuals with PD, two prominent considerations limit its effectiveness. First, individuals with PD(+) often struggle to integrate learned strategies into their daily communication due to deficits underlying sensorimotor integration, cognition, and motor learning (Adams & Dykstra, 2009; Olson et al., 2019; Scott & Caird, 1983). Cognitive decline, particularly in executive functioning, may further hinder the ability to apply learned communication strategies in real-life settings (Goldman & Litvan, 2011; Obeso et al., 2011). Second, challenges related to disease progression may make continued integration of speech therapy and/or strategies difficult. This may especially be the case for individuals with more cognitive involvement and/or a more rapid or severe symptom progression as is often observed in atypical Parkinsonism (Gates, Knowles, Mach, & Higginbotham, 2024). Fatigue, a common nonmotor symptom in PD, can also limit sustained engagement with these learned strategies, particularly later in the day and over time as fatigue worsens (Friedman et al., 2011). Furthermore, even individuals who are successfully and consistently able to use increased vocal loudness following behavioral therapeutic intervention may struggle in more adverse communicative environments, such as in the presence of noise (Dykstra et al., 2015). Additionally, family members often take on the increasing burden of managing communication as the disease progresses, a challenge that can be exacerbated by the patient's cognitive decline and inconsistent use of strategies. This shift in responsibility can lead to frustration and strained relationships, highlighting the need for family-centered interventions in speech-language pathology (Baylor et al., 2024).

Speech Amplification Devices

Speech amplification devices are a form of augmentative communication devices that an individual can wear to increase the audibility of their speech in the absence of (or in addition to) behavioral adjustments (Andreetta et al., 2016; Gates, Knowles, Mach, & Higginbotham, 2024; Gates, Knowles, Mach, Higginbotham, & Holder, 2024; Greene et al., 1972; Knowles et al., 2020; Page et al., 2023). An augmentative approach to managing the reduced loudness of hypophonia offers an option for reprieve to those individuals who have difficulty managing their symptoms with behavioral therapy alone. Speech amplification devices can broadly be classified into two types: voice amplifiers and one-way communication systems (see Knowles et al., 2020, and Page et al., 2023, for reviews). Voice amplifiers may be portable or stationary. Portable devices typically include a microphone and small amplifier worn by a talker around the waist, neck, or clipped to clothing; an example of this type is the ChatterVox amplifier (ChatterVox). Stationary devices typically consist of a microphone and transmitter worn by a talker that transmits the speech signal wirelessly to a larger amplifier positioned in a given location, such as the BoomVox (Griffin Laboratories). Finally, personal communication systems include a microphone and transmitter worn by a talker that transmits wirelessly to a receiver and headphones worn by a listener, such as the Easy Listener (Phonic Ear). While, traditionally, personal communication systems are designed to be used by individuals with hearing loss wearing the transmitter (Harkins & Tucker, 2007; Laplante-Lévesque et al., 2010), we have shown their potential use by talkers with hypophonia (HP) transmitting to a communication partner (Knowles et al., 2020; Page et al., 2023).

The present work builds on a previous study evaluating these three types of amplification devices in a cohort of individuals with hypophonia secondary to PD or atypical Parkinsonism (Knowles et al., 2020; Page et al., 2023). Knowles et al. (2020) compared three amplification devices worn by 22 individuals with hypophonia. Individuals read aloud sentences from the Sentence Intelligibility Test (SIT; Yorkston et al., 1996) to a communication partner seated 2 m away in a quiet and noisy environment. Utterances were also played to a group of naive listeners (NLs). All devices were associated with greater speech-to-noise ratios and sentence intelligibility for both listener groups. The personal communication system performed best, followed by the stationary amplifier and then the portable amplifier. These differences, however, were greatest in the presence of noise and for NLs. Page et al. (2023) further found that all three types of amplification devices were associated with improvements in communicative effectiveness and communicative participation relative to baseline.

As part of a larger study, the participants reported by Knowles and colleagues (Knowles et al., 2020; Page et al., 2023) also described a series of images to their partners while trialing the amplification devices, resulting in spontaneously produced utterances. The present study reports on this spontaneous speech task to determine whether amplification devices also provide the benefit to intelligibility identified in Knowles et al. (2020) in more naturalistic speaking contexts.

Intelligibility Differences Across Structured and Unstructured Speech Tasks

Several studies have demonstrated a relative increase in speech intelligibility of structured read material compared to spontaneous speech in talkers with PD (Johansson et al., 2022; Kempler & Van Lancker, 2002; Kent, 1996; Weismer, 1984; Yorkston & Beukelman, 1981). Reading material provides an external structure and cue that limits attentional demands during speaking. This may be particularly important for talkers with PD, who generally exhibit greater impairment on internally cued, self-generated movements compared to those that are externally cued in nonspeech (Cunnington et al., 1999; Georgiou et al., 1994) and speech tasks (Ho et al., 1999; Weir-Mayta et al., 2017). While read speech offers an external cue in the form of a written visual, spontaneous speech generally does not. Spontaneous speech in PD has been elicited via monologues (e.g., Tjaden & Wilding, 2011), structured conversations (Kempler & Van Lancker, 2002), and picture description (Johansson et al., 2022).

While most studies exploring speech task differences have reported greater intelligibility of read material, this finding is not universal. Tjaden and Wilding (2011) found no differences in intelligibility for paragraph reading and a spoken monologue for 12 individuals with PD. Bunton and Keintz (2008) similarly found that word and sentence reading was not significantly different from spoken monologues, though covertly recorded conversational samples were less intelligible than any of the controlled samples. Compared to fully unstructured spontaneous speech tasks such as monologues, picture description tasks offer a middle ground, in which a person may produce self-generated spontaneous speech but with some external support provided by the image they are describing. Picture description tasks also allow for more control of spoken content than open-ended monologues, while maintaining some of the authenticity of conversational speech (Kent & Kim, 2010). There may therefore be a trade-off in naturalness and cognitive demand that impact functional outcomes such as intelligibility in different settings and for different speakers.

