EVALUATING THE EFFECT OF INSTRUCTION AND TASK ON THE ACOUSTIC CHARACTERISTICS OF SPEECH PRODUCTION IN OLDER ADULTS

by

Natasha Marie Swink

A Thesis Submitted to the Faculty of the

DEPARTMENT OF SPEECH, LANGUAGE, AND HEARING SCIENCES

In Partial Fulfillment of the Requirements

For the Degree of

MASTER OF SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

2017

STATEMENT BY AUTHOR

The thesis titled *Evaluating the Effect of Instruction and Task on the Acoustic Characteristics of Speech Production in Older Adults* prepared by *Natasha Swink* has been submitted in partial fulfillment of requirements for a master's degree at the University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the Library.

Brief quotations from this thesis are allowable without special permission, provided that an accurate acknowledgement of the source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the Graduate College when in his or her judgment the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED: *Natasha Swink*

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

________________________________	April 17th, 2017
Kate Bunton, PhD, CCC-SLP *Associate Professor*	Date
________________________________	April 17th, 2017
Meghan Darling-White, PhD, CCC-SLP *Assistant Professor*	Date

ACKNOWLEDGEMENTS

This thesis would not have been possible without the compassion, kindness, patience, and immeasurable expertise of my committee. You created the most supportive environment imaginable. I cannot thank you enough:

Dr. Kate Bunton
Dr. Meghan Darling-White
Dr. Brad Story
Dr. Nicole Marrone

I also owe great thanks to my wonderful participants who shared with me lovely, and at times harrowing, tales of their lives past, present, and future.

DEDICATION

For M. L. Ferguson,
Who encouraged me to be steadfast and strong and taught me that one’s beauty and limitless potential is made manifest when they renounce fear and embrace love.
On January 12th, 2015, he experienced a severe traumatic brain injury following a terrible motorcycle accident. It left him much altered from the man I once knew and loved.
He sent me this letter on June 1st, 2013.

“I’m never going to give up on you.
I know you.
I’m proud of you.
I love you.
Hear me!

Like the first time, do you remember it? Take yourself back to that place and moment where the universe wrote a single fermata into the score of time on our account alone.

Let the miniscule hairs that line your ears stand at attention, stretching themselves ever forth in anticipation of their calling. Imagine their yearning, like a field of grass where no wind has blown for time immemorial, reanimated by a gust of sweet wind. Like the desert where our childish hearts wandered, when it swells with water suddenly and without warning, moving everything in its path and bringing life, the gift of a short and furious attempt to stretch forth from the dust that previously obscured its true colors.

Can you hear me? I love you, stand still. Remember the meaning this time.

We withhold ourselves. We call ourselves awkward and insecure. Stumbling like toddlers overwhelmed by the forces of the natural world ever opposing their uncertain little bodies, yet to have gained the strength, but inevitably destined to walk.

Aren’t we treading new ground together? Though we occasionally see the relics and ruins of the places where we have previously gone seeking shelter, none of those hearths held warmth, none of those paths led anywhere, not a single one of those companions stayed at our side.

You set me free every day. It’s a new feeling. I sometimes don’t know how to regard it and I make a fool of myself. Believe that you are never the enemy at those times. The enemy is the misunderstanding and its master is the fear.

You’re my soulmate. I cherish you. Please won’t you stay awhile longer?

Love,
M”

TABLE OF CONTENTS

LISTS OF TABLES AND FIGURES

Abstract

Older adults often experience hearing loss in one or both ears, and as a result, many participate in aural rehabilitation programs. Often these programs incorporate communication partners and train them to use compensatory strategies. One common compensatory strategy cited is encouraging communication partners to speak more clearly to their loved one with hearing loss. Clear speech often encompass several different strategies such as speaking slower, louder, or over-articulating. However, it is unclear what acoustic changes talkers employ when cued to speak in these different ways. The present study evaluated the effect of different cues (i.e., control (habitual), clear, slow, loud, and over articulate) and speaking tasks (oral reading versus monologue) on the acoustic characteristics of speech produced by eight older adults with hearing in the normal range. All speech was recorded in a sound treated booth and analyzed acoustically along six dimensions: articulation rate, percent change in fundamental frequency from control, change in sound pressure level from control, voice range density area, vowel space density area, and cepstral peak prominence. Results revealed statistically significant acoustic changes between conditions for all six acoustic measures. There was also significant effect of task for three acoustic measures. Findings show both group trends as well as individual talker variability. Further research is needed to determine how the acoustic changes associated with different instructional cues negatively or positively impact listeners with hearing loss.

Introduction

The *U.S. Census Bureau* reports that the number of individuals over 65 years of age has more than doubled in the last 50 years, and is projected to increase substantially over the next three to four decades (West, Cole, Goodkind, & He, 2014). Since nearly 45% of the individuals over age 65 having hearing loss in one or both ears (Cruickshanks et al., 1998), it is predicted that the number of older adults in need of hearing assistance and aural rehabilitation will also increase (Goman, Reed, & Lin, 2017). Given these projections, it is important to have clearly defined, evidence-based treatments that focus on increasing effective communication in an ecologically valid manner. Hearing aids and other assistive listening devices are able to provide a considerable benefit to their users. However, without the proper training and communication rehabilitation after fitting, patients with hearing loss using hearing aids may have lower functional outcomes than those who have been involved in some form of aural rehabilitation program (Boothroyd, 2007). Additionally, some studies have found that in the long-term, combined sensory management and group rehabilitation is the most cost-effective treatment paradigm for patients with hearing loss (Abrams, Chisolm, & McArdle, 2002)

Some aural rehabilitation programs focus on auditory-perceptual training modules, to target improvement in auditory skills for the hearing aid user (Boothroyd, 2007). Others, incorporate spouses and other caregivers in the process. These rehabilitation approaches that are aimed at counseling and educating communication partners about hearing loss focus on utilizing compensatory strategies (e.g., limiting noise when communicating, sitting on the side of the better ear). Strategies common in these programs to maximize communicative effectiveness utilize modification of the environment, introduction of a topic/key words, and changes in speech production behaviors for both communication partners. Current evidence on the effectiveness of these programs to improve communication between individuals with hearing loss and their partners, however, is limited (Preminger, 2003; Preminger & Meeks, 2010).

The idea of a communication partner speaking “clearly” to an individual with hearing loss has been present in the literature for some time, and is a commonly used speech modification strategy in rehabilitation programs; however, there is little evidence regarding the efficacy of this compensatory strategy. Research focused on clear speech has been performed with a wide range of ages, those with hearing loss and without, and even individuals with dysarthria secondary to neurodegenerative diseases or acquired brain injury. Some studies have shown that there are significant acoustic differences between habitual and clear speech for typical adult talkers (Ferguson, 2004; Krause & Braida, 2004; Lam & Tjaden, 2013).

Among the most prominent acoustic modifications in clear speech are changes in fundamental frequency, sound pressure level, speech and articulation rate, vowel dispersion, vowel duration, dynamic formant movement in vowels, voice range profile, voice onset time (VOT) for voiceless stop consonants, energy levels in long term spectra, short-term vowel spectra, frequency of stop burst releases (Ferguson & Kewley-Port, 2002; Krause & Braida, 2004, 2009). Decreased articulation rate is commonly associated with clear speech conditions (Picheny, Durlach, & Braida, 1986). Increased fundamental frequency and a higher second formant (F_2; in front vowels) as well as longer vowel durations and expanded vowel space area have also been observed in clear speech conditions (Ferguson & Kewley-Port, 2002). Other acoustic factors that may contribute to improved clarity include increased energy in the 1000-3000 Hz range of long-term spectra, increased depth of low frequency modulations of the spectral envelope, increased VOT for voiceless consonants, increased energy for the second and third formants (F_2, F_3) in short-term spectra, and an increased number of released word-final stop bursts (Krause & Braida, 2004; Picheny et al., 1986).

Research describing the clear speech of typical older adults exists, however, the small number of studies and participants is insufficient to draw conclusions about modifications to speech production for typical older adults (Caissie et al., 2005). In addition, the majority of research examining the acoustic characteristics of clear speech has been based on production of limited speech tasks including; non-words, real single words, real and nonsense sentences, and reading passages (Ferguson, 2004; Ferguson & Kewley-Port, 2002; Lam & Tjaden, 2013; Picheny, Durlach, & Braida, 1985; Picheny et al., 1986). These tasks elicit limited speech and thus, may allow participants to utilize an ideal clear speech that is not representative of how they would produce clear speech during a true communication exchange. Spontaneous speech samples for older adults have not been included in acoustic analyses across clear and habitual conditions, to date. Obtaining data and analyzing the acoustic characteristics of spontaneous speech of older adults will advance our knowledge about clear speech in naturalistic communication contexts, and improve the ecological validity of aural rehabilitation recommendations regarding clear speech as a strategy to improve communicative effectiveness.

Another limitation in the current literature is the type of participants used in the studies. Since the spouses of older adults with hearing loss are also typically older individuals, it is imperative that changes to speech production as a result of clear speech be examined in this population in order to determine if talkers are capable of producing the changes in speech production reported for younger talkers as well as whether their attempts at speaking more "clearly" provide an intelligibility benefit to older listeners with hearing loss.

Although there is currently limited evidence on the specific benefits to intelligibility that clear speech can provide to listeners with hearing loss, there has been preliminary research on the clear speech benefit to listeners with hearing ability within the clinically normal range. One study found that there was a wide array of benefit obtained from clear speech conditions for normal hearing adult listeners, with the maximum benefit coming from cueing the talker to over-enunciate during speech production (Lam & Tjaden, 2013). Similarly, Ferguson (2004) examined vowel intelligibility for adult talkers and listeners without hearing loss, and found that clear speech conditions provided a statistically significant benefit to listeners in their ability to correctly identify vowels in CVC words and stimuli from the Central Institute for the Deaf (CID) Everyday Sentences test. Though these studies provide promising data, the scope is limited to specific stimuli, and to listeners whose hearing ability is within the normal range. To our knowledge, the only study that examined the benefits of clear speech on vowel intelligibility for young adults with normal hearing and older listeners with hearing loss found that clear speech conditions were actually a detriment to vowel identification for listeners with hearing loss (Ferguson & Kewley-Port, 2002). In particular, identification of front vowels was negatively impacted by the clear speech conditions. This was not found to be true in the young individuals with normal hearing, and was not seen in conversational conditions for either group. Thus, drawing conclusions about the potential benefits of clear speech from recordings presented to young adult listeners is problematic.

Current literature about clear speech has revealed that while there are overall trends showing significant differences between habitual and clear speech, the types of strategies used and speaking tasks to elicit acoustic output varies greatly across studies and participants. However, there are some characteristics that are considered common components of clear speech, which are speaking slowly, loudly, and over-articulating or enunciating as compared to habitual speech. When providing instructions for clear speech, researchers have historically instructed individuals with a combination of cues, including speak slower, exaggerated articulation, and speak louder (Dromey & Ramig, 1998; Lam & Tjaden, 2013; Tjaden, Sussman, & Wilding, 2014). However, it is unknown if one of these cues is better than another or if the combination of these cues for clear speech is most beneficial for adult listeners with hearing loss. Therefore, further research is needed to examine which cue, if any, changes the acoustic output of speech production in older adults in a potentially beneficial way for their communication partner with hearing loss. This study attempts to tackle the first part of this gap in the literature with a focus on the acoustic characteristics of speech production.

Purpose Statement

The purpose of the current study was to establish the effect of instruction on acoustic characteristics of speech production for older adults with excellent hearing sensitivity. As a secondary goal, we examined the impact of two connected speaking tasks (reading vs. spontaneous speech) on speech production in the different cued conditions. The following research questions were addressed:

1. How does the type of instruction (i.e., cues for control (habitual), clear, slow, over articulate, loud speech) impact spectral and temporal acoustic characteristics of speech production in older adults with normal hearing ability?
2. Is there a statistically significant effect of speaking task (reading vs. spontaneous speech) on these acoustic characteristics of speech?

