THE EFFECTS OF DELAYED AUDITORY FEEDBACK AND STRUCTURED MOTOR LEARNING APPROACH IN ENHANCING SPEECH

INTELLIGIBILITY IN INDIVIDUALS WITH PARKINSON'S DISEASE: A PROOF-OF-CONCEPT STUDY

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Abstract: The proposed study assessed speech intelligibility gains and long-term retention, if any, through administering delayed auditory feedback (DAF) to people with hypokinetic dysarthria secondary to Parkinson's disease (HPSPD) within a structured motor learning approach. In this pre/post treatment design, eight participants practiced fifteen Harvard sentences five times each using DAF + structured motor learning approach for six consecutive days. Participant productions without DAF or feedback were recorded for purpose of perceptual data analysis before treatment began, immediately after six days of treatment, and one-month post-treatment. Fifteen naive listeners rated the participant's productions using perceptual outcome measures of speech intelligibility. The results of perceptual analysis revealed that participants' speech production was rated significantly more intelligible at immediate retention and delayed retention sessions in comparison to the baseline. The findings support our initial hypothesis that treatment incorporating DAF and structured motor learning would not only improve the participants' speech intelligibility but also facilitate long-term retention. The current findings also indicated that the participants continued to maintain their improved speech intelligibility after one month following the treatment. This is the first study to our knowledge that informs us of the outcomes of a novel treatment line that combined DAF accompanied with a structured motor learning approach. Further research must be conducted to generalize these findings; this line of research can have significant ramifications on service-delivery models in speech-language pathology for patients with HPSPD

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CHAPTER I

INTRODUCTION

Parkinson's disease is a common neurodegenerative disease that affects approximately six million individuals worldwide (Dorsey et. al, 2018). This disease is caused by a dysfunction in the basal ganglia that leads to a decrease in the inhibitory neurotransmitter, dopamine (Lang & Lozano, 1998). Parkinson's disease is a degenerative and slowly progressive disease that mainly affects those in their later years of life, with the age of onset being 60 years of age and can occur any time during adulthood. This leads to a wide range of motor and non-motor deficits that vary from patient to patient. Some of the more prominent motor symptoms include resting tremor, bradykinesia, or reduced range of movement, rigidity, postural reflexes, and akinesia, or a delay in the initiation of movement. Non-motor symptoms associated with Parkinson's disease include sleep disturbances, swallowing, and neuropsychiatric symptoms, such as depression (Sveinbjornsdottir, 2016).

The cause of the decrease in dopamine in the striatum that leads to Parkinson's disease is relatively unknown. A reduction in this inhibitory neurotransmitter leads to an influx of acetylcholine, the excitatory neurotransmitter, in the basal ganglia which leads to the main symptoms of Parkinson's disease. The imbalance between the neurotransmitters in the basal ganglia, acetylcholine, and dopamine, are thought to be the primary causes of motor symptoms evident in Parkinson's disease including rigidity and bradykinesia. Accompanied by these motor and non-motor symptoms of Parkinson's disease are hypokinetic dysarthria, a speech impairment that consists mainly of harsh vocal quality, reduced stress, monoloudness, and imprecise consonant production (Lieberman et al., 1992). People with Parkinson's disease also exhibit perceptually decreased loudness, variable rate of speech, and imprecise articulation, all of which affect speech intelligibility (Lieberman et al., 1992). Approximately 90% of those diagnosed with Parkinson's disease exhibit hypokinetic dysarthria secondary to Parkinson's disease (hereafter HDSPD) (Moya-Galé & Levy, 2019). Characteristics of HDSPD include phonation, articulation, and prosodic deficits marked by reduced vocal loudness, monopitch, reduced stress, monoloudness, imprecise consonants, repeated phonemes, and palilalia.

Review of Literature

While there has been strong evidence for treating phonatory and articulatory deficits in people with Parkinson's Disease (Baumgartner, Sapir, Ramig, 2001), there has been limited treatment evidence for treating speech rate deficits in individuals with Parkinson's disease. Accelerated speech rate is a common speech deficit in people diagnosed with HDSPD that impacts their speech intelligibility (Duffy, 2013; Skodda, 2011; Skodda & Schlegel, 2008).