Intelligibility Differences Driven by the Listener

Familiar Versus Unfamiliar Listeners

Speech intelligibility necessarily encompasses factors driven by both the speaker and the listener. Generally, the more familiar a person is with the speech they are hearing, the more accurate they are in understanding it; this is this case when listening to talkers with dysarthria (Borrie et al., 2017, 2018; Borrie & Lansford, 2021; Borrie, McAuliffe, & Liss, 2012; Hirsch et al., 2021; Liss et al., 2002; Spitzer et al., 2000), as well as when listening to speech that is “familiar” in other ways, such as accent or regional dialect (e.g., Adank et al., 2009; Baese-Berk et al., 2020; Bent & Baese-Berk, 2021, among others). A “familiar listener” can be defined either as someone familiar with the speech itself, that is, through prior exposure to the speech audio signal or similar speech patterns, or as a person familiar with the speaker, such as a family member or friend. Conversely, listeners who are unfamiliar, either with the talker in question or with the speech symptoms themselves, are often referred to as “naive” listeners.

Listeners can be familiarized with the dysarthric speech they are trying to understand, resulting in improvements in intelligibility compared to unfamiliarized listeners (Borrie & Lansford, 2021; Borrie, McAuliffe, & Liss, 2012). Such findings have led to the development of listener familiarization training as a communication partner–driven method of improving intelligibility (Lansford et al., 2018). This improvement can also generalize to new speakers (Borrie et al., 2017; Hirsch et al., 2021) but is not consistent across all dysarthria types (Borrie et al., 2018). Improvements have been more consistently documented for listener familiarization of more predictable degraded speech patterns, such as in speakers with hypokinetic dysarthria (Borrie, McAuliffe, Liss, O’Beirne, & Anderson, 2012; Borrie, McAuliffe, Liss, Kirk, O’Beirne, & Anderson, 2012; Borrie et al., 2013; Liss et al., 2002; Spitzer et al., 2000), compared to less predictable speech patterns such as in hyperkinetic dysarthria (Borrie et al., 2018; Lansford et al., 2019, 2020). While little empirical evidence exists on familiar listeners that are known partners of adult talkers (e.g., a spouse), data from parents listening to their children, compared to unfamiliar listeners, suggest there is a benefit to knowing the speaker (Flipsen, 1995).

The degree to which listener familiarity with a given talker does (or does not) facilitate listener intelligibility is of particular importance for an older adult population, as older adults have more difficulty understanding speech, especially in noisy listening environments, compared to younger adults (e.g., Schneider et al., 2000; Tun et al., 2002). Furthermore, age-related differences have been shown to be driven by different cognitive mechanisms present in aging, not simply age-related hearing changes (Ingvalson et al., 2017; Lansford et al., 2018). All these factors likely interact with any benefit of being familiar with the talker themselves, however. The extent to which a known partner's familiarity of a talker with hypophonia impacts intelligibility remains an open question. This is of particular clinical importance when providing recommendations designed to support communication.

Summary and Purpose of the Present Study

The present study extends the findings of Knowles et al. (2020) to evaluate the performance of three amplification devices on spontaneous speech, elicited via a picture description task with a communication partner, in HP secondary to PD(+). Here, we ask the following question: How does spontaneous speech intelligibility (elicited from a picture description task) differ across three amplification devices in quiet and in noise for familiar communication partners and unfamiliar NLs? We predict that all amplification devices will result in better intelligibility than no device and that the personal communication system will outperform the other devices. We also predict that intelligibility will be worse overall in the presence of noise, but the magnitude will differ across devices. These predictions are driven by the patterns reported in Knowles et al. (2020), which reported on these same talkers and listeners during a sentence reading task.

Method

The Human Subjects Research Ethics Board at Western University approved this study (Approval Number 106169). Participants provided written consent at the beginning of the study.

Participants

Three participant groups were included: HP, primary communication partners (PCPs) of the HP participants who served as familiar listeners, and NLs. The HP talker group consisted of 22 individuals with hypophonia secondary to PD (n = 20; 16 men, four women) or atypical Parkinsonism (n = 2 men). Atypical Parkinsonism manifested as MSA-predominant cerebellar ataxia (HP17) and suspected MSA-predominant Parkinsonism (HP19). Inclusion criteria for the HP participants included a neurological diagnosis of PD or Parkinsonism at least 6 months prior; the presence of hypophonia (as judged by an experienced speech-language pathologist, S.A.); at least 50 years of age; and no other history of other neurological, voice, or health disorders. Eight participants had deep brain stimulation of the subthalamic nucleus. All but one participant (HP13) were stabilized on anti-Parkinsonian medication and/or deep brain stimulation settings. Eight participants had previously received speech therapy. All participants presented with moderate-to-severe hypophonia as their predominant speech symptom, though all presented with other mild–moderate dysarthria symptoms consistent with hypokinetic dysarthria as well. Severity was judged by an experienced speech-language pathologist (S.A.) at the time of intake based on speech produced during conversation and baseline speech tasks. Hearing and cognitive status were screened but not exclusionary. Eight participants passed a 40–dB HL screening at 500, 1000, 2000, and 4000 Hz in both ears, while the remainder failed at one or more frequencies (hearing screening results were unavailable for four participants). Cognition was assessed using the Montreal Cognitive Assessment (Nasreddine et al., 2005), with nine participants receiving a score of < 21, the recommended cutoff for PD dementia (Dalrymple-Alford et al., 2010). One HP participant did not participate in the picture description task because they had vision difficulties on the day of testing; they were subsequently dropped from the picture description analyses presented here (HP10). Unified Parkinson's Disease Rating Scale scores for Part III (motor examination) were provided by a movement disorders specialist and neurologist (M.J.). Participant demographics for the HP group appear in Table 1.

Each HP participant was accompanied to the study by someone they determined to be a PCP who was, in most cases, a spouse. Five PCP participants failed the hearing screening for at least one frequency, two wore hearing aids, and hearing status was unavailable for two. There were no exclusion criteria for PCP participants, as the goal was to assess speech intelligibility from the perspective of a listener who commonly interacted with the HP participant.