Method

The methods utilized in this study were approved by the Institutional Review Board at the University of Arizona.

Participants

Eight talkers participated in the study, seven of whom had participated in prior research at the University of Arizona. At that time, they gave consent to be contacted for future research in the Department of Speech, Language, and Hearing Sciences. The eighth participant was the spouse of one of the seven who had previously participated. Participant characteristics are shown in Table 1, including gender, age, and educational level. The group consisted of one male and seven female participants, between 64 and 70 years of age, all with college-level educational backgrounds. Participants were required to have air conduction thresholds no greater than 25 dB HL in their better hearing ear at frequencies of 0.5, 1, 2, and 4 kHz. All participants completed a short background survey with questions about prior speech, language, or hearing disorders, current neurological status, and languages spoken. Participants self-reported no history of speech, language, and hearing disorders as well as no neurological disease that could impact performance on speech tasks.

Table 1: Age, Sex, and Education of participants

Participant	Sex	Age (years)	Education Level
1	Female	68	Associate's Degree
2	Female	67	Master's Degree
3	Female	69	2 Years College
4	Male	69	Doctoral Degree
5	Female	64	Doctoral Degree
6	Female	65	Master's Degree
7	Female	70	Master's Degree
8	Female	69	Master's Degree

Speech Tasks

Two different speech tasks were completed across the five conditions for all participants: a monologue sample and oral reading. For the monologue task, participants were instructed to speak on a topic of their choice for approximately two minutes. The experimenter provided sample topics to each participant. Suggested topics included the following: family, (former) career/occupation, favorite vacation, hobbies, favorite or recently seen movie. For the reading task, participants read aloud The Caterpillar passage (Patel et al., 2013), which consists of 197 words in sentences of varying type (i.e., statement, interrogative, exclamation), with a Flesch-Kincaid 5th grade reading level.

Equipment

All recordings were collected in a sound treated room. The recordings were obtained using an AKG CS420 head mountable microphone with a mouth to microphone distance of 6 cm and a digital recording system (ZOOM, H5 HandyRecorder). A 1000 Hz calibration tone was recorded at the start of each session.

Experimental Procedures

All tasks were performed in a sound treated booth to eliminate acoustic interference and protect the integrity of the audio recordings. The experimenter sat inside the sound booth with the participants in order to instruct and monitor productions, as well as manage recording equipment. The experimenter did not offer feedback, positive or negative, and presented with a neutral demeanor. When participants requested additional instruction beyond the designated cue, the experimenter offered to repeat the cue, and informed them that no additional information could be offered.

Participants completed each speech task in five different instruction conditions, for a total of 10 speech samples per participant (2 tasks x 5 conditions). The order of the speech tasks was counterbalanced across conditions. Conditions included control/habitual, clear, slow, loud, and over articulate. Table 2 contains the cues provided to the participants corresponding to each condition.

Table 2: Experimental conditions and corresponding verbal cues

Condition	Cue/Verbal Instruction
Control	"I would like you to speak as you normally would, such as having a conversation with a friend."
Clear	"Now, I would like you to imagine that this room is very noisy, and speak as clearly as you can."
Slow	"Now, I would like you to speak at what feels like half your normal speed." (Dromey & Ramig, 1998)
Loud	"Now, I would like you to speak twice as loud as normal." (Dromey & Ramig, 1998)
Over articulate	"Now, I would like you to over articulate or exaggerate the movement of your mouth when you speak." (Tjaden et al., 2014)

The control condition was always first, followed by the clear condition. The other experimental conditions were randomly ordered across participants in order to limit the effects of the other cued conditions on the clear condition. Each experimental session lasted no longer than one hour and participants were offered a cup of water, which they kept with them in the sound booth during the session.

Acoustic Analysis

The acoustic analysis software PRAAT (Boersma & Weenink, 2016) was used to segment the speech samples for each condition and task, as well as clip and delete any portions in which the experimenter was speaking, prior to running analyses. The mean length of the reading task was 94.5 sec and the mean length of the monologue task was 148.9 sec. All speech samples were analyzed using custom Matlab scripts (B. Story; Mathworks, 2017). There were 10 audio files

(*.wav) per participant (5 conditions X 2 tasks), each with a sampling frequency of f_s = 44,100 Hz and 16-bit amplitude resolution. Each file was processed with the following steps:

1. A periodicity detector based on the autocorrelation of overlapped 23 ms windows was used to find all segments of the signal that contained voicing. All subsequent analyses were performed only on these voiced segments. This analysis allows for determining location and duration of pauses.
2. The fundamental frequency, f_o, was determined with a cycle detection algorithm that measured the period of each consecutive glottal cycle in each file.
3. Amplitude in decibels (dB SPL) was determined by first multiplying the signal by the calibration factor obtained during the previously-described calibration procedure. Then the root mean square (RMS) value of the pressure signal (P_{RMS}) was calculated within consecutive, overlapped 23 ms windows and converted to dB SPL with $20\log_{10}(P_{RMS}/P_{ref})$ where P_{ref} = 0.00002 Pa.
4. Formants, F_1 and F_2, were tracked throughout all voiced segments of each signal. This was accomplished by first down-sampling each signal such that f_s= 10000 Hz, applying an autocorrelation-type linear predictive coding (LPC) algorithm to generate an estimate of the vocal tract frequency response, and finally finding the frequencies of the first two formant peaks with a parabolic peak-picking technique (Titze, Horii, & Scherer, 1987). The LPC analysis was based on overlapped 40 ms windows tapered at the left and right ends with a Gaussian window function (alpha = 2.5) to provide formant values every 5 ms.
5. A smoothed version of the cepstral peak prominence (CPPS) was determined across the duration of each signal (Hillenbrand & Houde, 1996). For consecutive 92.9 ms windows,

> the real cepstrum (spectrum of a spectrum) was first calculated and then smoothed with a 30 point averaging filter. A linear regression line was then fit to the smoothed cepstrum, and the amplitude of the peak corresponding to the fundamental period in the smoothed cepstrum and its location along the quefrency axis was found with a peak detector. The difference between the peak value and the regression line at the same quefrency was logged as the value of CPPS.

Based on the results of the analyses of voicing, fundamental frequency, dB SPL, and formants, several metrics were assessed for each speech sample. The following were the primary acoustic characteristics of interest:

Articulation rate. Each recording time was measured from onset of speaking to completion. Pauses with durations greater than 0.3 seconds were removed, and rate of articulation was calculated in units of syllables per second for the length of the sample.

Percent f_0 change. Mean fundamental frequency in Hertz for each participant was calculated in each condition and task and allowed for calculation of percent difference between control f_0 and f_0 in experimental conditions. Percent change was used to allow for comparison across participants.

SPL change. Mean sound pressure level (SPL) was measured for each participant in all tasks and conditions which allowed for calculation of a difference in sound level (dB SPL) for control speech versus experimental conditions.

Voice range density (VRDn). The SPL and f_o values were normalized to their median values, and f_o was converted to semitones. These values were utilized to plot a normalized voice range density plot (Story & Bunton, 2016, 2017) based on the entire speech sample. In a grid spanning the range from -6 to 6 semitones in the horizontal dimension, and from -6 to 6 dB in the vertical dimension, the number of [f_o, SPL] pairs present within a radius of 0.1 from every point in the grid were counted and assigned to the corresponding grid point as a density value. All density values were then normalized to the maximum density present across the grid so that the maximum density is always equal to 1.0. Plotted as a color map that varies from dark blue for low density, to red indicating high density, the voice range density provides a view of how the talker distributed their fundamental frequency and SPL over the duration of the file. Each voice range density plot was quantified by finding area enclosed by a convex hull at a density level of 0.25. In this case, the area measurement has units of dBHz.

Vowel space density (VSDn). Based on the first and second formant frequencies (F_1, F_2) that were measured across all voiced segments across the duration of the sample, a vowel space density plot was determined (Story & Bunton, in press, 2016, 2017). The first step was to normalize the formant values relative to the median such that $F_n^* = (F_n\text{-}F_n^{median})/F_n^{median}$ where n is the formant number; this process allows for comparison across talkers, genders, age, etc. A grid was then generated spanning a range from -1 to 1 along both the horizontal and vertical axes with an increment of 0.01. At every point in the grid, the [F_1^*, F_2^*] pairs that were located within a radius of 0.075 were counted and logged as the density value associated with the specific grid point. The density values were normalized to the largest density value so that the maximum was always 1.0. Vowel space density plots were generated for each task and condition. Similar to the voice range profile, the density of the normalized formant pair across each sample were plotted on the x and y axes, with color differentiation to represent density of the vocalic productions in the normalized vowel space over the duration of the file. Again, dark blue represented low density and red represented high. This allowed for discrimination between a talker's tendency to centralize (small, narrow vowel space) or disperse (large, wide vowel space) vowels.

Cepstral peak prominence – smoothed (CPPS): The CPPS is a number that indicates the degree of periodicity present in the acoustic signal measured in dB. A low number suggests a significant aperiodic spectral component such as would be expected in a breathy or rough voice, whereas a high number indicates that most of the energy is in the harmonic components.

Statistical Analysis

A two-way repeated measures analysis of variance (ANOVA) was used to investigate differences for six acoustic measures as a function of task and condition. The acoustic measures included: articulation rate, percent change in f_o, change in dB SPL, VPDn area, VSDn area, and CPPS. The between-participants factor of task consisted of two levels: reading and monologue. The within participant repeated measure of condition consisted of five factors: control, clear, slow, loud, and over articulate. Following a significant main effect of task, condition, or a significant interaction, post hoc analyses were completed. The alpha level for main effects was set at 0.05. Based on a Bonferroni correction, the alpha level for post hoc analyses was set at .003.

Results

Articulation Rate

Articulation rate by participant for the reading task is shown in Figure 1 and for the monologue task in Figure 2. For articulation rate, the main effect of task (monologue versus reading) was not statistically significant, ($F(1, 7) = 0.298$, $p = .602$). The main effect of experimental condition, however, was statistically significant ($F(4, 28) = 19.823$, $p < .001$). Pairwise comparisons showed significant statistical differences in articulation rate between the control and slow conditions ($p = .001$), clear and over articulate conditions ($p = .002$), clear and slow conditions (*p* = .000), and loud and slow conditions (*p* = .002). Participants utilized significantly slower articulation rates in the slow condition (*M* = 2.97 syll/sec, *SD* = 0.34) as compared to the control (*M* = 3.80 syll/sec, *SD* = 0.27), clear (*M* = 3.94 syll/sec, *SD* = 0.29), and loud (*M* = 4.15 syll/sec, *SD* = 0.50) conditions. Participants utilized significantly slower articulation rates in the over articulate condition (*M* = 3.44 syll/sec, *SD* = 0.44) as compared to the clear condition (*M* = 3.94 syll/sec, *SD* = 0.29).

The interaction between task and condition was also statistically significant (*F*(4, 28) = 6.519, *p* = .001). There were no statistically significant pairwise comparisons for the task by condition interaction effect. Based on mean data, participants increased articulation rate in the control (Reading: *M* = 3.89 syll/sec, *SD* = 0.27; Monologue: *M* = 3.70 syll/sec, *SD* = 0.25) and loud (Reading: *M* = 4.29 syll/sec, *SD* = 0.39; Monologue: *M* = 4.00 syll/sec, *SD* = 0.57) conditions, maintained articulation rate in the clear condition (Reading: *M* = 3.95 syll/sec, *SD* = 0.26; Monologue: *M* = 3.92 syll/sec, *SD* = 0.35), and decreased articulation rate in the slow (Reading: *M* = 2.89 syll/sec, *SD* = 0.39; Monologue: *M* = 3.05 syll/sec, *SD* = 0.31) and over articulate (Reading: *M* = 3.36 syll/sec, *SD* = 0.52; Monologue: *M* = 3.51 syll/sec, *SD* = 0.37) conditions during the reading task as compared to the monologue task. The following paragraphs describe the individual participant trends based on the mean data for each task and condition.