Treatments intended for modifying speech rate in individuals with HDSPD improves their speech intelligibility through two ways: (1) by increasing articulatory precision, and (2) by giving listeners additional time to process the speaker's degraded signal (Hammen & Yorkston, 1996). While our understanding on the treatment of speech rate deficits in individuals with HDSPD is limited, emerging research indicates that individuals with HDSPD demonstrate a vigorous response to speech rate control treatments by enhancing their speech intelligibility (Van Nuffelen, Bodt, Vanderwegen, Heyning, Wuyts, 2010; Van Nuffelen, Bodt, Wuyts, & Heyning, 2009; Hammen & Yorkston, 1996; Tjaden & Wilding, 2011). Among the many proposed speech rate control treatments, altered auditory feedback has been a popular treatment option in different clinical populations, especially in individuals with stuttering (Lowit, Dobinson, Timmins, Howell, & Kröger, 2010; Borsel, Reunes, Van den Bergh, 2003). Altered auditory feedback includes the provision of delayed auditory feedback (DSF) and/or frequency shifted feedback (FSF). Delayed auditory feedback refers to the temporal asynchrony between the produced speech and its feedback to the speaker's auditory system (Hashimoto & Sakai, 2003). Typically, DAF has ranged between 50 and 200 milliseconds (Lowit et al., 2010). Frequency shifted feedback is where the individual hears feedback in real-time at an altered frequency typically between -1/2 octave to +1/2 octave (Natke, Grosser, & Kalveram, 2001; Blanchet & Snyder, 2010). There are limited studies that have investigated the effect of treatment of speech rate deficits on speech intelligibility of individuals with HDSPD and they are reviewed below.

McLain (2018) investigated speech intelligibility in individuals with PD following rate modification using AAF (Altered Auditory Feedback) in comparison to an age-matched healthy control group. The researcher recruited five individuals with PD (clinical group) and five age-matched healthy controls (healthy group) aged 50 and above to participate. Participants in each group were instructed to read a standardized passage, i.e., the grandfather passage and elicit a monologue in their habitual speech rate and with administration of AAF. Feedback was altered by a fraction of an octave higher than normal frequency (1/20 of an octave) and delayed by 150 milliseconds. Perceptual analysis, with untrained, naïve listeners, was conducted to rate the intelligibility of the speakers on a seven-point Likert scale. Results indicated that altering speech feedback by 150 milliseconds and 1/20 an octave higher produced significantly greater speech intelligibility in people with Parkinson’s disease when compared to healthy controls (McLain & Kaipa, 2018).

Downie et al. (1981) evaluated the efficacy of DAF with a patient diagnosed with PD that exhibited unintelligible speech. The one participant in this study received DAF using a pocket-sized device, at 50 milliseconds and 200 milliseconds, for one year after which the device was no longer effective. After the first participant, the researchers recruited 10 additional patients with PD at varying levels of speech impairments to undergo the same treatment model (Downie et al., 1981). Results indicated that two individuals showed improvement through increased speech intelligibility for individuals with an increased rate of speech while consistently wearing the DAF device.

Rousseau and Watts (2002) evaluated the effects of DAF on speech rate and intelligibility. The authors recruited ten patients with PD and five healthy controls, with the PD participants equally divided into highly intelligible (5 patients) and low intelligibility (5 patients) groups. The participants in all groups read nine test sentences from the “Assessment of Intelligibility in Dysarthric Speech” (Yorkston & Beukelman, 1984) list while utilizing immediate auditory feedback and DAF at 50 and 150 milliseconds. There was not a statistically significant difference between groups during DAF administration at 50 milliseconds. However, there was a statistically significant difference between the control group and the highly intelligible group. Results indicated that advantages of the implementation of DAF for speakers with PD vary based on disease severity and client specificities.

A study conducted by Brendel et al. (2004) evaluated speech intelligibility improvement through utilizing DAF at 150 millisecond delay, FSF at ½ octave upward, and no altered feedback with sixteen patients with PD and 11 control patients. Each patient read one text passage in all three conditions: DAF, FSF, and NAF. Results indicated that patients' intelligibility decreased in DAF trials in comparison to NAF and FSF conditions. These findings suggest that AAF has a negative effect on speech intelligibility.

