Rhythm and Pitch differences between speakers with Dysarthria and Control speakers

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Abstract

Dysarthria is a motor speech disorder characterised by impaired articulation, slow speaking rate, voice disturbances, and rhythm disturbances. As a result, dysarthric speech is perceived by listeners to have poor intelligibility. While the factors above are widely claimed to be contributing to its lack of intelligibility, the focus of most research has solely been on articulation and speaking rate. This thesis aimed to investigate what the rhythmic and pitch variation are between adult Dutch speakers with dysarthria and a control group. Rhythm metrics were used as a measure for rhythm and pitch variation as a measure for pitch to try to identify where these disturbances lie. Speaker recordings were available from a corpus (COPAS) and selected if all speakers read a common text. Speech durations were extracted, and rhythm and pitch measures calculated. The results showed that no group significance between the dysarthric and control group, but sentence effects were significant for speech rate, rhythm metrics, and pitch variation between the dysarthric and control group. There was also one group and sentence interaction between the dysarthric and control group for one of the rhythm metrics (VarcoV). However, there was no significance found for speech rate, rhythm metrics and pitch variation within the dysarthric group. These results form part of preliminary groundwork in adding to the understanding of rhythm disturbances in dysarthria and suggest future research in optimising diagnosis using rhythm metrics and thereby, treatment.

1. Introduction

Communication deficits can be physically and socially challenging conditions for people to live with and often present with a wide set or speech impairments, including dysrhythmic speech. Anything that can be referred to as causing a disturbance in the natural flow of speech can lead to disordered rhythm, for example, a difficulty is producing speech sounds in the right order, a stammer, or a problem in retrieving the correct word. These examples may not always be classified as disordered rhythm, but rather a result of articulatory failures leading to changes in speech timing, that are primarily the result of neurogenic speech disorders.

Neurogenic speech problems or motor speech disorders (MSDs), are defined as “a group of speech disorders resulting from disturbances in muscular control—weakness, slowness or incoordination of the speech mechanism—due to damage to the central or peripheral nervous system or both” (Darley, Aronson, & Brown, 1969).

1.1. Dysarthria

Dysarthria is the most common MSD and can affect subsystems of speech such as respiration, phonation, articulation and velopharyngeal control. It results in low speech intelligibility that displays timing and accuracy disturbances. Dysarthria affects the control of muscles required for speech production, which causes changes to the speech signal. Listeners often describe people with dysarthria as having imprecise articulation, slow speaking rate, voice disturbances, and reduced prosodic variation (Mackenzie, 2011). Dysarthric speech is often described as being rough, effortful and mumbled. Reduced speech intelligibility is a common consequence of dysarthria and Ansel and Kent (1992) describe this reduction in intelligibility as “the most clinically and socially important aspect of dysarthria" (p. 297). A study showed that individuals with Parkinson's disease (PD) which resulted in dysarthria reported that reduced speech intelligibility impacted daily living despite only having mild dysarthria (Miller, Noble, Jones, and Burn, 2006). Participants in Miller et al.'s (2006) study expressed that some of the problems they encountered were making themselves understood in a normal conversation and dealing with the reactions of others.

Dysarthria can be the result of congenital or acquired conditions. Common causes of dysarthria include traumatic brain injury, stroke, multiple sclerosis, amyotrophic lateral sclerosis (ALS), tumour, postoperative complications, inflammatory, and metabolic diseases (Yorkston, 1996). Since there are a variety of brain structures that are affected in people with dysarthria, its presentation can have variation with each speaker.

Rhythm disturbances are often said to be a contributing factor to low intelligibility in dysarthria but has not been explored thoroughly. According to Liss et al. (2009), it is possible that some rhythm disorders may create a bigger challenge for listeners to perceive dysarthric speech than other disordered speech and may even inhibit the ease with which they can use cues for segmentation of speech. It is also important to establish whether rhythm disturbances can be reliably identified compared to control speakers and whether predictions can be made about where they may most likely be observed. This thesis aimed to shed light on the rhythm disturbances in dysarthria by comparing dysarthric speech to controlled speech. First, this paper will outline more about Dysarthria, and rhythm in dysarthria before investigating its role in dysarthric speech.

1.2. Speech Characteristics and Types of Dysarthria

A standard system of dysarthria classification employed in literature is that proposed by Darley, et al (1969). They suggested that the nervous system and area affected would allow perceptual features of the disorder to be identified. According to Darley et al., dysarthria can be categorized into seven types:

- Ataxic dysarthria is known to affect functions such as respiration, phonation, and articulation. This results in more stress being placed on all syllables, due to an added effort in articulation.
- Spastic dysarthria is recognized by its characteristic vocal harshness. The speaker is perceived to be straining his/her voice and long durations are noticed in transitions between phonemes and syllables. The fundamental frequency is low (F0) and may show some breaks.
- Hypokinetic dysarthria is associated with Parkinson's disease. Hoarseness is commonly present in this type. Intelligibility is also noticeably reduced as the speech is often soft and may accompany a compulsive repetition of syllables.
- Hyperkinetic dysarthria usually involves some involuntary movement and can be harsh to the ear. It noticeably presents with hypernasality and frequent pauses, including a complete lack of intelligibility.
- Flaccid dysarthria is the result of damage to the lower motor neurons involved in articulation. Often, a paralysis is observed on one vocal fold. The voice is harsh sounding with low volume and sometimes shrillness.

- Mixed dysarthria comprises of a combination of characteristics depending on the type and place of injury. Voice harshness is noticed if upper motor neurons are not functional. Conversely, if lower motor neurons are affected, the voice will sound breathy.
- Unclassified dysarthria covers all types that do not belong to the six above categories.

The classification into dysarthria types is based on muscle tone and disordered movement: spastic dysarthria results from excessive muscle tone and produces strained speech, but flaccid dysarthria results from decreased muscle tone and causes weak articulation and softness of voice (Lowit, 2014). Some dysarthrias such as Hypokinetic and Hyperkinetic dysarthria affect prosodic factors such as intonation and loudness where others such as Flaccid and Spastic dysarthria would be detrimental to articulation, or speech rate. What all dysarthrias have in common is reduced intelligibility, but some such as Ataxic dysarthria lead to greater rhythmic disturbances.