Four NLs (two men and two women, aged 23–29 years) unfamiliar with the talkers were recruited to listen to and transcribe the recorded utterances. All were native speakers of English who passed a 25–dB HL hearing screening in both ears and reported no history of speech, language, hearing, or neurological concerns. These listeners were graduate students in speech-language pathology or audiology, as reported by Knowles et al. (2020), but otherwise reported limited exposure to hypophonic speech. Listeners may not be considered truly "naive" compared to, for example, students in an unrelated profession, but they are referred to as such for simplicity. These NLs also heard recordings from a sentence reading task reported in Knowles et al. (2020) in a separate listening block on different days.

Devices

Devices are the same as those presented in Knowles et al. (2020) and Page et al. (2023). The no device (ND)

Table 1. Demographics.

Participant	Sex	Age	LED	Diagnosis	Years since diagnosis	DBS	UPDRS	UPDRS-Speech	MoCA	Hearing screening	PCP hearing screening
HP01	m	75	750	PD	9	No	40	3	16	Fail	Pass
HP02	m	54	0	PD	7	Yes	31	3	22	Fail	Pass
HP03	m	75	750	PD	8	No	49	2	23	Fail	Pass
HP04	f	78	800	PD	14	No	35	2	20	Fail	Fail
HP05	m	69	1,250	PD	11	No	43	2	13	NA	NA
HP06	m	67	550	PD	21	Yes	29	3	22	Fail	Hearing aids
HP07	f	72	0	PD	16	Yes	30	1	26	Pass	Fail
HP08	m	65	1,200	PD	15	No	20	1	21	Pass	Pass
HP09	m	79	800	PD	8	No	50	3	19	NA	Pass
HP10	m	75	2,000	PD	20	No	45	2	NA	NA	Fail
HP11	m	72	NA	PD	11	Yes	NA	NA	20	Pass	Pass
HP12	m	59	400	PD	10	Yes	37	2	24	Pass	Pass
HP13	m	71	400	PD	0.5	No	31	1	22	Fail	Pass
HP14	f	67	600	PD	31	Yes	43	2	19	Fail	Hearing aids
HP15	m	88	1,000	PD	18	No	23	2	14	NA	NA
HP16	m	70	100	PD	17	Yes	18	2	23	Fail	Pass
HP17	m	71	0	MSA-C	5	No	23	2	27	Fail	Fail
HP18	m	72	820	PD	2	No	45	3	25	Fail	Pass
HP19	m	59	1,350	MSA-P	8	No	52	3	26	Pass	Pass
HP20	m	65	1,200	PD	15	No	4	2	18	Pass	Pass
HP21	m	60	610	PD	12	No	17	2	29	Pass	Fail
HP22	f	68	750	PD	15	Yes	36	1	25	Pass	Pass

Note. LED = levodopa equivalence dosage; DBS = deep brain stimulation; UPDRS = Unified Parkinson's Disease Rating Scale (Part III: Motor); UPDRS-Speech = speech item score from the UPDRS; MoCA = Montreal Cognitive Assessment; PCP = primary communication partner; m = male; PD = Parkinson's disease; f = female; NA = not available; MSA-C = multiple systems atrophy cerebellar type; MSA-P = multiple systems atrophy Parkinsonian type.

condition was elicited first. Device A was a portable, wired, belt-pack–worn amplification device (ChatterVox, 5 W [ChatterVox]; herein referred to as the portable amplifier). Device B was a stationary wireless amplifier (Nady WA120-BT, 20 W [Nady Systems]; similar to the BoomVox [Griffin Laboratories]; herein referred to as the stationary amplifier). Device C was a personal communication system (Nady 351VR [Nady Systems], similar to the Easy Listener [Phonic Ear]). For the personal communication system condition, the PCP participant wore headphones attached to the Device C receiver. The amplifier for Device A was positioned on the HP participant's lap, and that for Device B was placed next to the HP participant's chair.

Conditions and Speech Task

Four device, two noise, and two task conditions were included. Device conditions included ND and each of the three devices. Two noise conditions included quiet ("no noise") and multitalker noise (Auditec Four Talker Noise [Auditec, Inc]; "noise") produced at 65 dB SPL. Noise was produced from two loudspeakers situated on a countertop at the same height as the tabletop microphone and positioned at a 2-m distance from the HP and PCP participants, respectively. The 65–dB SPL noise level was chosen to mimic standard background noise levels in busy public settings such as a restaurant (To & Chung, 2014). Noise levels were calibrated using a sound-level meter (dbA, slow setting) at the position of the recording microphone.

Spontaneous speech was elicited via a picture description task that involved the talker describing an illustrated picture scene to their partner one sentence at a time. Pictures were one of eight images, presented randomly across conditions. Pictures were selected to include detailed, engaging scenes that would elicit a broad range of descriptions. They included detailed illustrations of people involved in scenes that would lead most observers to imagine storylines about past and future events in the scenes. For example, several pictures involved copies of illustrations by the well-known artist, Norman Rockwell. Detailed, rather than simplistic, images were chosen in order to make the description task more natural and lead to more varied descriptions. This task is thus different in nature compared to highly controlled picture description tasks that are designed to elicit specific words and phrases.

The PCP participant's role was to repeat back each utterance their partner said to the best of their ability. To facilitate this, speaker participants were instructed to describe the picture in front of them one brief phrase or sentence at a time and then pause, at which point the PCP repeated back as much as possible of what they had heard. HP participants were encouraged to describe the picture itself but also talk more freely about what it reminded them of or anything else that came to mind. In this way, the pictures elicited a broad range of conversational topics and varied substantially across participants. The PCP was not shown the images their partner was describing until the end.

Protocol

HP and PCP participants were seated 2 m apart, facing each other. HP participants wore an AKG C520 headset condenser microphone positioned 6 cm from the upper corner of their lips in addition to the amplification device headset microphones. A tabletop Shure SM48 microphone was positioned on a table at a 2-m distance from the talker, directly to the right of the PCP participant but angled toward the HP participant and level with their head. Audio inputs were recorded for the headset microphone; the tabletop microphone; and, for the personal communication system (Device C), the audio from a secondary receiver on the same channel. Audio recording gain levels were consistently set for all participants. The PCP participant additionally wore a lavalier microphone connected to a mobile recorder to record their responses. PCP participants could see their partner's face but were unable to see the sentences or pictures. This setup, in which the HP and PCP participants were seated across from each other, was chosen to preserve the naturalness of a spoken in-person interaction and provide ecological validity. PCP participants thus could see the mouth of the HP participant while speaking (but could not see the pictures), and the HP participant heard the PCP's repetitions.