Wang et al. (2008) investigated the effects of DAF and FSF interventions on speech intelligibility with nine participants with PD and moderate to severe speech impairment. Each participant completed a counting task, passage reading, and a dialogue presented with a combination of DAF (50 to 220 milliseconds) and FSF (500 Hz up-shift). Results revealed that participants' speech intelligibility was improved for monologue tasks but not for reading tasks, although speech rate was slowed during reading tasks.

A comparison study conducted by Lowit et al. (2010) evaluated AAF to traditional rate-reduction intervention for ten individuals with PD. Treatment design were alternating in order to compare the effects of traditional rate-reduction treatment and AAF, each participant receiving both types of interventions (6-week intervention timeline for each approach) separated by a 6-week no-treatment phase. AAF intervention consisted of DAF at 100-200 milliseconds and FSF 1/4 octave frequency shift upward. Both interventions had similar treatment tasks that ranged from reading aloud short phrases to conversational speech. Results indicated that intervention utilizing AAF produced slower speech rate in comparison to traditional rate-reduction treatment. However, these findings do not suggest that speech intelligibility increased (Lowit et al., 2010).

Blanchet and Hoffman (2014) evaluated the effects of DAF compared to DAF and verbal feedback in three patients with PD. Each patient followed the same treatment regime that consisted of four treatment sessions in an A-B-A-B design. Speakers read 20 sentences and received four different DAF intervals: 0 milliseconds, 50 milliseconds, 100 milliseconds, and 150 milliseconds. Speakers received verbal feedback during the B phases. Results indicated the speech rate significantly decreased but intelligibility only significantly improved for one patient. While there was no improvement in speech intelligibility in the absence of DAF, there were similar improvements noted at all DAF intervals. Findings reveal that DAF at a rate of 150 milliseconds was beneficial for speech rate and speech intelligibility improvement.

While the above studies demonstrate the beneficial aspect of the use of AAF in enhancing speech intelligibility in individuals with HDSPD, they present two significant limitations. The first limitation concerns the use of a retention measure to demonstrate if learning did occur after termination of treatment. Previous research has established that retention is one of the critical outcome measures of speech motor learning (Kaipa et al., 2020; Kaipa et al., 2016). This lack of long-term retention data presents a formidable challenge to argue the effectiveness of current rate control treatment approaches for HDSPD. The second limitation that the previous studies present is the use of a structured motor learning approach as a part of the treatment regime. It is critical to understand that altering speech rate in people diagnosed with HDSPD requires them to learn a novel speech motor routine. The process of learning novel speech motor skills in people with HDSPD can be facilitated through treatments that incorporate structured speech motor learning approaches (Maas et al., 2008). The benefits of structured speech motor learning approaches are primarily observed in long-term retention of the speech motor skill(s) (Kaipa et al., 2016). It is noteworthy to emphasize that as people with HDSPD present with a motor-based speech disorder, it is only relevant to treat their speech deficits using treatment protocols that incorporate structured motor learning approaches.

Current study

Considering the above two limitations, the proposed study seeks to address this critical barrier to progress in the field by administering DAF to people with HDSPD within a structured motor learning approach, and by measuring the long-term retention gains, if any. Structured motor learning approaches utilize motor learning principles to facilitate speech motor learning (Kaipa et al., 2016). While some of the previous studies have used a combination of DAF and FSF to improve speech intelligibility in individuals with HDSPD, we decided to use just DAF as a rate control treatment for enhancing speech intelligibility in people with HDSPD. The main rationale for this was that we were interested in investigating the isolated effect of DAF on speech rate (if any) instead of additive effects of DAF and FSF. The proposed study will seek to understand: (1) the impact of rate reduction treatment on enhancing speech intelligibility in people with HDSPD, and (2) if rate reduction treatment results in long-term retention. The proposed study is a single group pilot intervention study that is intended to identify a therapeutic effect, if any. To this end, we posed two research questions: (1) Will there be changes in speech intelligibility of people with HDSPD with increased speech rate after a rate reduction treatment, and (2) will the changes in speech intelligibility after the treatment be retained over a period of one-month? Based on the previous literature, it was hypothesized that participants' speech intelligibility will improve following DAF administration with a structured motor learning approach immediately after treatment conclusion and one-month post-treatment.