It seems as though researchers do not agree on the answer to the question of whether speech rate and duration in speakers with dysarthria are different from control speakers. Some conflicting findings include whether speech rate differed between dysarthric and control speakers – Ackermann and Ziegeler (1991) found that speech rate did not differ, but Dorze, Ouellet, and Ryalls (1994) found differences. The conflicting findings can be explained by the different dysarthria etiologies studied. Only speakers with Parkinson's Disease (PD) do not differ in speech rate from control speakers, whereas all other dysarthric patients speak significantly more slowly than control groups (Refer to Table 1 for a summary of the perceptual features and neurological disorders underpinning different types of dysarthria; Ackermann & Ziegler, 1991; Dorze et al., 1994; Kent, Netsell, & Abbs, 1979; Liss et al., 2009).

Type of dysarthria	Dysarthric Etiology	Characteristics
Flaccid dysarthria	Bulbar palsy, Multiple Sclerosis (MS)	Hypernasality; Imprecise consonants; Breathy voice (continuous); Mono-pitch
Spastic dysarthria	Pseudobulbar palsy	Imprecise consonants; Mono-pitch; Reduced stress; Harsh voice; Mono-loudness; Low pitch; Slow rate; Hypernasality; Strained voice
Ataxic dysarthria	Cerebellar disorders	Imprecise consonants; Excess and equal stress; Irregular articulatory breakdown; Vowels distorted; Harsh voice
Hypokinetic dysarthria	Parkinson's Disease (PD)	Mono-pitch; Mono-loudness; Reduced stress; Imprecise consonants; Long silences; Short rushes; Harsh and Breathy voice
Hyperkinetic dysarthria	Dystonia and chorea	Imprecise consonants; Vowels distorted; Harsh voice; Irregular articulatory breakdown; Strained voice
Mixed types	Combination of disorders named above (usually flaccid-spastic)	Combinations of the characteristics named above

Table 1. Summary of the perceptual features of Dysarthria based on Darley et al. (1969)

One of the main findings encountered when measuring speech rate and duration is that dysarthric patients find it difficult to maintain rhythm and display abnormal word stress patterns (Liss et al., 2009). Further information about how word stress is affected in dysarthric speakers is needed to understand how impaired speech prosody impacts these speakers' communication. While rhythm is identified as the main feature characterizing dysarthria, assessment methods are mainly based on perceptual evaluations (Selouani, Dahmani, Amami, & Hamam, 2012). This can be problematic because these methods lack evaluation protocols that may help standardization of judgments between clinicians and/or evaluation tools (Selouani et al., 2012). Despite their numerous advantages including the ease of use, low cost and clinicians' familiarity with perceptual procedures, perceptual-based methods suffer a number of inadequacies and aspects affecting their reliability.

1.3. Rhythm in Dysarthria

According to Liss et al. (2009), "rhythm has been used to refer to the perceptually distinctive alternation of stressed and unstressed syllables—what we may qualify as contrastive rhythm." More recent research on speech rhythm seems to have focused on examining the cross-linguistic differences between syllable structures, such as identifying that Romance languages such as Spanish largely have CV) syllables, whereas Germanic languages such as Dutch, English have more consonant clusters (CCVC, CCVCC, CCCVC, etc.), particularly in stressed syllables (Liss et al., 2009). Rhythm differences are realized in differences between syllable structures, vowel reduction, and phonetic realization of stress. In Germanic languages, for example, unstressed vowels tend to be reduced.

Unlike rhythm differences found in cross-linguistic studies, in which differences were part of phonological constraints, rhythm abnormalities widely present in dysarthria occur at the articulatory level instead. The impact is on the perception of rhythm in speech as well as the flow of syllables. The perception of rhythmic disturbance is often variably described as having prolonged segments, rushed speech, reduced stress, increased stress, etc (Darley et al., 1969). Dysarthria also presents with a particular pattern of rhythmic disturbance that can aid in diagnosis, by helping their categorization into types of dysarthria. For example, hypokinetic dysarthria can present with short bursts of rapid speech while hyperkinetic dysarthria can have unpredictable rhythm (Liss et al., 2009).

Given previous claims on the distinction between dysarthria types based on the perceptual differences in rhythm, an important next step would be to quantify rhythm patterns in the disorder which would serve productively as a diagnostic tool as well as to assess the progress made during treatment. It is also likely that investigation into rhythmic disturbances will reveal that certain unusual patterns may not contribute to poor intelligibility where others might.

1.4. Rhythm Metrics

Liss et al. (2009) attempted to quantify rhythmic disturbances in dysarthric speech by combining numerous duration-based metrics that were previously used in studies to identify the speech rhythm differences between languages. These metrics were derived by extracting vocalic and consonantal intervals from speech segments (Dellwo, 2006; Low, Grabe, & Nolan, 2000; Ramus, Nespor, & Mehler, 1999), and ignoring high-level prosodic structure so as to include constant durations between subsequent vowels in the same consonant interval.

Liss et al. recognized the potential value of these metrics and used them to quantify rhythm in dysarthria types, adding consonantal measures as well (see Figure 1). They found that the metrics found distinct differences between the dysarthric and control group. They also found that VarcoV and n-PVI-V were the most discriminative between dysarthria types, but also that all the metrics were 80% successful in contributing to classifying speech into the various types of dysarthria. It was also found that consonantal metrics usually displayed congruencies to rhythm in normal speech so vocalic metrics were most suited to identify contrasts. Therefore, consonant metrics could only help distinguish between dysarthria types when consonants were highly irregular. However, they noted that their population included severe cases of dysarthria and that these metrics would need to be checked with mild and moderate levels of severity as well. Some metrics were also more sensitive to some types of dysarthria (largely ataxic) than others. Nevertheless, combining various metrics would prove to be a more robust method of investigation than isolation one or two.