Conditions were blocked by device, noise, and task. The ND condition was elicited first, followed by each of the three device conditions that were counterbalanced across participants. Within each device condition, the quiet condition was elicited before noise, and the sentence readings (reported in Knowles et al., 2020) were elicited before the picture description. New sentences and pictures were presented in each of the eight device–noise conditions.

Intelligibility of Spontaneous Speech

Spontaneous speech intelligibility scores derived from the picture description task were obtained using the procedure similar to that defined by Adams et al. (2008). All utterances produced by the HP participants were transcribed by the first author (T.K.) using the headset microphone recording to approximate a "ground truth" transcription. A trained research assistant independently transcribed all utterances from a subset of five of the HP participants in order to report reliability of the "ground truth" transcriptions. These five speakers were chosen to reflect a range of severity. The percent agreement between the first and second transcriber was 94.3%.

PCP utterances were then transcribed using the lavalier microphone recording. Six utterances per condition per participant were selected to be played to NLs and to be used in the final analyses. Final analyses included utterances between four and 22 words in length, on-topic, not including or overlapping with the PCP or investigators, and continuous (e.g., encompassing an entire utterance with discontinuities and disfluencies removed). When possible, the first six sentences uttered during each condition to meet these criteria were the ones chosen to include in the intelligibility analyses.

Later, NLs heard a subset of the utterances (four to six utterances per condition that met the criteria described above) that had been recorded from the tabletop microphone positioned next to the PCP participants (2-m recording distance). Utterances were presented at the natural sound pressure level at which they were recorded (i.e., not rescaled) in a sound-treated booth (Industrial Acoustic Company) via external speakers calibrated to 70 dB SPL at the listener's head. Selected utterances were played to listeners in two blocks (one for each noise condition). Within each block, the order of utterances was randomized for each listener, and each utterance was played twice. A random 10% of utterances were repeated for reliability. Listeners completed the self-paced listening task over approximately four to six visits usually lasting between 1 and 2 hr each and spaced approximately a week apart.

Listeners transcribed the talker's speech as accurately and completely as possible. If they could not understand anything, they were instructed to type "NA." Intelligibility for this subset of utterances was measured as a percentage of words correctly repeated by the PCP participant or transcribed by the NL. HP and PCP transcriptions were hand-checked by two trained research assistants, and intelligibility scores (percent correct of words understood) were verified and corrected if necessary according to the following criteria:

- Contractions and uncontracted versions of words were both counted as correct (e.g., if the participant said "we will" but the listener said "we'll," this was counted as "we will"; similarly, if they said "we will" instead of "we'll," this was also counted as correct).
- An alteration in word order was ignored as long as all words were uttered.
- Any additional words or morphemes added by the listener were ignored and not counted against the final score.
- Fillers and word repetitions uttered by the participant were not counted as a part of the transcript (e.g., "uh", "um", "the the boy…").
- Obvious typos typed by the NLs (e.g., letters swapped or a word missing an apostrophe) were counted as correct.

Statistical Analysis

To answer how the devices and presence of noise impacted speech intelligibility for each of our listener groups, we built two linear mixed-effects models using the *lme4* package (Version 1.1.35.3; Bates et al., 2015) in R (Version 4.4.3; R Core Team, 2024), one for each group. Fixed effects included device (four levels) and noise (two levels), as well as utterance length (number of words in the sentence; treated numerically) as a covariate. All possible interactions were permitted in the models. Random intercepts were included for talker/dyad and utterance order. In the NL model, random intercepts for listener were also included to account for variability in listener-specific effects. The dependent variable, intelligibility, was treated as percent words corrected (0%–100%).

To aid interpretation, we employed contrast coding methods to handle the multilevel categorical variables. The four-level device condition was contrast coded using reverse Helmert contrasts with the following interpretations: (a) portable versus stationary amplifier (A vs. B), (b) both amplifiers versus the personal communication system (A and B vs. C), and (c) all devices versus no device (A, B, and C vs. ND). Noise was treatment coded with the no-noise condition set as the reference level. Utterance length was entered as a numeric variable. We report significant pairwise comparisons (using the *emmeans* R package [Version 1.11.2; Lenth, 2020] and Tukey-adjusted p values) as appropriate to aid in interpretation of interactions.

Power Analysis

We conducted a series of power analyses to calculate the levels of statistical power of the linear mixed-effects regression models using simulated data. Using the *simr* R package (Version 1.0.7; Green & MacLeod, 2016), we ran 100 simulations of the models for each level of the effect size. We calculated the proportion of times the null hypothesis was correctly rejected (i.e., statistical power). With an α level of .05 (Type I error rate), the power analysis revealed that the power ranged from 59% to 100% to detect a small effect size for our models.

Results

Results are presented in Figure 1 and Appendix Tables A1 and A2. We report the results of each of the two models (PCP and NL groups), in order to describe the effects of the primary variables of interest within each group. Briefly, we found a main effect of noise and significant Device × Noise interactions for both groups, which we report below. Model estimates are reported on the original scale of percent words correct.

Main Effects of Device, Noise, and Utterance Length

There were no significant main effects of device for the PCP group's intelligibility scores when noise and utterance length were held at their reference level values. For the NL group, intelligibility was significantly worse in the ND condition compared to the three devices for the NL group (device vs. ND contrast: $\hat{\beta} = -2.51$; 95% confidence interval [CI] [−4.31, −0.71]; $p = .006$). There were no main effects of device for the other contrast levels for either of the listener groups. For both listener groups, we found a significant detrimental main effect of noise (PCP: $\hat{\beta} = -14.32$; 95% CI [−22.22, −6.41]; $p < .001$; naive: $\hat{\beta} = -31.09$; 95% CI [−35.57, −26.61]; $p < .001$) and sentence length (PCP: $\hat{\beta} = -1.71$; 95% CI [−2.36, −1.06]; $p < .001$; naive: $\hat{\beta} = -0.70$; 95% CI [−1.08, −0.33]; $p < .001$) on intelligibility scores.