CHAPTER II

METHODS

Participants

Initially, we aimed to recruit 14 participants for the current study. However, we had significant participant attrition and finally, a total of 8 individuals diagnosed with Parkinson's disease participated in this pre/post treatment design. The participants were recruited through convenience sampling primarily from Parkinson's disease support centers in the state of Oklahoma. The participant inclusion criteria were as follows: (1) a diagnosis of idiopathic Parkinson's disease, (2) accelerated speech rate leading to reduced speech intelligibility as identified by self or the family member, (3) a score of 23 or greater on the Montreal Cognitive Assessment to rule out cognitive deficits[1], (4) adequate hearing acuity (use of amplification devices in case of hearing loss), and (5) monolingual native speaker of American English. The participants were diagnosed with hypokinetic dysarthria by two independent clinical researchers who had sufficient experience in identifying dysarthric speech samples.

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[1] In the current study, although we followed a cutoff MoCA score of 26 to include participants in the clinical group, we recruited a couple of participants who scored below 26. We did for two main reasons. First, the participants and the caregivers reported that they did not have cognitive issues that affected their daily living. Second, some recent studies have indicated that the cutoff score of 26 leads to a higher proportion of false positives. So, a cutoff score of 23 is recommended for improved diagnostic accuracy (Davis et al., 2015; Carson et al., 2018).

Both researchers perceptually and independently analyzed all the participants' speech characteristics. The participants' speech deficits as identified by the two researchers ranged from hypophonia, articulation deficits to increased speech rate. The participants' acoustic speech rate was not measured, but the participant or the participant's family member was concerned about the speech rate to an extent that it limited the participant's speech intelligibility. The demographic information of participants including age, sex, disease duration, treatment history, Hoehn and Yahr Stage, UPDRS Score, deep-brain stimulation (DBS) treatment, and self-reported hearing acuity are provided in Table 1.

Table 1 – Participant Demographics

Participants	**Age**	**Sex**	**Disease Duration**	**Tx History**	**Hoehn and Yahr Stage**	**UPDRS Motor Examination Score**	**Self-Reported Hearing Acuity**
C.H.	80	Male	Date of onset: 2016 Duration: 5 years	Swallowing therapy once a month; Completed LSVT-Loud 2 years ago	1	33	No hearing issues; does not wear hearing aids
D.L.	69	Male	Date of onset: 2014 Duration: 8 years	In LOUD Crowd Support Group; Swallowing therapy 2.5 years ago	2	14	No hearing issues; does not wear hearing aids
D.B.	65	Male	Date of onset: 2005 Duration: 17 years	Speech therapy received three years ago	2	12	No hearing issues; does not wear hearing aids
K.B.	66	Female	Date of onset: 2019 Duration: 3 years	No therapy	1	31	No hearing issues; does not wear hearing aids
R.T.	68	Male	Date of onset: 2018 Duration: 4 years	In Loud Crowd Support Group; Speech therapy 2 years ago	3	43	No hearing issues; does not wear hearing aids

L.W.	79	Male	Date of onset: 2008 Duration: 14 years	In Loud Crowd Group; speech therapy 3 years ago	2	42	No hearing issues; does not wear hearing aids
D.R.	68	Male	Date of onset: 2016 Duration: 5 years	SPEAK Out! Two years ago; Loud Crowd PD support group presently	2	9	No hearing issues; does not wear hearing aids
A.F.	70	Male	Date of onset: 2018 Duration: 4 years	Speech therapy (received LSVT treatment in 2019); Part of LOUD Crowd	2	30	No hearing issues; does not wear hearing aids

Procedures

Each of the 8 participants participated in a baseline phase, a six-day treatment phase, an immediate retention phase at the end of the treatment phase, and a long-term retention phase one-month post-treatment. All phases were audio recorded using a digital voice recorder kept the same distance away, approximately fifteen centimeters from each participant for the purpose of analysis. A schematic representation of the treatment design is shown below in Table 2.

