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Syllabic tone variation by Sepedi speakers with dysarthria

by

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Summary

Background: Speech production in Bantu languages places great demands on neuromotor control, because unique speech motor behaviours such as syllabic tone variation and the aspiration of speech sounds require an additional level of vocal fold control compared to speech production in Germanic languages. As these motor behaviours play an important role in differentiating the meaning of words (Van der Merwe & Le Roux, 2014a), neuromotor speech disorders such as dysarthria may have a greater impact on communication in Bantu languages than in Germanic languages. The focus of this study was on syllabic tone variation in Bantu language speakers with dysarthria compared to typical speakers. Sepedi was the Bantu language investigated. Syllabic tone variation refers to pitch level changes for every syllable of words in a tone language (Zerbian & Barnard, 2008a) and requires manipulation of vocal fold length and mass over and above the voicing or devoicing of sounds within words. These pitch changes convey the lexical and grammatical meaning of words and may differentiate between the meanings of two orthographically identical words (Zerbian & Barnard, 2008a). Studies on lexical tone variation in speakers with dysarthria to date have focused mostly on the tone languages of Asia and Scandinavia (Kadyamusuma, De Blesser, & Mayer, 2011). No studies of tone variation in Bantu language speakers with dysarthria were found. Furthermore, past research only regarded tone variation in monosyllabic words, with no reference to how tone would be affected *across* bisyllabic words and *within* each of the two syllables of these words. No inquiries were made into the tone variation ability of speakers with dysarthria when producing short utterances compared to longer utterances and mostly speakers with congenital dysarthria were used as research participants. These shortcomings needed to be addressed to gain a more holistic and accurate view of the extent to which tone variation is a challenge for Bantu language speakers with dysarthria.

Aims: The first aim of the study was to determine whether a difference exists between typical Sepedi speakers and Sepedi speakers with dysarthria, in their ability to vary tone across CVCV words with a HL tone pattern. The second aim of the study was to determine whether a difference in tone variation exists between short and longer utterances in typical Sepedi speakers and Sepedi speakers with dysarthria.

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Method: A quasi-experimental, between-group comparison was used in the study. Speech samples were obtained from a control group of five typical Sepedi speakers and from an experimental group of four Sepedi speakers with dysarthria. These speech samples consisted of 20 consonant-vowel-consonant-vowel (CVCV) words with high-low (HL) tone variation produced in three- and also in six- /seven-syllable utterances (resulting in a total of 40 words). The speech samples were analysed acoustically using *Praat* software. To achieve the first aim, the following acoustic measures were obtained from the 40 words produced by participants: (1) Mean fundamental frequency (F_0) of syllable 1 (S1) and syllable 2 (S2), (2) Change in F_0 across words from the highest F_0 point of S1 to the lowest F_0 point of S2, (3) Intra-syllabic change in F_0 within S1 and S2. To achieve the second aim of the study, the change in F_0 across words in short utterances was compared to the change in F_0 across words in longer utterances for the typical speakers and speakers with dysarthria.

Results: Wilcoxon rank tests were used for statistical analyses. Descriptive statistics were performed and median values were used to achieve research aims. All of the control participants and participants with dysarthria produced S1 with a higher mean F_0 than S2, as was appropriate for the HL tone pattern ascribed to the target words. For most of the individuals from both groups, the mean F_0 of S1 was *significantly higher* than the mean F_0 of S2. However, one participant from each group produced an *insignificant* difference between the mean F_0 values of the two syllables. The control group produced *slightly greater* median F_0 changes across the words and within S1 than the dysarthria group, but the differences between the speaker groups for the change in F_0 across words and the change in F_0 within S1 were *insignificant.* In contrast to this, the control group produced a *significantly smaller* median change in F_0 within S2 than the dysarthria group. Individual speakers from both groups produced *unique patterns of F_0 changes* for all aspects of tone variation (change in F_0 across words and changes in F_0 within S1 and S2). Both speaker groups produced a *significantly greater* median change in F_0 across words in short utterances compared to long utterances. The difference in the change in F_0 across words between short and long utterances was *significantly greater* for the control group than for the dysarthria group.

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Conclusions: The speakers with dysarthria in the study maintained the ability to vary tone across bisyllabic words with an HL tone pattern. The dysarthria group only differed significantly from the control group with regard to the extent of tone reduction in the second syllable. This finding may point to possible difficulties in the required graded relaxation of the vocal folds. Individual differences in F_0 changes were found for both typical speakers and speakers with dysarthria, indicating that unique tone variation patterns may normally exist for all speakers. For both control and dysarthria groups, greater tone variation was observed in short compared to longer utterances. The role of increased utterance length in decreased F_0 variation was greater for the typical speakers than for the individuals with dysarthria.

KEYWORDS: Bantu languages, Sepedi, tone variation, dysarthria, phonation, change in fundamental frequency across words, change in fundamental frequency within syllables, acoustic analysis of tone variation, length of utterance

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Definitions of terminology

The following list of definitions is provided to clarify the meaning of terms used in the study. For some terms, these definitions provide important background information that would otherwise have interrupted the flow of the text.

- **Acquired dysarthria -** Dysarthria that occurs after an individual's speech has developed fully (Miller, 2010).
- **Aphasia -** A neurological language impairment that affects the comprehension and production of spoken and written language. It can affect predominantly one aspect of language or multiple communicative components, depending on the location of brain lesion (NAA, 2016).
- **Apraxia of speech -** A neuromotor speech disorder resulting from impaired ability to plan or program the sensorimotor commands necessary for speech (Duffy, 2013:4). Apraxia of speech does not involve the muscle paralysis or paresis, spasticity, or involuntary movements associated with dysarthria, nor does it involve the language deficits associated with aphasia. However, apraxia of speech frequently co-occurs with these conditions (ASHA, 2016).
- **Bantu languages -** A group of languages spoken in various parts of central and southern Africa which share numerous linguistic features (Ziervogel, 1967:7). Guthrie (1948) classified Bantu languages by dividing them into geographic zones, labelled alphabetically from A to S. Subdivisions of the languages are indicated numerically (Guthrie, 1948).
- **Coarticulation -** The process whereby one sound influences another, due to two or more sounds being articulated together. The coarticulation of tones occurs in much the same way as it does for vowels and consonants (Stevenson, 2015).
- **Congenital dysarthria -** Dysarthria caused by dysfunction in the motor control centres of the immature brain (Love, 2000).
- **Dysarthria -** A group of speech disorders reflecting problems with the neuromotor control and execution of speech (Duffy, Strand, & Josephs, 2014; Strand, 2013). Dysarthria is displayed in difficulty with the speed, strength, range of motion, or coordination of the muscles used for speech (Duffy, 2013:4;

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Strand, 2013). The result is problems in one or more of the following aspects of speech production: Phonation, respiration, articulation, resonance, and prosody (Duffy, 2013:4; Hageman, 2009:116).

- **Germanic languages -** A branch of Indo-European languages that includes English, Afrikaans, German, Dutch, Frisian, and the Scandinavian languages (Merriam-Webster Dictionary, 2011; Stevenson, 2015).
- **Prosodic features -** Suprasegmental aspects of speech. Prosodic features include the intonation, speech rate, stress, and rhythm of speech (Zerbian & Barnard, 2008b). Like tone, intonation relies on changes in the length and mass of the vocal folds. However, intonation indicates change of pitch at the sentence level, whereas tone indicates change of pitch at the word level (Zerbian & Barnard, 2010). In addition to the tone variation produced across words in Bantu languages, speakers of these languages also display intonation patterns in their speech.
- **Syllabic tone variation -** *Also referred to as lexical tone variation or word-level tone variation.* Syllabic tone variation refers to pitch level changes which are allocated to the individual syllables of words in the vocabulary of tone languages. These pitch changes convey the lexical and grammatical meaning of words and may distinguish between the meanings of two orthographically identical words (Zerbian & Barnard, 2008a). By changing the tone combination across words that are orthographically identical, the meaning of the word is changed. For example, in Sepedi, -lá.pà (HL tone) means “tired,” whereas –là.pá (LH tone) means “courtyard.”
- **Tone languages -** Languages which indicate pitch changes for every syllable of a given word in their vocabulary (Zerbian & Barnard, 2008a). All Bantu languages are tone languages but in this study, syllabic tone variation will be investigated in Sepedi (also known as *Sesotho sa Leboa* or *Northern Sotho).* Sepedi is a language that is typically spoken in the North-Eastern provinces of South Africa and belongs to the Sotho language family (Faaß, Heid, Taljaard, & Prinsloo, 2009).

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List of abbreviations

AMRs: Alternating Motion Rates

CN X: Cranial Nerve X (Vagus Nerve)

CP: Cerebral Palsy

CSL: Computerised Speech Lab (Model 4150B, Version 3.4, Kay PENTAX, 2010)

CVA: Cerebral Vascular Accident

CVCV: Consonant-Vowel-Consonant-Vowel

F_0: Fundamental frequency

HL: High-Low tone pattern across the two syllables of a word

IQR: Inter-Quartile Range

L1: First language

LMN: Lower Motor Neuron

PET: Positron Emission Tomography

S1: Syllable 1

S2: Syllable 2

SLP: Speech-Language Pathologist

STSI: Sepedi Test for Speech Intelligibility (Fouché & Van der Merwe, 1999)

UMN: Upper Motor Neuron

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Chapter 1

Literature review, problem statement and rationale

This chapter provides a foundation for the study. A preview to the field of syllabic tone variation in speakers with dysarthria is provided, by defining and describing tone languages, dysarthria, and the salient features of dysarthria. The physiology and neurological control of phonation are discussed as frame of reference for syllabic tone variation, and some features of tone variation in Bantu languages are described. Previous research on tone variation in speakers with dysarthria is presented and limitations are highlighted. Within this context the problem statement, rationale, and purpose of this study are also presented.

1. Introduction to the study

Bantu languages, like Germanic languages, are dependent on the coordinated interaction of articulation, phonation, respiration, and resonance for accurate speech production and adequate intelligibility (Dykstra, Hakel, & Adams, 2007; Freed, 2011; Yunusova, Weismer, Kent, & Rusche, 2005). When any one or any combination of these processes is disrupted by impairment to the neuromotor control processes, a neuromotor speech disorder, such as dysarthria, results (Duffy, 2013:4). Speech production in Bantu languages places great demands on neuromotor control, because unique speech motor behaviours such as tone variation and the aspiration of speech sounds require an additional level of vocal fold control (Van der Merwe & Le Roux, 2014a). These motor behaviours play an important role in differentiating the meaning of words (Van der Merwe & Le Roux, 2014a). The impact of dysarthria on communication may therefore be more severe in Bantu languages than in Germanic languages.

The focus of this study will be lexical tone variation in Bantu language speakers with dysarthria compared to typical speakers. Sepedi will be the Bantu language investigated.

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2. Dysarthria: Nature and characteristics

2.1 The nature of dysarthria

The term *dysarthria* is used to refer to a group of speech disorders resulting from problems in the neuromotor control and execution of speech (Duffy, Strand, & Josephs, 2014; Strand, 2013). Dysarthria reflects difficulty with the speed, strength, range of motion, or coordination of the muscles used for speech (Duffy, 2013:4; Strand, 2013). The result is in problems in one or more of the following aspects of speech production: Phonation, respiration, articulation, resonance, and prosody (Duffy, 2013:4; Hageman, 2009:116). There are different types of dysarthria, each associated with different underlying neuropathophysiology and distinct speech characteristics (Duffy, 2013:4; Duffy et al., 2014; Lansford, Liss, & Norton, 2014).

Table 1 shows the different types of dysarthria, as well as the site of the underlying lesion, perceptual speech characteristics, and associated clinical features. Information provided in the table was compiled from works by Duffy (2013), Duffy and colleagues (2014), and Strand (2013), unless otherwise indicated.

2.2 Speech characteristics

The perceptual speech characteristics associated with the dysarthrias listed in Table 1 are grouped according to the aspects of speech production that are affected (phonation, respiration, articulation, resonance, and prosody). The dysarthria type with which a speaker presents can often be identified on the grounds of unique clusters of salient perceptual speech features. These clusters of deviant speech are associated with specific neuromotor lesions (Dykstra et al., 2007).

2.3 Voice problems in dysarthria

Lesions to any areas involved in the neuromotor control of laryngeal behaviours may result in voice problems. The voice changes perceived in speakers with dysarthria are dependent on the nature and site of the neurological lesion (Boone, McFarlane, Von Berg, & Zraick, 2014:116).

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Table 1: Dysarthria types and the underlying neuropathophysiology, perceptual speech characteristics, and associated clinical features

Dysarthria type	Site of lesion	Perceptual speech characteristics	Associated clinical findings
Spastic	Usually bilateral lesion of the Upper Motor Neuron (UMN)	**Phonation and respiration** - Strained-harsh voice quality - Monopitch and monoloudness - Pitch breaks (Murdoch, Ward, & Theodoros, 2009:191) **Articulation** - Imprecise consonants - Distorted vowels **Resonance** - Hypernasality **Prosody** - Reduced speech rate - Reduced stress - Excess and equal stress (Murdoch et al., 2009:192)	- Acutely after lesions occur: Weakness and reduced muscle tone, more pronounced in distal than proximal muscles - Emerging over time: Spasticity and increased muscle tone - Impairment in fine, skilled movements - Reduced range of movement - Slowness of movement - Pseudobulbar palsy (bilateral spasticity of the muscles of the face and deglutition) (Strand, 2013; Murdoch et al., 2009:189) - Pathological oral reflexes - Hyperactive gag reflex
Unilateral UMN	Unilateral lesion of the UMN	**Phonation** - Mild harshness - Breathy-hoarse voice quality - Decreased loudness **Articulation**	- Features occur on the side of the body contralateral to the side of lesion. - Hemiplegia or hemiparesis - Weakness, hyporeflexia or hypotonia of limbs in acute stages following the lesion

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		- Imprecise articulation, especially imprecise consonants - Irregular articulatory breakdowns **Prosody** - Slow speech rate	- Spasticity, hyperactive reflexes or increased muscle tone of the limbs emerging over time - Impairment in fine, skilled movements - Paresis in the lower part of one half of the face at rest and during voluntary movements, including unilateral lingual weakness (Murdoch et al., 2009:189)
Hypokinetic	Damage to the basal ganglia, especially in the substantia nigra (Kent, 2000)	**Phonation and respiration** - Hoarseness - Roughness - Breathiness - Reduced loudness - Reduced utterance length **Articulation** - Repeated phonemes (palilalia) - Blurred or rushed Alternating Motion Rates (AMRs) - Imprecise consonants (Adams & Dykstra, 2009:167) **Prosody** - Monopitch and monoloudness - Short rushes of speech	- Bradykinesia (slow initiation of movement) (Duffy, 2013:166) - Akinesia (the absence of movement; for example, reduced arm swinging while walking or facial masking) (Duffy, 2013:166) - Rigidity (resistance to passive movement) (Strand, 2013) - Reduced range of movement - Resting tremor (rhythmic, involuntary movements while the body is at rest) (Strand, 2013) - Postural abnormalities (such as stooped posture, difficulty going from sitting to standing or poor adjustment of the body in

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		- Tendency towards rapid/ accelerated speech rate - Reduced stress	response to tilting or falling) (Duffy, 2013:167)
Hyperkinetic	Damage to the basal ganglia, especially in the putamen, caudate or both (Kent, 2000)	- Unpredictable and variable speech abnormalities, dependent on the effects of involuntary movements on speech (Duffy, 2013:200) **Phonation and respiration** - Abrupt moments of forced inspiration-expiration - Sudden arrests in voicing - Strained-harsh voice quality - Excess loudness variation **Articulation** - Distorted articulation - Irregular articulatory breakdowns **Resonance** - Intermittent hypernasality **Prosody** - Prolonged intervals - Prolonged phonemes - Variable speech rate - Variable patterns of stress	- An excess of unintentional movements - Dyskinesia (abnormal, involuntary body movements which can manifest in the oral muscles, as well as the laryngeal, pharyngeal and respiratory muscles) (Duffy, 2013:200; Zraick & LaPointe, 2009:154) - Ballismus (wild movements caused by sudden contractions of muscles) (Duffy, 2013:200) - Chorea (rapid, involuntary jerks in various parts of the body) (Strand, 2013) - Athetosis (slow, continuous movements of muscle groups at rest) (Strand, 2013) - Dystonia (prolonged co-contractions of agonist and antagonist muscle groups, causing the body to assume abnormal postures) (Strand, 2013) - Tremor (rhythmic, involuntary movements) (Duffy, 2013:200)

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		- Inappropriate silences	
Ataxic	Damage to the cerebellum	**Phonation** - Harshness - Monopitch and monoloudness **Articulation** - Inaccurate articulation (including imprecise consonants and vowel distortions) - Irregular articulatory breakdowns **Prosody** - Excess and equal stress - Prolonged phonemes - Prolonged speech intervals - Reduced speech rate	- Broad-based stance and gait - Intention tremor (a tremor that is apparent during movement or sustained body postures) (Duffy, 2013:145; Strand, 2013) - Romberg test (No difference in the steadiness of the body when eyes are open and closed) (Duffy, 2013:165) - Nystagmus (rapid back and forth movements of the eye at rest or during a lateral or upward gaze) (Duffy, 2013:165) - Ocular dysmetria (quick, small eye movements as the eyes attempt to fix on a target) (Duffy, 2013:165) - Hypotonia - Dysmetria (inability to control the range of body movements) (Duffy, 2013:165) - Dysdiadochokinesis (errors in the sequencing and speed of the constituent parts of a movement) (Duffy, 2013:165)

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			- Dyssynergia (errors in the speed and timing of body movements) (Duffy, 2013:165) - Normal oral mechanism not uncommon
Flaccid	Lesion of the Lower Motor Neuron (LMN)	Dependent on the cranial nerves involved but may include: **Phonation and respiration** - Breathiness - Hoarseness - Reduced loudness - Audible inspiration - Short phrases per expiratory cycle. **Articulation** - Imprecise articulation **Resonance** - Hypernasality **Prosody** - Reduced speech rate	- Dependent on the cranial nerves involved - Weakness - Atrophy and fasciculation in muscles - Hypotonia - Diminished reflexes
Mixed	Mixture of the above lesions	Mixture of characteristics, depending on the combination of lesions	Mixture of findings, depending on combination of lesions

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The following types of dysarthria may impact upon production:

- *Spastic dysarthria* - A tendency of the vocal folds to hyperadduct in spastic dysarthria may cause a strained-harsh voice quality (Boone et al., 2014:116; Duffy, 2013:133-134; Wildgruber, Ackermann, & Grodd, 2001). There may also be a slowing of the muscular adjustments required for normal pitch and loudness variation, contributing to monopitch and monoloudness (Boone et al., 2014:116; Duffy, 2013:133-134).
- *Unilateral UMN dysarthria* - Mild harshness or a breathy-hoarse voice quality and reduced loudness often occur in Unilateral UMN dysarthria (Boone et al., 2014:116; Buder, 2007:126).
- *Hypokinetic dysarthria* - Frequent phonatory difficulties occur in hypokinetic dysarthria (Duffy, 2013:173). These usually include breathiness, hoarseness, and a rapid voice tremor (Duffy, 2013:173-174). Monotony of pitch and reduced loudness have also been found (Ackermann & Ziegler, 1991; Boone et al., 2014:116; Buder, 2007:126).
- *Hyperkinetic dysarthria* - The involuntary movements associated with hyperkinetic dysarthria can be fast or slow, rhythmic or arrhythmic and may disrupt movements of the vocal folds (Duffy, 2013:202). This will result in phonatory problems such as sudden arrests in voicing or a strained-harsh voice quality (Duffy, 2013:202; Buder, 2007:126). Monotony of voice and low pitch have also been associated with hyperkinetic dysarthria (Buder, 2007:126).
- *Ataxic dysarthria* - Voice tremor has been found to occur in speakers with ataxic dysarthria (Ackermann & Hertrich, 1997), as well as excess and equal stress and excess loudness levels (Boone et al., 2014:116). Variable loudness levels have also been described in ataxic dysarthria (Buder, 2007:126).
- *Flaccid dysarthria* - Lesions to the Vagus nerve may result in a breathy voice quality (Boone et al., 2014:116), as well as harshness or hoarseness, monopitch, and monoloudness. Lesions to the recurrent or superior laryngeal nerve branches result in weakness or hypotonia of the laryngeal muscles (Buder, 2007:126; Duffy, 2013:105). Diplophonia and pitch breaks may also be associated with flaccid dysarthria (Buder, 2007:126).

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2.4 The impact of contextual factors on dysarthria speech signs

According to *Van der Merwe's Theoretical Framework for Speech Sensorimotor Control* (Van der Merwe, 2009:6) contextual factors may render certain speech tasks more difficult to control and produce than others. Tasko and McLean (2004) state correspondingly that the perceived severity of speech disorders may be dependent on the nature of the speech task. Contextual factors include the effect of length of utterance on speech production (Van der Merwe, 2009:6). The effect of length of utterance is evident from a study by Dykstra and colleagues (2007), which reports that speakers with severe dysarthria find the production of sentences more demanding and fatiguing than that of single words. In longer utterances, increased skills are needed for planning, programming, and executing speech. Variation in contextual factors such as length of utterance may therefore influence speech sensorimotor control and can affect treatment progress as well as research results (Van der Merwe, 2009:6).

These observations suggest that the use of an expanded range of speech tasks to evaluate aspects of speech production, such as both short and longer utterances, may provide a more holistic view of both typical and disordered speech (Tasko & McLean, 2004). Aspects of speech production such as tone variation therefore need to be considered in both short and long utterances.

3. The physiology of voice production

The term *phonation* refers to the voice production underlying both the segmental and suprasegmental aspects of speech (Brown, Laird, Pfordresher, Thelen, Turkeltaub, & Liotti, 2009). Phonation is a laryngeal function and is dependent on vocal fold movement which produces acoustic energy (Ludlow, 2005; Wong, Perrachione, Gunasekera, & Chandrasekaran, 2009). The laryngeal muscles involved in phonation are classified either as intrinsic or extrinsic (Boone et al., 2014:35; Ludlow, 2005).

Intrinsic laryngeal muscles are confined to the larynx and mostly have adductor (vocal fold closing) or abductor (vocal fold opening) functions (Ludlow, 2005). The thyroarytenoid, lateral cricoarytenoid, and interarytenoid muscles are all adductor muscles and the posterior crycoarytenoid muscle is an abductor muscle (Ludlow, 2005). The cricothyroid muscle is responsible for elongating the vocal folds and assists in determining vocal pitch (Ludlow, 2005).