Figure 1 summaries the rhythm metrics discussed in this section along with their definitions, as used by Liss et al. (2009), some of which are employed in this thesis:

Measure	Description
ΔV	Standard deviation of vocalic intervals.
ΔC	Standard deviation of consonantal intervals.
%V	Percent of utterance duration composed of vocalic intervals.
VarcoV	Standard deviation of vocalic intervals divided by mean vocalic duration (× 100).
VarcoC	Standard deviation of consonantal intervals divided by mean consonantal duration (× 100).
VarcoVC	Standard deviation of vocalic + consonantal intervals divided by mean vocalic + consonantal duration (× 100).
nPVI-V	Normalized pairwise variability index for vocalic intervals. Mean of the differences between successive vocalic intervals divided by their sum (× 100).
rPVI-C	Pairwise variability index for consonantal intervals. Mean of the differences between successive consonantal intervals.
nPVI-VC	Normalized pairwise variability index for vocalic + consonantal intervals. Mean of the differences between successive vocalic + consonantal intervals divided by their sum (× 100).
rPVI-VC	Pairwise variability index for vocalic and consonantal intervals. Mean of the differences between successive vocalic and consonantal intervals.
Articulation rate	Number of (orthographic) syllables produced per second, excluding pauses.

Figure 1. Definitions of rhythm metrics as used by Liss et al. (2009)

Ramus et al. (1999) used the standard deviations of vocalic and consonantal interval durations (Δ V and Δ C, respectively) along with the total vowel utterance duration (%V) to show that they were effective means of differentiating between groups of languages that were previously known to be rhythmically different (Dutch, English vs. French, Spanish). However, studies then criticized Darley's measures pointing out that the standard deviation metrics were problematic in capturing speaker differences because they were inversely proportional to speech rate. This was later corrected by Ramus (2002) when he suggested that the metrics would be normalized by dividing the standard deviation of the interval duration by the mean (VarcoV for vowels, VarcoC for consonants). After being tested by Dellwo (2006) and White and Mattys (2007a), these metrics were shown to be robust against changes in speech rate.

The pairwise variability indices (PVIs) were proposed as addition measures that also derive from vocalic and consonantal interval durations. The difference here was that these measures try to capture the successive property of rhythm. It does this by adding the differences between successive intervals based on the fact that languages that have high temporal stress contrast (such as English and Dutch) would tend to have larger durational differences between successive syllables. The PVI-V for vowels is rate normalized like VarcoV (nPVI-V) which would be crucial is analyzing dysarthric speech that could show large speech rate variations, but PVI-C is not (refer to Grabe & Low, 2002, for further information on PVIs).

White and Mattys (2007a, 2007b) compared all the above metrics and found that VarcoV and %V were the most effective in discrimination between languages as well as between varieties of English that are widely known to be rhythmically different. These metrics were also shown to be most robust to changes in speech rate. It was also noted that VarcoV and nPVI-V were highly correlated to each other, but in certain cases (based on etiology) VarcoV may prove to be more discriminative.

It was assumed that the above metrics would be suitable to apply to clinical research because some of the differences that were found between control and dysarthric speech seemed to mimic the differences noted between stress- and syllable-timed languages. For example, syllable-timed languages tended to have faster speech rate than stress-timed languages due to the extra stress in the later. Therefore, the metrics would successively lend themselves as a diagnostic tool by identifying rhythm deviations. In addition, it was suggested that since rhythm metric could capture the continuum of difference between stress- and syllable timed languages, they would also be able to capture the extent of rhythm deviation of impaired speech from normal speech. This would then become effective in judgement of severity of impairment and begin to be used in treatment as a tool for testing improvement.

Research followed that tried to investigate the above claim and used a variety of the metrics to do so. The PVI was first applied to clinical speech (Liss et al., 2007; Stuntebeck, 2002; Wang, Kent, Duffy, Thomas, Fredericks, 2006), then other metrics to a group of Swedish speakers with dysarthria (Hartelius, Runmarker, Andersen, Nord, 2000). These studies were able to establish that rhythm metrics such a PVI, VarcoV would be able to successfully distinguish between groups of speakers with severe levels of disordered speech and control speakers.

Before these measures can be fully accepted as valid tools, it is imperative that we need to take a step back and investigate whether they can indeed capture the intricacies of rhythmic performance in a disordered population in a clinically useful way. Little research is done with various types of dysarthria about whether rhythm metrics can show if rhythmic disturbances exist and where these disturbances lie, and whether they are more apparent when compared to a control group, or whether rhythmic disturbances can be identified within dysarthric speakers, at a sentential level. In addition, previous studies have largely focused on speakers with a severe level of dysarthria and have not included mild or moderate cases (especially when testing rhythm metrics on dysarthric speech) (Liss et al., 2009). Research has also rarely investigated dysarthric speech in any language other than English. This thesis attempted to fill this gap in the literature by investigating rhythmic and pitch disturbances that exist in dysarthric speakers of Dutch which would better inform diagnosis and treatment of dysarthria. The dysarthric participant pool included speakers of mild and moderate severity in order to investigate if rhythm metrics can identify rhythmic disturbances compared to a control (age- and gender matched) population.

1.5. Research Question and Hypothesis

The present study investigated the rhythmic and pitch variation between Dutch speakers with dysarthria and normal Dutch speakers, using rhythm metrics and pitch information. Based on previous research, these were the research question(s) and hypothesis of this study:

1. What are the rhythm and pitch variation differences between Dutch dysarthric speakers and control Dutch speakers?

   Hypothesis (a): Analysis will show that there are group differences in rhythm and may be captured by the rhythm metrics used. There may also be speech rate and pitch differences between groups where the dysarthric group will have a slower speech rate and more pitch variation compared to the control group.

   Hypothesis (b): There may also be significant speech rate, rhythm or pitch differences within the dysarthric group, between the various dysarthric etiologies.

   a. What does rhythm metrics tell us these differences are, and does it show consistent differences in specific areas of the speech signal?

      Hypothesis (c): There may be sentence level rhythm differences where the dysarthric group with have more rhythmic variations than the control group. This may indicate areas of likely rhythmic disturbances in the speech signal. There may also be group and sentence level interactions which would indicate that rhythm metrics are sensitive to various rhythm changes.

The study in this thesis employed speech rate as a measure and most of the vocalic metrics discussed previously in this chapter, namely ∆ V, %V, VarcoV and n-PVI-V as they have shown to be robust measures in identifying rhythmic differences and were more likely to capture the disturbances in the various etiologies of dysarthric groups included in this study. The etiologies that were included where speakers with Parkinson's disease (PD), Multiple Sclerosis (MS), and those who have had a Stroke, because of their association with specific types of dysarthria, and their characteristics which is elaborated in the next paragraph. This study also investigated pitch variation (the standard deviations of the fundamental frequency) in order to see if any group difference indeed existed.