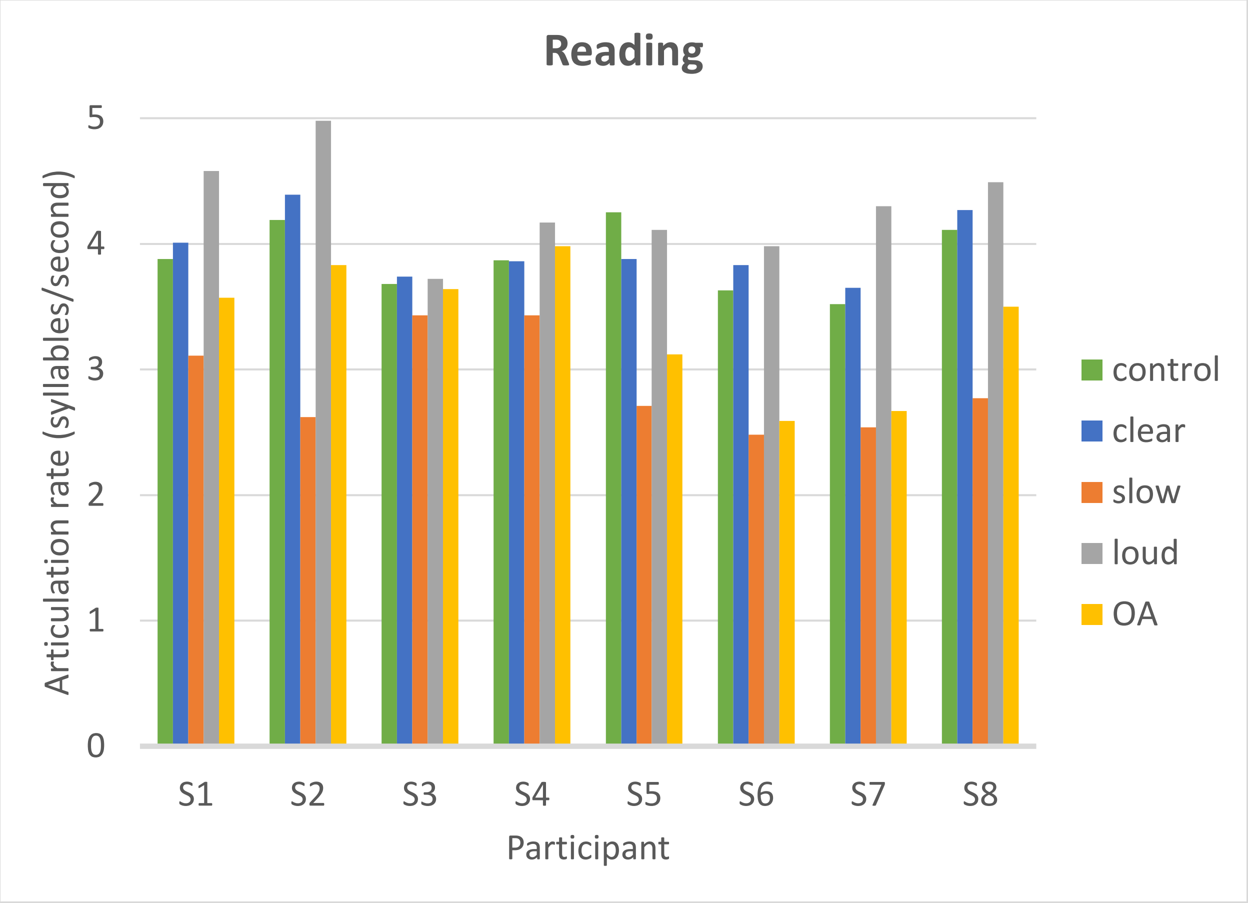

Figure 1: Articulation rate in syllables/second by participant and condition for the reading task. OA refers to the over articulate condition.

In the reading task, six of the eight participants (S1, S2, S3, S6, S7, and S8) increased their articulation rate for the clear speech condition, compared to the control condition (Figure 1). Similarly, all participants with the exception of one (S5), increased articulation rate for the loud condition. Trends in the opposite directions were observed for slow and over articulate conditions, as all participants reduced articulation rate in the slow condition and all but one participant (S4) reduced their rate of articulation in the over articulate condition.

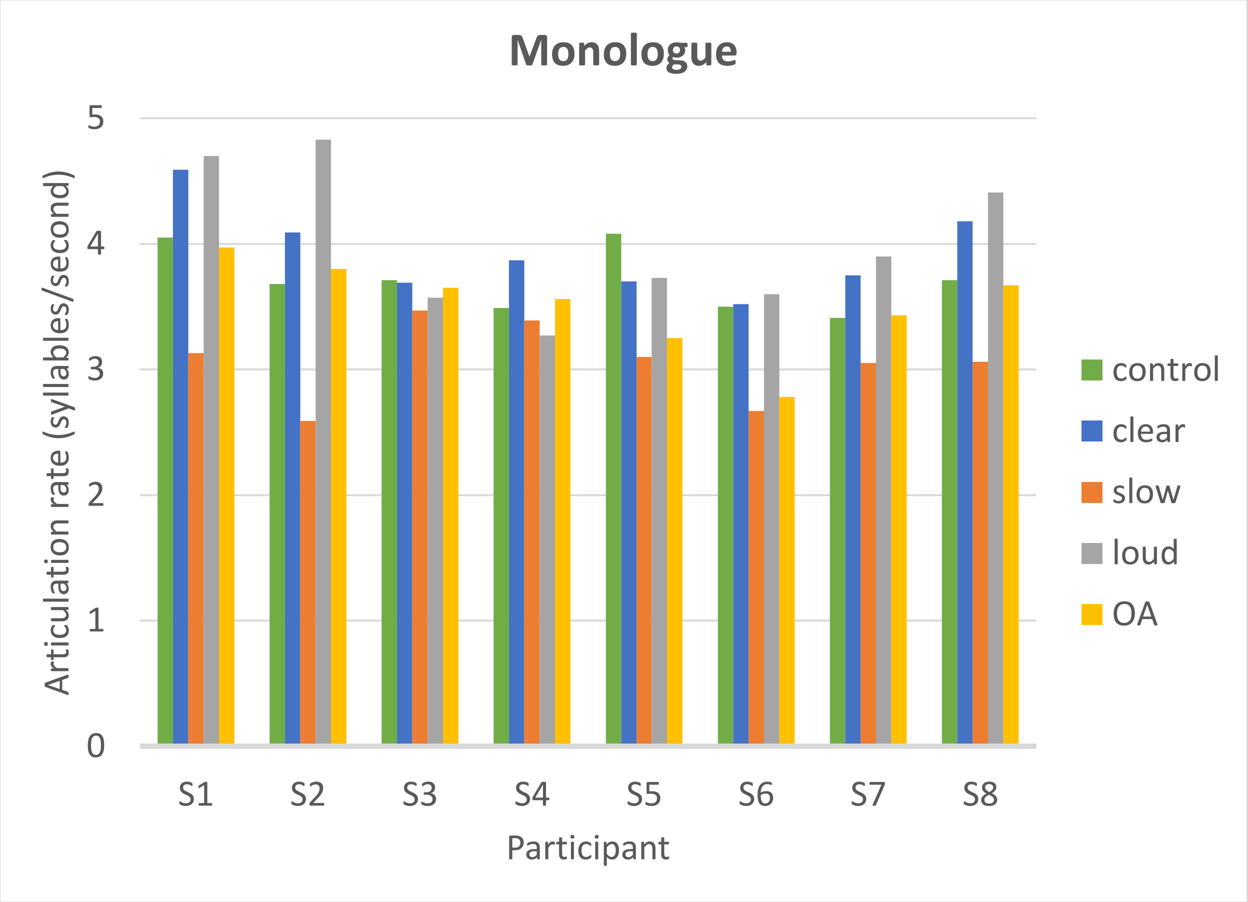

Figure 2: Articulation rate in syllables/second by participant and condition for the monologue task. OA refers to the over articulate condition.

Similar to the reading task, six of the eight participants (S1, S2, S4, S6, S7, and S8) increased their articulation rate for the monologue task in the clear speech condition, relative to the control condition (Figure 2). Five of these participants also increased their articulation rate during the reading task in the clear condition. Five participants (S1, S2, S6, S7, and S8) increased articulation rate and three participants (S3, S4, and S5) decreased articulation rate in the loud monologue compared to control. All participants reduced their rate of articulation in the slow condition as compared to their control condition monologue. While nearly all participants reduced their articulation rate in the over articulate condition during the reading task, only five participants (S1, S3, S5, S6, and S8) reduced their articulation rate during the monologue task.

Percent Fundamental Frequency (f_o) Change

Percent change in f_o relative to the control condition, by participant, can be seen in Figure 3 for the reading task and in Figure 4 for the monologue task. A decrease in f_o relative to the control condition is shown as a negative number (bars that extend below the zero line) and increase is shown as positive numbers (bars above the zero line). Percent change in f_o, for the main effect of task (monologue versus reading) was not statistically significant, ($F(1, 7) = 3.329$, $p = .111$). However, the main effect of experimental condition was statistically significant ($F(4, 28) = 13.826$, $p < .001$). Pairwise comparisons revealed no statistically significant differences between conditions. Mean data indicate that participants decreased their f_o in the slow condition ($M = -4.21\%$, $SD = 7.50$) and increased their f_o in the clear ($M = 9.98\%$, $SD = 12.23$), loud ($M = 24.28\%$, $SD = 18.11$), and over articulate ($M = 11.37\%$, $SD = 12.13$) conditions relative to the control condition.

The interaction between task and condition was also found to be statistically significant ($F(4, 28) = 5.101$, $p = .003$). There were no statistically significant pairwise comparisons for the task by condition interaction effect. Based on mean data, participants decreased their f_o in the reading task as compared to the monologue task in the slow condition (Slow: Reading: $M = -4.88\%$, $SD = 7.14$; Monologue: $M = -3.55\%$, $SD = 4.81$) and increased their f_o in the reading task as compared to the monologue task for all other cued conditions compared to the control condition (Clear: Reading: $M = 14.99\%$, $SD = 14.33$; Monologue: $M = 4.98\%$, $SD = 7.60$; Loud: Reading: $M = 29.81\%$, $SD = 21.24$; Monologue: $M = 18.76\%$, $SD = 4.75$; and Over articulate:

Reading: *M* = 12.83%, *SD* = 13.09; Monologue: *M* = 9.92%, *SD* = 11.79). The following paragraphs describe the individual participant trends based on the mean data for each task and condition.