Table 2 – Treatment (Tx) design. All factors are within subject.

Day 1	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Day 6**	**1-month post-tx**
Baseline +Tx	Tx	Tx	Tx	Tx	Tx + Imm. retention	Long-term retention

The baseline and each of the two retention sessions were approximately 15 minutes in length, and each of the treatment sessions were approximately 45 minutes in length. The experimental sessions took place in a location that was mutually agreed on by the researcher and the participant. The participants were instructed to sit comfortably in front of a computer monitor that displayed the stimuli for baseline, training, and retention sessions. The participants' productions during these three phases were audio recorded approximately fifteen centimeters from each participant for purpose of data analysis.

Training stimuli

The training stimuli during each of the six treatment sessions included 15 phonetically balanced Harvard sentences consistent for each participant, for a total of 90 sentences across the six-day treatment regime. The 90 sentences that were used for training as well as during baseline and retention sessions were drawn from the larger corpus of Harvard psychoacoustic sentences (IEEE, 1969). The sentence length of each of the 90 sentences ranged from 8-9 words. The sentences included imperatives and declaratives that are syntactically and semantically appropriate for training purposes. Each participant read 10 Harvard sentences across each of the baseline, immediate retention, and delayed retention sessions. The Harvard sentences have been routinely employed in studies investigating speech acoustics and speech intelligibility of people with dysarthria (Tjaden, Kain, & Lam, 2014; Stipancic, Tjaden, & Wilding, 2016).

Baseline phase

Prior to the beginning of the first treatment session, all participants read 10 Harvard sentences in their habitual speech rate. Each of the 10 sentences were displayed on the computer screen in a sequential manner through PowerPoint slides. Each slide contained a sentence, and the sentence was displayed until the participant had read it completely, and sentences chosen were not included in the treatment regime. The baseline phase preceded the treatment phase.

Treatment phase

Participants received rate control treatment for six sessions across six consecutive days. The proposed treatment involved delivering DAF of 150-millisecond delay (as per Lowit, Dobinson, Timmins, Howell, & Kröger, 2010) within the framework of structured motor learning approach. The participants received DAF through "SmallTalk DAF" (Casa Futura Technologies), which is a pocket-sized instrument that delivers DAF through headphones. Before the initiation of the first treatment session, each participant produced 10 Harvard sentences (that were used during baseline, treatment, or retention phase) delivered with a 150-millisecond auditory delay. This allowed participants to familiarize themselves with the DAF. Each treatment session required the participant to practice each of the 15 sentences in blocks of five practice trials for a total of 75 productions. Each sentence was displayed on the computer screen with a large readable font. The participant was required to read the sentence with DAF, pause for 4-seconds, and produce the sentence without DAF. When the participant completed four more practice trials in a similar fashion, the experimenter provided summary feedback regarding the participant's speech rate. If the participant produced the sentence with a fast speech rate in absence of DAF, the experimenter encouraged the participant to slow his/her speech rate and vice versa. Following this, the experimenter displayed the second sentence on the computer screen for the participant to complete the second practice block. Similarly, the participant completed the remaining sentences. The manner of practice and feedback provision was consistent across all the six treatment sessions for each participant.

Retention phase

After the completion of the sixth treatment session, the participants completed an immediate retention session following a 10-minute break. During the immediate retention session, the participants read 10 Harvard sentences that they had read during the baseline as well as 10 novel Harvard sentences that were not part of the treatment regime. Each of the sentences were displayed in a sequential manner on a computer screen. When the participants read all the sentences in the absence of DAF. The participants also completed a long-term retention session that took place one-month post-treatment, which mirrored the immediate retention phase.