Interactions Between Device and Noise

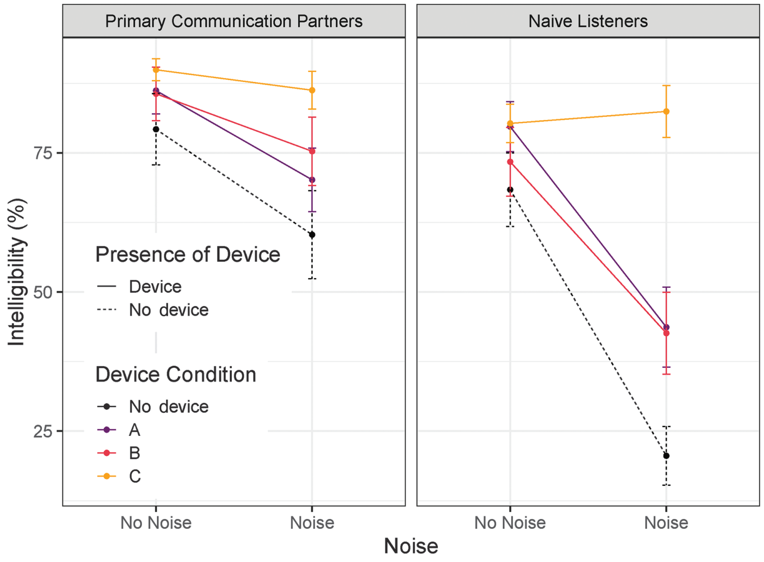
A two-way interaction between Device and Noise was found for both listener groups. Specifically, both groups demonstrated a significant interaction between Noise and the amplifier versus personal communication system contrast ([A and B vs. C] by Noise; PCP: $\hat{\beta} = 7.29$; 95% CI [0.81, 13.77]; $p = .027$; NL: $\beta = 14.29$; 95% CI [10.61, 17.98]; $p < .001$). This interaction demonstrates that there was a relatively greater decline in intelligibility in noise for the portable and stationary amplifiers (Devices A and B) compared to the personal communication system (Device C). A two-way interaction for the Noise × Device versus no device contrast was additionally found for the NLs ($\hat{\beta} = -7.82$; 95% CI [−10.31, −5.33]; $p < .001$).

Pairwise Comparisons Between Devices

Post hoc pairwise comparisons (see Appendix Table 2) were performed for the Device × Noise interactions that were found to be statistically significant above. We report the estimated marginal mean differences (in percentage points) for statistically different comparisons as appropriate below.

PCP Group. In no noise, there were no significant intelligibility differences between any of the devices for PCP group in the no-noise condition. In the noise condition, listener intelligibility for the PCPs was significantly greater for all devices (A, B, and C) compared to ND. Estimated differences ranged from 7.8% (Portable Amplifier A vs. ND) to 24.5% (Personal Communication System C vs. ND). Intelligibility was also greater for the personal communication system (C) compared to all other device conditions (Portable Amplifier A, 16.6% difference; Stationary Amplifier B, 11.1% difference). The portable and stationary amplifiers did not differ from one another (A = B). The observed device hierarchy in noise for the PCP listeners was as follows:

Figure 1. Spontaneous speech intelligibility across device types, noise conditions, and listener groups. Error bars reflect standard error. Device A = portable belt-pack amplification device; Device B = stationary wireless amplification device; Device C = one-way personal communication system.



personal communication system (C) > [portable amplifier (A) = stationary amplifier (B)] > ND.

NL Group. In no noise, post hoc testing confirmed significant intelligibility differences for most device comparisons for the NL group. All devices (A, B, and C) were associated with significantly higher intelligibility compared to ND, ranging from 5.9% (Stationary Amplifier B vs. ND) to 13.0% (Wireless Amplifier A vs. ND and Personal Communication System C vs. ND). The portable amplifier (A) and personal communication system (C) were both associated with higher intelligibility than the stationary amplifier (B; ~7% difference for both comparisons), but did not significantly differ from each other (A = C; ~0.3% difference). Overall, the observed hierarchy in no noise for the NL group was as follows: [personal communication system (C) = portable amplifier (A)] > stationary amplifier (B) > no device.

In the noise condition, the observed pattern for the NL group was the same as that for the PCP group in noise. That is, higher intelligibility was found for all devices (A, B, and C) compared to ND, as well as for the personal communication system (C) compared to all device conditions (A, B, and ND). Estimated differences compared to ND ranged from approximately 25% (both Amplifiers A and B vs. ND) to 64.1% (Personal Communication System C vs. ND). The personal communication system (C) was associated with nearly 40% higher intelligibility than both the portable (A: 38.5%) and stationary (B: 39.5%) amplifiers. The portable and stationary amplifiers (A and B) did not differ from one another (< 1% difference). The observed device hierarchy in noise for the NL group was likewise: personal communication system (C) > [portable amplifier (A) = stationary amplifier (B)] > ND. While the patterns between the two listener groups mirrored one another, the estimated marginal mean differences were larger in the NL group than in the PCP group (see Appendix Table 2).

Discussion

This study evaluated the effects of three amplification devices on intelligibility of spontaneous speech produced by individuals with hypophonia. Participants included 22 individuals with moderate-to-severe hypophonia who described pictures to a familiar PCP in quiet ("no noise") and in 65 dB SPL of noise ("noise"). Intelligibility scores were provided by these familiar partner listeners as well as by a group of NLs who heard and transcribed the utterances offline. These data extend findings from a larger project reported in Knowles et al. (2020), which reported on sentence reading intelligibility. Here, we discuss patterns observed in the current study and compare them with those from the sentence reading task.