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Extrinsic laryngeal muscles attach the larynx to other structures within the head and neck, and change the position of the larynx within the neck. They include the thyrohyoid muscle, which is important for swallowing, and the sternothyroid muscle which lowers vocal pitch (Boone et al., 2014:35; Ludlow, 2005)

At rest, the vocal folds remain abducted, forming a v-shaped glottal space with its apex located behind the thyroid cartilage (Borden, Harris, & Raphael, 2007:90). Voice production is dependent on vocal fold vibration and occurs as the vocal folds are adducted to the midline of the glottis by intrinsic laryngeal muscles (Borden et al., 2007:90; Ludlow, 2005; Wong et al., 2009). Expired air from the lungs causes an increase in subglottal pressure, which blows apart the vocal folds (abduction) (Boone et al., 2014:51). The mass of the vocal folds acts together with the Bernoulli effect to return them to the midline (adduction). The Bernoulli effect occurs when the increased airflow through the vocal folds creates negative pressure between and immediately below the vocal folds, sucking the vocal folds back together after they have been blown apart (Boone et al., 2014:51). The vocal folds are repetitively blown apart and sucked together, setting up a cyclic process of vocal fold vibration (Boone et al., 2014:51; Ludlow, 2005).

Vocal folds move periodically during vibration (i.e. they open and close in a rhythmical and regularly repeated pattern of movement). This movement results in a bombardment of air bursts which creates an audible sound pressure wave. This sound wave is also periodic (Borden et al., 2007:95; Ladefoged & Johnson, 2015:7). The rate of vocal fold vibration is referred to as the fundamental frequency (F_0) (Xu, 1994) and correlates with the number of times that the vocal folds are blown apart and come together per second (Borden et al., 2007:86). As in the case of all sound sources vibrating in a complex, periodic manner, the vocal folds generate a harmonic series of frequencies (Borden et al., 2007:95; Ladefoged & Johnson, 2015:24). Vocal fold vibration thus consists of a F_0 and many harmonics (whole-number multiples of the $F_{0)}$ (Borden et al., 2007:95).

Vocal fold vibration is mainly determined by the elasticity, mass, and tension of the vocal folds. A speaker's F_0 is therefore determined by the mass/ size of the individual's vocal folds, as well as that individual's ability to lengthen and tense the folds. Changing the length and tension of the vocal folds changes their effective mass; the F_0 is

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therefore either lowered or raised. To increase vocal pitch, the individual has to tense the vocal folds by stretching them; this raises the individual's F_0 (Ladefoged & Johnson, 2015:25). The perceived changes in vocal pitch result because of changes in the spacing between the harmonics of the sound source (Borden et al., 2007:86,98). Speakers of tone languages change the F_0 of vocal folds to vary intonation patterns across a sentence and additionally use changes in F_0 to contrast tone at the syllable level (Chang, 2012; Jeng, Weismer and Kent, 2006; Ma, Whitehill, & Chueng, 2009; Zerbian & Barnard, 2008a). To achieve changes in F_0, tone language speakers need to alter the tension of the vocal folds at the syllable level, as well as the volume of airflow from the lungs through the glottis (Ladefoged & Johnson, 2015:20). Speakers with dysarthria may be unable to control the laryngeal and respiratory mechanisms responsible for the accurate changes in F_0 needed at the syllable level for tone variation.

4. The neurological control of voice production

4.1 Overview

During voice production, the larynx undergoes numerous complex adjustments, including modulation of the vocal folds and refinement of subglottal air pressures (Schultz, Varga, Jeffries, Ludlow, & Braun, 2005). Phonation, including the rapid pitch changes responsible for tone variation and intonation, thus requires highly coordinated neuromuscular control (Loucks, Poletto, Simonyan, Reynolds, & Ludlow, 2007). This rapid dynamic control constitutes a remarkable human skill (Atkinson, 1976; 1978).

Researchers in the field of neurology have established that accurate interactions between the cortical and sub-cortical control systems are essential for normal laryngeal function (Ludlow, 2005). The UMNs, the basal ganglia, the cerebellum, and the LMNs have all been indicated as the neuromotor areas controlling phonation (Brown et al., 2009; Schultz et al., 2005; Simonyan, 2014; Strand, 2013).

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4.2 The role of the UMNs

Within each cerebral hemisphere, the UMNs consist of the motor cortex as well as the pyramidal and extrapyramidal tracts which descend from it (Duffy, 2013:39; Murdoch et al., 2009:288). The motor cortex is located in the posterior portion of the frontal lobe (Duffy, 2013:39; Strand, 2013). The pyramidal tracts are direct activation pathways which innervate the LMNs. They consist of the corticobulbar tracts (leading to and influencing the actions of the cranial nerves) and the corticospinal tracts (leading to and influencing the actions the spinal nerves) (Duffy, 2013:39).

The motor cortex conveys information for voluntary speech and voice production through pyramidal neurons within corticobulbar tracts, via the basal ganglia and thalamus (Duffy, 2013:39; Strand, 2013). These tracts reach LMNs in the brainstem, which are responsible for the necessary muscle contractions of the articulators, including the vocal folds (Strand, 2013). Input from each hemisphere's motor cortex and descending pathways predominantly innervate LMNs on the contralateral side of the body (although some cranial nerves receive bilateral innervation) (Duffy, 2013:41).

4.3 The role of the basal ganglia

The basal ganglia are a collection of subcortical nuclei that include the caudate nucleus, the putamen, the globus pallidus, the substantia nigra, and the subthalamic nuclei (Duffy, 2013:165; Strand, 2013). Their main functions lie in "opening the gates to intended movements and closing the gates to unwanted movements" (Duffy, 2013:48). They constitute a control circuit that is responsible for the initiation of voluntary movements, the initiation of motor programs for specific actions, and the inhibition of unwanted movements (Duffy, 2013:48). Through their diverse connections with vital areas of the cerebral cortex, the basal ganglia regulate input from the cortex regarding muscle activity (Duffy, 2013:47). With specific reference to speech production, the basal ganglia modulate articulation and phonation (Baldo & Dronkers, 2015; Merati, Heman-Ackah, Abaza, & Belamowicz, 2005; Schultz et al., 2005).

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4.4 The role of the cerebellum

The cerebellum is located posterior to the brainstem and is important for the control and programming of movement (Duffy, 2013:45). The cerebellum consists of an intricate outer cortex, two hemispheres that are divided into lobes, subcortical white matter paired with deep nuclei, and efferent and afferent projections to other parts of the central nervous system via the cerebral peduncles (Cannito & Marquardt, 2007:132). For speech production in general, the cerebellum is involved in the timing of movement components, the scaling of the size of muscle actions, and the coordination of sequences of muscle contractions of the speech muscles (Duffy, 2013:46-47).

With regard to phonation, the cerebellum is involved in the coordination and regulation of laryngeal activity (Ackermann & Hertrich, 2000; Brown et al., 2009; Guenther, Ghosh, & Tourville, 2006; Riecker, Ackermann, Wildgruber, Dogil, & Grodd, 2000; Schultz et al., 2005). Although the cerebellum is activated during both voiced and voiceless speech tasks, significantly greater activation of the cerebellum occurs during voiced speech, as indicated through Positron Emission Tomography (PET) scans (Schultz et al., 2005). Lobule VI, located posteriorly in the cerebellum, is one of the three main neuromotor areas controlling phonation (Brown et al., 2009). Lobule VI is activated by lip and tongue movement and is considered an essential part of the speech production circuitry (Brown et al., 2009). Ataxic dysarthria is most frequently associated with bilateral lesions of the cerebellar hemispheres or a unilateral lesion of the right cerebellar hemisphere (Duffy, 2013:144).

4.5 The role of the LMNs

LMNs are the last motor neurons in the neuromotor control of speech (Duffy, 2013:31). They have nerve fibres which wrap around muscle fibres, causing muscle contractions and resulting in movements of the articulators required for speech and movements of the intrinsic and extrinsic laryngeal muscles required for phonation (Duffy, 2013:32; Strand, 2013).

The LMNs comprise of cranial nerve nuclei in the brainstem and their axons in peripheral nerve fibres (Hageman, 2009:193). They are responsible for motor and sensory function of the head and neck (Strand, 2013). The most important cranial

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nerve in voice production is cranial nerve X (CN X), which is also known as the Vagus nerve (Boone et al., 2014:47). CN X consists of three branches in the neck, as the LMN travels out from the medulla (Boone et al., 2014:47; Strand, 2013). These branches are (Boone et al., 2014:47):

- *Pharyngeal branch* **-** Provides motor innervation to the pharynx and soft palate.
- *Superior laryngeal nerve -* Supplies the cricothyroid muscle, which lengthens the vocal folds and thus contributes to pitch range and pitch control.
- *Recurrent laryngeal nerve -* Supplies the intrinsic muscles of the larynx.

The superior and recurrent laryngeal nerves play the principal role in phonation. The more the F_0 deviates from the normal, relaxed voice, the stronger the activation of the involved muscles by the nerves (Jurgens, 2002).

4.6 The neurological control of voice pitch changes

Since tone variation conveys the linguistic meaning of words and individuals' language areas are usually situated in the left hemisphere, it follows that the higher cortical control responsible for tone processing and production typically lies in the left cerebral hemisphere. (Kadyamusuma, De Blesser, & Mayer, 2011). At a lower level of neurological control, the underlying voice pitch changes required for intonation and for tone variation both depend on the same ability of a speaker to change the F_0 of vocal fold vibration (Chang, 2012; Jeng et al., 2006; Ma et al., 2009; Zerbian & Barnard, 2008a). A speaker's production of F_0 changes is mainly controlled by the UMN, basal ganglia, cerebellum, and the LMNs (especially CN X). Any damage to these neurological areas has the potential to impact upon a speaker's tone variation ability.

5. Bantu languages and their distinct phonetic features

As introduction to the problem that tone variation may present to Bantu language speakers with dysarthria, some background information regarding Bantu languages and the phenomenon of lexical tone variation will be provided in the following sections.

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5.1 Bantu languages

Of South Africa's 11 official languages, English and Afrikaans are Germanic languages. The other nine official languages are classified as Bantu languages (Van der Merwe & Le Roux, 2014a; b:125). The term *Bantu languages* refers to a group of languages spoken in various parts of central and southern Africa which share numerous linguistic features (Ziervogel, 1967:7). Guthrie (1948) classified Bantu languages by dividing them into geographic zones, labelled alphabetically from A to S. Subdivisions of the languages are indicated numerically (Guthrie, 1948).

The Bantu language focused on in this study is Sepedi, otherwise known as *Sesotho sa Leboa* or *Northern Sotho,* which is labelled S.32 according to Guthrie's 1948 classification. Sepedi is typically spoken in the North-Eastern provinces of South Africa and belongs to the Sotho language family (Faaß, Heid, Taljaard, & Prinsloo, 2009).

Sepedi is a tone language and thus phonetic description indicates pitch level changes for every syllable of a given word in its vocabulary (Zerbian & Barnard, 2008a). These pitch changes convey the lexical and grammatical meaning of words and may distinguish the meaning between two orthographically identical words (Zerbian & Barnard, 2008a). Pitch changes within words are referred to as tone, whereas change of pitch at the sentence level is known as intonation (Zerbian & Barnard, 2010). Inaccurate tone production may result in the substitution of inappropriate words in a sentence or may cause words to become jargon (Coetzee, De Jager, & Van der Merwe, 2011).

5.2 Syllabic tone variation

Syllabic tone variation is observed on vowels and syllabic consonants (Van der Merwe & Le Roux, 2014a; b:135). South African Bantu languages have two tone levels, namely high and low (Kadyamusuma et al., 2011; Zerbian & Barnard, 2008a). Tones are described relative to an individual speaker's pitch range (Wong et al., 2009). High tones occur at the higher end of a speaker's pitch range (Wong et al., 2009) and are considered active tones, comprising of established pitch targets which need to be reached during articulation (Zerbian & Barnard, 2008a). Low tones are default tones and their pitch is determined by the presence and location of high tones (Zerbian &

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Barnard, 2008a). Low tones occur at the lower end of a speaker's pitch range (Wong et al., 2009).

By changing the tone combination across words that are orthographically identical, the meaning of the word is changed. For example, in Sepedi, -lá.pà (high-low tone) means "tired," whereas –là.pá (low-high tone) means "courtyard."

5.3 The distinct phonetic features of Bantu languages, including tone variation

Distinct phonetic features exist in Bantu languages that occur in addition to those common to Germanic languages. These distinct features include the type of airstream mechanism used, the nature of airstream release, and lexical tone variation.

- *Type of airstream mechanism:* Germanic languages only require a pulmonic airstream for speech production. Air is expelled from the lungs, through the vocal tract, through the movement of respiratory muscles (Ladefoged & Maddieson, 1996:144). In addition to a pulmonic air stream, Bantu languages also use glottalic egressive, glottalic ingressive, and velaric airstreams. The glottalic egressive airstream involves rapid elevation of the larynx to significantly increase subglottic pressure and is used to produce ejective sounds in Bantu languages. The glottalic ingressive airstream requires rapid lowering of the larynx and is used to produce implosive sounds (Ladefoged & Maddieson, 1996:145-146). The velaric airstream is used to produce click sounds by enclosing a volume of air in the mouth and then enlarging the enclosed section of the oral cavity through tongue movement, thus decreasing intra-oral air pressure (Ashby, 2006). Speech production in Bantu languages involves a multiple airstream mechanism which requires alternation between the different airstream types or even simultaneous control of more than one airstream. The actions of the respiratory muscles to achieve altering and simultaneous airstream control require complex sensorimotor control (Van der Merwe & Le Roux, 2014a).
- *Nature of airstream release:* Speech sounds in Bantu languages may be voiced, voiceless, or aspirated. The aspiration of speech sounds is phonemic and may therefore change the meaning of a word. Aspirated sounds are indicated in the orthography of Bantu languages with an /h/ (Van der Merwe & Le Roux, 2014a;

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b:129). Aspiration requires greater airflow to be forced through the vocal folds than for normal voicing and the arytenoid cartilages may remain further apart than during the production of voiceless sounds (Ladefoged & Maddieson, 1996:147). The movement of the vocal folds, together with the manipulation of the airstream that is needed to produce aspirated sounds, require an additional level of control above that which is required for the abduction and adduction of the vocal folds for voiced and voiceless sounds (Van der Merwe & Le Roux, 2014a; b:129).

- *Lexical tone variation:* Lexical tone variation is achieved by changing the length and tension of the vocal folds, which is determined by laryngeal muscle contraction and relaxation (Zhang, 2008). This must be sequenced and finely controlled at the syllable level to produce the necessary pitch variation and therefore requires a high level of neurological control.

6. Previous research on tone variation in dysarthria: A critical evaluation

In this section, previous research on tone variation in dysarthria will be discussed. Studies of intonation in speakers with dysarthria will also be described. The acoustic and perceptual analysis methods used in tone and intonation studies will be presented and significant findings from the research will be highlighted. In subsequent sections, the research will be assessed and evaluated.

6.1 Studies of intonation

Studies of intonation are briefly discussed in this section. Both tone variation and intonation rely on the same vocal fold adjustments that are necessary to produce changes in F_0. If intonation is significantly affected in speakers with dysarthria, tone variation would most likely be similarly affected and this would confirm the need to study tone variation in speakers with dysarthria. The acoustic and perceptual methods used in these studies also contribute to establishing the best methods for detecting and describing the pitch changes necessary for tone variation. (See Appendix A for detailed information regarding studies of intonation and tone variation in speakers with dysarthria).

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In past research, both perceptual and acoustic analysis methods were used to study intonation in speakers with dysarthria. For perceptual analyses, typical listeners were asked to listen to and identify various aspects of speech prosody in sentences produced by the participants with dysarthria. Ma and colleagues (2009) used only perceptual analysis methods to characterise prosodic impairment in Cantonese speakers with hypokinetic dysarthria. Where acoustic analysis was used in other intonation studies, most of the researchers utilised *Praat* software in their investigations, affirming the use of this software in studying F_0 variation. MacPherson, Huber and Snow (2011) examined the effect of Parkinson's disease on speakers' intonational markings in sentences by measuring F_0 values with *Praat.* They found impaired intonation in this population. Two studies combined perceptual and acoustic analysis methods in examining intonation; both employed *Praat* software in their acoustic analysis. Patel and Campellone (2009) investigated the acoustic and perceptual cues to contrastive stress in speakers with dysarthria and typical speakers and Ma, Whitehill and So (2010) investigated the intonation contrasts of Cantonese speakers with hypokinetic dysarthria due to Parkinson's disease. All of the studies of intonation concluded that F_0 variation ability at the sentence level is reduced in speakers with dysarthria (Ma et al., 2010; MacPherson et al., 2011; Patel & Campellone, 2009). In line with this, Ma and colleagues (2009) found that monotonous pitch is one of the most severely affected prosodic characteristics in speakers with hypokinetic dysarthria. As monotonous pitch is the perceptual correlate of flat F_0 contours, it could reasonably be expected that reduced tone variation would also be found in this population.

6.2 Studies of tone variation

With regard to research methods, three types of studies on tone variation were found in previous research. Firstly, perceptual studies used only listeners' perceptions to investigate the lexical tone variation of speakers with dysarthria. Secondly, acoustic studies used only acoustic analysis to measure tone variation in speakers with dysarthria. Thirdly, combination studies used a mixture of perceptual and acoustic analyses to investigate tone variation.

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6.2.1 Perceptual studies

A single study using only perceptual analysis in its investigation of tone variation in speakers with dysarthria was found in reviewing past research. Ciocca, Whitehill and Ma (2004) explored the link between the F_0 characteristics of Cantonese speakers with dysarthria and the speakers' tone intelligibility. Research participants were speakers with congenital dysarthria due to cerebral palsy (CP). Listeners were asked to identify words and their intended tones as they were produced by speakers with dysarthria and a control participant. Four speakers with dysarthria were included as experimental participants and one typical speaker was used as a control. It was found that the tones produced by speakers with dysarthria were more poorly recognisable than that of the control speaker and that this could result in significantly impaired communication abilities in speakers with dysarthria.

Two limitations of the study by Ciocca and colleagues (2004) were found. Firstly, the use of one typical speaker as a control does not result in a well-designed quasi-experimental research design and can therefore not be regarded as a high level of stringency (ASHA, 2004). Findings from this study need to be reduplicated with a greater number of participants before generalizations about the tone intelligibility of speakers with dysarthria can be made. Secondly, the authors acknowledged that some speakers with dysarthria have greater difficulty producing longer utterances than single words. However, only single, monosyllabic words were used as research stimuli. The tone variation ability of speakers with dysarthria needs to be studied in greater utterance lengths, as utterance lengths have implications for speech sensorimotor control (Van der Merwe, 2009:6). This needs to be addressed in future research.

6.2.2 Acoustic studies

In reviewing past research, one study was found that used only acoustic analysis methods to measure tone variation in speakers with dysarthria. Ng (2001) aimed to analyse the contour tones produced by 19 adult Cantonese speakers with dysarthria due to CP, compared to 18 typical speakers. The author used the *Soundscope/ 16.2.17* acoustic analysis software to obtain measures of F_0 at five points spread out across various single, monosyllabic words. The mean F_0 and the difference between

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the minimum and maximum F_0 values in the words were calculated. No measures of F_0 were made in longer utterances.

Ng (2001) found that F_0 variation was significantly greater for male speakers with dysarthria than control speakers but that female speakers with dysarthria did not have F_0 variation that was significantly different to that of controls. It was concluded that abnormal patterns of F_0 variation generally occur in speakers with congenital dysarthria. These findings cannot be generalised to speakers with acquired dysarthria; congenital dysarthria is different from acquired dysarthria due to the unique variables associated with sustaining a neurological lesion concurrent to speech development (Murdoch & Horton, 1998:373). These variables include the impact of development on speech motor learning and the recovery potential of the two speaker populations. Young age has been found to be favourable for recovery following neurological damage (Murdoch & Horton, 1998:373). Acoustic studies of tone variation need to be conducted on adults with acquired dysarthria to determine if similar results are found in this population.

6.2.3 Combined perceptual and acoustic studies

Three studies were found that used a combination of perceptual and acoustic analysis methods to investigate the tone variation of speakers with dysarthria. Each of the studies had different research aims, participants, and analysis methods, and they are therefore discussed separately.

Khouw and Ciocca (2007) investigated which parts of the vowel segment in monosyllabic Cantonese words provide the most information on tone identity in typical Cantonese speakers. The authors used *Praat* acoustic analysis software to determine the F_0 at nine equally distributed time points across the vowels of words. The average F_0 was calculated for the vowel and the change in F_0 was calculated within eight segments of the vowel between the points investigated. Thirty Cantonese speakers were asked to listen to the target words and to identify their tones in terms of direction, magnitude, and relative F_0 level. Acoustic and perceptual measures were combined in the study and it was found that the change in F_0 across the later segments of the vowel play the greatest role in tone identity (Khouw & Ciocca, 2007). No reference was made to disordered speech.

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Jeng and colleagues (2004) investigated the link between the tone intelligibility and the tone variation ability of 30 Mandarin speakers with dysarthria due to CP. Only monosyllabic words were produced by participants. Thirty-six Mandarin listeners were asked to listen to the target words as produced by speakers with dysarthria and to identify the words. *C-Speech* analysis software was used in the research for acoustic analysis of the words. All words were divided into five equally distributed time points and the mean, maximum, and minimum F_0 values were calculated from these points. As part of the perceptual study, listeners were asked to identify the target words as produced by the speakers with dysarthria, and to identify the tone of the words. The authors concluded that tone intelligibility is a significant issue in speakers with CP, but that consonant intelligibility, which is frequently affected in dysarthria, is a greater problem in this population. As with the study by Ng (2001), the findings of this study only apply to the tone variation of speakers with congenital dysarthria and cannot be generalized to speakers with acquired dysarthria.