Perceptual Data Analysis

Fifteen naïve listeners without prior exposure to Parkinsonism speech were recruited through Oklahoma State University to rate speech intelligibility. Listeners all exhibited 1) self-reported adequate hearing acuity, 2) ranged in age from twenty to thirty years old, 3) and included both male and female listeners, nine females and six males. Two-hundred forty speech samples were played; each sample contained five Harvard sentences consistent across baseline, immediate retention, and delayed retention and five novel Harvard sentences that were not part of the treatment regime, totaling 30 productions for each participant. The order of presentation of the participants' productions was randomized across the three phases of data collection. Listeners rated their overall speech intelligibility of the participant productions at baseline, immediate retention, and delayed retention using a 5-point Likert scale (1-highly unintelligible; 5- highly intelligible). The listening experiment took place in a laboratory-type setting that was devoid of auditory and visual distractions, volume was kept consistent for each listener and listeners were able to ask for repetition of stimuli as needed. The duration of the session ran approximately 45 minutes. The tasks were administered through high-fidelity headphones for each listener. Listeners provided a mean rating of each participant's intelligibility at baseline, immediate retention, and delayed retention.

Statistical analysis

The overall speech intelligibility ratings assigned by the listeners for the mean intelligibility of 30 sentences produced by each participant at each stage (baseline, immediate retention, and delayed retention) were inputted to SPSS (version 26.0; IBM Corp., Armonk, NY). As the data was ordinal in nature, the data was analyzed using Friedman ANOVA to compare the outcomes across each of the three phases. If there was a significant learning effect, the results were followed up using Wilcoxon signed-rank tests. As multiple use of Wilcoxon-signed rank test leads to a family-wise error, the alpha was set at 0.017 for significance.

Inter-rater reliability

Inter-rater reliability for the perceptual ratings of the participants’ speech samples was based on randomly choosing and re-measuring 20% of the data (i.e., 48 out of 240 speech samples) and performing a Spearman’s rank-order correlation. The results indicated that there was strong, positive correlation, which was statistically significant (rs(22) = .763 p < .01).

CHAPTER III

CONCLUSION

Results

The results of the Friedman ANOVA indicated a significant main effect of treatment $\chi^{2(2)}$ =24.32, $p < 0.01$. The mean ranks for the baseline intelligibility, immediate retention intelligibility and delayed retention intelligibility were 1.75, 2.06, and 2.19, respectively. In order to compare the differences in intelligibility ratings at baseline, immediate retention, and delayed retention phases, post-hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at $p < 0.017$. There were significant differences between the intelligibility ratings during baseline ($M = 3.67$, $SD = 1.37$) and immediate retention ($M = 4.00$, $SD = 1.06$), with immediate retention phase garnering better ratings ($Z = -3.64$, $p < 0.01$), between baseline ($M = 3.67$, $SD = 1.37$) and delayed retention phase ($M = 4.614$, $SD = 1.00$), with delayed retention phase garnering better ratings ($Z = -4.09$, $p < 0.01$).

However, there was no statistical difference in intelligibility ratings between the delayed and immediate retention ratings, (Z = -2.06, p = 0.039), although data indicates that there is more learning after treatment stops. Descriptive statistics for the baseline, immediate retention, and delayed retention intelligibility ratings are provided in Table 3.

Table 3 - Descriptive Statistics for baseline, immediate, and delayed retention intelligibility ratings

	N	**25th**	**Percentiles 50th (Median)**	**75th**
Baseline intelligibility	120	3	4	5
Immediate retention intelligibility	120	3	4	5
Delayed retention intelligibility	120	4	4	5

Effect size

The Cohen's d benchmarks were used to determine the magnitude of the effect size (Cohen, 1992) The effect size between the baseline and immediate retention phases was d = 0.26. The effect size between the baseline and delayed retention phases was d = 0.38. Finally, the effect size between immediate and delayed retention phases was d = 0.38. It is interesting to note that all the three effect sizes indicated a small effect (0.2-0.5) as per Cohen's d benchmarks.

Discussion

The current study aimed to investigate the outcomes of a week-long treatment that incorporated DAF and structured motor learning approach in enhancing the speech intelligibility of individuals with Parkinson's disease. To this end, we recruited eight people diagnosed with Parkinson's disease. The participants were also diagnosed with hypokinetic dysarthria based on their speech deficits including increased speech rate that warranted a rate reduction treatment. Each of these eight participants completed a week-long treatment regime that involved speaking sentences in the presence of DAF using a structured motor learning approach. At the end of the treatment session, all the participants completed an immediate retention session. This was followed by a delayed retention session that was conducted one month after the termination of the treatment. The participants' speech samples were recorded at baseline, immediate retention, and delayed retention phases for the purpose of perceptual analysis. The results of perceptual analysis revealed that participants' speech production was rated significantly more intelligible at immediate retention and delayed retention sessions in comparison to the baseline. The findings support our initial hypothesis that treatment incorporating DAF and structured motor learning would not only improve the participants' speech intelligibility but also facilitate long-term retention. This is one of the first studies to have measured long-term retention outcomes following a rate reduction treatment. The findings are discussed along the lines of the two research questions that were initially posed.