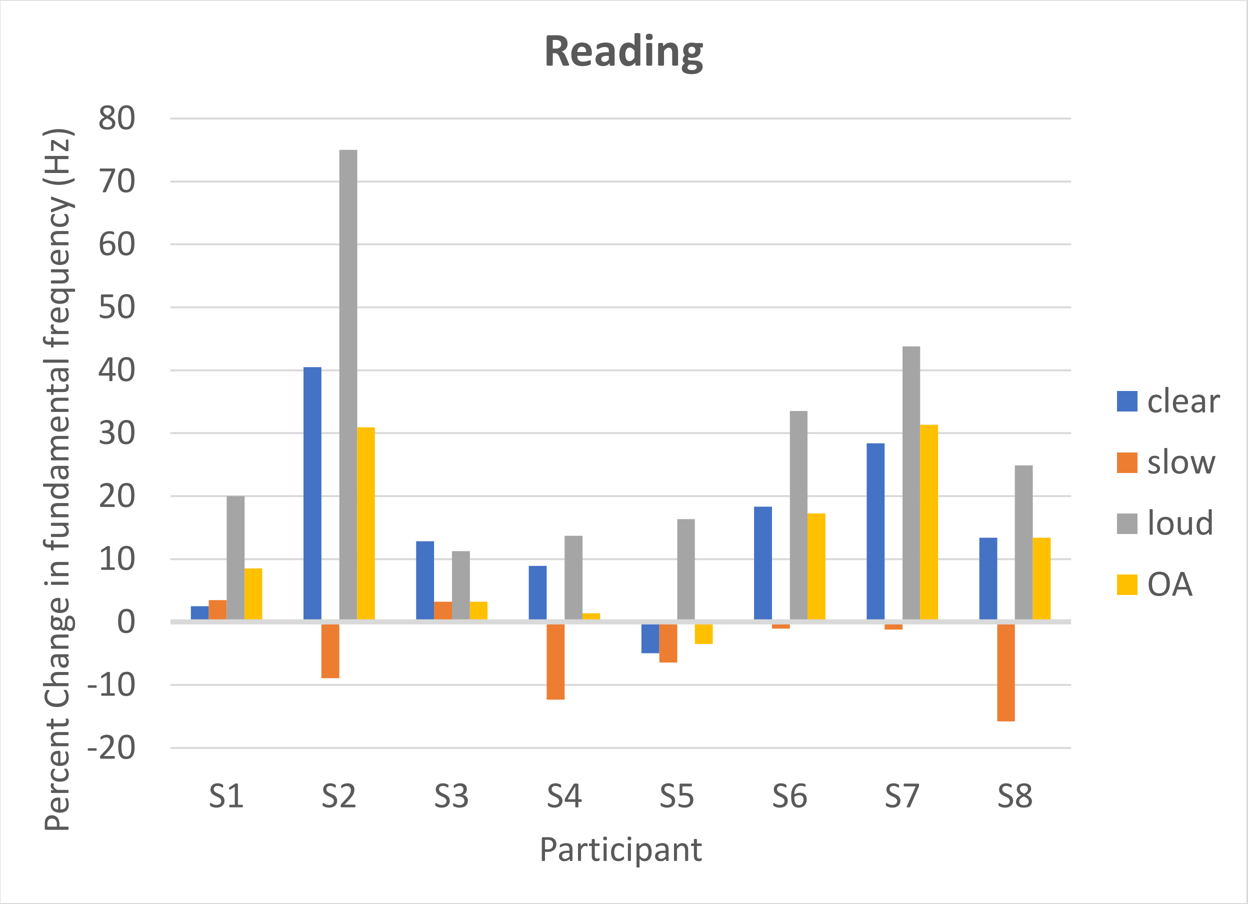

Figure 3: Percent change in f_o relative to the control condition, by participant for the reading task. The zero line corresponds to an f_o equivalent to the control condition. OA refers to the over articulate condition.

In the reading task, all but one participant (S5) increased their f_o in the clear condition, relative to the control condition (Figure 3). Only two participants (S1 and S3) increased their f_o in the slow condition, while all others decreased their f_o. All eight participants increased their f_o in the loud condition. Lastly, all participants except one (S5) increased f_o in the over articulate condition.

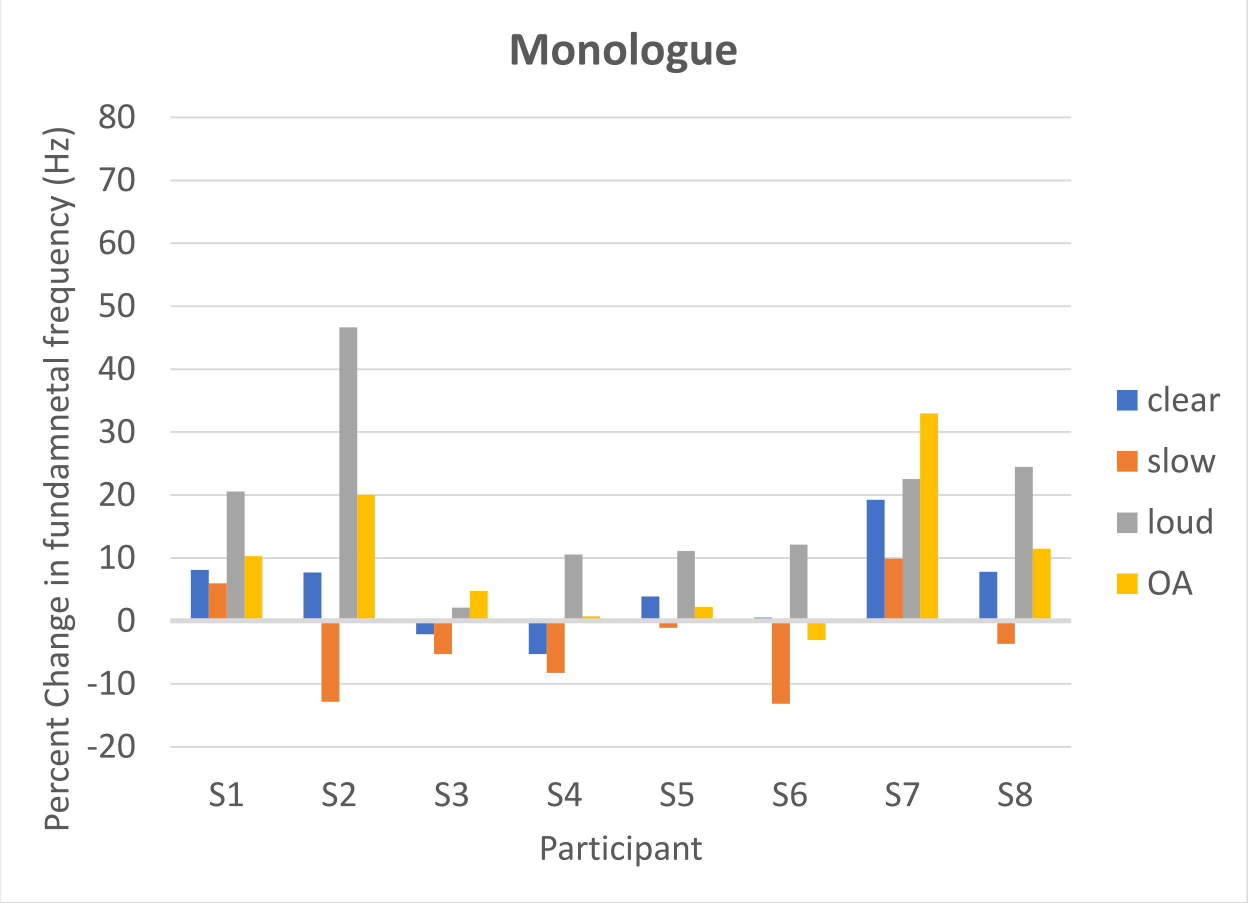

Figure 4: Percent change in f_o relative to the control condition, by participant for the monologue task. The zero line corresponds to an f_o equivalent to the control condition. OA refers to the over articulate condition.

In the monologue task, five of the eight participants (S1, S2, S5, S7, and S8) increased their f_o in the clear condition, relative to the control condition (Figure 4). Only two participants (S1 and S7) increased their f_o in the slow condition, while all others decreased f_o. Similar to the reading task, all participants increased their f_o in the loud condition. Lastly, all participants except one (S6) increased f_o in the over articulate condition.

Sound Pressure Level (SPL) Change

Change in dB SPL relative to the control condition, by participant, can be seen in Figure 5 for the reading task and in Figure 6 for the monologue task. Decreases in SPL are shown as negative numbers and increases as positive numbers. For change in SPL, the main effect of task (monologue versus reading) was not statistically significant, (*F*(1, 7) = 0.544, *p* = .485). However, the main effect of experimental condition was statistically significant (*F*(4, 28) = 13.639, *p* = .000). Pairwise comparison revealed statistically significant differences between the control and loud conditions (*p* = .000) and the clear and loud conditions (*p* = .001). Participants used significantly greater intensity in the loud condition (*M* = 12.99 dB, *SD* = 4.81) than in either the control or clear conditions (*M* = 2.03 dB, *SD* = 1.89) conditions. The interaction between task and condition was not statistically significant (*F*(4, 28) = 0.398, *p* = .809). The following paragraphs describe the individual participant trends based on the mean data for each task and condition.

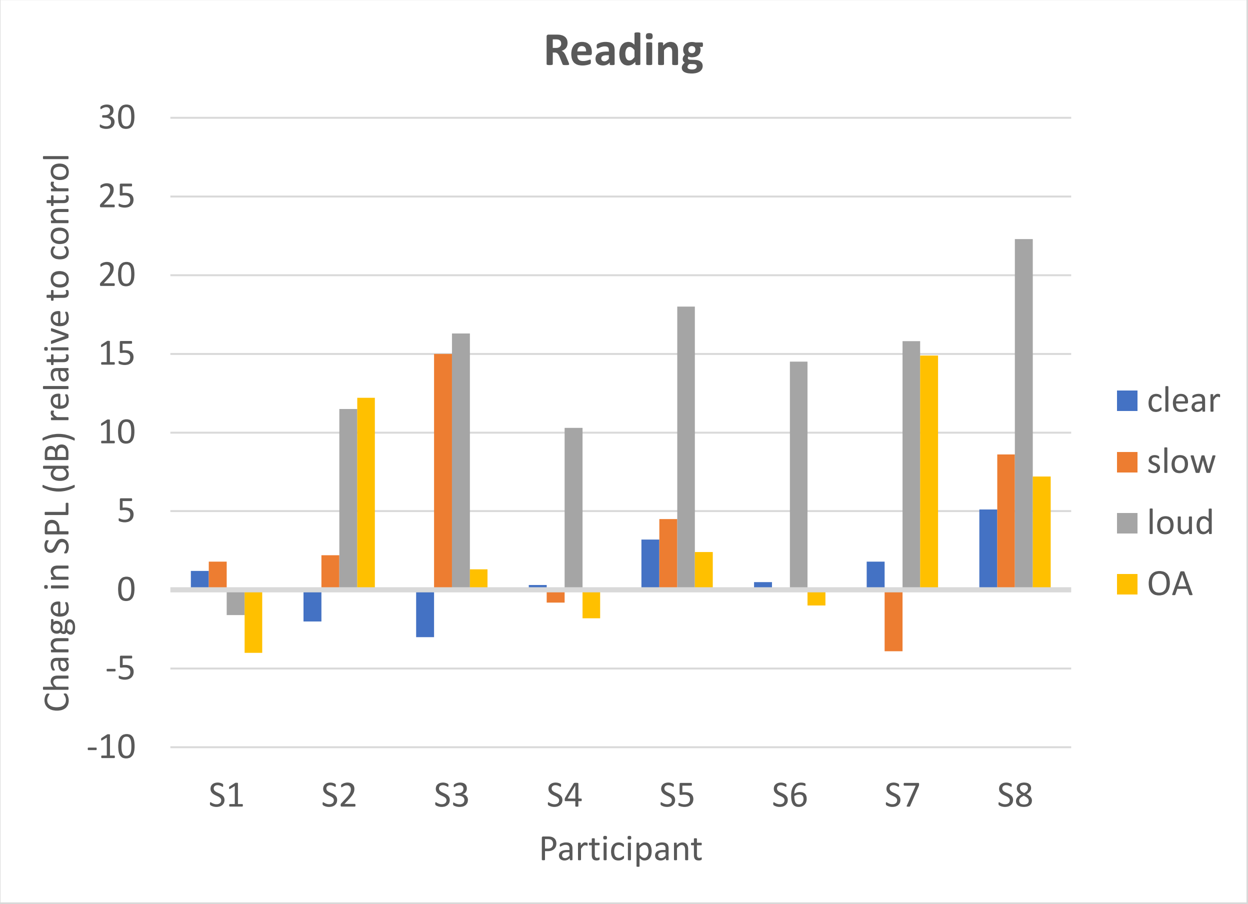

Figure 5: Change in SPL (dB) relative to the control condition, by participant for the reading task. The zero line corresponds to an SPL (dB) equivalent to the control condition. OA refers to the over articulate condition.

In the reading task, all but two participants (S2, S3) increased their vocal intensity in the clear condition, relative to the control condition (Figure 5). One participant (S7) decreased their level in the slow condition, while all others increased or maintained their levels. All participants increased their level in the loud condition (S1 maintained a similar SPL). Half of the participants (S1, S2, S7, and S8) increased their level in the over articulate condition.