Wong and Diehl (1999) aimed to determine the degree to which tone production is affected by the limited pitch range of speakers with dysarthria. They asked a speaker with hypokinetic dysarthria due to Parkinson's disease and a typical speaker to produce single words in isolation, as well as when preceded by a carrier phrase (a longer utterance). The single words were monosyllabic minimal pairs (the words were orthographically identical but differed from each other by tone). Only six words were used as stimulus materials. Acoustic analysis was used to calculate the pitch range for each speaker (the difference between each speaker's highest and lowest F_0 produced across all words), as well as each speaker's tonal space (the difference between each speaker's highest and lowest F_0 within each word). The authors compared the pitch range and tonal space between the speaker with dysarthria and the typical speaker. In addition, seven Cantonese listeners were requested to identify either the isolated target word or the target word within a longer utterance. Conclusions of the study focused mainly on the perceptual consequences of having a restricted pitch range. The authors did not study speakers' ability to vary F_0 in short *compared to* longer utterances, but rather studied listeners' perception of tone variation produced by speakers in short *and* longer utterances as a whole. Wong and Diehl (1999) concluded that pitch range and tonal space were more restricted in the speaker with dysarthria when compared to the typical speaker, and that listeners found it more

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challenging to identify tones produced by the speaker with dysarthria. The authors did not distinguish between production of tones in short and longer utterances. Findings based on the productions of one experimental and one control participant cannot be considered rigorous and cannot be generalized to the greater populations of typical speakers and speakers with dysarthria.

6.3 Critical evaluation of previous research

Researchers agree that impaired production of F_0 changes is found in speakers with dysarthria and that this impairment is significant (Ciocca et al., 2004; Ng, 2001; Wong & Diehl, 1999). Where impaired tone variation has been found in speakers with dysarthria, it has been noted to have a significant effect on the communication ability of these individuals (Ciocca et al., 2004). However, only a few studies have investigated tone variation and clinical disorders of lexical tone (Wong et al., 2009) and critical evaluation of the research has revealed shortcomings in this field. These shortcomings include the narrow range of languages studied, the syllable structure of words investigated, the utterance lengths utilised in the studies, and the issue of congenital versus acquired dysarthria in research participants. These shortcomings will subsequently be discussed.

- *Narrow range of languages:* Tone languages are currently widely spoken across Asia, Africa, Scandinavia, and the Americas (Wong et al., 2009). Despite this, studies of tone variation in speakers with communication impairments cover only a few of the many tone languages spoken across the world. Most of the existing literature on tone languages in speakers with dysarthria involves Asian languages such as Cantonese and Mandarin. No studies investigating the F_0 changes of Bantu language speakers with dysarthria were found. Current discussions regarding speakers' ability to perform the fine vocal fold adjustments necessary to produce F_0 changes within the structure of Bantu languages are therefore based on research from other languages. Applying Asian tone variation research to African languages is inappropriate. Not only do syntactical differences exist between Asian and African languages, but the tonal inventories of African languages differ vastly from those of languages from Asia (Gandour, 2006).

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- *Syllable structure of words:* All of the reviewed studies used only monosyllabic words as stimulus materials. Vocal fold control over more complex syllable structures such as bisyllabic words was therefore not studied, despite the fact that words increasing in syllable structure are known to place greater demands on speech sensorimotor control (Van der Merwe, 2009:6). Word stems in Bantu languages often consist of two syllables (Taljaard & Snyman, 1993). In future research, F_0 changes in bisyllabic words would need to be measured both *across* the two syllables, as well as *within* each syllable to gain an accurate understanding of tone variation in these words. Additionally, the tones of each syllable would need to be measured as they relate to one another, in terms of magnitude and direction of F_0 change, as well as relative F_0 level.
- *Utterance length:* In most previous research, the length of utterance within which F_0 changes were evaluated was kept consistently short, despite acknowledgement that some speakers with dysarthria have greater difficulty producing longer utterances than single words (Ciocca et al., 2004). The only study that did investigate tone variation in both short and longer utterances focused its discussion only on listeners' perception of tone variation in short and longer utterances as a whole. The study did not compare changes in F_0 in short utterances and long utterances (Wong & Diehl,1999).
- *Congenital versus acquired dysarthria:* The majority of relevant studies on tone variation used speakers with congenital dysarthria due to CP as research participants. Comparatively, little research has been done into tone variation in acquired dysarthria. The speech of individuals with congenital dysarthria may differ from the speech of individuals with acquired dysarthria, due to the impact of developmental processes on speech motor learning (Murdoch & Horton, 1998:373). Findings concerning the F_0 changes of speakers with congenital dysarthria can therefore not be generalized to speakers with acquired dysarthria.

In conclusion, existing research on the tone variation of speakers with dysarthria has entailed perceptual studies by typical listeners, acoustic analyses of speakers' F_0 variation, or a combination of both. A narrow range of languages were investigated and researchers regarded pitch at various time points across monosyllabic words in tone languages, with no reference to how these pitch points relate to each other or

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how tone would be affected in bisyllabic words. No inquiries were made into the tone variation ability of speakers with dysarthria when producing short utterances compared to longer utterances and mostly speakers with congenital dysarthria were used as research participants. Shortcomings in this field of study need to be addressed to gain a more holistic and accurate view of the extent to which tone variation is a challenge for Bantu language speakers with acquired dysarthria.

7. Problem statement, rationale, and research questions

Studies on the topic of lexical tone variation in speakers with dysarthria to date have focused mostly on the tone languages of Asia and Scandinavia (Kadyamusuma et al., 2011). No studies of tone variation in Bantu language speakers with dysarthria were found. In South Africa, the majority of typical speakers and speakers with dysarthria are Bantu first-language speakers, yet nothing is known about how tone variation is affected in this population. The issue can therefore not be sufficiently addressed in intervention with this population. Acoustic information regarding the ability of speakers with dysarthria to vary syllabic tone within syllables and across words may furthermore clarify the process of vocal fold neuromotor control and the breakdown of control at the speech execution level, as well as how it compares for short and long utterances. In light of the limitations in the amount and type of research that has been conducted in the field of tone variation as a whole and in the tone variation of Bantu L1 speakers with dysarthria specifically, as well as the numerous shortcomings in the past research, there is a clear need for a study investigating the tone variation ability (in short utterances and in long utterances) of Bantu language speakers with acquired dysarthria.

The research questions that were addressed in the current study are as follows:

- Is there a difference between typical first language (L1) speakers of Sepedi, a Bantu language, and L1 Sepedi speakers with dysarthria, in their ability to vary F_0 in bisyllabic consonant-vowel-consonant-vowel (CVCV) words with high-low (HL) tone variation, as they occur in three-syllable utterances?
- Is there a difference in F_0 variation for HL tone variation in CVCV words, in three-syllable utterances compared to six- or seven-syllable utterances, for typical L1 Sepedi speakers and L1 Sepedi speakers with dysarthria? Does a

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difference exist between the two speaker groups in their F_0 variation in three-syllable utterances compared to six- or seven-syllable utterances?

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Chapter 2
Method

The main aim of the present study was to investigate the tone variation of Sepedi speakers with dysarthria by comparing their performance in both short and long utterances to the performance of typical Sepedi speakers. This chapter describes the method selected for the study by presenting the research aims and design. Ethical considerations, participants, stimuli and apparatus, procedures, validity, and reliability are also discussed.

1. Aims of the study

1.1 Main aims

- To determine whether there is a difference between Sepedi first-language (L1) speakers who have dysarthria and typical L1 Sepedi speakers, in their ability to vary fundamental frequency (F_0) in consonant-vowel-consonant-vowel (CVCV) words with high-low (HL) tone variation across the two syllables of the target words.
- To determine if there is a significant difference in F_0 variation across CVCV words with HL tone variation in three-syllable utterances compared to six-/ seven-syllable utterances in both typical L1 Sepedi speakers and L1 Sepedi speakers with dysarthria, and to compare the performance of the two speaker groups regarding their F_0 variation in three-syllable utterances vs six- or seven-syllable utterances.

1.2 Sub-aims

To achieve the first main aim, the following sub-aims were set:

- To determine if there is a significant difference between the mean F_0 of the first syllable (S1) of the target word and the word's second syllable (S2) as spoken by individual typical speakers and speakers with dysarthria, as an indication of the *change in pitch between the two syllables of the words.*

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- To determine the *extent of change in F_0 across each target word* by calculating the difference between the highest F_0 point in S1 and the lowest F_0 point in S2 within the two groups (typical speakers and speakers with dysarthria), as well as for individual speakers.
- To determine the *extent of change in F_0 within each syllable* of the target words by calculating the difference between the highest and lowest F_0 points within each S1 and S2 of the target words. Data was obtained for each of the two groups (typical speakers and speakers with dysarthria), as well as for individual speakers.

To achieve the second main aim, the following sub-aims were set:

- To determine if there is a significant difference *in the extent of change in F_0 across each word,* from the highest F_0 point in S1 to the lowest F_0 point in S2, between *three-syllable utterances* and *six-/ seven-syllable utterances* as spoken by typical speakers.
- To determine if there is a significant difference *in the extent of change in F_0 across each word,* from the highest F_0 point in S1 to the lowest F_0 point in S2, between *three-syllable utterances* and *six-/ seven-syllable utterances* as produced by speakers with dysarthria.
- To determine if there is a significant difference between the two speaker groups *in the extent of change in F_0 across each word,* from the highest F_0 point in S1 to the lowest F_0 point in S2, in *three-syllable utterances* compared to *six-/ seven-syllable utterances*.

2. Research design

Research was conducted in two phases. Firstly, word stimuli to use during data collection were compiled. During this phase two pilot studies were undertaken, (1) to validate a preliminary list of words, and (2) to validate pictures that depict the target words. Secondly, the main study entailed data collection with a control group of typical speakers and an experimental group of speakers with dysarthria.

The research design of the main study was that of a quasi-experimental, between-group comparison. Data obtained from a control group were compared to data

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obtained from an experimental group. These groups were similar with regard to all variables except the one under investigation (Maxwell & Satake, 2006:182). Speech samples obtained from both speaker groups were analysed acoustically with regard to different aspects of tone variation. The control group consisted of five speakers and the experimental group consisted of four speakers. Both individual and group data were considered.

3. Ethical considerations

The researcher obtained ethical clearance from the Faculty of Humanities Research Ethics Committee at the University of Pretoria, as well as from the Gauteng Department of Health and the Tshwane District Research Committee (See Appendix B). CEOs and facility managers from participating health care institutions also gave permission for the study to be conducted. Consent forms including information regarding the study were sent to the research committees and health care institutions via e-mail in order to obtain permission (See Appendix C).

The researcher did not expose research participants to any physical or psychological harm (Leedy & Ormrod, 2014:107). Written informed consent was required from all participants prior to the commencement of data collection (Gravetter & Forzano, 2003). It was explained to participants that their participation was voluntary and that they would have the right to withdraw from the study at any time without negative consequences (APA, 2002 as cited in Gravetter & Forzano, 2003). Informed consent was obtained when participants signed letters that were given to them, explaining the nature of the study and of their potential participation, as well as their rights. A translator translated the informed consent form into Sepedi for participants who had difficulty understanding English (both English and Sepedi consent forms are included in Appendix D). A L1 Sepedi interpreter was also present during the signing of the consent form to answer questions and clarify any instructions which were not understood by participants.

In respecting research participants' right to privacy, the researcher took all of the necessary precautions to protect the information provided by them (APA, 2002 as cited in Gravetter & Forzano, 2003). The researcher was the only individual who had access to the information provided by participants. Anonymity was ensured by assigning

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numbers to research participants in lieu of their names on all recordings and forms utilized during data collection.

4. Participants

4.1 Sampling approach

Purposive sampling was used for the validation of the word list and picture cards, as well as for the main study. The research sample included participants who were considered to have the most representative attributes of the target population (Maxwell & Satake, 2006:97). The target population included typical L1 Sepedi speakers and Sepedi speakers with dysarthria.

4.2 Participant selection and description: Pilot studies, selection process of participants and data collection assistants

Several categories of participants were included throughout the research process. They will be discussed separately, according to their roles in the study.

4.2.1 Participants of Pilot study 1

For the development and validation of the word list, pilot study participants were required to be typical Sepedi L1 speakers, with a minimum Matric/Grade 12 qualification. A pilot study is best performed on a group similar to the one forming the population of the main study (Bell, 2010). Ten participants who were from the same geographical area as the participants in the main study were selected. All participants were from Mamelodi, a residential area in the South-East of Tshwane.

4.2.2 Participants of Pilot study 2

For the validation of the picture cards to depict the target words, pilot study participants were required to be typical Sepedi L1 speakers, with a minimum Grade 12

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qualification. Six participants were selected and all of them were from Mamelodi, as were the other participants of the study.

4.2.3 Participant who validated the final word list and sentences

Following the first pilot study, a linguist who was considered an expert in Sepedi and who was from the Tshwane region further assisted in the validation of the word list. The linguist possessed a D.Phil. in Sepedi. In addition to validating the word list, she assisted in the selection of short and longer utterances containing the target words to compare the tone variation of the words in utterances of varying length.

4.2.4 Participants who judged the diagnosis of dysarthria in the experimental group

In the selection of experimental participants, three Speech-Language Pathologists (SLPs) assisted in confirming experimental participants' diagnoses of acquired dysarthria and in identifying specific dysarthric speech characteristics to further contribute to the diagnosis. Each SLP had a minimum of four years' experience working with dysarthria and all worked at state institutions in the Tshwane area, having regular contact with Sepedi L1 speakers although they were not L1 Sepedi speakers themselves.

4.2.5 Participant who judged speech intelligibility

In the selection of participants for the main study, the *Sepedi Test for Speech Intelligibility (STSI)* (Fouché & Van der Merwe, 1999) was administered to both control and experimental participants to determine their degree of speech intelligibility. A listener was required to analyse the speech samples obtained. She was a L1 Sepedi speaker who was an SLP from the same geographical area as the research participants. The listener had more than five years' experience working as an SLP for adults with neurological speech and language impairments.

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4.2.6 Participant who acted as model and interpreter

In the data collection procedures for the main study, a speaker was required who could act as model for control and experimental participants to produce the target words in short and long utterances. The model needed to be a L1 Sepedi speaker who lived in the same geographical area as the research participants. The model speaker who was selected was an SLP with three years' experience working with patients who had neuromotor speech disorders. She also acted as interpreter during the study.

4.2.7 Participant who acted as consultant in acoustic analyses and reliability measures

Since only one person (the researcher) had the task of performing the acoustic analysis of the data, a second rater was required in order to measure reliability. Inter-rater reliability of the acoustic analysis process could be established by having a second rater re-analyse 20% of the target words initially analysed acoustically by the researcher, using *Praat* software (discussed further in section 9 on validity and reliability). The second rater was required to be an SLP who was trained extensively in the use of the *Praat* acoustic analysis software. The selected SLP had past experience in using *Praat* software for the acoustic analysis of populations with speech disorders for research purposes.

4.3 Control group selection criteria and description

Control participants were required to be L1 Sepedi speakers who originated from the same geographical area and background as experimental participants, to control for variations in dialect. They were also required to demonstrate normal speech intelligibility and needed to obtain an intelligibility score of between 90 and 100% on the *STSI* (Fouché & Van der Merwe, 1999). Participants from both control and experimental groups were required not to have any other current or past medical conditions which would have the potential to impact upon their speech or language, such as respiratory conditions or disorders affecting their laryngeal or oral-motor ability. Individuals with hearing impairment, voice disorders, fluency disorders and other speech or language disorders were also excluded as research participants.

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Background information on the typical L1 Sepedi speakers (control group) is presented in Table 2. Codes C1 to C5 were allocated to control participants to ensure anonymity. The use of a minus sign in Table 2 and all of the tables thereafter implies that a factor was not applicable to the participant. The use of a plus sign implies that a factor was applicable to the participant.

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Table 2: Background information obtained for the control participants C1 to C5

Background information	**C1**	**C2**	**C3**	**C4**	**C5**
Gender	Female	Female	Female	Male	Female
Age (years)	20	25	35	34	27
Home language and hours/ day spoken	Sepedi; 12	Sepedi; 12	Sepedi; 12	Sepedi, 14	Sepedi; 15
Residential area	Mamelodi	Mamelodi	Mamelodi	Mamelodi	Mamelodi
Co-morbidities	-	-	-	-	-
Highest level of education	Grade 12	Grade 12 IT certificate	Grade 12	Diploma in Electronics	Bachelor's degree
Occupation	Student	Unemployed	Unemployed	Salesman	Speech therapist & audiologist
Past medical conditions or communication disorders	-	-	-	-	-
Current medical conditions or communication disorders	-	-	-	-	-
Past medication	-	-	-	-	-
Current medication	-	-	-	-	-
Past therapy	-	-	-	-	-
Current therapy	-	-	-	-	-
Past smoker	-	-	-	-	-
Current smoker	-	-	-	-	-
Past alcohol consumption	+ (Moderately over weekends)	+ (Moderately over weekends)	-	-	-
Current alcohol consumption	+ (Moderately over weekends)	+ (Moderately over weekends)	-	-	-
STSI results	100%	100%	100%	100%	100%

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4.4 Experimental participant selection criteria and description

Experimental participants were required to be L1 Sepedi-speaking individuals with confirmed diagnoses of acquired dysarthria in conjunction with confirmed neurological lesions, without aphasia, apraxia of speech (AOS), or cognitive difficulties. As neither formal Sepedi aphasia assessment protocols nor standardized assessments of AOS are available, differential diagnosis was based on subjective analyses of the participants' receptive language ability, grammatical accuracy of sentences, speech production ability, and nature of speech errors. Participants' conversational speech, picture naming, and word repetition were analysed. Oral-motor examinations and whole body clinical observations were conducted by the SLPs as well as an occupational therapist and a physiotherapist working at the healthcare institution where the study was conducted. The experimental participants presented with no cognitive difficulties, and no receptive or expressive language difficulties were found. All of the participants presented with physical signs such as muscle weakness, difficulty coordinating muscle movements, and problems with muscle tone, which contributed to their speech production difficulties. The speech errors noted were consistent and not affected by length of utterance, differentiating it from AOS (McNeil, Robin, & Schmidt, 2009:251). These signs were consistent with the documented speech characteristics of dysarthria. Additionally, the *STSI* was administered to the experimental participants and yielded an intelligibility score, providing insight into the degree of dysarthria severity for all of the individuals with dysarthria (Fouché & Van der Merwe,1999). Reduced speech intelligibility is one of the salient features of dysarthria, rendering intelligibility measures applicable in quantifying dysarthria (Yorkston & Beukelman, 1978).

The background information and speech characteristics of the L1 Sepedi speakers with dysarthria are presented in Tables 3 through 10. Codes S1 to S3 were allocated to the three SLPs who judged the diagnosis of dysarthria in the experimental group (see 4.2.4). Codes P1 to P4 were allocated to experimental participants to ensure anonymity.

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Table 3: Background information obtained for experimental participant P1

Background information	**P1**
Gender	Female
Age (years)	68
Home language and hours/ day spoken	Sepedi; 17
Residential area	Mamelodi
Highest level of education	Grade 7
Occupation	Seamstress
Primary diagnosis and diagnosing professional	3 Cerebral Vascular Accidents (CVAs) starting March 2013; diagnosed by neurologist
Scan availability	- (Only neurologist's report available)
Results of neurologist report	Lesions of the basal ganglia and right motor cortex
Co-morbidities	Rheumatoid Arthritis; Hypertension; High cholesterol; Diabetes
Aphasia, cognitive difficulties or AOS	-
Affective or personality difficulties	-
Current communication disorders	Mixed dysarthria
Physical condition	• Left-sided hemiplegia (increased tone) • Left-sided facial paresis (lower half of left side of the face, including cheeks, lips, tongue)
Current medication	Medication for hypertension, high cholesterol and diabetes. Unable to specify names of medication.
Current therapy	• Speech therapy (biweekly for 1 month prior to data collection) • Physiotherapy (biweekly for 1 month prior to data collection)
Past medical conditions or communication disorders	-
Past medication	-
Past therapy	Acute Speech Therapy as in-patient in hospital after CVA
Past smoker	-
Current smoker	-
Past alcohol consumption	-
Current alcohol consumption	-

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Table 4: Speech characteristics of experimental participant P1

Speech characteristic	S1	S2	S3
1. Articulation			
Imprecise articulation	+	-	-
Irregular articulatory breakdowns	-	+	+
Distorted consonants	+	+	+
Distorted vowels	-	-	-
Telescoping of syllables (sounds flow into each other and cannot be distinguished)	-	-	-
Generally distorted speech	+	+	+
Other… (Specify in adjacent column)	-	-	-
2. Phonation			
Breathiness	-	+	-
Hoarseness	-	-	-
Strained-harsh voice quality	+	+	+
Other… (Specify in adjacent column)	-	-	-
3. Respiration			
Short utterances per expiratory cycle	-	-	-
Audible expiration	-	-	-
Other… (Specify in adjacent column)	-	-	Talking on residual air
4. Resonance			
Hypernasality	+	+	-
Other… (Specify in adjacent column)	-	-	-
5. Prosody			
Slow speech rate	+	+	+
Rapid/ accelerated speech rate	-	-	-
Excess and equal stress	-	-	-
Inappropriate pitch, loudness or duration variation	+	-	+
Reduced stress	+	+	-
Monotone	-	-	-
6. *STSI* result		78%	

**S1 to S3 refer to the SLPs who identified the speech characteristics in the participants' speech*

Participant P1 was a 68-year-old female, diagnosed with lesions of the basal ganglia and right motor cortex due to multiple CVAs. She was diagnosed with mixed dysarthria by the SLPs, based upon her speech characteristics and neurological lesions. All three SLPs agreed that participant P1 presented with distorted consonants and slow speech rate, both of which are salient features of dysarthria. They also agreed that she had a strained-harsh voice quality and that her dysarthria was mild. P1's *STSI* results yielded an intelligibility score of 78%.