Device and Noise Differences

The present study revealed a device hierarchy, indicating that the highest intelligibility was found for a personal one-way communication system (Device C). The other two amplifiers, a large stationary device (Device B) and a traditional portable belt-pack amplifier (Device A) did not significantly differ from one another in most cases but were generally found to be better performing than no device at all. This device hierarchy matched the one found in Knowles et al. (2020) for listener intelligibility of read sentences for these same talkers and listener groups. Intelligibility was, as expected, consistently higher across devices and listener groups in no noise compared to in noise. This is consistent with previous literature demonstrating that intelligibility declines in noise for talkers with PD both for read sentences (Chiu & Forrest, 2018) and conversational speech (Dykstra et al., 2012).

Even in noise, intelligibility with the one-way communication system (Device C) remained relatively high, as visible in Figure 1. This device, which provides a direct transmission of a talkers' speech to the listener via headphones, had the highest speech-to-noise ratio for read sentences across the three devices reported in Knowles et al. (2020). These acoustic advantages likely explain the consistent intelligibility benefit of this type of device over the more traditional amplifiers, especially in noise.

Differences Within Listener Groups

The device hierarchy and effects of noise were similar for both listener groups, though the baselines and magnitude of the effects differed between them. Familiar PCP listeners were overall more accurate than the unfamiliar NL group, and this difference was even more pronounced in the noisy adverse listening condition ("noise"). This difference is visible in Figure 1 and captured by the magnitudes of the model and pairwise estimates, though note we did not directly compare groups in the models.

On one hand, this observation that familiar listeners were overall more accurate than NLs, especially in noise, may be unsurprising. The PCP group, who sat across from the talkers, not only were more familiar with their own partners' speech patterns but also had access to visual cues not offered to the NLs who heard the recorded utterances later. Greater listener familiarity of a talker is associated with increased speech intelligibility in the literature (Borrie & Lansford, 2021; Borrie, McAuliffe, & Liss, 2012; Tjaden & Liss, 1995). Furthermore, being able to see a speaker's face is also well reported to aid speech perception (Grant & Seitz, 2000; Helfer, 1997; Schwartz et al., 2004; e.g., Van Engen et al., 2014).

However, this difference is also notable given the limitations of the listening task. PCP participants were, for the most part, older adults, some of whom had hearing loss, compared to a younger cohort of NLs with typical hearing. Older adults have been shown to be less accurate listeners and report lower comprehensibility compared to young and middle-aged adult listeners of typical talkers (Tuomainen et al., 2019) and of talkers with PD (Parveen et al., 2019), at least when perceiving auditory-only signals of unfamiliar talkers. In general, older adults have more difficulty understanding speech, especially in noisy listening environments, compared to younger adults (e.g., Schneider et al., 2000; Tun et al., 2002). When provided the opportunity to become familiarized with dysarthric speech, older and younger listeners show similar intelligibility gains, even when different at baseline (Lansford et al., 2018). These age-related challenges have been linked to changes in auditory and sensory processing (Cervera et al., 2009; Füllgrabe et al., 2015; Rajan & Cainer, 2008; Roberts & Allen, 2016), even in the presence of typical hearing thresholds. That is, age-related differences in intelligibility are driven by different cognitive mechanisms beyond age-related hearing changes (Ingvalson et al., 2017; Lansford et al., 2018). Taken together with the current results, this suggests the importance of studying how, exactly, more ecologically valid communication contexts and listener familiarity may compensate for other challenges associated with aging.

Another reason this difference is notable is that, due to the nature of the task, the NL group could have also become familiar with the content of the pictures being described. This would have aided the NLs but not the PCPs. The PCPs only heard their own partners' speech and, thus, did not have the benefit of potential familiarity with the picture description content afforded to the NLs who transcribed productions from all speakers. While care was taken to mitigate content familiarity for the NL group (e.g., in the choice of the picture stimuli and randomization of the presentation in the listening task), it may have occurred. Despite these challenges that could have disadvantaged the PCP listeners, they performed more accurately than the NL group in both noise conditions, a pattern consistent with that for read sentences reported in Knowles et al. (2020). This suggests that the actual benefit or effect size of being a familiar listener may actually be greater in real-life settings.

Speech Task Differences: Comparison With Knowles et al. (2020)

As stated above, the overall pattern of results across devices, noise, and listener groups was very similar in the present study compared to the sentence reading results reported in Knowles et al. (2020). That is, we did not find robust evidence of task-driven differences in these data. In order to make data-informed comparisons with the sentence reading results reported in Knowles et al. (2020), we combined both data sets, including intelligibility scores from both tasks and both listener groups pooled together.[1] Indeed, in this pooled data, we found no main effect of speech task, indicating that when listener group, noise condition, and device condition were held constant, speech task was not a robust predictor of intelligibility differences.

Previous literature suggests that when task differences do emerge in the speech intelligibility of people with PD, spontaneous speech intelligibility often tends to be lower than that of read speech (Johansson et al., 2022; Kempler & Van Lancker, 2002; Kent, 1996; Weismer, 1984; Yorkston & Beukelman, 1981). Our current findings, however, suggest a more nuanced difference. In fact, mean intelligibility in noise was actually lower for the SIT data reported in Knowles et al. (2020) compared to the spontaneous speech data reported here, especially for the NLs. The post hoc analysis of the pooled speech task and listener group data supported this observation: NLs were less accurate in transcribing the SIT sentences than the spontaneously spoken utterances for all three devices in Noise (see Supplemental Material S1).

It is possible that the context provided by the speaker during the picture description task aided the NLs compared to trying to understand semantically anomalous sentences, characteristic of the SIT. Semantic context, which increases the predictability of a spoken utterance, tends to aid speech understanding across varying levels and types of noise (Bradlow & Alexander, 2007; Dubno et al., 2000; Smayda et al., 2016; Van Engen et al., 2014) The findings on semantic context reflect differences when predictability is controlled across low- versus high-context sentences, though this effect may also persist when context is available in more naturalistic speech, such as in the picture description presented here. In the present study, references to the picture content were mentioned multiple times by multiple speakers, which could have benefited the NLs who heard utterances from all talkers and may have been better able to predict common themes. Explicit knowledge of the content being described has been shown to benefit listeners of talkers with PD describing pictures (Johansson et al., 2022), thus likely aiding the NLs in this task.