The particular etiologies in this study are usually associated with certain types of dysarthria. PD is associated with Hypokinetic dysarthria and therefore usually displays mono-pitch and loudness, compulsive syllable repetitions, rushed speech, long pauses, and particularly low intelligibility. Liss et al (2009) found that these characteristics where confirmed in their study using rhythm metrics to quantify the various dysarthrias. PD is also known to sound slightly more intelligible in prepared speech compared to spontaneous speech (Kim, Kent, & Weismer, 2011). MS is usually associated with Flaccid dysarthria, but patients can also present with Mixed dysarthria. This indicates that speakers will likely have mono-pitch, hypernasality, and continuous breathy voice. Patients who have had a stroke can present with Flaccid, Hypokinetic, Spastic, or Mixed dysarthria and therefore can have a combination of speech abnormalities. These features have been shown in previous studies and with rhythm metrics though with severe cases. However, given the characteristics outlined above, the pitch measure may be able to pick up on this mono-pitch and the rhythm metrics could pick up on the rushed speech and syllable repetitions.

The following section will outline the method of this study as well as the measures employed, and analysis conducted. This will be followed by an outline of the results, which will be discussed in the subsequent sections before making conclusions.

2. Method

2.1. Participants

For this study, a Dutch Corpus of Pathological and Normal Speech (COPAS) was used to select thirty adult speakers of Dutch. Of the participants, 20 were men and 10 were women. The participants were selected from the corpus based on being diagnosed with dysarthria and having read a common text titled Text Marloes (See Appendix A for full text). This text is a standardized text with a balanced representation of Dutch phonemes. It is often used in clinical practice. The patient group was narrowed down further in order to control for etiology and severity of dysarthria (5 for each type of etiology) leading to a total of 15 patients. The Patient group was then age-and gender-matched with a control group consisting of 15 speakers. The pathological group was aged between 33 and 85 years with a mean age of 57. The control group was aged between 27 and 77 years, with a mean age of 54 years. Other details about the dysarthric participants can be found in Table 1.

Group	Dysarthria Etiology	Gender	Age (in years)
Patient	PD	M	66
Patient	PD	M	85
Patient	stroke	F	76
Patient	PD	M	51
Patient	PD	F	85
Patient	stroke	M	78
Patient	MS	M	53
Patient	stroke	F	43
Patient	stroke	M	46
Patient	stroke	F	35
Patient	MS	M	51
Patient	MS	F	68
Patient	MS	M	33
Patient	PD	M	48
Patient	MS	M	33
Control	n/a	M	46
Control	n/a	M	41
Control	n/a	M	55
Control	n/a	F	77
Control	n/a	F	67
Control	n/a	M	27
Control	n/a	M	77
Control	n/a	F	77
Control	n/a	F	35
Control	n/a	M	59
Control	n/a	M	59
Control	n/a	M	46
Control	n/a	M	52
Control	n/a	F	43
Control	n/a	M	50

Table 2. Participant information

2.2. Stimuli Recording

The recordings were available as part of COPAS and were made in a quiet clinical setting without a sound treated box. The recordings were done with a controlled microphone, recorded by means of a mini-disc (Sony MZR700) and later transferred to a notebook. The transfer was done with a freely available wave editor (Audacity).

2.3. Measurements

2.3.1. Durational measures

All speech samples were analyzed using Praat (Boersma & Weenik, 2006) software. For calculation of the rhythm metrics, CV and VC boundaries were identified and labeled by visual inspection of speech waveforms and spectrograms according to standard segmentation criteria (Peterson & Lehiste, 1960), with labels placed at the point of zero crossing on the waveform. The primary indicator of a VC boundary was the end of a pitch period preceding a break in the formant structure, with a corresponding drop in waveform amplitude. CV boundaries were primarily determined as beginning at the start of the pitch period coinciding with the onset of regular formant structure. Following White and Mattys (2007), vocalic intervals were identified and measured only when there was visible evidence of a voiced vowel. Devoiced vowels and syllabified consonants were included in the adjacent consonant interval. Vocalic and consonant interval durations were extracted using a custom Praat script on the boundary label files. Following Low et al (2000), silent pauses that occurred as inhalations during sentences or murmuring were excluded and the durations of successive vowels or consonants were summed to form one interval duration, both when immediately adjacent and when separated by a pause. This standard procedure removed the need for linguistic judgments about prosodic constituency in the calculation of what are intended to be fundamentally acoustic metrics (see Grabe & Low, 2002; Ramus et al., 1999).

2.3.2. Pitch Measures

The minimum and maximum pitch for each sentence per speaker was checked in Praat ensuring that the fundamental frequency did not exceed 400Hz for males and 600Hz for females. Then the Standard Deviation of the fundamental frequency (F0) in Hertz for each sentence per speaker (8 data points per speaker) was collected for statistical analysis as provided from the Praat pitch object.

2.3.3 Calculation of Rhythm Metrics

Rhythm metrics were calculated for each of the eight sentences of the Text Marloes spoken by each of the fifteen speakers for each group (Patient and Control). They were all based on interval durations in milliseconds, listed as follows:

- Speech rate, the number of syllables per second per sentence for each speaker
- Δ V, the standard deviation of vocalic interval duration.
- %V, the sum of vocalic interval duration divided by the total duration of vocalic and consonantal intervals and multiplied by 100.
- VarcoV, the standard deviation of vocalic interval duration divided by the mean vocalic interval duration and multiplied by 100.

The PVI utilises the difference in duration of successive intervals, either vocalic or consonantal. The raw pairwise variability index (rPVI) is simply the mean of the differences between successive intervals; the normalised pairwise variability index (nPVI) is the mean of the differences between successive intervals divided by the sum of the same intervals. The PVI calculated here is:

- nPVI-V, the normalised Pairwise Variability Index for vocalic intervals.