Will there be changes in speech intelligibility of people with Parkinson's disease with increased speech rate after a rate reduction treatment?

The studies that were summarized in the introduction section point to the beneficial nature of the rate reduction treatment in enhancing speech intelligibility in individuals with HDSPD. Although there has been no prior research to our knowledge that evaluated a combination of DAF and structured motor learning approach to enhance speech intelligibility in individuals with HDSPD, some comparisons can be made. For example, Blanchet and Hoffman (2014) evaluated the effects of DAF compared to DAF and verbal feedback in three patients with PD. Results indicated the speech rate significantly improved for all patients, but intelligibility only significantly improved for one patient. While there was no improvement in speech intelligibility in the absence of DAF, there were similar improvements noted at all DAF intervals, including intervals that provided DAF and verbal feedback. Findings reveal that DAF at a rate of 150 milliseconds was beneficial for speech rate and speech intelligibility improvement. The findings from most of the above-mentioned studies in the introduction are in line with the results of the current study.

It is critical to understand how rate reduction treatment aids enhancing speech intelligibility for patients with Parkinson's disease. Ziegler et al. (1988) examined the speech patterns of patients with Parkinson's disease and concluded that a main speech characteristic among these patients was articulatory undershoot that contributed to the perception of an increased speech rate. In articulatory undershoot the speaker takes a shorter than normal time to switch from an opening movement for a vowel to a closing movement for the upcoming consonant, in other words, the coarticulation time is extremely shortened (Skodda, 2011). This characteristic speech pattern often leads to perceived increased speech rate and therefore decreased speech intelligibility. Rate reduction treatment discourages articulatory undershoot and improves the speaker's articulatory precision as well as giving listeners additional time to comprehend the degraded acoustic signal.

On a broader level, the effects of AAF on speech rate can be attributed to the relationship between the auditory feedback and certain aspects of speech motor control (Guenther, 2006; Hashimoto & Sakai, 2003). Auditory feedback loop has a long latency period (about 200 ms), and this latency period renders auditory feedback less useful to monitor and correct segmental speech characteristics (Perkell et al., 2000). However, the effects of auditory feedback are apparent on suprasegmental speech characteristics, including speech rate that are sustained over a longer period. A person receiving AAF experiences interruptions between actual speech output and the excepted auditory feedback. In order to overcome this interruption, the speaker is likely to slow his articulatory gestures to maintain the flow of speech production, resulting in slow speech rate (Chon, Kraft, Zhang, Loucks, & Ambrose, 2013). Additional theoretical explanation for the effect of altered auditory feedback on speech rate is offered by the EXPLAN model (Howell, 2004). Howell proposed that whenever there are alterations to speech control in the form of AAF, it results in a profound effect on the timing process involved in fluent speech production. The EXPLAN model mentions that there is a central timekeeper located in the cerebellum, and this timekeeper is disrupted when it receives asynchronous inputs in the form of DAF or FSF. The timekeeper keeps track of the different events that are timed with speech production tasks. However, the timekeeper fails to keep track of these timed events when the auditory feedback it receives is not synchronous with the speech production process. As a result, the activities regulated by the timekeeper (in this case, speech production) are slowed, thus resulting in a slowed rate of speech. It is possible that both the above theoretical models may act synergistically rather than in a mutually exclusive fashion to alter the speech production process under the influence of AAF.