Another task difference that may be attributable to the NLs' performance is syntactic complexity. SIT sentences vary in their lexical characteristics and complexity (Stipancic et al., 2022), which was not explicitly controlled

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[1] We do not report on those pooled model results directly here and instead use them to inform comparisons across tasks and listener groups in the broader context of this project. Model results and pairwise comparisons from these pooled data sets can be found in Supplemental Material S1.

for in Knowles et al. (2020) or the current study. It is possible that, overall, utterances used by the current talkers to describe pictures may be structurally simpler than SIT sentences. Greater lexical and syntactic complexity has been associated with poorer speech intelligibility, especially when listening to more severely impaired speech severity in talkers with PD and in the presence of noise (Chiu & Forrest, 2018).

Comparison across both spontaneous speech and SIT sentences in the current studies suggests that the device hierarchy we report here is valid and robust, despite methodological differences between the tasks and potential content knowledge that could have aided the NLs. From the speakers' perspective, both the read sentences and the picture description tasks may have provided similar amounts of structure and thereby similar attentional demands, as has been suggested in previous reports of PD (Weir-Mayta et al., 2017). Our findings are also consistent with those of Tjaden and Wilding (2011) and Bunton and Keintz (2008), who found no differences between spoken monologues and read speech intelligibility provided by unfamiliar listeners of talkers with PD. It is worth mentioning, however, that our current findings reflect spontaneous speech elicited in a picture description task (in which a listener repeated the talker's utterances back to them), which differ from other spontaneous speech tasks such as monologues or true conversation.

Limitations

The current study presents a relatively small cohort of heterogeneous speakers with PD(+) and their PCPs. As discussed above, several methodological limitations warrant caution in interpretation. Importantly, the task demands imposed on the two listener groups differed in several ways, including modality, working memory demands, and access to repeated contextual clues. The two tasks were not designed to be identical listening tasks; rather, they were intended to reflect familiar listening and unfamiliar listening scenarios. One limitation, thus, is that these listening tasks are not directly comparable and differences between them go beyond solely the listener's familiarity with the speech.

We made several methodological decisions to mitigate the potential confounds of content familiarity for the NL group. First, as described in the Method section, the pictures were illustrations rich in detail chosen specifically to elicit a broad range of descriptions. Therefore, speakers' descriptions of the same scene varied substantially. For example, "The cop is a typical small town cop—overweight" (PD15) and "Policeman is sitting at the counter" (PD07) describe the same part of a scene from one picture. Note that this is distinct from a highly controlled picture description task in which pictures are designed to elicit specific words and phrases (e.g., Diapix pictures; Baker & Hazan, 2011). Second, the order of the pictures presented to speakers was fully randomized across conditions, so utterances the listeners heard varied in whether they appeared in noise and across devices. Third, listeners heard a subset of the utterances (up to six per condition), and these were fully randomized for the listeners within a noise condition.

During the speech production task, speakers may have subconsciously altered their productions based on how much they perceived their partner to understand or not understand. At the same time, this is likely more representative of how typical speech interactions occur and warrants future systematic study in PD. Previous research has demonstrated that specifically requesting clarification results in altered speech patterns in talkers with PD (Moon, 2005; Watkins, 2005), but more subtle changes in naturalistic speech that require the speaker to realize the listener has misunderstood them have not been investigated.

The small number of listeners is another potential limitation, though a growing body of evidence suggests that relatively few listeners are needed to obtain accurate estimates of intelligibility (Abur et al., 2019; Dahl et al., 2025). In particular, Dahl et al. (2025) found that a minimal acceptable threshold, defined as intelligibility estimates that deviated from a speaker's mean benchmark within a minimally detectable difference (Stipancic et al., 2016) at least 80% of the time, was achievable with a minimum of two inexperienced listeners transcribing at least nine SIT sentences. We acknowledge, however, that there is no current precedent for transcribing spontaneous speech. Determining best practices for spontaneous speech intelligibility testing remains a valuable direction for future research.

Finally, it is worth noting that intelligibility was scored as the number of words correctly uttered (by the PCPs) or transcribed (by the NLs); word order was not considered in the accuracy of the transcriptions. Nevertheless, future research investigating spontaneous speech perception should consider ways in which to control for or limit demands on working memory that could impact results.

Clinical Implications and Future Directions

A consistent hierarchy and benefit of amplification device use has been established in this cohort of speakers across speech acoustics and intelligibility (Knowles et al., 2020), as well as communicative participation and communicative effectiveness (Page et al., 2023). While the one-way personal communication system (Device C) was shown to exceed the performance of the other devices, all three devices provided benefit over no amplification, particularly in adverse listening conditions ("noise"). These speakers were selected as potential clinical candidates for amplification devices on the basis of moderate-to-severe hypophonia. Results provide further evidence to the clinical utility of speech amplification as an augmentative management tool for hypophonia. The personal communication system, in particular, has consistently demonstrated efficacy in comparison to the belt-pack and stationary amplifier options.

Integrating these findings with perspectives of speech-language pathologists treating this population, as reported in Gates and colleagues (Gates, Knowles, Mach, & Higginbotham, 2024; Gates, Knowles, Mach, Higginbotham, & Holder, 2024), underscores the potential clinical benefit of amplification devices for at least some clients with PD or Parkinsonism and moderate-to-severe hypophonia. Qualitative interviews with speech-language pathologists have suggested that amplification devices may be particularly helpful for those with PD who report challenges producing or maintaining louder speech in noisy environments or those with more advanced cognitive decline (Gates, Knowles, Mach, Higginbotham, & Holder, 2024). Future work will aim to integrate qualitative perspectives of individuals with hypophonia and their partners on the benefits and challenges associated with using a device. Longer term studies following the patterns of use would also aid in providing sustainable clinical recommendations. Future work should systematically evaluate the acoustic quality of such devices. This would aid in a better understanding of how amplification may or may not benefit speakers with different speech symptom clusters, as discussed in Gates, Knowles, Mach, and Higginbotham (2024).