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Table 5: Background information obtained for experimental participant P2

Background information	**P2**
Gender	Male
Age (years)	30
Home language and hours/ day spoken	Sepedi; 16
Residential area	Mamelodi
Highest level of education	Grade 12
Occupation	Unemployed
Primary diagnosis and diagnosing professional	Closed head injury in May 2015; diagnosed by physicians
Scan availability	- (Only physicians' report available)
Results of neurologist report	Physicians report diffuse brain injury
Co-morbidities	-
Aphasia, cognitive difficulties or AOS	-
Affective or personality difficulties	-
Current communication disorders	Mixed dysarthria associated with diffuse closed head injury
Physical condition	• Balance issues • Whole body weakness and hypotonia • Nystagmus
Current medication	Analgesics, unspecified
Current therapy	Weekly Speech Therapy and Physiotherapy since the acute stage
Past medical conditions or communication disorders	-
Past medication	-
Past therapy	-
Past smoker	-
Current smoker	-
Past alcohol consumption	+ (Occasionally)
Current alcohol consumption	-

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Table 6: Speech characteristics of experimental participant P2

Speech characteristic	S1	S2	S3
1. Articulation			
Imprecise articulation	+	-	+
Irregular articulatory breakdowns	-	+	+
Distorted consonants	+	+	+
Distorted vowels	-	+	+
Telescoping of syllables (sounds flow into each other and cannot be distinguished)	+	-	+
Generally distorted speech	-	-	+
Other… (Specify in adjacent column)	-	-	-
2. Phonation			
Breathiness	+	+	-
Hoarseness	-	-	+
Strained-harsh voice quality	-	-	-
Other… (Specify in adjacent column)	Soft voice	Soft voice	-
3. Respiration			
Short utterances per expiratory cycle	+	-	+
Audible expiration	-	-	-
Other… (Specify in adjacent column)	-	-	-
4. Resonance			
Hypernasality	-	-	-
Other… (Specify in adjacent column)	-	-	-
5. Prosody			
Slow speech rate	+	+	+
Rapid/ accelerated speech rate	-	-	-
Excess and equal stress	-	-	-
Inappropriate pitch, loudness or duration variation	+	+	+
Reduced stress	+	+	+
Monotone	+	+	+
6. *STSI* result		74%	

**S1 to S3 refer to the SLPs who identified the speech characteristics in the participants' speech*

Participant P2 was a 30-year-old male, with a confirmed closed head injury. His physical condition and speech characteristics indicated possible cerebellar involvement and the diffuse nature of his closed head injury indicated possible mixed dysarthria. All three SLPs agreed that participant P2's speech was dysarthric. They also agreed that he presented with distorted consonants, slow speech rate, and numerous prosodic difficulties, including inappropriate pitch, loudness or duration variation, reduced stress, and monotonous speech. One listener described the participant's dysarthria as mild and the other two described it as moderate. P2's *STSI* results yielded an intelligibility score of 74%. Despite the diffuse nature of his brain

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injury, no comorbid conditions such as aphasia, AOS or cognitive difficulties were found.

Table 7: Background information obtained for experimental participant P3

Background information	**P3**
Gender	Female
Age (years)	54
Home language and hours/ day spoken	Sepedi; 15
Residential area	Mamelodi
Primary diagnosis and diagnosing professional	CVA, neurologist at rehabilitation hospital (2013)
Scan availability	- (Only neurologist's report available)
Results of neurologist report	Lesion of the right motor cortex
Co-morbidities	Hypertension
Aphasia, cognitive difficulties or AOS	-
Affective or personality difficulties	-
Current communication disorders	Mixed dysarthria
Physical condition	• Left-sided hemiplegia • Left-sided facial paresis (lower half of left side of the face, including cheeks, lips, tongue)
Current medication	Blood pressure medication, unspecified
Current therapy	- (Defaulted)
Highest level of education	Grade 10
Occupation	Housewife
Past medical conditions or communication disorders	-
Past medication	-
Past therapy	1 month in rehabilitation hospital as in-patient (speech-, occupational- and physiotherapy)
Past smoker	-
Current smoker	-
Past alcohol consumption	-
Current alcohol consumption	-

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Table 8: Speech characteristics of experimental participant P3

Speech characteristic	S1	S2	S3
1. Articulation			
Imprecise articulation	+	-	-
Irregular articulatory breakdowns	-	+	+
Distorted consonants	+	+	-
Distorted vowels	-	+	-
Telescoping of syllables (sounds flow into each other and cannot be distinguished)	+	+	+
Generally distorted speech	+	+	+
Other… (Specify in adjacent column)	-	-	-
2. Phonation			
Breathiness	-	+	-
Hoarseness	-	-	-
Strained-harsh voice quality	-	-	-
Other… (Specify in adjacent column)	-	-	-
3. Respiration			
Short utterances per expiratory cycle	-	-	+
Audible expiration	-	-	-
Other… (Specify in adjacent column)	-	-	-
4. Resonance			
Hypernasality	-	-	-
Other… (Specify in adjacent column)	-	-	-
5. Prosody			
Slow speech rate	-	-	-
Rapid/ accelerated speech rate**	+	+	+
Excess and equal stress	-	+	+
Inappropriate pitch, loudness or duration variation	+	+	+
Reduced stress	-	-	-
Monotone	+	+	+
6. *STSI* result		48%	

**S1 to S3 refer to the SLPs who identified the speech characteristics in the participants' speech*

*** S1 to S3 indicated that P3's increased speech rate may be associated with telescoping of syllables in her speech*

Participant P3 was a 54-year-old female, diagnosed with a lesion of the right motor cortex following a CVA. All three SLPs agreed that P3 presented with telescoping of syllables in her speech, as well as generally distorted speech, rapid speech rate (possibly associated with the telescoping of syllables), inappropriate pitch, loudness or duration variation, and monotonous speech. If participant P3's communication disorder was diagnosed exclusively on the grounds of her reported site of lesion, P3 could have unilateral UMN dysarthria. However, due to the nature and severity of the participant's speech characteristics noted by all three SLPs, P3 was suspected of having mixed dysarthria, with possible cerebellar involvement. One listener described P3's dysarthria as moderate and the other two described it as severe. Her *STSI* results yielded an intelligibility score of 48%.

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Table 9: Background information obtained for experimental participant P4

Background information	**P4**
Gender	Male
Age (years)	65
Home language and hours/ day spoken	Sepedi; 16
Residential area	Mamelodi
Primary diagnosis and diagnosing professional	CVA (occurred in May 2015); Neurologists at tertiary hospital
Scan availability	- (Only neurologist's report available)
Scan results	Lesions of the basal ganglia and left-sided lesion of motor cortex
Co-morbidities	Hypertension
Aphasia, cognitive difficulties or AOS	-
Affective or personality difficulties	-
Current communication disorders	Mixed dysarthria
Physical condition	• Right-sided hemiplegia • Right-sided facial paresis (lower half of the right side of the face, including cheeks, lips, tongue) • Bradykinesia (slowness of movement) • Facial masking
Current medication	Hypertension medication, unspecified
Current therapy	Speech Therapy and Physiotherapy (biweekly)
Highest level of education	Grade 8
Occupation	Past: Material supply Currently: Retired
Past medical conditions or communication disorders	+ Stomach ulcer
Past medication	-
Past therapy	-
Past smoker	+ (< 40 years)
Current smoker	-
Past alcohol consumption	-
Current alcohol consumption	-

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Table 10: Speech characteristics of experimental participant P4

Speech characteristic	S1	S2	S3
1. Articulation			
Imprecise articulation	+	+	+
Irregular articulatory breakdowns	-	-	-
Distorted consonants	+	-	-
Distorted vowels	-	+	-
Telescoping of syllables (sounds flow into each other and cannot be distinguished)	-	-	-
Generally distorted speech	+	+	+
Other… (Specify in adjacent column)	-	-	-
2. Phonation			
Breathiness	-	+	-
Hoarseness	+	+	+
Strained-harsh voice quality	-	-	+
Other… (Specify in adjacent column)	-	-	-
3. Respiration			
Short utterances per expiratory cycle	-	-	+
Audible expiration	-	-	-
Other… (Specify in adjacent column)	-	-	-
4. Resonance			
Hypernasality	-	-	-
Other… (Specify in adjacent column)	-	-	-
5. Prosody			
Slow speech rate	-	-	+
Rapid/ accelerated speech rate	-	-	-
Excess and equal stress	-	-	-
Inappropriate pitch, loudness or duration variation	-	+	-
Reduced stress	-	+	-
Monotone	-	+	-
***STSI* result**	63%		

**S1 to S3 refer to the SLPs who identified the speech characteristics in the participants' speech*

Participant P4 was a 65-year-old male, diagnosed with lesions of the basal ganglia and a left-sided lesion of the motor cortex after suffering a stroke. On the grounds of P4's speech characteristics and neurological lesions, he was diagnosed with mixed dysarthria. All three SLPs agreed that P4's speech was dysarthric. They also agreed that he presented with imprecise articulation, generally distorted speech, and a hoarse voice quality. Two of the listeners agreed that participant P4 had mild dysarthria and one of the listeners indicated that he had moderate dysarthria. The participant's *STSI* results yielded an intelligibility score of 63%.

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5. Stimuli development

In the current study, tone variation was investigated across bisyllabic CVCV verb stems, as they occurred within three- and six-syllable utterances. For the sake of simplified reading, these verb stems will be referred to as “words” within this text. An initial word list was selected to be utilised in the study and was evaluated by means of a pilot study. After the final word list was compiled, short and long utterances were selected within which these words were included. Pictures were then selected to elicit stimulus words and were evaluated through a second pilot study. Through this process, the final experimental stimuli were obtained.

5.1 Criteria for stimulus word selection

Only CVCV words were included in the study, as words with this syllable structure constitute the majority of stem words in Sepedi (Taljaard & Snyman, 1993). Although Sepedi nouns are considered more tonal than verbs (they contrast tone on every syllable) (Zerbian & Barnard, 2008b; 2010), different noun classes would require different prefixes to be included (Mphasha, 2006). This would result in different syllable structures of the stimulus words - a potentially confounding variable. Only verbs were therefore included in the list of target words, as their prefixes would allow for a more consistent syllable structure. The verbs selected were all positive. In Sepedi, most positive verbs end in the /a/-sound (Olivier, 2009). The consistency of the syllable structure, positive form, and final /a/-sound of words selected contributed to the consistency of research stimuli.

Only words with a high-low (HL) tone pattern were included as research stimuli. The tone pattern of the target words needed to be kept constant as a variety of aspects of tone variation were analysed acoustically and comparisons drawn between typical speakers and speakers with dysarthria. The consonant sounds in the target words could not be controlled, as this would severely limit the number of stimulus words generated, resulting in a limited number of utterances produced by participants.

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5.2 Compilation of the preliminary word list

The tone of words in the lexicon of tonal languages is largely unpredictable (Zerbian & Barnard, 2010). Hence, the *Comprehensive Northern Sotho Dictionary* (Ziervogel & Mokgokong, 1985), a tone-marked pronunciation dictionary, was used to select target words. Ziervogel and Mokgokong are widely considered to be appropriate authorities on tone specification for Sepedi stem words (Raborife, Ewert, & Zerbian, 2010). Thirty target words meeting selection criteria were included in the preliminary word list.

5.3 Pilot study 1: Evaluation of the preliminary word list

A pilot study was conducted to determine whether the 30 words included in the target word list were accurate and commonly used in Sepedi. In this way flaws in the test stimuli to be used for data collection could be identified and corrected (Bell, 2010) and validity of the data collection materials determined (Leedy & Ormrod, 2014:205).

Ten individuals who met participation criteria for the pilot study (see 4.2.1 in this chapter) were requested to give feedback on the preliminary word list, by indicating whether the words were commonly used in Sepedi, whether the correct forms of the words were provided, whether the HL tone pattern of the words was correct, and whether the correct English translation of the words were given. Participants' feedback was organised according to how many individuals agreed on the suitability of each word, how many disagreed, and participants' reasons for disagreeing. A linguist was also asked to review the initial word list (see 4.2.3 in this chapter for participant criteria). If eight or more of the participants and the linguist agreed on the suitability of a target word, the researcher included the word in the final word list. Based upon these criteria, 20 out of the 30 words were suitable for inclusion in the main study.

5.4 Short and long utterance selection

After selecting the final 20 words, short and longer utterances containing the words were selected to compare the tone variation of the words in utterances of varying length:

- *Short utterances:* Each target word was included in a three-syllable infinitive phrase, consisting of the prefix "go" (meaning "to" and produced as /xo/)

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combined with the word. For example, the word, "-bona," meaning "see," was included in the three-syllable utterance, "Go bona," meaning "To see." This process yielded 20 short utterances.

- *Long utterances:* Each target word was placed in a six- or seven-syllable utterance, consisting of the phrase "Monna o a" combined with the target CVCV word. For example, "Monna o a bona," meaning "The man is seeing." If "Monna o a…" ("The man is…") did not make semantic sense for a particular target word, a similar utterance was used instead. For example, "Mpša e a goba" ("The dog is barking") was used as the longer utterance for "-goba," meaning "bark." 20 Longer utterances were generated, all constituting positive statements and containing the target word in the final position of the utterance.

The aforementioned Sepedi linguist assisted the researcher in selecting short and long utterances that were acceptable in terms of structure and meaning, as well as choosing utterances that would be commonly used by L1 Sepedi speakers.

5.5 Selection of the pictures to elicit stimulus words

Twenty A5-sized picture cards containing target words and one example picture card were developed to elicit target utterances from participants. Each picture card illustrated one word. The picture cards had a white background, with a cream-coloured border, and displayed a picture of the target word in the centre of the card. The target CVCV Sepedi word, as well as its English translation, was printed at the top of the card. Below the target word there were two sentences to clarify the meaning of the word: A Sepedi sentence and its English translation. At the bottom of the picture card, the two utterances to be produced by the participants could be found. The first utterance was the short utterance ("Go"-word) and was labelled number one. The second utterance was the longer utterance ("Monna o a" + word) and was labelled number two. See Appendix F for copies of the picture cards.

At this stage in the development of the stimulus materials, the linguist assisted the researcher by confirming that the sentences used to clarify the meaning of the target words were correctly formulated and culturally appropriate.

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5.6 Pilot study 2: Evaluation of the appropriateness of stimulus materials, instructions, and presentation

The aims of the pilot study for stimulus materials were as follows:

- To determine whether the picture cards were easily interpretable and whether they clearly depicted target words. This was especially important because words exist in Sepedi that are orthographically identical but that vary in tone allocation, thus changing the meaning of the word. (Such words, known as minimal pairs, were not included in the study).
- To ensure that the instructions given to the participants were clearly understood and easily followed.
- To ensure that the presentation of the picture cards occurred at a correct pace, so that all recordings would have sufficient time between the short and long utterances as produced by each participant. This ensured that the sound recordings would not be distorted when cut for acoustic analysis.

Six participants meeting pilot study participant criteria (see 4.2.2 in this chapter) were shown the 20 picture cards. The same experimental conditions, instructions, and procedures used for the main study were followed in this pilot study for validation of these processes. Upon completion of the procedure with all 20 picture cards, participants were asked questions regarding the data collection procedure, including whether instructions given to them were clear, whether pictures clearly depicted target words, and whether the words utilized were commonly used in Sepedi (See Appendix G for the questions given to pilot study participants in their consent form).

Participants indicated that all of the instructions given to them were clear and that the words and pictures on the picture cards were generally understandable. The participants expressed some confusion, however, as the longer utterances on the picture cards mostly commenced with “Monna o a…” (“The man is…”), even if a woman was depicted in the illustration on the picture card. This confusion was eliminated in the final data collection procedure, by providing an explanation that the illustrations and sentences at the top of the picture cards were only present to clarify the meaning of the target word and that they had no immediate bearing on the utterances to be produced. For example, even if there was a woman reprimanding a

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child in the picture, the longer utterance to be produced remained “Monna o a kgala” (“The man is reprimanding.”) From the recordings made in the pilot study, it was further determined that the presentation of the picture cards occurred at a correct pace to ensure that the sound recordings were not distorted when cut for acoustic analysis.

5.7 Experimental stimuli

Table 11 indicates the final word list of 20 words used in the study, as well as their inclusion in short and long utterances. Following the second pilot study, all 20 picture cards depicting the words and utterances were deemed appropriate for use as stimulus materials in the main study.

6. Apparatus

6.1 Apparatus for data collection

Recordings were made using an Olympus digital voice recorder, model VN-731PC, with the microphone placed at a fixed distance of 20cm from each participant’s mouth. This distance was maintained consistently throughout the study. All recordings were made in the same, isolated room to ensure that the sound levels of all recordings were kept as constant as possible throughout the study.

6.2 Apparatus for acoustic analysis

Previous research methodologies in the study of tone variation (indicated in Appendix A) were considered before the researcher selected the acoustic analysis apparatus to use. It was noted that the majority of past studies used the *Praat* acoustic analysis software for the acoustic analysis of tone variation. The researcher selected the *Praat (Version 5.3.56, Boersma & Weenink, 2013)* and compared it to the *Computerized Speech Lab (CSL) (Model 4150B, Version 3.4, Kay PENTAX, 2010).* These software programmes were used to compute the pitch contours of the first and second syllables (S1 and S2) of the target HL words produced by control participant C1.

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A few word productions of C1 were used to compare analysis results across the *Praat* software and the *CSL.* The aims of comparing the two programmes included determining if the results obtained from the programmes were similar, and determining which F_0 measurements to use in answering the research questions. The pitch contours computed by both programmes followed the same pattern. The F_0 values obtained from the *Praat* showed a high correlation with the F_0 values yielded by the *CSL.* It was decided that *Praat* would be used for acoustic analysis as it could be downloaded and used on any personal computer, making it easily accessible.

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Table 11: Final word list, including the short and long utterances selected and their English translations

Target Sepedi word*	English translation	Short utterance	English translation	Long utterance	English translation
-bona	See	Go bona	To see	Monna o a bona	The man is seeing
-fala	Scrape clean	Go fala	To scrape clean	Monna o a fala	The man is scraping clean
-fela	Finish	Go fela	To finish	Meetse a a fela	The water is finishing
-kgoka	Bind	Go kgoka	To bind	Monna o a kgoka	The man is binding
-thopa	Win	Go thopa	To win	Monna o a thopa	The man is winning
-bopa	Mould/ fashion with clay	Go bopa	To mould/ fashion with clay	Monna o a bopa	The man is moulding with clay
-goba	Bark	Go goba	To bark	Mpša e a goba	The dog is barking
-thala	Draw a line	Go thala	To draw a line	Monna o a thala	The man is drawing a line
-mona	Suck	Go mona	To suck	Monna o a mona	The man is sucking
-bata	Flatten by pounding	Go bata	To flatten by pounding	Monna o a bata	The man is flattening by pounding
-fega	Hang/ suspend	Go fega	To hang/ suspend	Monna o a fega	The man is hanging
-nyanya	Suckle	Go nyanya	To suckle	Ngwana o a nyanya	The baby is suckling
-kala	Weigh on a scale	Go kala	To weigh on a scale	Monna o a kala	The man is weighing on a scale
-kgala	Reprimand/ warn/ prevent from doing	Go kgala	To reprimand/ warn/ prevent from doing	Monna o a kgala	The man is reprimanding
-phaka	Park	Go phaka	To park	Monna o a phaka	The man is parking
-roka	Stitch	Go roka	To stitch	Monna o a roka	The man is stitching
-tima	Extinguish/ put out a fire	Go tima	To extinguish/ put out a fire	Monna o a tima	The man is extinguishing (a fire)
-gama	Milk	Go gama	To milk	Monna o a gama	The man is milking
-loma	Bite	Go loma	To bite	Mpša e a loma	The dog is biting
-rata	Love	Go rata	To love	Monna o a rata	The man is loving

**The verb stems used as research stimuli are referred to as "words" within this text for simplified reading*

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7. Procedures

7.1 Data collection

- *Determining if participation criteria were met:* Firstly, potential research participants were asked to sign informed consent documents. To determine if they met participation criteria, participants were then called into the data collection room individually and the background questionnaire and *STSI* were administered. If the individuals met control or experimental participation criteria, the main study commenced subsequently. Both control and experimental participants were allowed a rest period of four minutes after the *STSI* had been conducted to minimise fatigue. Thereafter, data collection procedures commenced.
- *Environment:* All data collection was conducted in the same isolated room to keep sound levels constant. The model/ interpreter sat at a table opposite the participant and the researcher sat next to the participant to present the picture cards and to control the recording equipment.
- *Instructions:* The researcher initiated data collection procedures by informing the participants that they would be shown 21 picture cards, one of which was an exemplar card. The researcher explained what was on the picture cards and participants were instructed to read the words and sentences at the top of the card, as well as look at the picture in the middle of the card to assist in determining the meaning of the target word. The Sepedi interpreter was available to read the Sepedi words and sentences to the participants if they were not literate. The researcher explained that participants would be required to repeat the short and long utterances typed below the picture on each card (labelled numbers one and two respectively) after the Sepedi model. The researcher elaborated that the model would first read the short utterance aloud and would then count to five with her fingers and point to the participant when it was his/ her turn to repeat the short utterance after the model. The model would then read the long utterance aloud and would again count to five with her fingers and point to the participant when it was his/ her turn to repeat the long utterance after the model. Counting to five before participants repeated the utterances after the model allowed sufficient recording time on either side of the

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utterance, for the recordings to be cut at a later stage without distorting the sound. The researcher emphasised the fact that the picture and sentences at the top of the picture cards were only present to clarify the meaning of the target word and that they had no immediate bearing on the utterances to be produced. She gave the example that even if a woman appeared in the picture, the participant would still have to repeat “Monna o a…” (“The man is…”) after the model. After the researcher provided the instructions to the participants in English, all instructions were repeated to the participants in Sepedi by the model/ interpreter. See Appendix H for the detailed instructions given to the participants.

- *Procedures:* After the instructions were given to the participants and they were shown the exemplar picture card, the participants were allowed time to go through the picture cards themselves to gain an idea of the speech tasks required of them. When they were ready to begin the speech tasks, participants were asked to indicate this by a nod of the head. At this time, questions were also allowed from the participants if any aspect of the data collection process was unclear to them. Thereafter, data collection followed the procedures that had been explained to the participants during the instructions. The short and long utterances appearing on each picture card were spoken in succession before the next picture card was shown. This was done to spread fatigue equally between short and long utterances, thereby eliminating it as a confounding variable. Participants were given a 30 second rest period after every three picture cards. After the utterances on all 20 picture cards had been produced by the participants, their individual data collection sessions were complete.

7.2 Recording

For each participant, the short and long utterances produced for each target word were recorded in one audio file. There were therefore 20 audio files recorded per participant. Each of the audio files also contained the short and long utterances produced by the model to ensure that the target word of the participant’s audio file was clearly identifiable. Recordings were digitised at a sampling rate of 44.1 Kz and were automatically recorded as *Windows Media Audio (WMA)* files. These files were

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converted to *Windows Wave (WAV)* files as necessitated for acoustic analysis, using the *Hamster Free Audio Converter (1.0.20.0)* (Hamstersoft, 2012). Each short and long utterance for target words produced by the participants was then cut from their respective audio files using *Audacity (2.1.0)* (Softtonic, 2015) and saved separately according to participant, target word, and whether it was a short or long utterance. This yielded 40 audio files per participant (20 target words in short utterances and 20 target words in long utterances).