2.5. Statistical Analysis

Multiple repeated measures ANOVAs were used to analyse whether groups differed in speech rate (including and excluding pauses), rhythm metrics, or F0 (variability) between groups, as well as within group (dysarthria). Sentence was used as the within-subjects variable and Group as the between-subjects measure. All measures were checked for any group, sentence or group and sentence interaction effects. SPSS (Version 25.0) was used to conduct all analyses.

3. Results

To determine if there were any significant group differences in the different rhythm and F0 measures a series of Repeated Measures ANOVAs were conducted testing for group (between-speaker) and sentence effects (within-speaker), as well as their interactions. Repeated measure ANOVAs were also conducted to determine if there were any significant within-group (dysarthric group) differences in the different rhythm and F0 measures, split based on their etiology (PD, Stroke, and MS).

3.1. Between-group Results (Dysarthric Group vs. Control Group)

3.1.1. Rhythm measures

Speech rate

The speech rate data contained no outliers and the data was normally distributed, as assessed by boxplot and Shapiro-Wilk test ($p > .05$), respectively. The assumption of sphericity was violated for the within-subject effect of Sentence, as assessed by Mauchly's test of sphericity, $\chi2(2) = 52.341$, $p = .003$. Therefore, Greenhouse-Geisser correction was applied. The Repeated Measures ANOVA showed that the overall Group effect was not significant ($F(1, 28) = 14.160$, $p > 0.1$), but the Sentence effect was significant, indicating that speech rate generally differed across sentences ($F(4.640, 129.922) = 14.432$, $p < .001$, partial $\eta2 = 0.340$). The Group by Sentence interaction was not significant ($F(4.640, 129.922)= 0.612$, $p > 0.1$).

ΔV

The ΔV data contained no outliers and the data was normally distributed, as assessed by boxplot and Shapiro-Wilk test ($p > .05$), respectively. The assumption of sphericity was violated for the within-subject effect of Sentence, as assessed by Mauchly's test of sphericity, $\chi2(2) = 78.155$, p =

.0005. Therefore, Greenhouse-Geisser correction was applied. The Repeated Measures ANOVA showed that the overall Group effect was not significant ($F(1, 28) = 7.461$, $p > 0.1$), but the Sentence effect was significant, indicating that △V generally differed across sentences ($F(3.447, 96.524) = 8.248$, $p < .001$, partial $\eta 2 = 0.228$). The Group by Sentence interaction was not significant ($F(3.447, 96.524)= 0.901$, $p > 0.1$).

%V

The %V data contained no outliers and the data was normally distributed, as assessed by boxplot and Shapiro-Wilk test ($p > .05$), respectively. The assumption of sphericity was violated for the within-subject effect of Sentence, as assessed by Mauchly's test of sphericity, $\chi 2(2) = 43.073$, p = .027. Therefore, Greenhouse-Geisser correction was applied. The Repeated Measures ANOVA showed that the overall Group effect was not significant ($F(1, 28) = 0.601$, $p > 0.1$), but the Sentence effect was significant, indicating that %V generally differed across sentences ($F(4.642, 129.978) = 10.994$, $p < .001$, partial $\eta 2 = 0.282$). The Group by Sentence interaction was not significant ($F(4.642, 129.978)= 1.434$, $p > 0.1$).

VarcoV

The VarcoV data contained no outliers and the data was normally distributed, as assessed by boxplot and Shapiro-Wilk test ($p > .05$), respectively. The assumption of sphericity was violated for the within-subject effect of Sentence, as assessed by Mauchly's test of sphericity, $\chi 2(2) = 40.512$, p = .048. Therefore, Greenhouse-Geisser correction was applied. The Repeated Measures ANOVA showed that the overall Group effect was not significant ($F(1,28) = 1.51$, $p > 0.1$), but the Sentence effect was significant, indicating that VarcoV generally differed across sentences (F(4.913, 137.557) = 12.462, $p < .001$, partial $\eta 2 = 0.308$). The Group by Sentence interaction was also significant (F(4.913, 137.557)= 2.612, $p < 0.05$). This interaction is displayed in Figure 5, showing the VarcoV group means over the different sentences. Figure 2 shows that, across sentences, the group difference is not constant, and across sentences the groups tend to diverge.