Conclusions

This study investigated how speech amplification devices impacted spontaneous speech intelligibility for HP. Of the three devices studied, intelligibility was greatest when speech was transmitted through the personal communication system compared to the stationary and belt-pack amplifiers and compared to no device. This was especially true in noise compared to no noise and for NLs compared to familiar listeners. Findings replicate those reported in Knowles et al. (2020) of this same speaker cohort partaking in a sentence reading task. Results add to an increasing body of evidence supporting how speech amplification technology can support communication in individuals with pervasive hypophonia.

Data Availability Statement

The data sets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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Appendix (p. 1 of 2)

Model Output and Pairwise Comparisons

Table A1. Model output.

	Familiar primary communication partner listeners			Unfamiliar naive listeners		
Predictors	**Estimates**	**95% CI**	***p***	**Estimates**	**CI**	***p***
(Intercept)	97.95	[87.00, 108.89]	**< .001**	79.95	[68.72, 91.18]	**< .001**
Device A vs. B	−4.94	[−13.15, 3.27]	.238	−1.33	[−5.92, 3.27]	.572
Device A, B, vs. C	−0.34	[−4.85, 4.17]	.883	−0.51	[−3.09, 2.06]	.695
Device vs. No Device	−0.42	[−3.50, 2.66]	.790	−2.51	[−4.31, −0.71]	**.006**
Noise [Noise vs. No Noise]	−14.32	[−22.22, −6.41]	**< .001**	−31.09	[−35.57, −26.61]	**< .001**
Sentence length	−1.71	[−2.36, −1.06]	**< .001**	−0.70	[−1.08, −0.33]	**< .001**
Device A vs. B × Noise [Noise vs. No Noise]	6.90	[−4.70, 18.49]	.243	−1.70	[−8.33, 4.92]	.614
Device A, B, vs. C × Noise [Noise vs. No Noise]	7.29	[0.81, 13.77]	**.027**	14.29	[10.61, 17.98]	**< .001**
Device vs. No Device × Noise [Noise vs. No Noise]	−1.82	[−6.13, 2.48]	.407	−7.82	[−10.31, −5.33]	**< .001**
Device A vs. B × Sentence length	0.58	[−0.35, 1.51]	.219	−0.27	[−0.79, 0.25]	.310
Device A, B, vs. C × Sentence length	0.10	[−0.42, 0.63]	.699	0.19	[−0.11, 0.49]	.210
Device vs. No Device × *n* words sentence	−0.12	[−0.46, 0.22]	.482	−0.01	[−0.21, 0.18]	.884
Noise [Noise vs. No Noise] × Sentence length	0.06	[−0.84, 0.96]	.895	0.16	[−0.35, 0.68]	.529
(Device A vs. B × Noise [Noise vs. No Noise]) × Sentence length	−0.48	[−1.78, 0.82]	.468	0.58	[−0.16, 1.32]	.125
(Device A, B, vs. C × Noise [Noise vs. No Noise]) × Sentence length	−0.39	[−1.15, 0.37]	.317	−0.29	[−0.72, 0.14]	.190
(Device vs. No Device × Noise [Noise vs. No Noise]) × Sentence length	−0.07	[−0.55, 0.41]	.782	0.11	[−0.16, 0.39]	.422
Random effects						
σ^2	437.03			618.42		
τ_{00}	464.44 $_{\text{participant.std}}$			22.12 $_{\text{order\_n}}$		
	4.07 $_{\text{utteranceID}}$			546.26 $_{\text{participant.std}}$		
				15.46 $_{\text{listener.std}}$		
ICC	0.52			0.49		
N	21 $_{\text{participant.std}}$			21 $_{\text{participant.std}}$		
	14 $_{\text{utteranceID}}$			4 $_{\text{listener.std}}$		
				91 $_{\text{order\_n}}$		
Observations	870			3,855		
Marginal R^2/Conditional R^2	0.120/0.575			0.296/0.638		

Note. Estimates reflect % correct intelligibility scores for familiar primary communication partner listeners (left) and naive listeners (right). Bolded values reflect *p* values less than .05. CI = confidence interval; Device A = portable belt-pack amplification device; Device B = stationary wireless amplification device; Device C = one-way personal communication system; ICC = intraclass correlation coefficient.

Appendix (p. 2 of 2)

Model Output and Pairwise Comparisons

Table A2. Pairwise comparisons between devices for the familiar primary communication partner listeners (left) and unfamiliar naive listeners (right) models for spontaneous speech intelligibility.

Familiar primary communication partner listeners						**Unfamiliar naive listeners**			
Device contrast	**Noise**	**Estimate (% words correct)**	***SE***	***t* ratio**	***p* value**	**Estimate (% words correct)**	***SE***	***t* ratio**	***p* value**
A - B	No Noise	0.296	2.831	0.104	> .999	7.062	1.645	4.293	< .001
A - C	No Noise	–1.401	2.859	–0.490	.961	0.313	1.681	0.186	.998
A - No Device	No Noise	5.328	2.827	1.884	.235	12.990	1.666	7.797	< .001
B - C	No Noise	–1.697	2.899	–0.585	.937	–6.750	1.718	–3.929	.001
B - No Device	No Noise	5.032	2.880	1.747	.3	5.928	1.709	3.468	.003
C - No Device	No Noise	6.729	2.872	2.343	.089	12.678	1.726	7.344	< .001
A - B	Noise	–5.572	2.864	–1.945	.21	0.963	1.706	0.564	.943
A - C	Noise	–16.633	2.904	–5.728	< .001	–38.519	1.710	–22.522	< .001
A - No Device	Noise	7.817	2.892	2.703	.035	25.564	1.708	14.967	< .001
B - C	Noise	–11.061	2.884	–3.836	.001	–39.481	1.680	–23.507	< .001
B - No Device	Noise	13.389	2.869	4.667	< .001	24.601	1.682	14.624	< .001
C - No Device	Noise	24.450	2.896	8.444	< .001	64.082	1.711	37.463	< .001

Note. Estimates reflect differences in % words correct. Device A = portable belt-pack amplification device; Device B = stationary wireless amplification device; Device C = one-way personal communication system.