7.3 Data analysis

Praat acoustic analysis software was used by the researcher to determine the following F_0 values of the target words in short and longer utterances:

- The mean F_0 of S1
- The minimum F_0 of S1
- The maximum F_0 of S1
- The mean F_0 of S2
- The minimum F_0 of S2
- The maximum F_0 of S2

The following steps were used to obtain the measurements:

- All target words produced within short and long utterances by one participant were analysed first before moving on to the next participant. Target words were uploaded onto *Praat* as audio files one at a time. Firstly, target words within short utterances were analysed, then target words within longer utterances. None of the default settings on *Praat* were changed for this process.
- *Praat* was opened on a *Dell Inspiron 3521* laptop computer. Two windows appeared on the computer screen: An objects window and a picture window. In the objects window, *"Open"* was selected in the toolbar and then *"Read from file"* to select an audio file for analysis. Once an audio file was selected, the *"View and edit"* option was chosen from the toolbar. This allowed the automatic generation of a waveform and spectrogram for the utterance in the editor window, a third window which opened automatically on the computer screen.

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- The autocorrelation pitch tracker of *Praat* generated a pitch contour for the spectrogram. The pitch contour appeared as a blue line, superimposed on the spectrogram for the entire utterance.
- Using the waveform and spectrogram, the first syllable of the target word was selected by dragging the cursor to the syllable boundaries. Visual and auditory inspection of the images was used to confirm selection. (Auditory playback of the selected syllable occurred when the *"View"* option was selected on the toolbar of the editor window, followed by *"Play or stop"* from the drop down menu).
- After the first syllable was selected, the pitch contour was used to obtain the mean pitch (mean F_0), maximum pitch (maximum F_0) and minimum pitch (minimum F_0) of the syllable. *Praat* automatically generated these values and displayed them on the screen when the researcher selected *"Pitch"* from the toolbar at the top of the editor window and the relevant option from the drop down menu. The *"Get pitch"* option was selected to determine the mean F_0. The *"Get maximum pitch"* option was selected to determine the maximum F_0 and the *"Get minimum pitch"* option was selected to determine the minimum pitch of the syllable. The same process was repeated for the second syllable of the word and then for all of the syllables of all of the words in short and long utterances produced by every participant. The relative F_0 values correlated with what was heard from the recordings and seen in the spectrograms for all participants.

Figure 1 shows an example of an editor window appearing on the computer screen during data analysis. It depicts the waveform (at the top of Figure 1) and the spectrogram (at the bottom of Figure 1) generated for the word "-bona" within a short utterance as produced by participant C2. The first syllable of the word was selected for analysis and it is therefore highlighted in pink. The blue line superimposed on the spectrogram is the pitch contour and one can see that the first syllable is produced with a higher pitch than the second syllable. The word therefore has a characteristic HL tone pattern.

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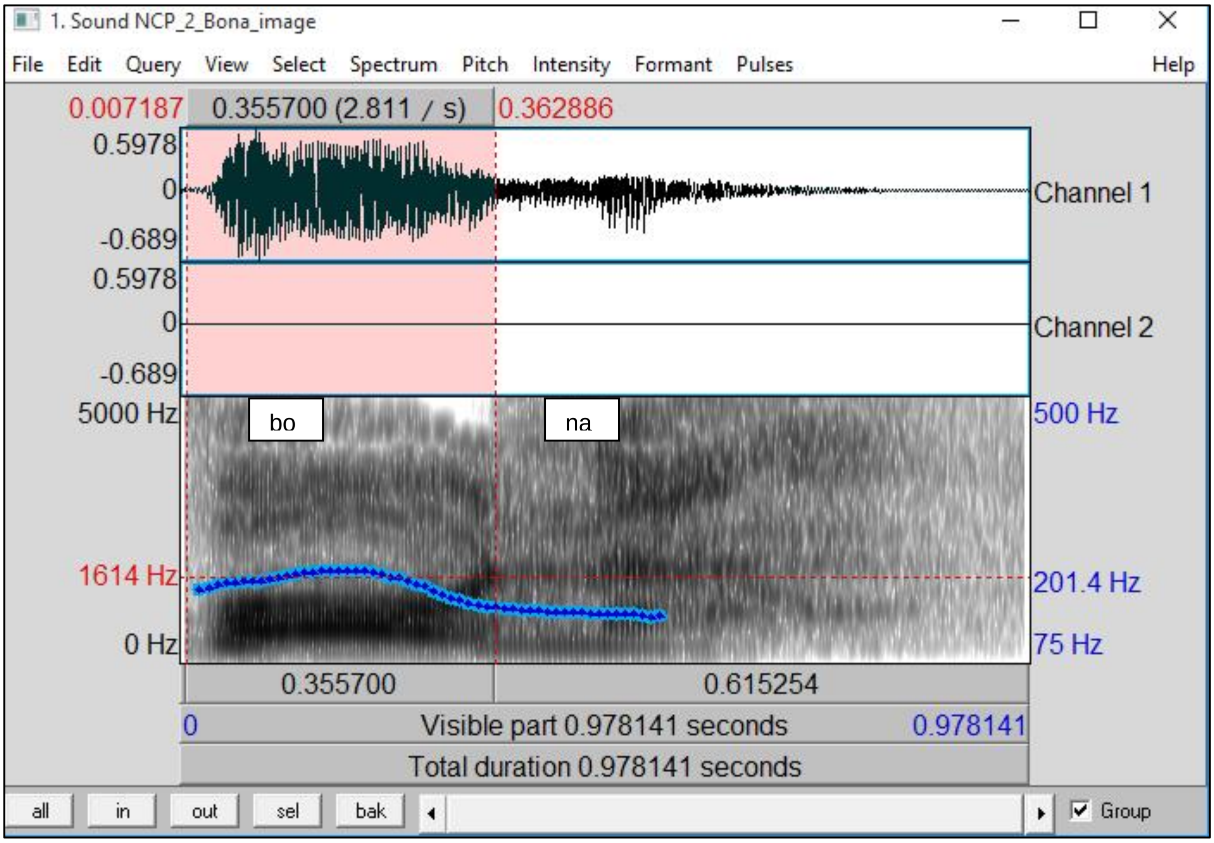

**This window includes the waveform and spectogram generated for "-bona" within a short utterance produced by participant C2. The first syllable of the word is selected and is therefore highlighted in pink.*

Figure 1: Example of an editor window opened in *Praat* for data analysis

8. Data processing

8.1 Capturing of individual data

The first part of data processing focused on the individual participants. The F_0 values obtained from *Praat* were used in the following calculations for *every* target word within short *and* long utterances for *individual participants*:

- The mean F_0 of S1 and the mean F_0 of S2 were noted for all 20 of the words, so that it could be determined by statistical analysis whether the mean F_0 of S1 differed significantly from the mean F_0 of S2 within individual speakers.
- The change in F_0 across each word was then obtained, from the highest F_0 point in S1 to the lowest F_0 point in S2 (Maximum F_0 of S1 minus Minimum F_0 of S2).

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- The change in F_0 within S1 was obtained (Maximum F_0 of S1 minus Minimum F_0 of S1) and
- The change in F_0 within S2 was obtained (Maximum F_0 of S2 minus Minimum F_0 of S2)

The F_0 values obtained from these calculations were entered into *Microsoft Excel (2014)* in the following way:

- Three *Microsoft Excel* spreadsheets were compiled to keep the data used for the different sub-aims separate.
- On the first spreadsheet, participant codes (C1 to C5 and P1 to P4) were entered on the y-axis and target words, first within short utterances and then within long utterances, were entered on the x-axis. For each word, the researcher then entered the mean F_0 in S1 and the mean F_0 in S2 on the spreadsheet. (The mean F_0 values for words within short utterances were kept separate from the mean F_0 values for words within long utterances). This spreadsheet was used in the statistical comparison of the mean F_0 of S1 to the mean F_0 of S2 for individual control and experimental participants.
- On the second spreadsheet, participant codes were entered on the y-axis and target words, first within short utterances and then within long utterances, were entered on the x-axis. For each word within short utterances and then within long utterances, the researcher entered the following values on the spreadsheet: Change in F_0 across each word from the highest F_0 point of S1 to the lowest F_0 point of S2, change in F_0 within S1 and change in F_0 within S2. This spreadsheet was used in the statistical comparison of the F_0 values between control and experimental groups and in the comparison of the control group and individual speakers to determine if statistically significant differences existed between the speakers.
- On the third spreadsheet, all participant codes were again plotted on the y-axis and the target words on the x-axis. The researcher then entered two values on the spreadsheet for each target word: The change in F_0 across the words from the highest F_0 point of S1 to the lowest F_0 point of S2 as it occurred in short utterances, and the change in F_0 across the words as it occurred in long utterances. This spreadsheet was used in the statistical analysis of the change

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in F_0 across words in short compared to long utterances within control and experimental groups and for individual speakers.

Raw data appearing on all of the spreadsheets are presented in Appendix I.

8.2 Processing of the data

The data captured on the spreadsheets (section 8.1) allowed comparisons of F_0 values to be made within and between speaker groups. The data did not follow bell-shaped frequency distribution curves for either the control or the experimental group, nor for individual participants, therefore non-parametric Wilcoxon rank tests were used for statistical analyses. Descriptive statistics were performed and median values and the associated inter-quartile ranges were obtained.

Median values were considered to best represent the data for the control group and the experimental group, as well as the individual participants, because medians are less affected by skewed data than mean values. At all steps of data processing, Inter-Quartile Ranges (IQRs) were also obtained to provide indications of the extent of difference between individual data within groups. It is common for IQRs to be reported in research along with medians as an indication of how far from the median individual F_0 values are spread (Leedy & Ormrod, 2013:299). However, only median F_0 values were used to achieve the research aims.

Statistical analyses were used to determine whether significant differences in median F_0 values existed between data sets. All statistical analyses were performed with *STATA: Data Analysis and Statistical Software, v.12*. A $p \leq 0.05$ was deemed statistically significant in all tests.

The following calculations were undertaken in data processing to achieve the first main aim of the study:

- *Comparing the mean F_0 of S1 to that of S2:* For each control speaker and each speaker with dysarthria, medians were obtained for the mean F_0 values of S1 and S2 for the target words that they produced. The median F_0 value of S1 was then compared to the median F_0 value of S2 for individual speakers, to determine whether a statistically significant difference existed between the F_0 values of the two syllables. This would determine whether the tone of the two

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syllables within HL words differed significantly from each other as produced by control speakers and speakers with dysarthria. It would also yield an indication of whether S1 was produced with a higher F_0 than S2 by all speakers, as would be necessary in order to achieve a HL tone pattern. No group comparisons were made at this stage of data processing, as the mean F_0 values would be influenced by the voice pitch of male and female speakers within the groups.

- *Comparing the change in F_0 across words for both groups and individual speakers:* The median change in F_0 across the words, from the highest F_0 of S1 to the lowest F_0 of S2, for the experimental group was compared to that of the control group to determine if a statistically significant difference existed between the two groups. The median changes in F_0 across the words for individual speakers with dysarthria were also compared to that of the control group as a whole to determine if a statistically significant difference existed between any of the individual speakers with dysarthria and the control group. Additionally, the median changes in F_0 across words for individual control group speakers were calculated at this stage, to determine if individual control speakers differed from the typical speakers as a group. Such comparisons would reveal the significance of the results of the individual speakers with dysarthria who differed from the control group.
- *Comparing the changes in F_0 within S1 and within S2 for both groups and individual speakers:* The median change in F_0 within S1 for the control group was compared to that for the experimental group to determine if a statistically significant difference existed between the two groups. The same was done for S2. The median changes in F_0 within S1 and within S2 for individual speakers with dysarthria were also compared to that of the control group as a whole to determine if a statistically significant difference existed between any of the individual speakers and the control group. As was done before, the median changes in F_0 across words for individual control group speakers were additionally calculated, to determine if individual control speakers differed from the typical speakers as a group. Such comparisons would reveal the significance of the results of the individual speakers with dysarthria who differed from the control group.

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Data processing to achieve the second main aim of the study consisted of the following calculations:

- *Comparing the change in F_0 across words for three- and six-/ seven-syllable utterances, both within groups and for individual speakers:* The median change in F_0 across words, from the highest F_0 of S1 to the lowest F_0 of S2, within three-syllable utterances as produced by the control group, experimental group, and individual speakers were obtained, as well as the median change in F_0 across words within six-/ seven-syllable utterances. The median change in F_0 across words within three-syllable utterances was then compared to the median change in F_0 across words within six-/ seven-syllable utterances to determine any statistically significant differences between the change in F_0 across words in short and longer utterances for the control group, experimental group, and individual speakers.
- *Comparing the change in F_0 across words in three-syllable (short) and six-/ seven-syllable (long) utterances between the two speaker groups:* Firstly, the median change in F_0 across words in long utterances was subtracted from the median change in F_0 across words in short utterances for the control group. This was obtained as an indication of the difference in F_0 changes across words in short compared to longer utterances. Then the median change in F_0 across words in long utterances was subtracted from the median change in F_0 across words in short utterances for the experimental group. These values were compared to each other to determine if the experimental group differed significantly from the typical speakers with regard to the extent of change in F_0 in short compared to long utterances.

8.3 Number of words processed for results

Forty words were produced by each participant for data analysis and processing (20 words within short utterances and 20 words within long utterances). Out of these 40 words, some words occurred where participants showed devoicing of S1 or S2. Devoicing implies that no voice was produced on the syllable and thus no F_0 value could be obtained. Both typical speakers and speakers with dysarthria devoiced S2 in certain words. Some speakers with dysarthria also devoiced S1 in certain words.

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Devoiced syllables were not included in the processing of results. See Appendix J for a full list of devoiced syllables.

To obtain the F_0 values for the words and syllables in the study, the total number of utterances used for data processing was calculated as *the total number of utterances produced by each participant, multiplied by the number of participants in the group under investigation, minus the number of devoiced words/ syllables in the target condition.* For example, if one were investigating the mean F_0 for S1 within the group of speakers with dysarthria, a total of 152 syllables would be analysed. This was derived from 40 words produced, multiplied by 4 participants with dysarthria (to equal 160), minus 8 devoiced first syllables (equals 152).

9. Validity and reliability

The term *validity* indicates the degree to which research tools measure what they are purported to measure (Leedy & Ormrod, 2013:91). Several steps were taken to ensure validity of the test stimuli, data collection, and data analysis procedures.

Firstly, a pilot study was implemented to determine whether the words included in the target word list were accurate and commonly used in Sepedi. In addition to the 10 participants who assisted with the initial pilot study, a Sepedi linguist with D.Phil. in Sepedi was asked to review the words. She agreed with findings from the pilot study. A final list of 20 CVCV words was developed for use in the main study. The Sepedi linguist also assisted with the selection of short and long utterances in which to include target words, as well as generating Sepedi sentences to clarify the meaning of the words for participants.

A second pilot study was conducted with six participants to determine whether the picture cards depicting the target words and utterances were easily interpretable and whether they clearly portrayed target words. This pilot study also aimed to determine whether data collection procedures such as the instructions given to participants and the presentation of picture cards were clear. It was concluded that the picture cards were clear and easily interpretable. Instructions were slightly adapted based upon the pilot study participants' recommendations to eliminate confusion caused by the difference between the gender of people appearing in the pictures and utterances printed on the picture cards.

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Thirdly, the researcher used both the *Praat* and the *CSL* to compute pitch contours of the syllable nuclei for the words produced by participant C1. The pitch contours computed by both programmes followed the same pattern and similar F_0 values were generated by the *Praat* and the *CSL.*

Face validity indicates whether, on the surface, research tools appear to be measuring a particular characteristic (Leedy & Ormrod, 2013:91). The pilot studies and the comparison of the *Praat* and *CSL* demonstrated face validity of the test stimuli, data collection, and acoustic analysis procedures. *Content validity* indicates whether a research tool measures a representative sample of the area being investigated (Leedy & Ormord, 2013:91-92). Content validity was ensured through the use of L1 Sepedi speakers as research participants. All participants in the experimental group were required to have confirmed diagnoses of dysarthria by three SLPs, as well as a diagnosis of a neurological lesion by a medical practitioner. Participants were therefore representative of the disorder that the researcher investigated.

The term *reliability* indicates the consistency with which a research tool produces a reliable result (Leedy & Ormrod, 2013:93). Measurements of F_0 were conducted electronically and relatively automatically by means of the *Praat.* This increased reliability of the measurements obtained. Inter-rater reliability of the acoustic analysis process was established by having another investigator who met participation criteria (see 4.2.7 in this chapter) re-measure the maximum F_0, minimum $F_{0,}$ and mean F_0 for both syllables of 20% of the words initially measured. Point-to-point agreement between the results of the initial analysis and the re-analysis was determined for the F_0 values under investigation. If the F_0 values obtained by the second investigator were within 6 Hz of those obtained by the first investigator, the F_0 values were considered correct. For the maximum F_0 values, reliability was 96%. For the minimum F_0 values, reliability was 90% and for the mean F_0 values, reliability was 90%. The high agreement levels between the results confirm the reliability of the data analysis methods.

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Chapter 3

Results and Discussion

1. Introduction

In this chapter, the results of the study are presented in accordance with the research aims and sub-aims. The first main aim of the study was to determine whether a difference exists between typical Sepedi speakers and Sepedi speakers with dysarthria, in their ability to vary F_0 in CVCV words. After the results of the first main aim have been presented, they will be discussed.

The second main aim of the study was to determine if there is a significant difference in F_0 variation in three-syllable utterances compared to six-/seven-syllable utterances as spoken by typical Sepedi speakers and Sepedi speakers with dysarthria, and to determine whether a difference exists between the two speaker groups in this regard. Presentation of the results of the second main aim will be followed by a discussion.

Forty words were produced by each participant for data analysis and processing (20 words in the context of short utterances and 20 words in the context of long utterances). Where devoicing of syllables occurred, these syllables were not included in data processing. All of the data for the control and experimental *groups,* as well as for the *individual* control and experimental participants, were skewed. Consequently, non-parametric Wilcoxon rank tests were used for statistical analyses. Both median values and associated inter-quartile ranges were obtained for the data but only median F_0 values were used to achieve the research aims.

2. Results: A comparison of tone variation in typical speakers and speakers with dysarthria

In the presentation of results and the ensuing discussion the term “dysarthria group” will, for ease of reference, be used to refer to the group of speakers with dysarthria.

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2.1 Difference in mean F_0 between syllable 1 (S1) and syllable 2 (S2)

The difference in mean F_0 between S1 and S2 was investigated within individuals as an indication of the change in pitch across the target words produced by all participants. The purpose was to determine whether the words produced by the individual typical speakers and speakers with dysarthria had a significantly higher F_0 on S1 than S2, as is suggested by the HL tone pattern ascribed to them. Medians were obtained for all of the mean F_0 values of S1 and S2 and were then compared in order to achieve the research aims. (Raw data can be found in Appendix I). No group comparisons were made, as the mean F_0 values of the syllables would be influenced by the voice pitch of male and female speakers within the groups.

2.1.1 Difference in mean F_0 between S1 and S2 within individual control participants

The median F_0 values of S1 and S2 for the individual control participants are displayed in Table 12. The statistical significance of the differences between the F_0 values is also indicated. The p-values displayed in bold are statistically significant. All of the typical speakers produced the target words with a higher tone on S1 than on S2. Participants C2 to C5 produced S1 with a *significantly higher* median F_0 than S2 (all participants obtained p-values <0.001). Participant C1 was the only typical speaker who did not produce S1 with a significantly higher median F_0 than S2 (p=0.575). Participant C1 was the youngest typical speaker who participated in the study. She obtained a 100% intelligibility score on the *STSI,* as did all of the other typical speakers.

Table 12: Median F_0 values of S1 and S2 for the individual control participants (n=5), as well as the p-values obtained when comparing the F_0 values of S1 and S2 within individual participants

Participants	Median F_0 of S1 (Hz)	IQR* (Hz)	Median F_0 of S2 (Hz)	IQR* (Hz)	P-values** *(Obtained using the Wilcoxon signed rank test)*
C1	194.41	17.98	192.31	36.97	0.58
C2	180.55	41.85	149.34	15.16	**<0.001**
C3	181.45	18.49	149.35	9.02	**<0.001**
C4	124.44	22.20	94.95	8.38	**<0.001**
C5	217.42	30.48	167.71	20.47	**<0.001**

**IQRs provide an indication of the spread of the data. Not used to achieve research aims.*

*** P-values obtained when the median F_0 values of S1 and S2 of words were compared to each other within each speaker. A p ≤ 0.05 was deemed statistically significant in all tests.*

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The data that are displayed in Table 12 are also presented visually in Figure 2, as it allows for easier comparison of the F_0 values within individual control participants.

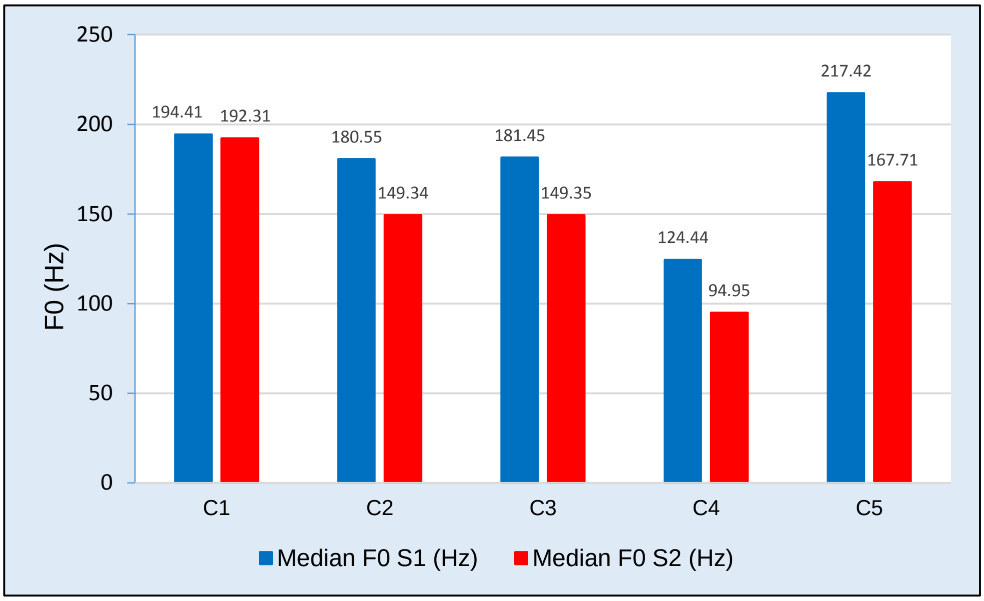

Figure 2: A comparison of the median F_0 of S1 and S2 within the individual control participants (n=5)

2.1.2 Difference in mean F_0 between S1 and S2 within individual speakers with dysarthria

The median F_0 values of S1 and S2 for the individual participants with dysarthria are displayed in Table 13. The statistical significance of the differences between the F_0 values is also indicated. The p-values displayed in bold are statistically significant. All of the speakers with dysarthria produced the target words with a higher tone on S1 than S2. Three out of the four participants with dysarthria produced S1 with a *significantly higher* median F_0 than S2. This includes P1 ($p=0.05$), P2 ($p<0.001$) and P3 ($p<0.001$). Participant P4 was the only participant with dysarthria who did not produce S1 with a significantly higher median F_0 than S2 ($p=0.83$). P4 was the oldest male speaker with dysarthria in the study. He achieved an intelligibility score of 63% on the *STSI*. This was the second lowest intelligibility score achieved by a speaker with dysarthria in the study, the lowest score being 48% as achieved by participant P3.