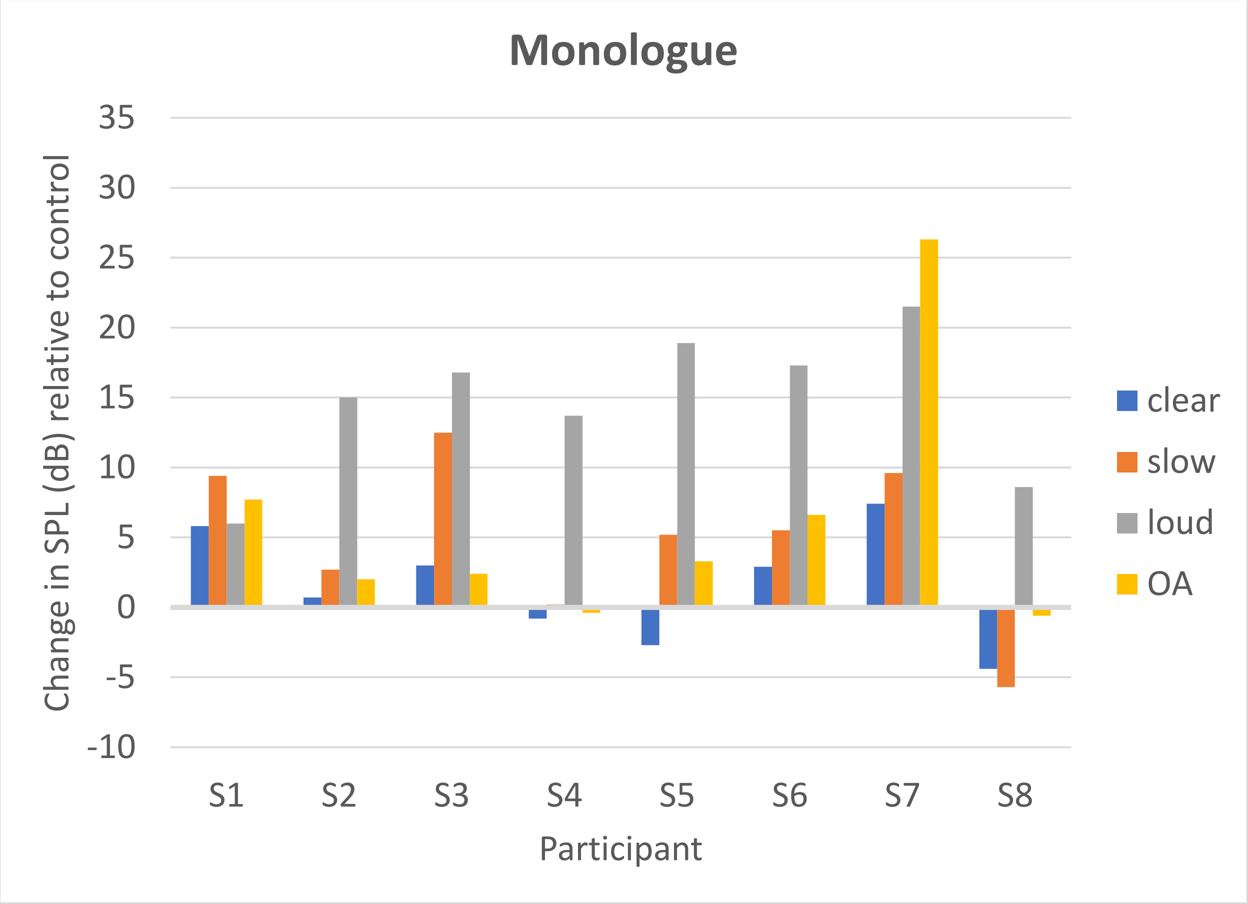

Figure 6: Change in SPL (dB) relative to the control condition, by participant for the monologue task. The zero line corresponds to an SPL (dB) equivalent to the control condition. OA refers to the over articulate condition.

In the monologue task, the majority of participants either maintained their vocal intensity or showed an increase in the experimental conditions as compared to the control condition. Six of eight participants (except S5, S8) increased their level in the clear condition, relative to the control condition (See Figure 6). All participants except one (S8) increased their level in the slow condition. All participants increased their SPL in the loud and over articulate conditions.

Voice Range Density (VRDn) Area

To show a change in VRDn across experimental conditions, the measured area in each condition was divided by the area for the control condition. A ratio of VRDn area by participant, relative to the control condition, can be seen in Figure 7 for the reading task and in Figure 8 for the monologue task. A ratio of 1.0 indicates that there was no change in area across conditions. A ratio greater than one (bars above the line) represent an increase in the area for that condition while a ratio less than one (bars below the line) indicate a decrease in VRDn area. The main effect of task (monologue versus reading) was statistically significant, ($F(1, 7) = 7.376$, $p = .030$). The VRDN area was significantly larger in the reading task ($M = 1.18$, $SD = 0.33$) as compared to the monologue task ($M = 1.11$, $SD = 0.27$). The main effect of experimental condition was also statistically significant ($F(4, 28) = 6.474$, $p = .001$). Pairwise comparison revealed no statistically significant differences between conditions. Based on mean data, participants maintained (Slow: $M = 1.01$, $SD = 0.31$) or increased (Clear: $M = 1.15$, $SD = 0.31$; Loud: $M = 1.27$, $SD = 0.34$; Over articulate: $M = 1.30$, $SD = 0.38$) their VRDn area as compared to the control condition ($M = 1.00$, $SD = 0.00$).

The interaction between task and condition for VRDn area was found to be statistically significant ($F(4, 28) = 2.713$, $p = .050$), however, no pairwise comparisons were found to be statistically significant. Mean data indicate that participants decreased VRDn area in the slow condition relative to the control condition (Reading: $M = 0.97$, $SD = 0.18$; Monologue: $M = 1.05$, $SD = 0.23$), maintained VRDN area in the loud condition (Reading: $M = 1.25$, $SD = 0.32$; Monologue: $M = 1.29$, $SD = 0.38$), and increased VRDn area in the clear (Reading: $M = 1.23$, $SD = 0.35$; Monologue: $M = 1.07$, $SD = 0.25$) and over articulate (Reading: $M = 1.46$, $SD = 0.41$; Monologue: $M = 1.14$, $SD = 0.30$) conditions during the reading task as compared to the monologue task. The following paragraphs describe the individual participant trends based on the mean data for each task and condition.

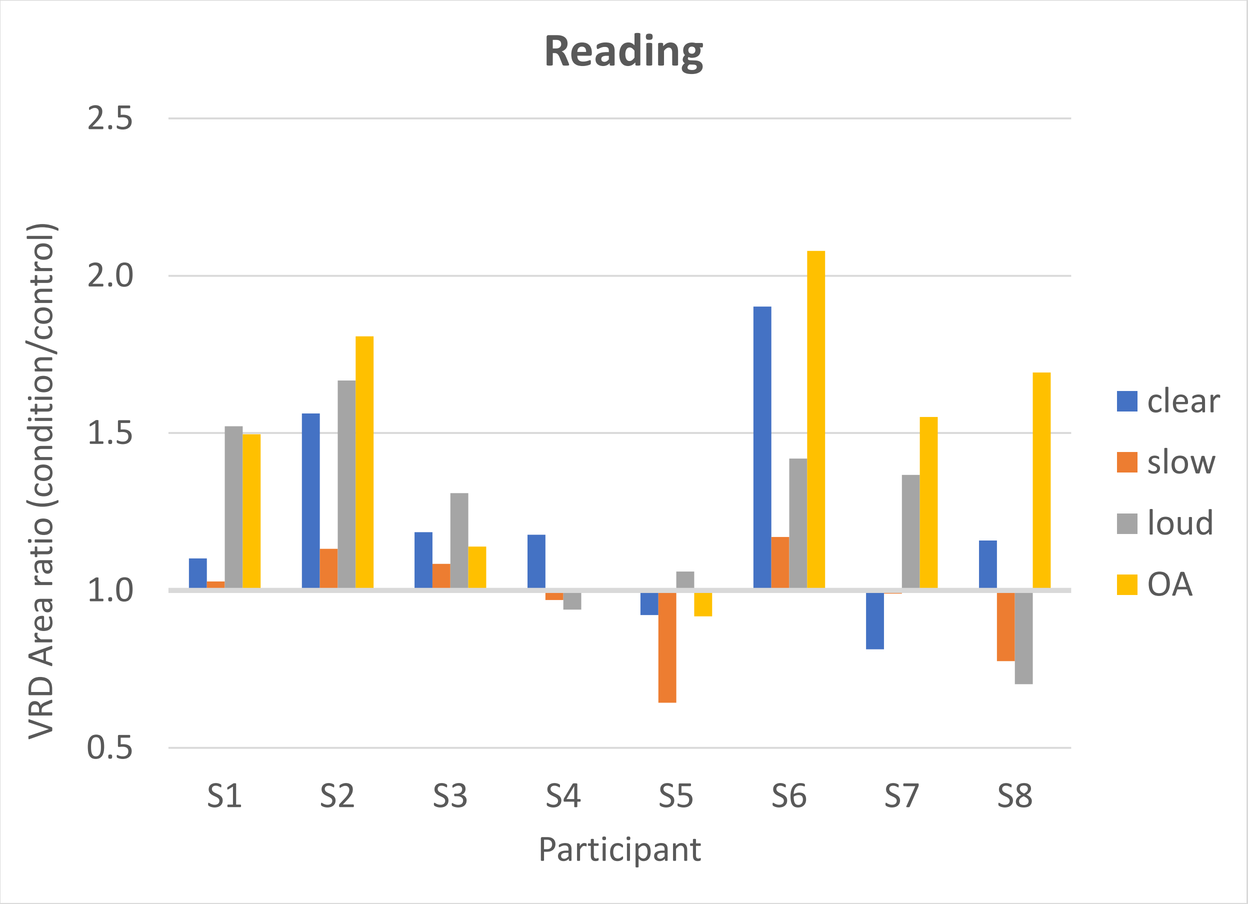

Figure 7: VRDn area ratio by participant for the reading task. A value of 1.0 represents equivalent VRDn area to the control condition. OA refers to the over articulate condition.

In the reading task, six participants increased their VRDn area in the clear condition relative to the control condition (Figure 7), while two decreased their VRDn area (S5 and S7). In the slow condition, four participants increased VRDn area (S1, S2, S3, and S6), while three individuals (S4, S5, and S8) decreased VRDn area and one participant (S7) showed no change. All but two participants (S4 and S8) increased VRDn area in the loud condition. Six of eight participants increased VRDn area in the over articulate condition, while one participant (S5) decreased VRDn area, and one (S4) demonstrated no change.