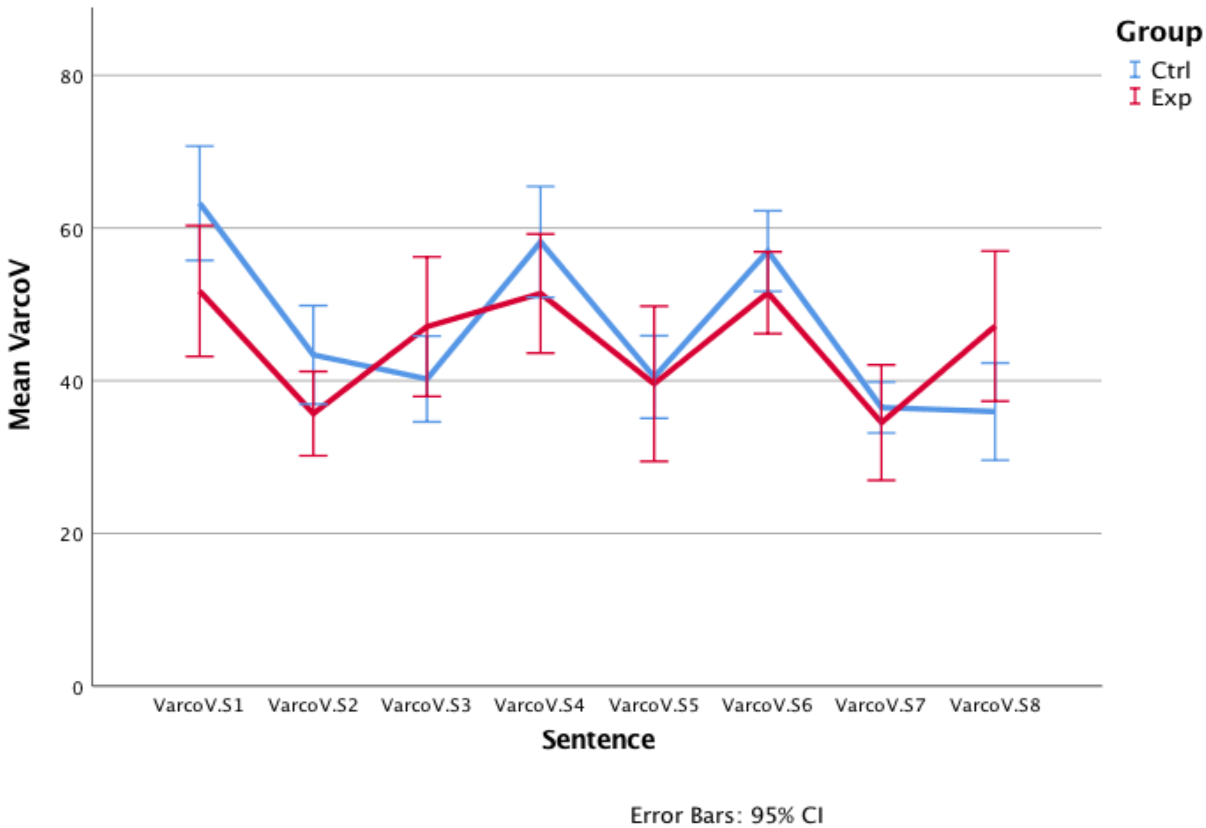

Figure 2. Mean VarcoV per Sentence across Groups

n-PVI-V

The n-PVI-V data contained no outliers and the data was normally distributed, as assessed by boxplot and Shapiro-Wilk test (*p* > .05), respectively. The assumption of sphericity was violated for the within-subject effect of Sentence, as assessed by Mauchly's test of sphericity, $\chi 2(2)$ =

40.632, p = .047. Therefore, Greenhouse-Geisser correction was applied. The Repeated Measures ANOVA showed that the overall Group effect was not significant (F(1, 28) = 0.874, p > 0.1), but the Sentence effect was significant, indicating that n-PVI-V generally differed across sentences (F(4.956, 138.758) = 12.390, p < .001, partial η2 = 0.307). The Group by Sentence interaction was not significant (F(4.956, 138.758)= 2.106, p > 0.1).

3.1.2. F0 variability Measure

F0 SD

The F0 SD data contained no outliers and the data was normally distributed, as assessed by boxplot and Shapiro-Wilk test (*p* > .05), respectively. The assumption of sphericity was violated for the within-subject effect of Sentence, as assessed by Mauchly's test of sphericity, χ2(2) = 96.987, p = .0005. Therefore, Greenhouse-Geisser correction was applied. The Repeated Measures ANOVA showed that the overall Group effect was not significant (F(1, 28) = 0.624, p > 0.1), but the Sentence effect was significant, indicating that F0 SD generally differed across sentences (F(3.531, 98.862) = 12.390, p < .001, partial η2 = 0.104). The Group by Sentence interaction was not significant (F(3.531, 98.862)= 0.505, p > 0.1).

3.2. Within-group Results (Dysarthric Group)

3.2.1. Rhythm measures

Speech rate

The speech rate data contained no outliers and the data was normally distributed, as assessed by boxplot and Shapiro-Wilk test (*p* > .05), respectively. The assumption of sphericity was not violated for the within-subject effect of Sentence as assessed by Mauchly's test of sphericity,

$\chi 2(2) = 36.828$, $p = .124$. The Repeated Measures ANOVA showed that the overall Group effect was not significant ($F(2, 12) = 0.466$, $p > 0.1$), the Sentence effect was not significant ($F(3.245, 38.945) = 3.149$, $p > 0.1$), and the Group by Sentence interaction was not significant ($F(6.491, 38.945)= 0.851$, $p > 0.1$).

ΔV

The ΔV data contained no outliers and the data was normally distributed, as assessed by boxplot and Shapiro-Wilk test ($p > .05$), respectively. The assumption of sphericity was violated for the within-subject effect of Sentence, as assessed by Mauchly's test of sphericity, $\chi 2(2) = 57.078$, $p = .001$. Therefore, Greenhouse-Geisser correction was applied. The Repeated Measures ANOVA showed that the overall Group effect was not significant ($F(2, 12) = 0.345$, $p > 0.1$), the Sentence effect was not significant ($F(2.958, 35.486) = 2.458$, $p > 0.1$), and the Group by Sentence interaction was not significant ($F(5.916, 35.486)= 0.574$, $p > 0.1$).

%V

The %V data contained no outliers and the data was normally distributed, as assessed by boxplot and Shapiro-Wilk test ($p > .05$), respectively. The assumption of sphericity was not violated for the within-subject effect of Sentence as assessed by Mauchly's test of sphericity, $\chi 2(2) = 36.541$, $p = .130$. The Repeated Measures ANOVA showed that the overall Group effect was not significant ($F(2, 12) = 1.529$, $p > 0.1$), the Sentence effect was not significant ($F(7, 84) = 3.221$, $p > 0.1$), and the Group by Sentence interaction was not significant ($F(14, 84)= 0.430$, $p > 0.1$).

VarcoV

The VarcoV data contained no outliers and the data was normally distributed, as assessed by boxplot and Shapiro-Wilk test ($p > .05$), respectively. The assumption of sphericity was not violated for the within-subject effect of Sentence as assessed by Mauchly's test of sphericity, $\chi2(2) = 30.123$, $p = .352$. The Repeated Measures ANOVA showed that the overall Group effect was not significant ($F(2, 12) = 0.324$, $p > 0.1$), the Sentence effect was not significant ($F(7, 84) = 3.489$, $p > 0.1$), and the Group by Sentence interaction was not significant ($F(14, 84)= 0.732$, $p > 0.1$).

n-PVI-V

The n-PVI-V data contained no outliers and the data was normally distributed, as assessed by boxplot and Shapiro-Wilk test ($p > .05$), respectively. The assumption of sphericity was not violated for the within-subject effect of Sentence as assessed by Mauchly's test of sphericity, $\chi2(2) = 35.960$, $p = .144$. The Repeated Measures ANOVA showed that the overall Group effect was not significant ($F(2, 12) = 1.646$, $p > 0.1$), the Sentence effect was not significant ($F(7, 84) = 2.819$, $p > 0.1$), and the Group by Sentence interaction was not significant ($F(14, 84)= 0.821$, $p > 0.1$).