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Table 13: Median F_0 values of S1 and S2 for the individual participants with dysarthria (n=4), as well as the p-values obtained when comparing the F_0 values of S1 and S2 within individual participants

Participants	Median F_0 of S1 (Hz)	IQR* (Hz)	Median F_0 of S2 (Hz)	IQR* (Hz)	P-values** *(Obtained using the Wilcoxon signed rank test)*
P1	154.00	31.38	131.41	21.53	**0.05**
P2	137.96	7.72	122.82	9.31	**< 0.001**
P3	221.69	13.57	204.09	11.05	**< 0.001**
P4	107.73	13.25	85.42	145.19	0.83

**IQRs provide an indication of the spread of the data. Not used to achieve research aims.*

*** P-values obtained when median F_0 values of S1 and S2 of words were compared to each other within each speaker. A $p \leq 0.05$ was deemed statistically significant in all tests.*

The data that are displayed in Table 13 are also presented visually in Figure 3, as it allows for easier comparison of the F_0 values within individual speakers with dysarthria.

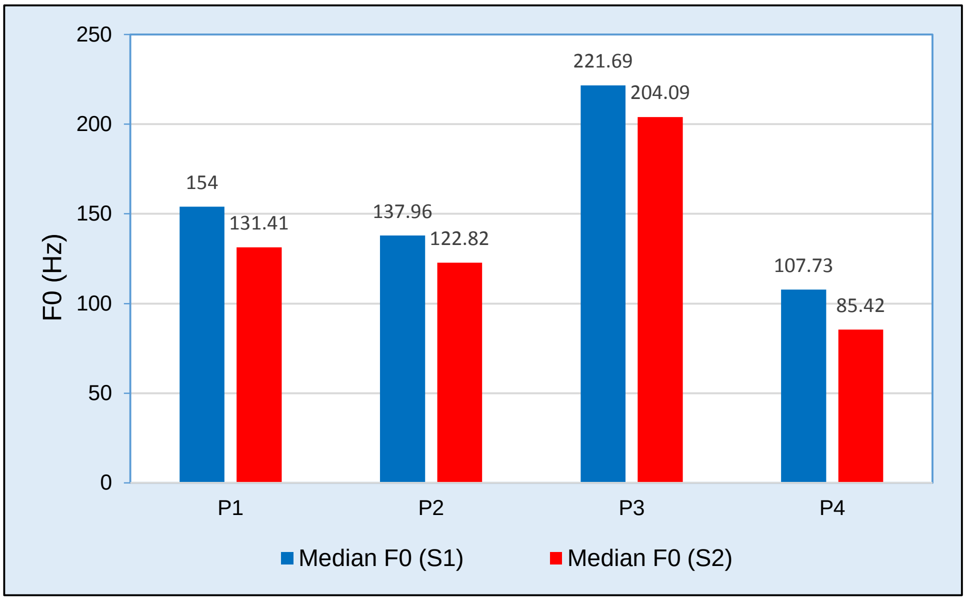

Figure 3: A comparison of the median F_0 of S1 and S2 within the individual speakers with dysarthria (n=4)

2.2 Change in F_0 across the words from the highest F_0 point of S1 to the lowest F_0 point of S2

On the spectrograms generated by *Praat* for each word, a highest pitch point could be identified in S1 and a lowest pitch point could be identified in S2. This provided an

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indication of the change in F_0 across the words and the amount (extent) of change was calculated as the maximum F_0 of S1 minus the minimum F_0 of S2 for each word. Median changes in F_0 across words were obtained for speaker groups and individual participants. (Raw data can be found in Appendix I).

2.2.1 Change in F_0 across words: Comparison of the control and dysarthria groups

Table 14 displays the median changes in F_0 across the words, from the highest F_0 point of S1 to the lowest F_0 point of S2, for the control and dysarthria groups. The statistical significance of the difference between the F_0 changes of the two groups is also indicated. The control group showed a median change in F_0 of 53.22 Hz across the words. The dysarthria group showed a median change in F_0 of 47.96 Hz across the words. The control group produced a median change in F_0 that was 5.26 Hz larger than that of the dysarthria group; no significant difference was found between the two groups ($p=0.17$) with regard to the extent of change.

Table 14: Median changes in F_0 across the words for the control and dysarthria groups, as well as the p-value obtained when comparing these F_0 changes between the speaker groups

Participants	Median change in F_0 across words (Hz)	IQR* (Hz)	P-value** *(Obtained using the Wilcoxon rank sum test)*
Control group (n=5)	53.22	44.78	0.17
Dysarthria group (n=4)	47.96	32.00	

**IQRs provided an indication of the spread of the data. Not used to achieve research aims.*

*** P-values obtained when median changes in F_0 across words for the control and dysarthria groups were compared. A $p \leq 0.05$ was deemed statistically significant in all tests.*

The data that are displayed in Table 14 are presented visually in the box plots in Figure 4, to enhance interpretation of group comparisons. The median change in F_0 across words for each of the groups is indicated by the dark blue lines within the boxes. Inspection of these lines reveals that the median change in F_0 for the control group is slightly greater than that for the dysarthria group. The sizes of the groups' IQRs are indicated by the blue boxes. Although only median F_0 values were used to answer the research questions of the current study, it is noteworthy that the control group showed greater variability than the dysarthria group in how far from the median the data points were distributed (as indicated through a greater IQR). The control group had an IQR

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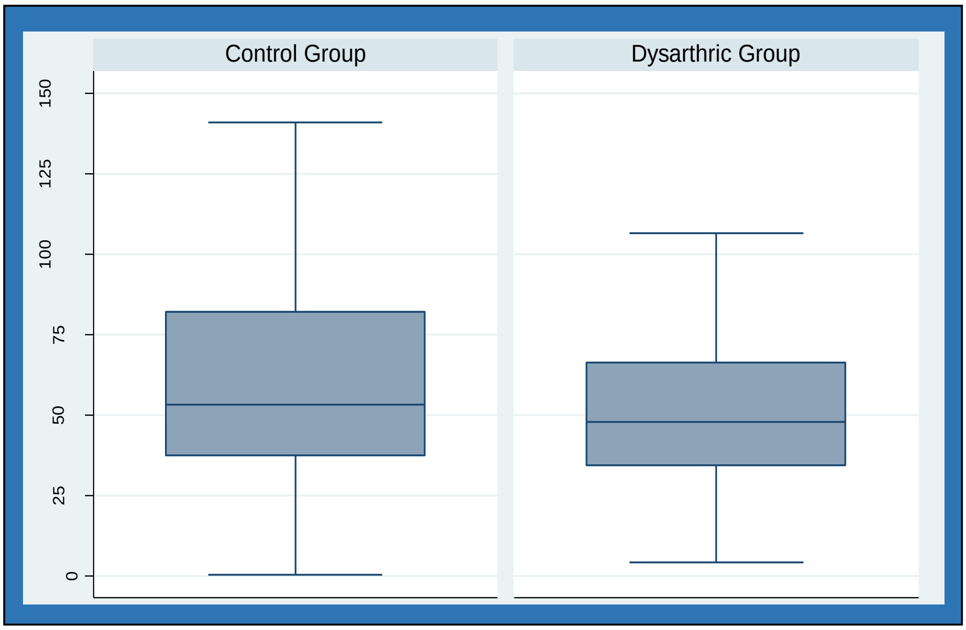
of 44.78 Hz and the dysarthria group had an IQR of 32.00 Hz. The lines or "whiskers" extending from the boxes in Figure 4 indicate the minimum and maximum values that were obtained for the groups' changes in F_0 across words.



**For visual clarity, the extreme outlying maximum F_0 values for both groups are not included in the figure. The outlying maximum change in F_0 across words was 411.51 Hz for the control group and 444.81 Hz for the dysarthria group.*

Figure 4: A comparison of the median changes in F_0 across words between the control group (n=5) and the dysarthria group (n=4)

2.2.2 Change in F_0 across words: Comparison of the individual control speakers to the control group

The change in F_0 across words was first compared between the individual control speakers and the control group as a whole, before individual speakers with dysarthria could be compared to the control group. Such comparisons would reveal the significance of the results of the individual speakers with dysarthria. Table 15 displays the median changes in F_0 across words for the individual control speakers, as well as the median change in F_0 across words and the IQR obtained across the 40 words produced by the control group as a whole. If the *individual* control speakers' median values fell *within 50%* of the *group's* measurements (in other words, if it fell within the group's IQR) (Leedy & Ormrod, 2014:299), then it could be said that the individuals' median values did not differ significantly from the median value for the control group. As indicated in Table 15, two out of the five participants differed significantly from the

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control group in terms of the median change in F_0 across words. C1's median change in F_0 (34.90 Hz) was *significantly smaller* than that of the control group as a whole (53.22 Hz) and C5's median change in F_0 (103.89 Hz) was *significantly greater* than that of the control group. These significantly different F_0 changes are indicated in bold in Table 15.

Table 15: Median changes in F_0 across words for the individual control speakers (n=5), as well as the control group's median change in F_0 across words and the control group's IQR

Participant	Individual median change in F0 across words (Hz)	Median change in F0 across words for the control group (Hz)	Group IQR *(Range of the middle 50% of the control group data: Minimum and maximum values indicated)*
C1	34.90*	53.22	37.31-82.08
C2	58.13		
C3	52.44		
C4	44.81		
C5	103.89*		

The individual F_0 changes indicated in bold fall **outside the group's IQR and therefore differ significantly from the control group's median change in F_0 across words*

2.2.3 Change in F_0 across words: Comparison of the individual speakers with dysarthria to the control group

Table 16 displays the median changes in F_0 across the words from the highest F_0 point of S1 to the lowest F_0 point of S2 for the individual speakers with dysarthria. Table 16 also presents the statistical significance of the difference between these changes in F_0 compared to the control group. The p-values indicated in bold are statistically significant. P1 (78% intelligibility score obtained on the *STSI),* produced a median change in F_0 of 66.36 Hz across the words. This value was *significantly greater* than the median change in F_0 for the control group, who produced a change in F_0 of 53.22 Hz across the words (p=0.02). P2, (74% in the *STSI),* produced a median change in F_0 of 31.12 Hz across the words. This value was *significantly smaller* than the median change in F_0 produced by the control participants (p=0.001). No significant differences were observed in the F_0 across words for participants P3 (48% in the *STSI*) and P4 (63% in the *STSI)* compared to the control group. P3 obtained a p-value of 0.75 and P4 obtained a p-value of 0.24.

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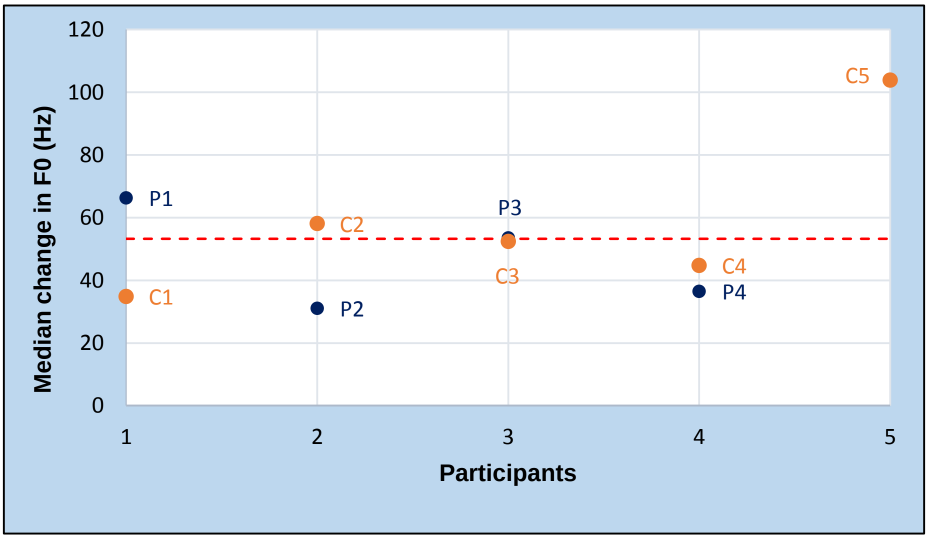
Table 16: Median changes in F_0 across the words for the individual speakers with dysarthria, as well as the p-values obtained when comparing these F_0 changes to the control group

Participants	Median change in F_0 across words (Hz)	IQR* (Hz)	P-values** *(Obtained using the Wilcoxon rank sum test)*
P1	66.36	43.55	**0.02**
P2	31.12	20.47	**0.001**
P3	53.61	16.91	0.75
P4	36.46	80.70	0.24

**IQRs provided an indication of the spread of the data. Not used to achieve research aims.*

*** P-values obtained when median changes in F_0 across words for the individual participants with dysarthria were compared to the control group. A $p \leq 0.05$ was deemed statistically significant in all tests.*

Figure 5 displays the median change in F_0 across words for the individual control participants and participants with dysarthria, compared to the median change in F_0 for the control group (53.22 Hz). Figure 5 displays similar data to that of Tables 15 and 16 but is included in this section as it visually summarises individual findings for the control participants and participants with dysarthria, thereby facilitating comparison between the speakers. The change in F_0 across words for two of the control participants, C1 and C5, differed significantly from that of the control group, as did the changes in F_0 for P1 and P2, who are two participants with dysarthria. As indicated in Figure 5, the change in F_0 across words for the other control speakers (C2, C3 and C4) and speakers with dysarthria (P3 and P4) was similar to that of the control group.



**The broken orange line across the scatter plot shows the median change in F_0 across the words produced by the control group (53.22 Hz)*

Figure 5: Median changes in F_0 across words: Individual control participants (n=5) and participants with dysarthria (n=4) compared to the control group

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2.3 Change in F_0 within S1

The change in F_0 within S1 was calculated as the difference between the maximum and minimum F_0 values of S1 for each word. Median changes in F_0 within S1 were obtained for speaker groups and individual participants. (Raw data can be found in Appendix I).

2.3.1 Change in F_0 within S1: Comparison of the control and dysarthria groups

Table 17 displays the median changes in F_0 within S1 for the control and dysarthria groups. The statistical significance of the difference between the F_0 changes of the two groups is also indicated. The control group produced a median change in F_0 of 31.59 Hz within S1. The dysarthria group produced a median change in F_0 of 27.15 Hz within S1. The difference in the change in F_0 between the two groups was thus 4.44 Hz. This difference was not significant ($p=0.07$).

Table 17: Median changes in F_0 within S1 for the control and dysarthria groups, as well as the p-value obtained when comparing these F_0 changes between the speaker groups

Participants	Median change in F_0 within S1 (Hz)	IQR* (Hz)	P-values** *(Obtained using the Wilcoxon rank sum test)*
Control group (n=5)	31.59	30.57	0.07
Dysarthria group (n=4)	27.15	24.50	

**IQRs provide an indication of the spread of the data. Not used to achieve research aims.*

*** P-values obtained when median changes in F_0 within S1 for the dysarthria group were compared to the control group. A $p \leq 0.05$ was deemed statistically significant in all tests.*

The data that are displayed in Table 17 are presented visually in the box plots in Figure 6, to enhance interpretation of the group comparisons. The median changes in F_0 for each of the groups are indicated by the dark blue lines within the boxes. Inspection of these lines reveals that the median change in F_0 within S1 for the control group is slightly greater than that for the dysarthria group. The sizes of the groups' IQRs are indicated by the blue boxes. Although only median F_0 values were used to answer the research questions, as with the change in F_0 across words, it is noteworthy that the control group showed greater variability than the dysarthria group in how far from the median the data points were distributed (as indicated through a greater IQR). The control group had an IQR of 30.57 Hz and the dysarthria group had an IQR of 24.50

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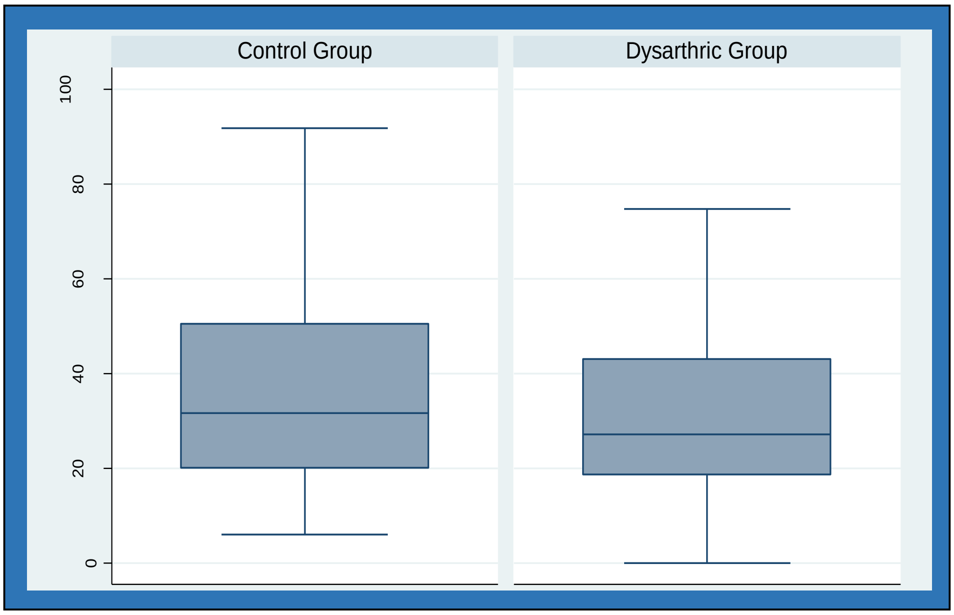
Hz. The lines or "whiskers" extending from the boxes in Figure 6 indicate the minimum and maximum values that were obtained for the groups' changes in F_0 within S1.



For visual clarity, extreme outlying maximum F_0 values for both groups were not included in the plots. The outlying maximum change in F_0 within S1 was 418.60 Hz for the control group and 447.30 Hz for the dysarthria group.

Figure 6: A comparison of the median changes in F_0 within S1 between the control group (n=5) and the dysarthria group (n=4)

2.3.2 Change in F_0 within S1: Comparison of the individual control speakers to the control group

As with the change in F_0 across words, the change in F_0 within S1 was first compared between the individual control speakers and the control group as a whole, before individual speakers with dysarthria could be compared to the control group. Such comparisons would reveal the significance of the results of the individual speakers with dysarthria. Table 18 displays the median changes in F_0 within S1 for the individual control speakers, as well as the median change in F_0 within S1 and the IQR obtained across the 40 words produced by the control group as a whole. If the *individual* control speakers' median values fell within the *group's* IQR, then it could be said that the individuals' median values did not differ significantly from that of the control group. As indicated in Table 18, three out of the five control participants differed significantly from the control group in terms of the median change in F_0 within S1. The significantly different F_0 changes are indicated in bold in Table 18. C1's median change in F_0 (20.00 Hz) was *significantly smaller* than that of the control group as a whole (31.59 Hz) and

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C5's median change in F_0 (75.90 Hz) was *significantly greater* than that of the control group. Both of these individual controls also differed significantly from the group as a whole in terms of the change in F_0 across words. C3 produced a *significantly smaller* change in F_0 within S1 (24.74 Hz) compared to the control group. She did not differ very much from the other speakers in terms of age or background history and her length of time spent speaking Sepedi during the day was similar to that for the other control participants.

Table 18: Median changes in F_0 within S1 for the individual control speakers (n=5), as well as the control group's median change in F_0 within S1 and the control group's IQR

Participant	Individual median change in F_0 within S1 (Hz)	Median change in F_0 within S1 for the control group (Hz)	Group IQR *(Range of the middle 50% of the control group data: Minimum and maximum values indicated)*
C1	**20.00***	31.59	29.98-50.55
C2	33.87		
C3	**24.74***		
C4	27.67		
C5	**75.90***		

The individual F_0 changes indicated in bold fall **outside the group's IQR and therefore differ significantly from the control group's median change in F_0 across words*

2.3.3 Change in F_0 within S1: Comparison of the individual speakers with dysarthria to the control group

Table 19 displays the median changes in F_0 within S1 for the individual participants with dysarthria compared to the control group and indicates the statistical significance of this comparison. The p-values displayed in bold are statistically significant. Three out of the four participants with dysarthria produced changes in F_0 that differed significantly from that of the control group. These were participants P1 (78% on *STSI*) and P2 (74% on STSI) and P4 (63%on STSI). P1 obtained a p-value of 0.001, P2 obtained a p-value < 0.001 and P4 obtained a p-value of 0.02. No statistically significant difference was found between P3's (48% on *STSI*) median change in F_0 and that of the control group (p=0.06). P1 and P3 showed *greater* median changes in F_0 than the control group, who produced a median change in F_0 of 31.59 Hz within S1. P2 and P4 produced *smaller* changes in F_0 than the control group.