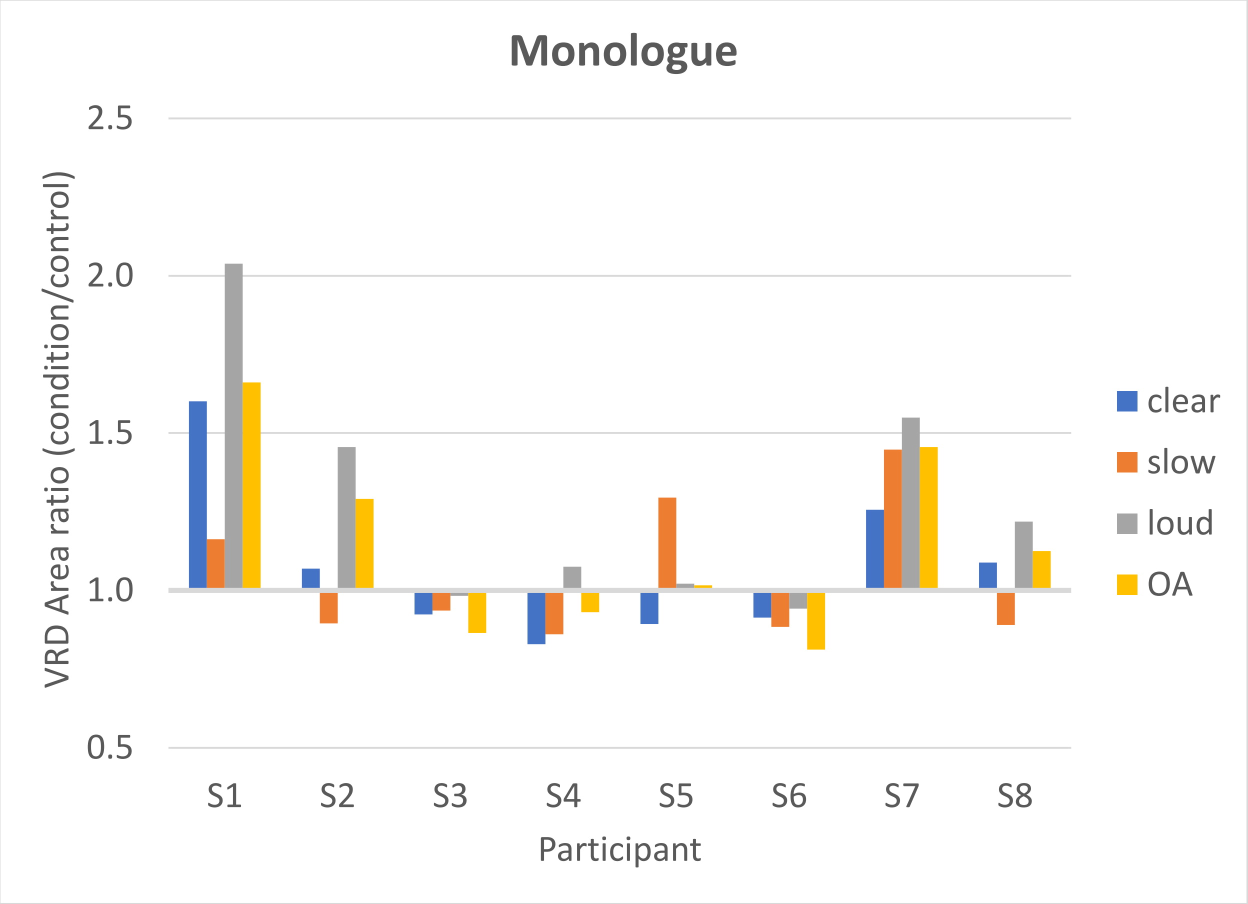

Figure 8: VRDN area ratio by participant for the monologue task. A value of 1.0 represents equivalent VRDn area to the control condition. OA refers to the over articulate condition.

In the monologue task, four participants (S1, S2, S7, and S8) increased VRDn area in the clear condition relative to the control condition, while the remaining half decreased their VRDn area (Figure 8). In the slow condition, only three participants increased VRDn area (S1, S5, and S7), while the remaining five individuals decreased VRDn area. All but two participants (S3 and S6) increased VRDn area in the loud condition. Lastly, five participants (S1, S2, S5, S7, and S8) increased VRDn area in the over articulate condition, while the remaining three participants decreased VRDn area.

Vowel Space Density (VSDn) Area

Similar to VRDn, a ratio of area based on the normalized vowel space density for each condition relative to the control condition was calculated to show changes across condition. The ratio by participant, relative to the control condition, can be seen in Figure 9 for the reading task and in Figure 10 for the monologue task. Reductions in the ratio based on VSDn area are shown as values of less than one (bars that extend below the line) and increases are shown as values above one (bars above the line). The main effect of task (monologue versus reading) was statistically significant, (*F*(1, 7) = 18.862, *p* = .003). The VSDn area was significantly smaller in the reading task (*M* = 1.07, *SD* = 0.18) as compared to the monologue task (*M* = 1.09, *SD* = 0.29). The main effect of experimental condition was also statistically significant (*F*(4, 28) = 11.759, *p* = .000). Pairwise comparison revealed statistically significant differences between the control and over articulate conditions (*p* = .002) as well as the clear and over articulate conditions (*p* = .000). VSDn area was significantly larger for the over articulate condition (*M* = 1.31, *SD* = 0.28) than the control (*M* = 1.00, *SD* = 0.00) and clear (*M* = 0.99, *SD* = 0.18) conditions. The interaction between task and condition was not found to be statistically significant (*F*(4, 28) =1.582, *p* = .206). The following paragraphs describe the individual participant trends based on the mean data for each task and condition.

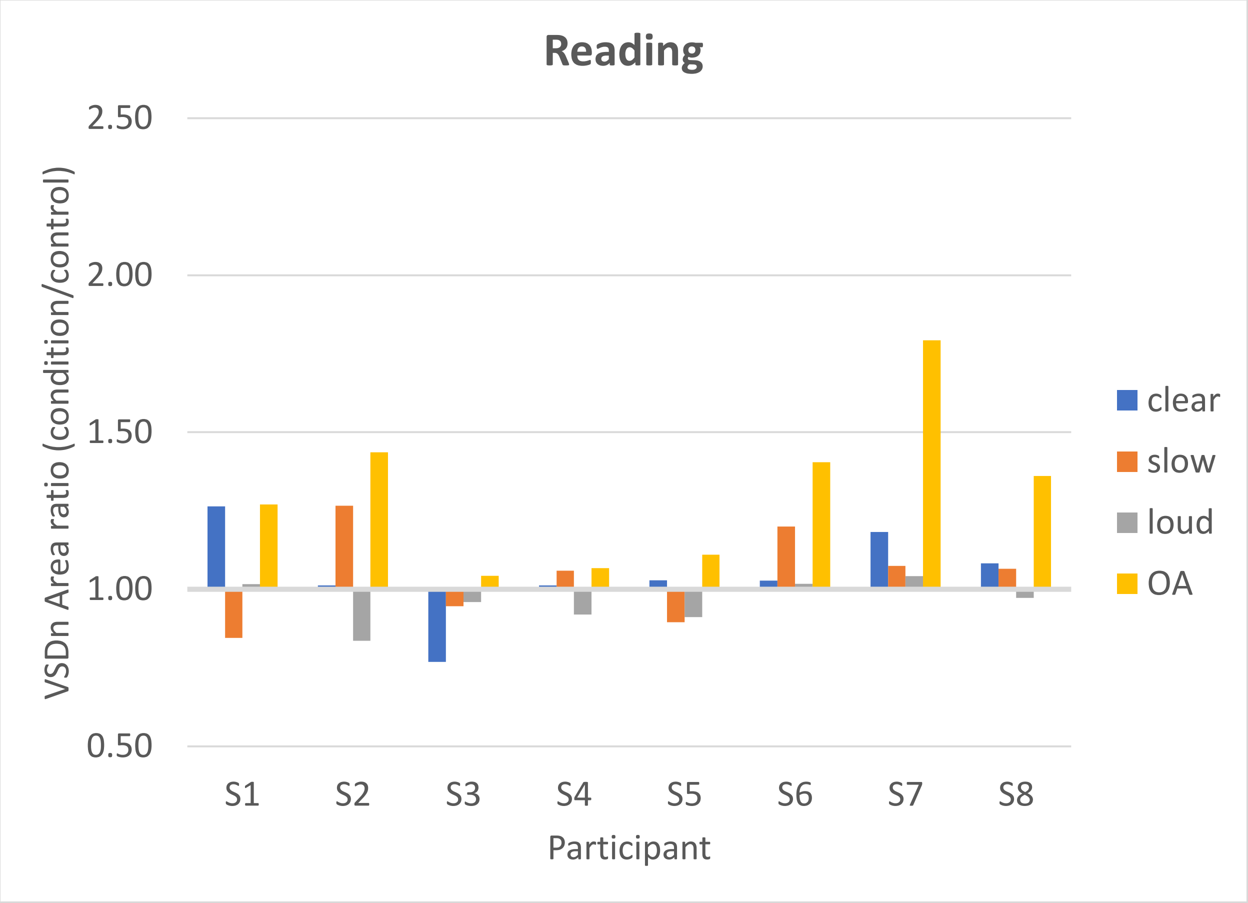

Figure 9: VSDn area ratio, relative to the control condition, by participant for the reading task. A value of 1.0 represents equivalent VSDn area to the control condition. OA refers to the over articulate condition.

For the reading task, five participants (S1, S5, S6, S7, and S8) increased VSDn area in the clear condition relative to the control condition, while one (S3) decreased VSDn area, and two participants showed no change (Figure 9). In the slow condition, five participants increased VSDn area, while the remaining three (S1, S3, and S5) decreased VSDn area. Three participants (S1, S6, and S7) increased VSDn area in the loud condition, while the remaining five participants decreased VSDn area. All eight participants increased VSDn area in the over articulate condition.

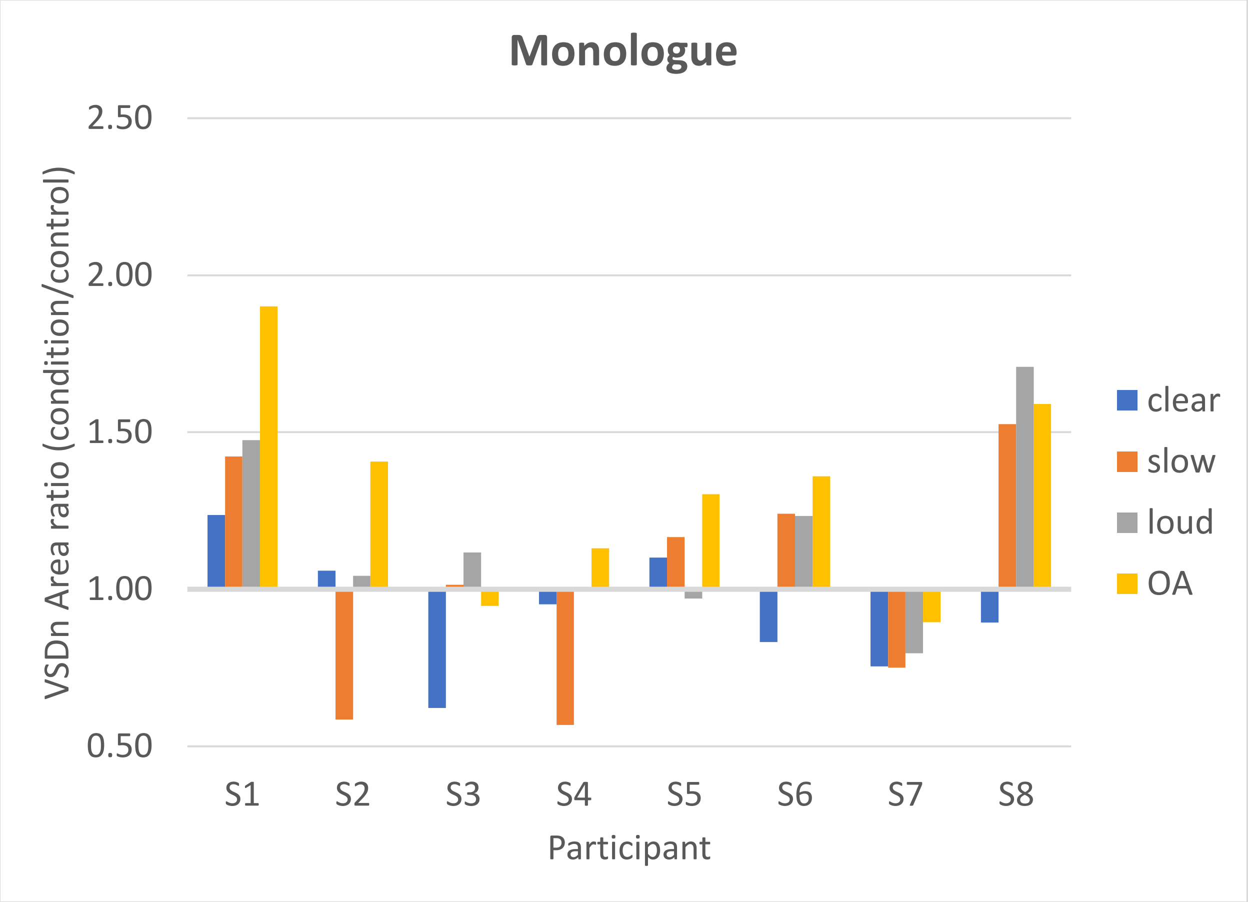

Figure 10: VSDn area ratio relative to the control condition by participant for the monologue task. A value of 1.0 represents equivalent VSDn area to the control condition. OA refers to the over articulate condition.