3.2.2. F0 Measure

F0 SD

The F0 SD data contained no outliers and the data was normally distributed, as assessed by boxplot and Shapiro-Wilk test ($p > .05$), respectively. The assumption of sphericity was violated for the within-subject effect of Sentence, as assessed by Mauchly's test of sphericity, $\chi2(2) =$

51.550, p = .005. Therefore, Greenhouse-Geisser correction was applied. The Repeated Measures ANOVA showed that the overall Group effect was not significant (F(2, 12) = 0.044, p > 0.1), the Sentence effect was not significant (F(3.105, 37.261) = 0.953, p > 0.1), and the Group by Sentence interaction was not significant (F(6.210, 37.261)= 0.572, p > 0.1).

F0 SD was not statistically significant for any of the factors.

Based on the analysis conducted above, the between-group results (dysarthric group vs. control group) show that Speech rate only showed sentence (but no group) effects, ∆V only showed sentence (but no group) effects, %V only showed sentence (but no group) effects, VarcoV showed sentence and group and sentence interaction (but no group) effects, n-PVI-V only showed sentence (but no group) effects, and F0 SD w only showed sentence (but no group) effects. The within-group results (PD vs. Stroke vs. MS) show that speech rate, ∆V, %V, VarcoV, n-PVI-V, and F0 SD were **not** significant for any of the factors (group, sentence, or group and sentence interaction).

4. Discussion and Conclusion

Rhythm disturbances have often been cited as a characteristic of Dysarthria which in-turn, supposedly, contribute to its low intelligibility. However, rhythm disturbances have seldom been the focus of previous research. This thesis aimed to fill this gap in the literature by investigating what the rhythm and pitch differences are between Dutch adult speakers with dysarthria and normal speakers, by using rhythm metrics and pitch variation to explore this. Rhythm metrics were shown in previous studies to be a potentially robust measure for discriminating between speakers with dysarthria and a control group, as well as reliably categorizing types of dysarthria based on the rhythm differences. These studies largely used a clinical population with severe dysarthria (Liss et al., 2009; Low et al., 2000) leaving the rhythm metrics yet to be tested on mild and moderate levels of dysarthric severity. The Dysarthric population in this thesis used recordings from patients with mild to moderate dysarthria in order to explore if the rhythm metrics (△V, %V, VarcoV, n-PVI-V) could discern between the dysarthric and control group, as well as within the dysarthric group (based on etiology). The rhythm metrics used were previously suggested as robust measures for rhythm in dysarthria (Dellwo, 2006; Liss et al., 2009; Low et al., 2000). In addition, speech rate and pitch variation were also used as measures in order to isolate group differences between the dysarthric and control groups.

Summary of Between-group comparison results

The results in the previous chapter showed that for the between-group results, (which investigated the rhythm and pitch differences between speakers with dysarthria and control speakers), there were no Group differences in speech rate, rhythm, or pitch variation. The results however, showed that Speech rate, all rhythm metrics, and pitch variation showed a sentence effect. There were no Group and Sentence interactions found for any of the measures except VarcoV.

Summary of Within-group results

The within-group results (which investigated the rhythm and pitch differences between each etiology of the dysarthric group – PD, Stroke, MS) showed there were no Group differences, Sentence differences, or Group and Sentence interactions for speech rate, rhythm, or pitch variation.

4.1. Discussion

The results showed that with regard to the research question of this thesis and its predictions, the following was found:

Hypothesis (a) was rejected: Analysis **did not** show that there are group differences in rhythm and as it was not captured as part of the rhythm metrics used. There were also **no** pitch variation differences between groups.

Hypothesis (b) was rejected: There were **no** significant rhythm or pitch differences within the dysarthric group between the various dysarthric etiologies.

Hypothesis (c) partially accepted: There were **sentence level rhythm differences across the dysarthric and control group** but did not indicate that specific sentences or specific parts of sentences consistently showed larger rhythmic disturbances in the speech signal. There were **no** group and sentence level interactions between the dysarthric and control group except for VarcoV, and no interactions within the dysarthric groups (etiologies).

The results of this thesis have implications for the use/ extent of use of rhythm metrics to characterize disordered speech. The lack of differentiation between dysarthric and control groups by the rhythm metrics and the pitch variation measure was unexpected. The results showed no significant group differences between dysarthric group and control group which may be due to rhythm metrics not being sensitive to mild dysarthria, which is contradictory to previous studies that showed strong sensitivity of the investigated rhythm metrics to severe dysarthria since they were able to distinguish between dysarthric speakers and control speakers, as well as between types of dysarthria (Liss et al., 2009). However, the interpretation of the results should be done with some caution as the dysarthric population in this study is small and the distribution between mild and moderate severity is not equal. Therefore, additional analysis methods, and additional experiments will need to be conducted in order to arrive at a robust characterization of a speaker's speech patterns.

The results which were significant for Sentence-level variation, show that rhythm metrics are sensitive to lower-level changes such as between specific phrases and words which contribute to the overall sentential differences as seen in previous studies (Dellwo & Wagner, 2003; Lowit et al., 2001). However, given that there were no overall group changes observed, it is possible that when investigating mild and moderate severity levels in dysarthria, rhythm metrics may need to be combined with other measures such as intensity, loudness, fundamental frequency, and the variability of sonorant and voiced durations that may better isolate rhythmic nuances (Fuchs, 2016). In other words, rhythm metrics may not be sensitive to rhythmic disturbances in dysarthria unless they are severe dysarthrics. Alternatively, there may not be any rhythmic disturbances between the dysarthric group and control group used in this thesis. This cannot be confirmed in the results of this thesis but would need to be explored in the future as a viable explanation.

Another explanation for the results could be that severity of the dysarthria affected the quantity of rhythmic disturbances observed. Although the speech recordings were 8 sentences long, it is possible that in order for the rhythm metrics to ascertain a fixed pattern of disturbances for each speaker, an even longer speech sample was required. VarcoV was the only metric that had a sentence and group interaction, which showed that there are rhythmic differences between the dysarthric and control group but only at specific points (sentences). A larger speech sample could then allow the metrics to extract the patterns of rhythmic disturbance distinctly and accurately. Therefore, rhythm metrics may still be effective in identifying rhythmic disturbances in the speech signal but will require more 'information' (longer speech samples) as an input, in order to reliably do so.