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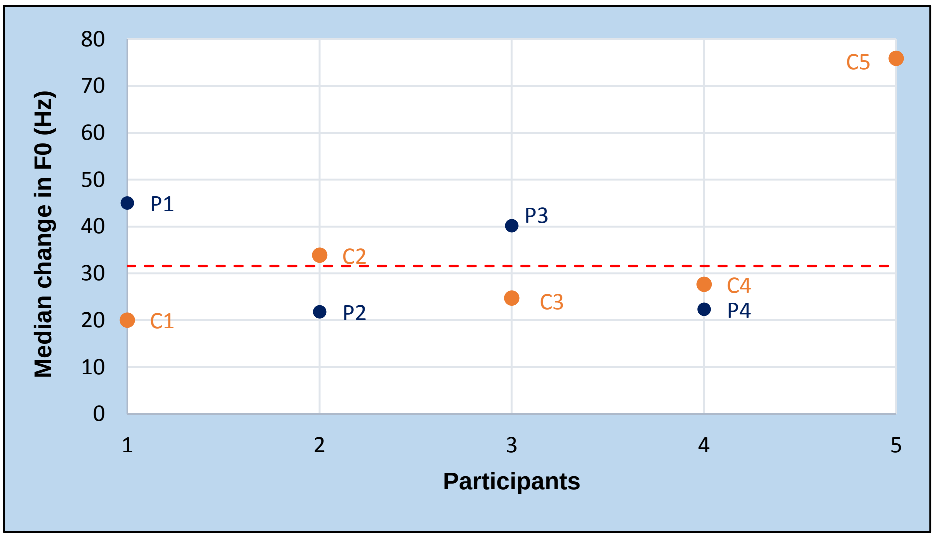
Table 19: Median changes in F_0 within S1 for the individual speakers with dysarthria, as well as the p-values obtained when comparing these F_0 changes to the control group

Participants	Median change in F_0 within S1 (Hz)	IQR* (Hz)	P-values** *(Obtained using the Wilcoxon rank sum test)*
P1	44.99	44.80	**0.001**
P2	21.79	13.88	**<0.001**
P3	40.19	17.85	0.06
P4	22.32	16.38	**0.02**

**IQRs provide an indication of the spread of the data. Not used to achieve research aims.*

*** P-values obtained when median changes in F_0 within S1 for the individual participants with dysarthria were compared to the control group. A $p \leq 0.05$ was deemed statistically significant in all tests.*

Figure 7 displays the median changes in F_0 within S1 for the individual control participants and participants with dysarthria, compared to the median change in F_0 of the control group (31.59 Hz). Figure 7 displays similar data to that of Tables 18 and 19 but is included in this section as it visually summarises individual findings for the individual control participants and participants with dysarthria. The changes in F_0 within S1 for the control participants C1, C3 and C5 differed significantly from that of the control group, as did the F_0 changes for P1, P2 and P4, who were participants with dysarthria. As indicated in Figure 7, the changes in F_0 within S1 for the other control speakers (C2 and C4) and one speaker with dysarthria (P3) did not differ significantly from that of the control group



*The broken orange line across the scatter plot shows the median change in F_0 across the words produced by the control group (31.59 Hz)

Figure 7: Median changes in F_0 within S1: Individual control participants (n=5) and participants with dysarthria (n=4) compared to the control group

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2.4 Change in F_0 within S2

The change in F_0 within S2 was calculated as the difference between the maximum and minimum F_0 values of S2 for each word. Median changes in F_0 within S2 were obtained for speaker groups and individual participants. (Raw data can be found in Appendix I).

2.4.1 Change in F_0 within S2: Comparison of the control and dysarthria groups

Table 20 displays the median changes in F_0 within S2 for the control and dysarthria groups. The statistical significance of the difference between the F_0 changes of the two groups is also indicated. The control group produced a median change in F_0 of 14.75 Hz within S2. The dysarthria group produced a median F_0 change of 21.53 Hz within S2. This was 6.78 Hz *greater* than that of the control group. A *statistically significant difference* was found between the control and dysarthria groups in this regard (p=0.04).

Table 20: Median changes in F_0 within S2 for the control and dysarthria groups, as well as the p-value obtained when comparing these F_0 changes between the speaker groups

Participants	Median changes in F_0 within S2 (Hz)	IQR* (Hz)	P-values** *(Obtained using the Wilcoxon rank sum test)*
Control group (n=5)	14.75	15.51	**0.04**
Dysarthria group (n=4)	21.53	31.55	

**IQRs provide an indication of the spread of the data. Not used to achieve research aims.*

*** P-values obtained when median changes in F_0 within S2 for the dysarthria group were compared to the control group. A $p \leq 0.05$ was deemed statistically significant in all tests.*

The data that are displayed in Table 20 are presented visually in the box plots in Figure 8, to enhance interpretation of the group comparisons. The median changes in F_0 for each of the groups are indicated by the dark blue lines within the boxes. These lines show that the dysarthria group had a greater median change in F_0 within S2 than the control group. The sizes of the groups' IQRs are indicated by the blue boxes. Although only median F_0 values were used to answer the research questions, it is noteworthy that the dysarthria group showed greater variability than the control group in how far from the median the data points were distributed (as indicated through a greater IQR). The dysarthria group had an IQR of 31.55 Hz and the control group had a smaller IQR

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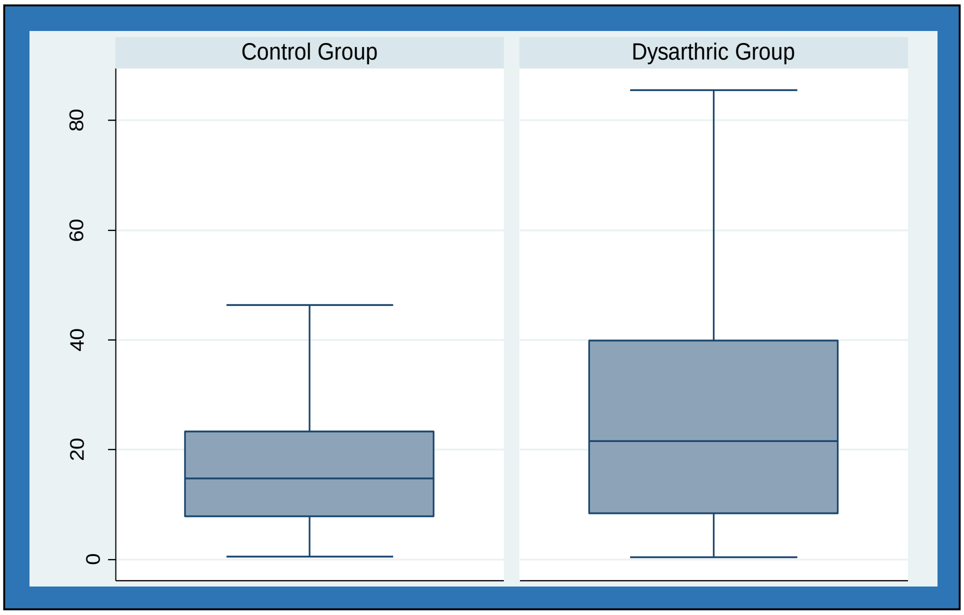
of 15.51 Hz. This is in contrast to the change in F_0 across words and the change in F_0 within S1, where the control group showed greater variability than the dysarthria group. The "whiskers" of the plots indicate the maximum and minimum changes in F_0 within S2.



For visual clarity, the extreme outlying maximum F_0 values which occurred for both groups were not included in the plots. The outlying maximum change in F_0 within S2 was 412.54 Hz for the control group and 436.79 Hz for the dysarthria group.

Figure 8: A comparison of the median changes in F_0 within S2 between the control group (n=5) and the dysarthria group (n=4)

2.4.2 Change in F_0 within S2: Comparison of the individual control speakers to the control group

The change in F_0 within S2 was first compared between the individual control speakers and the control group as a whole, before individual speakers with dysarthria could be compared to the control group. Table 21 displays the median changes in F_0 within S2 for the individual control speakers, as well as the median change in F_0 within S2 and the IQR obtained across the 40 words produced by the control group as a whole. If the *individual* control speakers' median values fell within the *group's* IQR, then it could be said that the individuals' median values did not differ significantly to that of the control group. As indicated in Table 21, none of the individual control participants differed significantly from the control group as a whole. Although participant C4's median change in F_0 within S2 (7.21 Hz) fell outside the control group's IQR, it only

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differed from the IQR by 0.60 Hz and is therefore not significantly different from the control group's median change in F_0.

Table 21: Median changes in F_0 within S2 for the individual control speakers (n=5), as well as the control group's median change in F_0 within S2 and the control group's IQR

Participant	Individual median change in F_0 within S2 (Hz)	Median change in F_0 within S1 for the control group (Hz)	Group IQR *(Range of the middle 50% of the control group data: Minimum and maximum values indicated)*
C1	19.70	14.75	7.81-23.32
C2	16.18		
C3	13.38		
C4	7.21*		
C5	19.83		

**This change in F_0 (7.21 Hz) remains fairly close to the control group's IQR and is therefore not significantly different to the control group*

2.4.3 Change in F_0 within S2: Comparison of the individual speakers with dysarthria to the control group

Table 22 displays the median changes in F_0 within S2 for the individual speakers with dysarthria compared to the control group and indicates the statistical significance of this comparison. The p-values displayed in bold are statistically significant. All four participants with dysarthria showed statistically significant differences in the change in F_0 within S2 compared to the control group. P1 (78% on *STSI*) produced a median change in F_0 of 23.11 Hz, which was *significantly greater* than that of the control group ($p=0.02$) and P3 (48% on *STSI*) produced a median change in F_0 of 40.19 Hz, which was also *significantly greater* than that of the control group ($p<0.001$). P2 (74% on *STSI*) produced a median change in F_0 of 8.33 Hz ($p<0.001$), which was *significantly smaller* than that of the control group ($p<0.001$) and P4 (63% on *STSI*) produced a median change in F_0 of 6.80 Hz ($p=0.01$), which was also *significantly smaller* than that of the control group.

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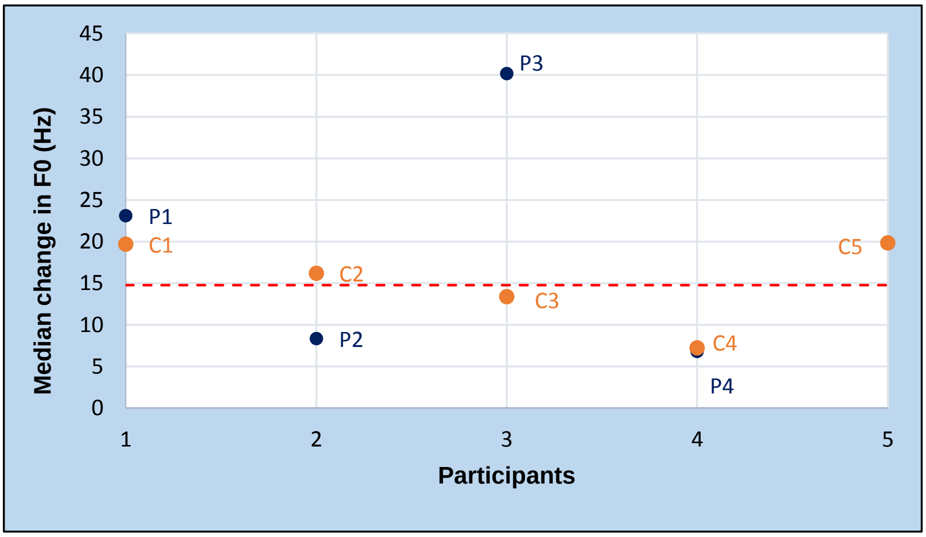
Table 22: Median changes in F_0 within S2 for the individual speakers with dysarthria, as well as the p-values obtained when comparing these F_0 changes to the control group

Participants	Median changes in F_0 within S2 (Hz)	IQR* (Hz)	P-values** *(Obtained using the Wilcoxon rank sum test)*
P1	23.11	14.34	**0.02**
P2	8.33	7.03	**<0.001**
P3	40.19	17.85	**<0.001**
P4	6.80	14	**0.01**

**IQRs provide an indication of the spread of the data. Not used to achieve research aims.*

*** P-values obtained when median changes in F_0 within S2 for the individual participants with dysarthria were compared to the control group. A $p \leq 0.05$ was deemed statistically significant in all tests.*

Figure 9 displays similar data to that of Tables 21 and 22 but is included in this section as it visually summarises individual findings for the individual control participants as well as the participants with dysarthria, and may assist in the interpretation of results. All of the speakers with dysarthria differed significantly from the control group in terms of the median changes in F_0 within S2. Although C4 differed slightly more from the control group than the other individual controls, all of the control speakers were similar to the control group in terms of their median changes in F_0 within S2.



**The broken orange line across the scatter plot shows the median change in F_0 across the words produced by the control group (14.75 Hz)*

Figure 9: Median changes in F_0 within S2: Individual control participants (n=5) and participants with dysarthria (n=4) compared to the control group

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2.5 Summarised comparison of all acoustic measures between the groups and individual speakers

Three aspects of tone variation were measured acoustically to achieve the first main aim of the study: (1) The difference in mean F_0 between S1 and S2 of the words for individual control speakers and speakers with dysarthria (2) The change in F_0 across each word, from the highest F_0 point in S1 to the lowest F_0 point in S2 within control and dysarthria groups and for individual speakers (3) The change in F_0 within S1 and S2 within control and dysarthria groups and for individual speakers. A summarised comparison of these acoustic measures is presented in 2.5.1 to 2.5.3.

2.5.1 Comparison of all acoustic measures between groups

Figure 10 visually displays the median changes in F_0 across words (blue bars in the graph), median changes in F_0 within S1 (red bars), and median changes in F_0 within S2 (green bars) for the control and dysarthria groups. As indicated in Figure 10, the control group produced *slightly greater* median F_0 changes across the words *and* within S1 than the dysarthria group. The differences between the speaker groups in this regard were *insignificant,* however*;* a p-value of 0.17 was obtained when comparing the change in F_0 across words between the groups and a p-value of 0.07 was obtained when comparing the change in F_0 within S1 between the groups. As indicated by the green bars in Figure 10, the control group produced a *significantly* smaller median change in F_0 within S2 than the dysarthria group (p=0.04).

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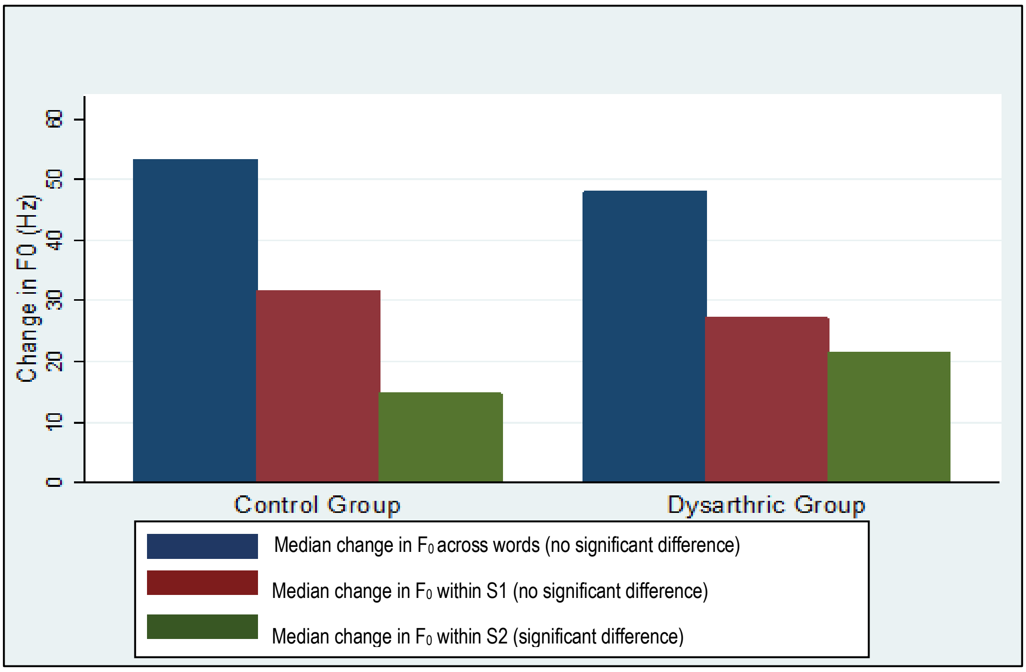

Figure 10: Median changes in F_0 across words, within S1 and within S2 in the control group (n=5) compared to the dysarthria group (n=4)

2.5.2 Comparison of all acoustic measures between individual control speakers and the control group

All of the control speakers produced the target words with a higher F_0 on S1 than S2. Participants C2 to C5 produced S1 with a *significantly* higher median F_0 than S2 (all participants obtained p-values <0.001). Participant C1 was the only typical speaker who did not produce S1 with a significantly higher median F_0 than S2 (p=0.575). F_0 changes were first compared between the individual control speakers and the control group as a whole, before individual speakers with dysarthria could be compared to the control group.

Table 23 compares the change in F_0 across words, as well as the changes in F_0 within S1 and S2 between the individual control speakers and the control group. For both the change in F_0 across words and the change in F_0 within S1, participant C1 produced *significantly smaller* F_0 changes than the control group as a whole and participant C5 produced *significantly greater* F_0 changes than the control group as a whole. In terms of the change in F_0 within S1, C3 also produced a *significantly smaller* change in F_0 than the control group. Participants C2 and C4 produced all F_0 changes *similarly* to

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the control group as a whole. The control speakers' F_0 changes within S2 did not differ significantly from each other.

Table 23: Median changes in F_0 across words, within S1 and within S2: Relative size of the median changes in F_0 produced by the individual control speakers compared to the control group

Acoustic measures	C1	C2	C3	C4	C5
Change in F_0 across words	**Significantly smaller** median change in F_0 than the control group	**Similar** median change in F_0 to control group	**Similar** median change in F_0 to control group	**Similar** median change in F_0 to control group	**Significantly greater** median change in F_0 to the control group
Change in F_0 within S1	**Significantly smaller** median change in F_0 than the control group	**Similar** median change in F_0 to control group	**Significantly smaller** median change in F_0 than the control group	**Similar** median change in F_0 to control group	**Significantly greater** median change in F_0 than the control group
Change in F_0 within S2	**Similar** median change in F_0 to control group	**Similar** median change in F_0 to control group	**Similar** median change in F_0 to control group	**Fairly similar** median change in F_0 to control group	**Similar** median change in F_0 to control group

2.5.3 Comparison of all acoustic measures between individual speakers with dysarthria and the control group

All of the speakers with dysarthria produced the target words with a higher F_0 on S1 than S2. Three out of the four participants with dysarthria produced S1 with a *significantly higher* median F_0 than S2. This includes P1 ($p=0.05$), P2 ($p<0.001$), and P3 ($p<0.001$). Participant P4 was the only participant with dysarthria who did not produce S1 with a significantly higher median F_0 than S2 ($p=0.83$).

Table 24 compares the median changes in F_0 across words, median changes in F_0 within S1, and median changes in F_0 within S2 for the individual speakers with dysarthria and the control group. For all of these acoustic measures, Participants P1 and P3 showed *greater* changes in median F_0 than the control group. Participants P2 and P4 showed *smaller* changes in median F_0 than the control group. Table 24

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displays the significance of these differences between individual speakers with dysarthria and the control group.

Table 24: Median changes in F_0 across words, within S1 and within S2: Relative size of the median changes in F_0 produced by the individuals with dysarthria compared to the control group

Aspect of tone variation	P1	P2	P3	P4
Change in F_0 across words	**Significantly greater** median change in F_0 than control group (p=0.02)	**Significantly smaller** median change in F_0 than control group (p=0.001)	**Greater** median change in F_0 than control group (but not significant) (p=0.75)	**Smaller** median change in F_0 than control group (but not significant) (p=0.24)
Change in F_0 within S1	**Significantly greater** median change in F_0 than control group (p=0.001)	**Significantly smaller** median change in F_0 than control group (p<0.001)	**Greater** median change in F_0 than control group (but not significant) (p=0.06)	**Significantly smaller** median change in F_0 than control group (p=0.02)
Change in F_0 within S2	**Significantly greater** median change in F_0 than control group (p=0.02)	**Significantly smaller** median change in F_0 than control group (p<0.001)	**Significantly greater** median change in F_0 than control group (p<0.001)	**Significantly smaller** median change in F_0 than control group (p=0.01)

3. Discussion: A comparison of tone variation in typical speakers and speakers with dysarthria

The tone variation produced by typical speakers and by speakers with dysarthria was contrasted by means of three different comparisons. Firstly, acoustic measures were compared between control and dysarthria groups. Secondly, measures were compared between individual control speakers and the control group and thirdly, measures were compared between individual speakers with dysarthria and the control group. The acoustic measures were calculated across 40 target words within short and long utterances and included the mean F_0 values of S1 and S2, the change in F_0 across words, and the changes in F_0 within S1 and S2 of the words. Group and individual comparisons of the acoustic measures will be discussed separately.

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3.1 Comparisons of all acoustic measures across groups

The change in F_0 across words, as well as the changes in F_0 within S1 and S2, were compared between the control and dysarthria groups to contrast their tone variation ability. No group comparisons were made of the mean F_0 values of the syllables; this would be influenced by the voice pitch of male and female speakers within the groups.

3.1.1 Change in F_0 across words

On the spectrograms generated by *Praat* for all of the words produced by the participants, a highest F_0 point could be identified in S1 and a lowest F_0 point could be identified in S2. The difference between these maximum and minimum F_0 points was calculated to obtain an indication of the change in F_0 across the target words. As displayed in Figure 4, the control group produced a median change in F_0 that was only slightly greater than that of the dysarthria group. The difference between the groups' change in F_0 across words was found to be *statistically insignificant,* which suggests that the dysarthria group did not present with significantly impaired tone variation across the target words. Patel and Campellone (2009) similarly found that speakers with dysarthria retain the ability to mark changes in F_0 across the context of an entire word.

3.1.2 Change in F_0 within S1

The change in F_0 within S1 was calculated as the difference between the maximum and minimum F_0 values of S1 for each word. Within the target words, S1 was allocated a high tone. To achieve an increase in F_0 within S1, speakers would have to increase tension in the vocal folds by lengthening the folds (Ladefoged & Johnson, 2015:25). As displayed in Figure 6, the control group produced a slightly greater change in F_0 within S1 than the dysarthria group. However, the difference between the speaker groups' change in F_0 was *not statistically significant,* which suggests that the dysarthria group did not present with markedly reduced ability to lengthen and tense the vocal folds within the context of a single syllable.

The results reveal a tendency for the control group to produce *slightly greater* but *insignificant* F_0 changes than the dysarthria group across words and within S1 of the

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words, indicating that these aspects of tone variation may not be severely affected in dysarthria.