For the monologue task, five participants (S3, S4, S6, S7, and S8) decreased VSDn area in the clear condition relative to the control condition, while the remaining three increased VSDn area (Figure 10). In the slow condition, five participants increased VSDn, while the remaining three (S2, S4, and S7) decreased VSDn area. Five participants (S1, S2, S3, S6, and S8) increased VSDn area in the loud condition, while two participants decreased VSDn area (S5 and S7), and one (S4) showed no change. Six of eight participants increased VSDn area in the over articulate condition, while the remaining two (S3 and S7) decreased VSDn area.

Cepstral Peak Prominence – Smoothed (dB)

Smoothed cepstral peak prominence (CPPS) by participant, for all conditions, can be seen in Figure 12 for the reading task and in Figure 12 for the monologue task. The main effect of task (monologue versus reading) was statistically significant, ($F(1, 7) = 12.491$, $p = .010$). Participants demonstrated a significantly higher CPPS in the reading task ($M = 7.64$ dB, $SD = 0.77$) as compared to the monologue task ($M = 7.23$ dB, $SD = 0.60$). The main effect of experimental condition was also statistically significant ($F(4, 28) = 21.830$, $p < .001$). Pairwise comparison revealed statistically significant differences between the control and clear conditions ($p = .010$), control and loud condition ($p < .001$), clear and loud condition ($p < .001$), loud and over articulate conditions ($p < .001$), and loud and slow conditions ($p < .001$). Participants demonstrated a significantly higher CPPS in the clear condition ($M = 7.50$ dB, $SD = 0.56$) as compared to the control condition ($M = 7.02$ dB, $SD = 0.72$). Participants demonstrated a significantly higher CPPS in the loud condition ($M = 8.14$ dB, $SD = 0.58$) as compared to the control ($M = 7.02$ dB, $SD = 0.72$), clear ($M = 7.50$ dB, $SD = 0.56$), slow ($M = 7.14$ dB, $SD = 0.76$), and over articulate ($M = 7.37$ dB, $SD = 0.39$) conditions.

The interaction between task and condition was statistically significant ($F(4, 28) = 1.582$, $p = .206$. The reading and monologue tasks were significantly different from one another during the clear condition ($p = .001$). CPPS during the clear condition was significantly greater in the reading task ($M = 7.89$ dB, $SD = 0.33$) than the monologue task ($M = 7.10$ dB, $SD = 0.45$).

The following paragraphs describe the individual participant trends based on the mean data for each task and condition.

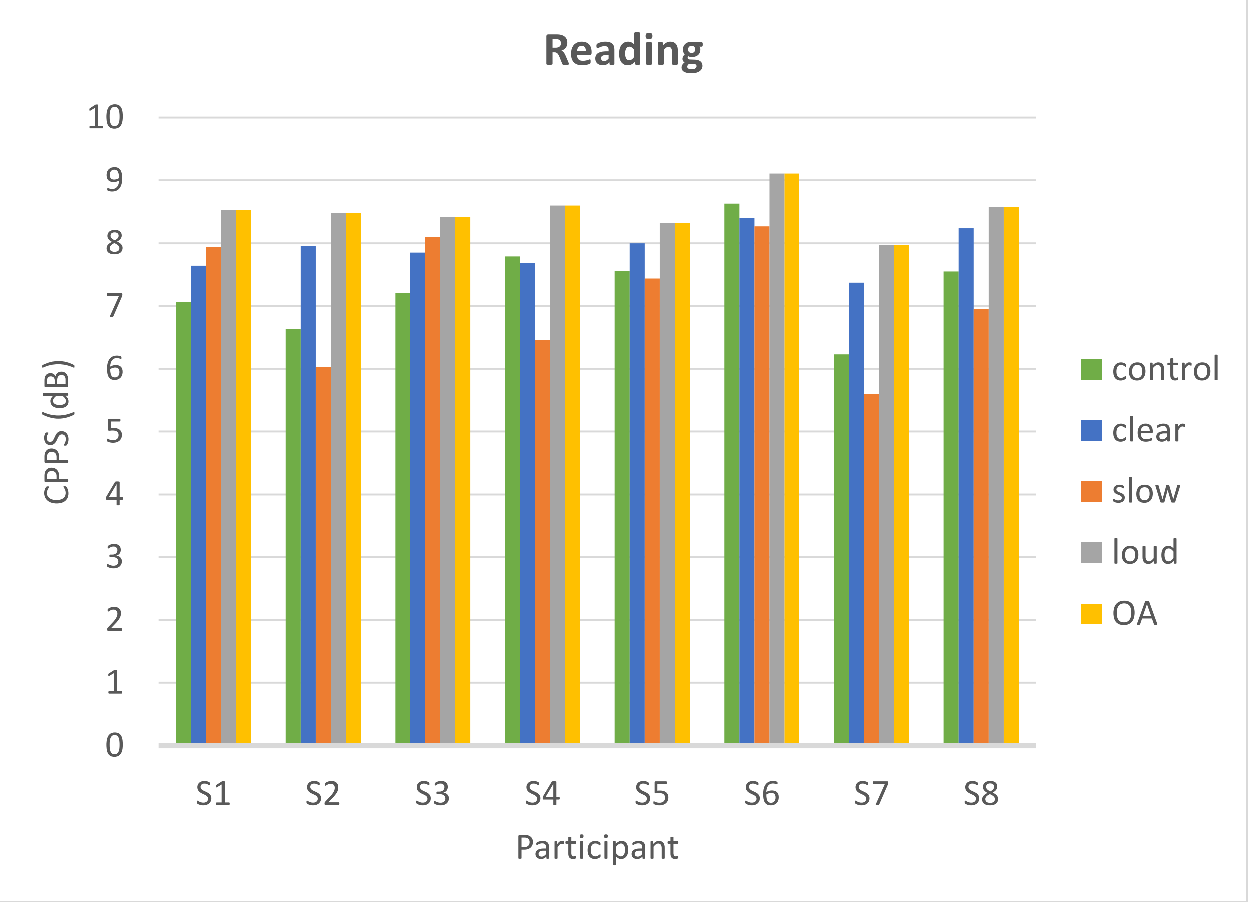

Figure 11: CPPS by participant for the reading task. OA refers to the over articulate condition.

During the reading task, six of eight participants had a larger CPPS in the clear condition than in the control condition, while the remaining two participants (S4 and S6) demonstrated decreased CPPS (Figure 11). Only two participants (S1 and S3) showed increased CPPS in the slow condition, while the remaining six showed decreased CPPS relative to the control condition. All participants showed increased CPPS for both the loud and over articulate conditions.

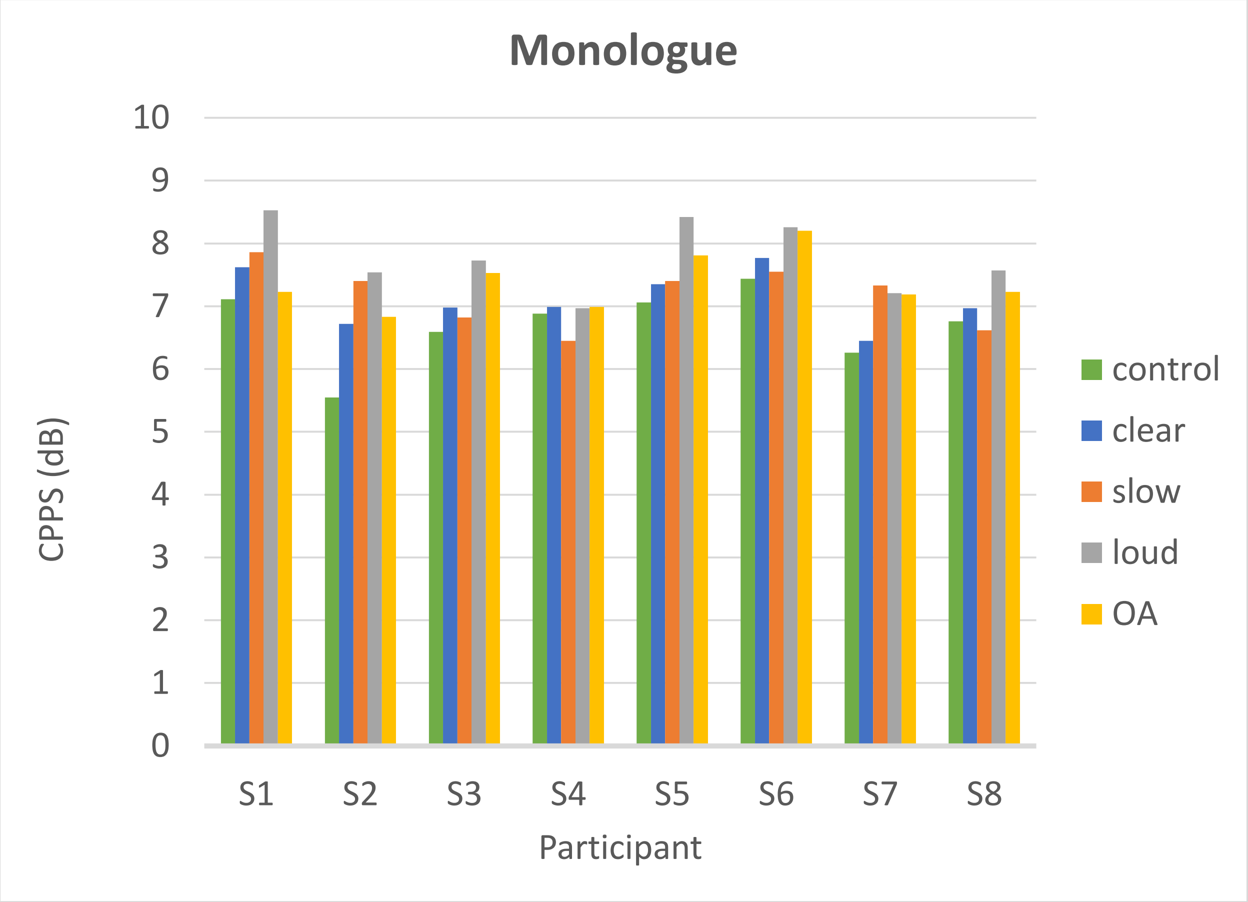

Figure 12: CPPS by participant for the monologue task. OA refers to the over articulate condition.

In the monologue task, all participants had a larger CPPS in the clear condition than in the control condition (Figure 12). Six of eight participants showed increased CPPS in the slow condition, while the remaining two (S4 and S8) showed decreased CPPS relative to the control condition. All participants showed increased CPPS for both the loud and over articulate conditions.

Discussion

The current study examined how the type of instruction impacted the acoustic characteristics of speech production in older adults with normal hearing during both reading and spontaneous speech tasks. While there was a large amount of variability across participants, results indicated that the acoustic characteristics were influenced by both the type of instruction and the type of speaking task.

Effect of Instruction

Each cued condition elicited a significant acoustic change in speech production for at least one of the dependent variables as compared to the control condition (habitual speech). In the clear condition, participants significantly increased CPPS as compared to the control condition. This indicates that participants utilized a higher degree of periodicity in their voice during the clear condition and represents an enhancement of the periodic component of the speech signal. CPPS has not previously been reported in regard to clear speech. Although not statistically significant, mean data indicate that participants tended to increase their f_o during clear speech. Changes in f_o are also a measure of vocal function. The increase in f_o is consistent with previous data (Ferguson & Kewely-Port, 2002). VRDn area, which increased during clear speech, represents how participants changed the frequency components in relation to intensity. The majority of participants increased the overall area, but it is not known whether their strategies may have differed. In other words, some speakers could have produced greater changes in only one dimension or utilized both dimensions simultaneously resulting in a change in speech production in a given condition. Further explorations of the shape of the VRDn area are important to identify whether talkers increase both components, frequency and intensity, similarly, or if some talkers rely more heavily on changes for one component over the other.