The current findings did indicate that the participants continued to maintain their improved speech intelligibility even one month after the treatment, but they did not continue to improve. One of the core speech deficits in people with HDSPD is accelerated speech rate. The main aim of a rate reduction line of treatment is to improve speech intelligibility and this requires individuals to get habituated to novel speech routine. This change in the speech behavior can be easily achieved when the treatment incorporates a structured motor learning approach. It is common for a structured motor learning approach to employ principles of motor learning (PMLs) in the treatment regime. PMLs refer to a set of principles that facilitate motor learning (Mass et al, 2008).

Will the changes in speech intelligibility after the treatment be retained over a period of one-month?

The findings of the current study indicated that participants not only demonstrated improvement following the treatment but also maintained one-month after the termination of the treatment. Prior studies have documented the role of principles of motor learning in remediating speech deficits in people with PD. For example, Ramig et al. (2001) assessed the long-term retention effects of Lee-Silverman voice treatment (hereafter LSVT) for alleviating voice deficits in patients with idiopathic Parkinson’s disease. In this comparison study, two groups received two varying treatment types, respiratory effort treatment (hereafter RET), and LSVT. Outcome measures included acoustic analyses of voice loudness and inflection in voice fundamental frequency during sustained vowel phonation, reading and monologue tasks. Immediately after therapy and with a two-year follow-up, LSVT voice treatment proved more statistically significant results than RET, concluding that LSVT is effective in providing long-term maintenance of the effects learned in treatment.

Kaipa et al. (2016) investigated the role of PMLs in facilitating speech motor learning in individuals with PD. The authors compared the role of four different practice conditions in speech motor learning. Participants with PD were divided into four varying groups to assess the practice structure effect on spatial and temporal learning of novel speech utterances. The study concluded that individuals with PD will demonstrate subsequent to systematic application of PMLs. Additionally, regardless of practice structure, repeated practice is effective in facilitating speech-motor learning in individuals with PD.

As mentioned above, learning a novel speech routine requires systematic motor learning approach. So a main reason that participants in the current maintained their speech intelligibility gains one month after treatment can be attributed to the incorporation of PMLs in the treatment regime. The structured motor learning approach involved constant repetition along with the provision of a summary feedback after every five productions. This helped participants to self-evaluate their productions in a systematic manner and correct them when necessary.

Effect size

While emerging research has documented the benefits of DAF in enhancing speech intelligibility of individuals with HDSPD, these studies seldom discuss the effect size of the intervention. Although the treatment effect size in the current study was small (as per Cohen's d benchmarks), it is critical to understand to remember that Cohen's benchmarks were not intended for universal use across all areas of treatment research (Shaver, 1993; Thompson, 1999). We need to determine appropriate graduated criteria for labeling the magnitude of effect size that is specific to an area of research. For example, Robey (1998) found that the treatment effect size for individuals with aphasia during the acute stage averaged about d = 1.39, which is relatively large compared to treatment effect sizes for a range of speech and language disorders. Within the context of the current study, Cohen's benchmarks may prove useful only as initial referents in instances when no prior estimates of effect size are available (Schafer, 1993). Future research needs to carefully examine treatment effect for similar studies so that we have appropriate benchmarks for effect size.

Limitations

While the current study does present some interesting findings, it not without limitations. First, although the current study was meant to be a preliminary investigation, the small sample size, lack of gender distribution, and lack of a control group could prevent the findings from being extrapolated to a larger population. The second limitation was that the outcome measure did not include the participants' everyday conversation as this would have predicted the generalization of the treatment effect to the real world. The third limitation is that there were no hearing screenings performed on speakers with HPSPD and naïve listeners, only self-reported hearing acuity was reported. The final limitation concerns the listeners' perceptual ratings. Due to the listener fatigue in rating each of the participant's productions, each of the listener assigned an overall intelligibly rating at the end of the perceptual listening session. This could have resulted in either underestimating or overestimating the participants' speech intelligibility.

Conclusion

Despite these limitations, this is the first study to our knowledge that informs us of the outcomes of a novel treatment line that combined DAF along with a structured motor learning approach. The findings suggest that this line of treatment does not only enhance speech intelligibility but also help people with HDSPD to maintain their intelligibility gains. Future research should expand this study by recruiting a larger sample size and including retention measures beyond one month time period. This line of research can have significant ramifications on service-delivery models in speech-language pathology.

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