Another factor that may have caused the results in this thesis is that previous studies show rhythm metrics are most accurate in identifying and categorising ataxic dysarthria (Henrich, Lowit, Schalling, & Mennen, 2006; Liss et al., 2009). That is, rhythm metrics have shown the most sensitivity to ataxic dysarthria and most accurately categorized it based on its rhythmic disturbances. This suggests that at least ataxic dysarthria (if not other types) might have more salient rhythmic disturbances that can be picked up by rhythm metrics. This thesis included patients with hypokinetic, and flaccid dysarthria types and some speakers whose classification was unknown. Ataxic dysarthria was not investigated in this thesis, and therefore if included, may have shown highly contrasting rhythmic patterns. Once again, this has only been established with severe cases, and therefore cannot be generalized to mild and moderate cases without further investigation.

Finally, small sample size is frequently cited as reasons for lack of statistical significance, which can be said to apply in this study. There is certainly a possibility that a larger sample group of about 30-45 speakers with dysarthria as in Liss et al (2009) and Lanford and Liss (2014) would have resulted in more affirmative group differences for the speech rate, the rhythm metrics and the pitch variation.

The lack of any differences in speech rate between the dysarthric group and control group was unexpected but coincides with certain research that also did not find group differences in speech rate between dysarthric speakers and normal speakers (Ackermann & Ziegler, 1991). However, further research did suggest that only speakers with Parkinson's Disease (PD) do not differ in speech rate from normal speakers, whereas all other dysarthric patients speak significantly more slowly than control groups (Dorze et al., 1994; Kent et al., 1979; Liss et al., 2009). This could explain the lack of overall speech rate differences between the dysarthric and control group in this thesis, since a third of the dysarthric group were speakers with Parkinson's disease. Speech rate missed significance for group effect only marginally, therefore future research that includes a larger group with more types of dysarthria may be more conclusive on speech rate differences between dysarthric speech and normal speech.

Rhythm in speech is associated with the temporal organization of speech sounds and therefore moderates articulation (rate) in speech production. An important aspect of the investigation of speech rhythm involves the sound envelope which is “the acoustic power summed across all frequencies for a given frequency range” (Fujii & Wan, 2014) and any bursts in the sound envelope represent the rhythm of vocalization. fMRI studies have shown that the sound envelope or rhythm is processed in the brainstem, the thalamus, and the auditory regions in the temporal cortex, which may be lateralized to right hemisphere. Clinical studies have indeed shown that dysrhythmic production is associated with an impairment in the basal ganglia, thalamus and supplementary motor area (Fujii &Wan, 2014). Research into rhythmic speech can help understand more about the impairment as well as where it is localized. It is possible that the dysarthric group part of this thesis may also show impairments in the areas mentioned, and future research may help confirm this, also aiding in an understanding of where speech rhythm is localized in different types and severities of dysarthria.

4.2. Conclusion

This thesis aimed to explore what the rhythm and pitch differences are between Dutch adult speakers with dysarthria and a control group, using speech rate, rhythm metrics and pitch variation as measures. The results showed that there were no significant group differences between dysarthric speakers and control speakers in speech rate, rhythm and pitch variation. There were significant differences at a sentence level, which indicates that both groups varied across their sentences with regard to their speech rate, their rhythm, and their pitch variation. There was no group and sentence interactions. In addition, results showed that within the dysarthric group, speakers with different etiologies did not vary at the group-level or sentence-level in speech rate, rhythm, and pitch variation. No interaction between group and sentence was found either.

The results of this thesis do provide insight into rhythm metrics and highlight the importance of future research in order to conclusively ascertain their use as a diagnostic tool. This thesis is also a stepping stone in understanding rhythmic disturbances in dysarthria and suggests exciting future prospects of investigation which may elucidate the extent to which rhythm contributes to low intelligibility in dysarthria and why. This thesis has shown that rhythm metrics may have limited sensitivity to rhythm disturbances and questions their validity as a measure for rhythmic disturbances in dysarthria. Below are some more suggestions for future research that could be essential in uncovering the role rhythm plays in dysarthria.

4.2.1. Future Research

Future research should use rhythm metrics to analyse longer speech samples with a larger group including various types of dysarthria. This investigation may have several clinical implications. First, if any overall success in classification is found, it would suggest that rhythm metrics may provide an objective method to differential diagnosis. Therefore, more studies are required in order to determine whether if mild severity level is distinguishable from control speakers and, further, whether mild (or moderate) severity levels lend themselves to dysarthria type classification. It is possible a mild severity level would make classification of dysarthria types a larger challenge if the perceptual characteristics between speakers are too similar. It would then be essential to investigate if rhythm metrics could exceed the specificity of perceptual judgements for all severity levels. This would also suggest the potential for rhythm metrics to be used to track progress of dysarthric speakers across treatment.

An important practical and theoretical question that needs immediate attention is the ways in which rhythmic disturbances could contribute to the characteristic low intelligibility of dysarthria. This thesis questions the use of rhythm metrics as a measure for rhythmic disturbances in dysarthria, as well as the extent that rhythm plays a role in mild to moderate dysarthria severity. However, further research on rhythmic disturbances in dysarthria may be useful in order to gain a greater understanding of how this may affect speech production. This would be essential in informing how articulation in dysarthria speech production functions, and perhaps lend itself to an understanding of other motor speech disorders.

5. Appendices

Appendix A: Text Marloes heard in participant recordings

Papa en Marloes staan op het station.

Ze wachten op de trein.

Eerst hebben ze een kaartje gekocht.

Er stond een hele lange rij, dus dat duurde wel even.

Nu wachten ze tot de trein eraan komt.

Het is al vijf over drie, dus het duurt nog vier minuten.

Er staan nog veel meer mensen te wachten.

Marloes kijkt naar links, in de verte ziet ze de trein al aankomen.

(Papa and Marloes are at the station.

They wait for the train.

First they bought a ticket.

There was a very long line, so that took a while.

Now they wait for the train to arrive.

It's already five past three, so it takes another four minutes.

There are many more people waiting.

Marloes looks to the left, in the distance she sees the train coming.)

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