In the loud condition, two variables were significantly different from the control condition. The change in SPL in the loud condition was statistically significant, as would be expected, given the nature of the cue. Additionally, CPPS was significantly greater in the loud condition as compared to the control. While, CPPS has not been examined in the clear speech literature, our findings are consistent with the expected physiologic changes most talkers make during loud speech. Increased intensity is often the result of increased alveolar pressure, which can result from modifications at the laryngeal level (e.g., increased phonatory effort, more complete vocal fold closure) leading to increased periodicity of the signal. While not statistically significant, the group mean data revealed participant trends of increased f_o, and increased VRDn area in the loud condition relative to control. The increase in VRDn area was expected as it reflects the combined increase in both frequency and intensity, both of which increased in the loud condition.

For the over articulate condition, only VSDn area was statistically different from the control condition. Over-articulation can include consonant-related articulation differences, but also exaggerated production of vowels (Ferguson & Kewley-Port, 2002). Given the nature of the speech cue presented in the present study “to move the mouth in an exaggerated manner”, it is not surprising that the participants in this study tended to produce vowels in a more distinctive or extreme manner, dispersing them away from a centralized vowel space. In addition, group mean data revealed trends of increased f_o and VRDn area in the over articulate condition relative to the control.

In the slow condition, rate of articulation was the singular dependent variable that was significantly different from the control condition. The cue given elicited overall slower articulation for all participants in the slow condition across both speech tasks (Picheny et al., 1986). Though it was not statistically significant, it was interesting to see that slow was the only condition in which the majority of participants reduced their fundamental frequency relative to the control condition. Previous studies examining acoustic characteristics of speech in normal populations have found similar results (Dromey & Ramig, 1998). This is posited to be related to the monotonous quality and reduced naturalness of excessively slow speech.

While there were a number of statistically significant differences between the cued conditions and many of the group trends aligned with predictions based on the cue given; there was also considerable variability across talkers. It appears that individual talkers may have interpreted the cuse to modify their speech production in different ways. For example, Participant 3 made very small changes to speech production except those related to overall SPL. Participant 7, in contrast, adjusted their speech production differently in all 4 experimental conditions. The individual differences seen in the present study clearly show that the type of instruction has an impact on behavior. In clinical use the specific instructions may need to be modified to obtain the desired result or benefit based on individual responses.

Effect of Speaking Task

In general, the effect of speech task on participant performance was mixed. Statistically significant effects for tasks were found for measures of VRDn, VSDn, and CPPS. Participants produced increased VRDn area and CPPS, but decreased VSDn area in the reading task as compared to the monologue task. Participants also produced significantly greater CPPS in the clear condition during the reading task as compared to the monologue task. These acoustic changes during the reading task may be related to the fact that the monologue task was more cognitively taxing and participants did not have the ability to pre-plan or focus on the necessary behavioral changes. The reading passage was also artificially loaded with prosodic elements that required changes in f_o and intensity which likely impacted the VRDn area measure in particular. The decreased VSDn area was surprising in the reading task relative to the monologue, as it would be logical to assume that without the formulation requirements for a monologue participants would be able to focus more of their resources on articulation. One way to explore this further would be to look at the phonetic composition of the speech produced in both tasks. It is likely that the frequency of specific consonants and vowels varies between the tasks and may influence specific acoustic measures such as vowel space.

Given that the goal of rehabilitation programs is to be able to produce the compensatory strategy in a naturalistic communication environment, the fact that participants produced each cue in roughly the same manner during spontaneous speech as during reading indicates that these cues should be roughly as effective in either task. Overall, the changes in speech production seen during these longer connected speech samples gives promising ecological validity to the use of instructional cues by talkers in everyday communication exchanges. It is an encouraging finding, which should be examined in greater depth, in order to further validate the use of cues for modifying speech production to benefit listeners with hearing loss.

Limitations

Several limitations from previous studies were addressed in the current study. For example, previous research has assessed clear speech in normal young adults and adults, but not older individuals, as was the population in this study. Additionally, previous research did not look at spontaneous speech. The present study also looked at the combined change in f_o and intensity as the VRDn rather than considering each change in isolation. This is advantageous as participants may employ strategies to maximize the combined benefit of these two variables on intelligibility.

There were also some limitations in the current study. Namely the sample was small (n=8) and primarily female. Also, the age range of the participants was somewhat narrow, with ages ranging from 64-70 years old. These two limitations arose largely because we wanted to include only participants who had hearing in the normal range and it can be challenging to find these individuals in an older population (>70 years of age), given the prevalence of hearing loss among older adults (West et al., 2014).

Future Directions and Clinical Implications

The results of the present study reinforce several of the findings previously published in the literature. First, the type of cue utilized to elicit speech production has an effect on the output. Though each cue examined in this study produced significant changes in at least one dependent measures, there was little to no consistency between the cues. Further work examining the impact of each of these changes on intelligibility will help elucidate which specific cues are most beneficial. The finding that participants tend to utilize the same behavior strategies in response to a given instructional cue in roughly the same manner during reading and spontaneous speech, provides ecological valid to the use of these cues in rehabilitative programs to train individuals to use clear speech strategies. Consistent with other studies, there was variability across participants. While this study provides a good starting point to understand the acoustic changes produced in response to different cues in typical older adults, a greater number and wider variety of participants is needed to draw more concrete conclusions. It is also imperative that future research be conducted to understand how changes in each of these cues impacts understanding for individuals with hearing impairment as well as other communication disorders. Understanding how each cue, individually and in combination, impacts both acoustic characteristics and intelligibility will provide clinicians with the ability to give a recommendation that is ecologically valid and most likely to have a positive impact.

References

Abrams, H., Chisolm, T. H., & McArdle, R. (2002). A cost-utility analysis of adult group audiologic rehabilitation: Are the benefits worth the cost? *Journal of Rehabilitation Research & Development*, *39*(5), 549.

Boersma, P., & Weenink, D. (2016). Praat (Version 6.0.23). Amsterdam, The Netherlands: Phonetic Sciences, University of Amsterdam. Retrieved from http://www.praat.org/

Boothroyd, A. (2007). Adult aural rehabilitation: What is it and does it work? *Trends in Amplification*, *11*(2), 63–71. https://doi.org/10.1177/1084713807301073

Caissie, R., McNuttn Campbell, M., Frenette, W. L., Scott, L., Howell, I., & Roy, A. (2005). Clear speech for adults with a hearing loss: Does intervention with communication partners make a difference? *Journal of the American Academy of Audiology*, *16*(3), 157–171. https://doi.org/10.3766/jaaa.16.3.4

Cruickshanks, K. J., Wiley, T. L., Tweed, T. S., Klein, B. E. K., Klein, R., Mares-Perlman, J. A., & Nondahl, D. M. (1998). Prevalence of hearing loss in older adults in Beaver Dam, Wisconsin: The epidemiology of hearing loss study. *American Journal of Epidemiology*, *148*(9), 879–886. https://doi.org/10.1093/oxfordjournals.aje.a009713

Dromey, C., & Ramig, L. O. (1998). Intentional changes in sound pressure level and rate: Their impact on measures of respiration, phonation, and articulation. *Journal of Speech, Language, and Hearing Research*, *41*, 1003–1018.

Ferguson, S. H. (2004). Talker differences in clear and conversational speech: Vowel intelligibility for normal-hearing listeners. *The Journal of the Acoustical Society of America*, *116*(4), 2365. https://doi.org/10.1121/1.1788730

Ferguson, S. H., & Kewley-Port, D. (2002). Vowel intelligibility in clear and conversational speech for normal-hearing and hearing-impaired listeners. *The Journal of the Acoustical Society of America*, *112*(1), 259. https://doi.org/10.1121/1.1482078

Goman, A. M., Reed, N. S., & Lin, F. R. (2017). Addressing Estimated Hearing Loss in Adults in 2060. *JAMA Otolaryngology–Head & Neck Surgery*. https://doi.org/10.1001/jamaoto.2016.4642

Hillenbrand, J., & Houde, R. A. (1996). Acoustic correlates of breathy vocal quality: dysphonic voices and continuous speech. *Journal of Speech, Language, and Hearing Research*, *39*(2), 311–321. https://doi.org/10.1044/jshr.3902.311

Krause, J. C., & Braida, L. D. (2004). Acoustic properties of naturally produced clear speech at normal speaking rates. *The Journal of the Acoustical Society of America*, *115*(1), 362. https://doi.org/10.1121/1.1635842

Krause, J. C., & Braida, L. D. (2009). Evaluating the role of spectral and envelope characteristics in the intelligibility advantage of clear speech. *The Journal of the Acoustical Society of America*, *125*(5), 3346. https://doi.org/10.1121/1.3097491

Lam, J., & Tjaden, K. (2013). Intelligibility of clear speech: Effect of instruction. *Journal of Speech Language and Hearing Research*, *56*(5), 1429–1440. https://doi.org/10.1044/1092-4388(2013/12-0335)

Patel, R., Connaghan, K., Franco, D., Edsall, E., Forgit, D., Olsen, L., … Russell, S. (2013). “The Caterpillar”: A novel reading passage for assessment of motor speech disorders. *American Journal of Speech-Language Pathology*, *22*(1), 1. https://doi.org/10.1044/1058-0360(2012/11-0134)

Picheny, M. A., Durlach, N. I., & Braida, L. D. (1985). Speaking clearly for the hard of hearing I: Intelligibility differences between clear and conversational speech. *Journal of Speech Language and Hearing Research*, *28*(1), 96. https://doi.org/10.1044/jshr.2801.96

Picheny, M. A., Durlach, N. I., & Braida, L. D. (1986). Speaking clearly for the hard of hearing II: Acoustic characteristics of clear and conversational speech. *Journal of Speech Language and Hearing Research*, *29*(4), 434. https://doi.org/10.1044/jshr.2904.434

Preminger, J. E. (2003). Should Significant Others Be Encouraged to Join Adult Group Audiologic Rehabilitation Classes? *Journal of the American Academy of Audiology*, *14*(10), 545–555. https://doi.org/10.3766/jaaa.14.10.3

Preminger, J. E., & Meeks, S. (2010). Evaluation of an Audiological Rehabilitation Program for Spouses of People with Hearing Loss. *Journal of the American Academy of Audiology*, *21*(5), 315–328. https://doi.org/10.3766/jaaa.21.5.4

Story, B. H., & Bunton, K. (in press). Vowel space density as an indicator of speech performance. *Journal of the Acoustical Society of America Express Letters*.

Story, B. H., & Bunton, K. (2016). Formant measurement in children's speech based on spectral filtering. *Speech Communication*, *76*, 93–111. https://doi.org/10.1016/j.specom.2015.11.001

Story, B. H., & Bunton, K. (2017). An acoustically-driven vocal tract model for stop consonant production. *Speech Communication*, *87*, 1–17. https://doi.org/10.1016/j.specom.2016.12.001

Titze, I. R., Horii, Y., & Scherer, R. C. (1987). Some technical considerations in voice perturbation measurements. *Journal of Speech and Hearing Research, 30*(2), 252–260. https://doi.org/10.1044/jshr.3002.252

Tjaden, K., Sussman, J. E., & Wilding, G. E. (2014). Impact of clear, loud, and slow speech on scaled intelligibility and speech severity in Parkinson's disease and multiple sclerosis. *Journal of Speech Language and Hearing Research*, 779. https://doi.org/10.1044/2014_JSLHR-S-12-0372

West, L. A., Cole, S., Goodkind, D., & He, W. (2014). *65+ in the United States: 2010* (Special Studies) (pp. 23–212). U.S. Census Bureau. Retrieved from https://www.census.gov/content/dam/Census/library/publications/2014/demo/p23-212.pdf