3.1.3 Change in F_0 within S2

The change in F_0 within S2 was calculated as the difference between the maximum and minimum F_0 values of S2 for each word. In contrast to the change in F_0 across words and the change in F_0 within S1, where the control group produced *insignificantly greater* changes in F_0 than the dysarthria group, the control group produced a *smaller* median change in F_0 within S2 than the dysarthria group and the difference between the two groups was *statistically significant,* as displayed in Figure 8*.*

Within the target words, S2 was allocated a low tone. To achieve a lowering of F_0 within S2, speakers would have to relax the vocal folds (Ladefoged & Johnson, 2015:25). A greater lowering of F_0 within S2 may reflect decreased control over the vocal apparatus. For accurate tone production, laryngeal control and timing are imperative (Jeng et al., 2006). Furthermore, F_0 changes depend on precise adjustments in the mass and tension of the vocal folds, as well as the volume of airflow through the glottis (Ng, 2001). The dysarthria group may have been unable to grade these adjustments suitably within the context of S2. The second syllable occurred at the end of the words in the final position of short and long utterances. The speakers with dysarthria may have presented with fatigue or decreased breath support at the end of the utterances, resulting in reduced accuracy of F_0 changes during the production of S2.

The results of the current study regarding the changes in F_0 within S1 and S2 imply that graded relaxation of the vocal folds was more compromised for the speakers with dysarthria than their ability to produce tension in the vocal folds.

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3.2 Comparisons of all acoustic measures within individual control speakers and between individual control speakers and the control group

The mean F_0 values of S1 and S2 were compared within individual control speakers. The change in F_0 across words, as well as the changes in F_0 within S1 and S2, were compared between the individual control speakers and the control group.

3.2.1 Difference in mean F_0 between S1 and S2 within individual control participants

By investigating the difference in mean F_0 between S1 and S2, it was determined whether the words produced by the individual typical speakers had a significantly higher F_0 on S1 than S2, as is suggested by the HL tone pattern ascribed to them. Medians were obtained for all of the mean F_0 values of S1 and S2 and were then compared in order to achieve the research aims. All of the typical speakers produced the target words with a higher tone on S1 than on S2, as displayed in Figure 2, and thus appropriately produced the target words with a HL tone pattern. Participant C1 was the only typical speaker who did *not* produce S1 with a *significantly higher* median F_0 than S2. Participant C1 was the youngest typical speaker who participated in the study but no other background factors distinguished her from the other control participants. C1 obtained a 100% intelligibility score on the *STSI,* as did all of the other typical speakers. The fact that variations exist in the magnitude of F_0 changes between typical speakers may suggest that normal differences occur in the production of tone variation in this population, even without the presence of speech impairments.

3.2.2 Change in F_0 across words, as well as changes in F_0 within S1 and S2 compared between the individual control speakers and the control group

The change in F_0 across words, as well as the changes in F_0 within S1 and S2, were first compared between the individual control speakers and the control group as a whole, before individual speakers with dysarthria could be compared to the control group. Such comparisons would reveal the significance of the results of the individual speakers with dysarthria. These acoustic measures will be discussed together in this section, as it assists in interpreting the results of the typical speakers.

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Findings of the individual control speakers' F_0 changes indicate that participants C1 and C5 differed significantly from the control group. C1's median change in F_0 across words and median change in F_0 within S1 were both *significantly smaller* than that of the control group as a whole. C5's median change in F_0 across words and median change in F_0 within S1 were both *significantly greater* than that of the control group as a whole. As discussed before, no factors in participant C1's background history differentiated her from the other typical speakers. Even though she was the youngest of the controls, her age was not significantly lower than that of the other speakers. In contrast to C1, a distinction can be made between C5 and the other control speakers. C5 had a Bachelor's degree in Speech-Language Pathology and Audiology and although she was never explicitly told that the purpose of the study was to compare HL tone variation between typical speakers and speakers with dysarthria, her education and significant amount of time speaking Sepedi every day (15 hours per day, which was more than that spoken by the other controls) may have increased her level of awareness of speech and phonetic features such as tone variation in words, resulting in greater F_0 changes in her speech. Similar to C1, participant C3 (who only differed significantly from the control group in terms of the change in F_0 within S1) did not differ very much from the other control speakers in terms of her age or background history. C3 spent similar lengths of time speaking Sepedi during the day as the other control participants. No significant differences were found between the individual control speakers and the control group as a whole, for the change in F_0 within S2.

The finding that only two out of the five control speakers *consistently* produced F_0 changes *similarly* to the control group as a whole indicates variability in tone variation amongst the typical speakers. When looking at the IQRs of the control group for the acoustic measures, the control group was found to have significant variability in how far from the median individual data points were distributed for the change in F_0 across words and the change in F_0 within S1 (as displayed in Figures 4 and 6 respectively). Less variability was found for the control group in terms of the change in F_0 within S2 (as seen in Figure 8). The variability of the F_0 changes for the control speakers indicates a possibility that tone variation is a phonetic feature in the speech of typical Sepedi speakers which varies from person to person, even if an individual's speech is typical and intelligible. Differences in the tone variation between individual speakers

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with dysarthria and the control group therefore cannot only be attributed to the presence of dysarthria; typical speaker differences also need to be considered.

3.3 Comparisons of all acoustic measures within individual speakers with dysarthria and between individual speakers with dysarthria and the control group

3.3.1 Difference in mean F_0 between S1 and S2 within individual speakers with dysarthria

All speakers with dysarthria were successfully able to produce S1 of the target words with a higher mean F_0 than S2, as was appropriate for their HL tone pattern. These results indicate that the speakers with dysarthria were able to differentiate between high and low tones in bisyllabic words. As in the case of the control speakers, only one speaker with dysarthria (participant P4) did *not* produce S1 with a *significantly higher* median F_0 than S2. P4 was the oldest male speaker with dysarthria in the study. He achieved an intelligibility score of 63% on the *STSI*. This was not the lowest intelligibility score achieved for the speakers with dysarthria; the lowest score was 48% as achieved by P3. The fact that there were speakers from both control and dysarthria groups who did not produce a significant difference in the relative F_0 values for the two syllables suggests that this phenomenon may be due to normal speaker differences also observed in the typical speakers, rather than being caused by factors such as P4's 40-year history of smoking. Although a positive association between laryngeal pathology and tobacco use has been proven in research, a generalised lowering of smokers' mean F_0 is usually found in this population, instead of a lowering of the mean F_0 of S1 relative to S2, as was observed for P4 (Gonzalez & Carpi, 2004).

Mixed results regarding tone variation in speakers with dysarthria have been reported in past literature. However, the current study's findings, which indicate that control speakers and speakers with dysarthria have similar abilities to contrast the mean F_0 values of the two syllables in bisyllabic words, confirm findings from a study on tone variation by Jeng and colleagues (2006). Through acoustic analysis, these authors

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found that Mandarin speakers with dysarthria due to cerebral palsy *retained* the ability to use patterns of mean F_0 to distinguish high and low tones.

3.3.2 Change in F_0 across words, as well as changes in F_0 within S1 and S2 compared between the individual speakers with dysarthria and the control group

Jeng and colleagues (2006) found that F_0 data is more variable for speakers with dysarthria than for control speakers. Significant differences were, however, also found in the F_0 changes of individual control speakers in the current study. If typical speakers vary in their abilities to produce F_0 changes it seems reasonable to expect that individual speakers with dysarthria will vary as well. For the current study, the change in F_0 across words, as well as the changes in F_0 within S1 and S2 for the individual speakers with dysarthria, will now be compared to the corresponding changes for the control group, bearing in mind that typical speaker differences in tone variation do exist.

Just as the individual control speakers displayed varying patterns of F_0 changes for tone variation, the individual speakers with dysarthria also displayed varying patterns of F_0 changes in the current study. The unique patterns of tone variation for individual speakers with dysarthria were especially evident for the change in F_0 across words and the change in F_0 within S1. Whereas the dysarthria group as a whole differed *insignificantly* from the control group with regard to the median changes in F_0 across words and within S1, Participant P1 (74% on *STSI*) presented with *significantly greater* median F_0 changes than the control group for these measures and participant P2 (78% on *STSI*) presented with *significantly smaller* median changes in F_0 for these measures. P4 (63% on *STSI*) presented with a *significantly smaller* median change in F_0 within S1 than the control group and P3 (63% on *STSI*) did not differ significantly from the control group for either of these measures.

All four participants with dysarthria showed statistically significant differences in their changes in F_0 within S2 compared to the control group. P1 (74% on *STSI*) and P3 (48% on *STSI*) both produced *significantly greater* median changes in F_0 within S2 than the control group. In contrast to this, P2 (78% on *STSI*) and P4 (63% on *STSI*) both produced *significantly smaller* median changes in F_0 within S2 than the control group. Although the graded relaxation of the vocal folds was compromised for all of

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the speakers with dysarthria, a consistent pattern of impairment was not observed in this population. Some speakers with dysarthria produced *exaggerated* changes in F_0 compared to the control group and some speakers with dysarthria produced *reduced* changes in F_0 compared to the control group. This again points to unique patterns of tone variation in individuals with dysarthria.

Additional trends were noted in the tone variation produced by individual speakers with dysarthria. Participants P1 and P3 showed *greater* F_0 changes compared to the control group for all of the acoustic measures (change in F_0 across words and changes in F_0 within S1 and S2). Participants P2 and P4 showed *smaller* F_0 changes compared to the control group for all of the acoustic measures. Reasons why two speakers produced greater F_0 changes and why two speakers produced smaller F_0 changes could relate to (1) time post onset of dysarthria and (2) gender. Firstly, participants P1 and P3 were both recorded for the study two years post onset, whereas P2 and P4 were both recorded only two months post onset. It is possible that after two years of dysarthria, speakers P1 and P3 had both taught themselves to exploit their limited control over F_0 variation by significantly exaggerating the F_0 changes necessary for HL tone variation. This may have been done to compensate for the limited pitch variation perceived by themselves. Secondly, speakers P1 and P3 were both female whereas speakers P2 and P4 were both male. The fact that the female speakers with dysarthria showed greater F_0 changes and the male speakers with dysarthria showed smaller F_0 changes compared to the control group correlate with findings by Ng (2001), who indicated that female speakers with dysarthria demonstrate increased tone variation and male speakers with dysarthria demonstrate decreased tone variation. In their research, Kent, Kent, Rosenbek, Weismer, Martin, Sufit and Brooks (1992) acknowledged a possibility that differential patterns of dysarthria may exist in male speakers compared to female speakers. One explanation for this may include the fact that male larynxes are larger and, as such, require greater muscular forces to achieve phonatory adjustments than the female larynx, resulting in smaller F_0 changes in male dysarthric speech (Kent et al., 1992).

Participants P1 and P2 differed the most significantly from the control group and showed significant differences compared to the typical speakers in terms of the change in F_0 across words and the changes in F_0 within S1 and S2. P1 and P2 had similar intelligibility scores of 78% and 74% respectively. Participant P3 differed the

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least significantly from the control group and only showed a significant difference compared to typical speakers for the change in F_0 within S2, despite presenting with the most severe dysarthria and the lowest intelligibility score (48% on *STSI*). P4 (63% on *STSI*) showed significant differences compared to the control group for the changes in F_0 within both S1 and S2. Due to the unique patterns of tone variation observed in the typical speakers and speakers with dysarthria, the reduced intelligibility scores obtained by the individuals with dysarthria, varying from 48% to 78% on the *STSI,* could not be ascribed to impaired tone variation. Furthermore, no link between different dysarthria types and tone variation ability could be made from the findings of this study. All experimental participants presented with mixed dysarthria and various combinations of sites of lesion.

As indicated above, a variety of factors need to be taken into account when regarding the tone variation of individual speakers with dysarthria. However, it should be considered that the differences in tone variation observed in individuals with dysarthria may be due to normal speaker differences also found in typical speakers.

4. Results: Change in F_0 across the words from the highest F_0 point of S1 to the lowest F_0 point of S2 in short versus longer utterances in typical speakers and speakers with dysarthria

To determine whether there was a difference in the F_0 variation of CVCV words with a HL tone pattern in short compared to longer utterances (second main aim), the change in F_0 across the words from the highest F_0 point of S1 to the lowest F_0 point of S2 was investigated in three- compared to six-/seven-syllable utterances in typical speakers and speakers with dysarthria.

4.1 A comparison of short versus longer utterances in typical speakers

The change in F_0 across words was compared in three- and six-/seven-syllable utterances for the typical speakers. This was a *within group* comparison. Table 25 indicates the median changes in F_0 across words in short and longer utterances for the control group. The median change in F_0 within three-syllable utterances was 66.94 Hz. The median change in F_0 within six-/seven-syllable utterances was 38.37 Hz. The

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control group produced a significantly greater median change in F_0 across words in short utterances than long utterances (p<0.001). The change in F_0 was 28.57 Hz greater in short utterances than in long utterances. Individual control participants generally followed the group trend and displayed greater F_0 changes within short compared to longer utterances.

Table 25: Control group- Median changes in F_0 across words in short and long utterances, as well as the p-values obtained when comparing the median changes in F_0 between the two utterance lengths

Utterance type	Median change in F_0 (Hz)	IQR* (Hz)	P-value** *(Obtained using the Wilcoxon signed rank test)*
Short utterances	66.94	47.36	**<0.001**
Long utterances	38.37	25.71	

**IQRs provide an indication of the spread of the data. Not used to achieve research aims.*

***P-values obtained when median changes in F_0 across words for typical speakers were compared in short utterances and long utterances. A p< 0.05 was deemed statistically significant in all tests.*

4.2 A comparison of short versus longer utterances in speakers with dysarthria

The change in F_0 across words was compared in three- and six-/ seven-syllable utterances for the speakers with dysarthria. Table 26 indicates the median changes in F_0 across words in short and longer utterances for the dysarthria group. The median change in F_0 within short utterances was 56.79 Hz, whereas the median change in F_0 within long utterances was 45.65 Hz. It is clear that the speakers with dysarthria produced a significantly greater change in F_0 across words in short utterances compared to long utterances (p=0.01). The change in F_0 across words was 11.14 Hz greater in short utterances than in long utterances.

Table 26: Dysarthria group- Median changes in F_0 across words in short and long utterances, as well as the p-values obtained when comparing the median changes in F_0 between the two utterance lengths

Utterance type	Median change in F_0 (Hz)	IQR* (Hz)	P-value** *(Obtained using the Wilcoxon signed rank test)*
Short utterances	56.79	29.20	**0.01**
Long utterances	45.65	29.08	

**IQRs provide an indication of the spread of the data. Not used to achieve research aims.*

***P-values obtained when median changes in F_0 across words for speakers with dysarthria were compared in short utterances and long utterances. A p< 0.05 was deemed statistically significant in all tests.*

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The change in F_0 across words was also compared in three- and six-/ seven-syllable utterances for the individual speakers with dysarthria to determine if the individual speakers followed the trend of the dysarthria group as a whole. To simplify this comparison for individual speakers with dysarthria, Figure 11 graphically depicts the median changes in F_0 across words within short and long utterances for participants P1-P4. All participants with dysarthria produced a greater change in F_0 across words in short utterances than long utterances.

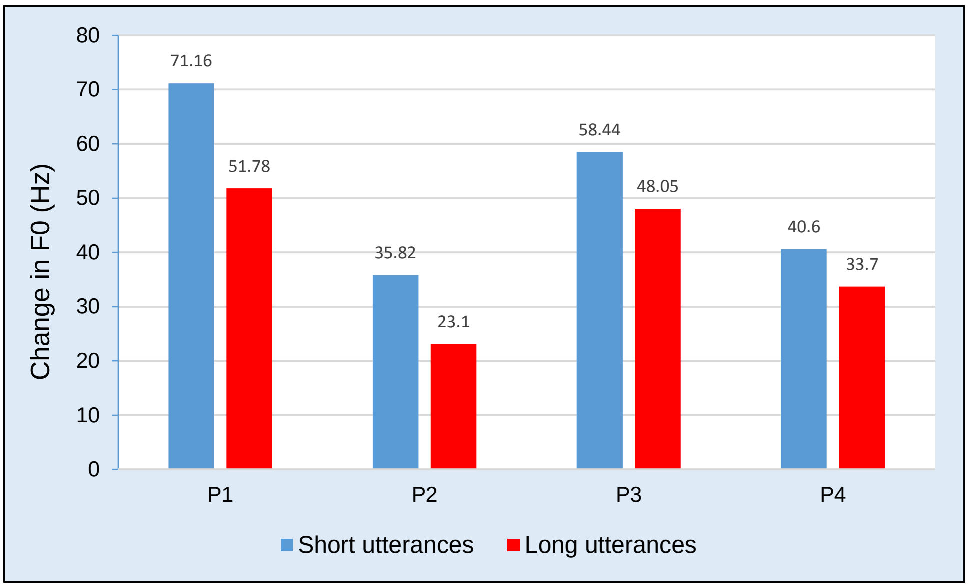

Figure 11: Individual speakers with dysarthria (n=4): Median changes in F_0 across words in short and long utterances

Table 27 displays the p-values obtained when comparing the median changes in F_0 across words in short and long utterances for the individual speakers with dysarthria. Contrary to the significant difference in the change in F_0 across words between the different utterance lengths for the dysarthria group *as a whole,* the differences in change in F_0 for short compared to long utterances were not statistically significant for any of the participants *individually.* The reason for the difference when regarding participants individually may lie in the sample size; no significant difference was found when the utterance lengths were compared for single participants but the difference became significant when the sample size increased to four participants with dysarthria.

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Table 27: P-values obtained when comparing the median changes in F_0 across words in short versus long utterances for the individual speakers with dysarthria

Participants	P-values* (Obtained using the Wilcoxon rank sum test)
P1 (78% in *STSI*)	0.13
P2 (74% in *STSI*)	0.08
P3 (48% in *STSI*)	0.13
P4 (63% in *STSI*)	0.5

** A p≤ 0.05 was deemed statistically significant in all tests. P-values were obtained using the Wilcoxon signed rank test.*

4.3 Groups compared with regard to amount of change in F_0 across the words in short versus longer utterances

Both groups displayed a greater change in F_0 within short than longer utterances. For the control group the difference in F_0 change between the utterance lengths was 28.57 Hz, while for the dysarthria group it was 11.14 Hz. The difference in the change in F_0 across words between short and long utterances was significantly greater for the control group than for the dysarthria group ($p < 0.001$).

4.4 Summary of change in F_0 across the words in short versus longer utterances

Both the control and dysarthria groups produced a significantly greater median change in F_0 across words in short utterances compared to long utterances. The differences in change in F_0 for short compared to long utterances were not statistically significant when the speakers with dysarthria were regarded individually. The difference in the change in F_0 across words between short and long utterances was significantly greater for the control group than for the dysarthria group.

5. Discussion: Change in F_0 across the words from the highest F_0 point of S1 to the lowest F_0 point of S2 in short versus longer utterances in typical speakers and speakers with dysarthria

In the current study, target CVCV words with a HL tone pattern occurred at the end of all utterances. For both speaker groups in the study, greater tone variation was found in short utterances than in longer utterances. This was indicated by greater median changes in F_0 across target words in three-syllable compared to six-/seven-syllable

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utterances. In longer utterances, increased skills are needed for the planning, programming, and execution of speech for both typical speakers and speakers with speech impairments (Van der Merwe, 2009:6). Longer utterances require greater control of expiration and coordination of vocal fold movements. Tone variation may therefore not be as pronounced in long utterances as in short utterances.

Further explanations for the smaller F_0 changes that occurred in longer utterances may lie in the phenomena of declination and coarticulation. *Declination* refers to a general tendency for the average F_0 of speech to decline over an utterance (Xu, 1999). In the current study, there was a longer period for the average F_0 to decline in longer utterances before the target words were produced at the end of the utterance, compared to short utterances. As expected due to declination, the F_0 values for the two syllables in the target words at the end of the longer utterances were produced with reduced variation. The phenomenon of coarticulation may also have an effect on tone variation. *Coarticulation* refers to the fact that speech sounds are often altered in running speech, due to influences from surrounding sounds (Gandour, Potisuk, Dechongkit, & Ponglorpisit, 1992). The coarticulation of tones occurs in much the same way as it does for vowels and consonants. Longer utterances result in increased tonal coarticulation and the mean F_0 height is often affected by this. The F_0 height of a syllable may be either increased or flattened, depending on the tones of the adjacent syllables in the sentence (Gandour et al., 1992; Xu, 1994). The tones of the target words at the end of the longer utterances may have been more influenced by the F_0 values of the other words in the utterance, thereby resulting in reduced F_0 variation.

In the current study, the role of increased utterance length in decreasing F_0 variation was greater for the control group than for the dysarthria group. For individual speakers with dysarthria, no significant differences in F_0 changes were found for short utterances compared to long utterances, as indicated in Table 27. This may be due to a smaller sample size used when comparing individual speakers with dysarthria to the control group, than when comparing the dysarthria group as a whole to the controls. Coarticulation possibly played a role in the smaller effect of utterance length on F_0 variation for the dysarthria group. Three out of the four participants with dysarthria (P1, P2, and P4) were noted to have a slow speech rate by at least one of the diagnosing SLPs. As coarticulation occurs more frequently at increased speech rates (Tjaden, 2000), it is unlikely that coarticulation would occur to the same extent for the majority

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of speakers with dysarthria compared to the control speakers. If the effect of tonal coarticulation is smaller in the slower speech of individuals with dysarthria, the F_0 changes in the target words may have been less affected by the context of longer utterances than in the case of typical speakers. Larger sample sizes may, however, may be needed to support this finding.

6. Summary of Chapter 3

In this chapter, the results of the current study were presented in accordance with research aims and sub-aims, and subsequently discussed. Results and comparisons for typical speakers and speakers with dysarthria were presented for individuals and groups.

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Chapter 4

Conclusions

In this chapter, the conclusions regarding the current study and their implications are presented, along with a discussion of the study's limitations and recommendations for future research.

1. Conclusions

This study investigated the lexical tone variation produced by speakers of Sepedi, a Bantu language. The first aim of the study was to determine whether a difference exists between typical Sepedi speakers and Sepedi speakers with dysarthria, in their ability to vary tone across CVCV words with an HL tone pattern. The second aim of the study was to determine whether a difference in tone variation exists between short and longer utterances produced by typical Sepedi speakers and Sepedi speakers with dysarthria. Speech samples were obtained from a control group of five typical Sepedi speakers and from an experimental group of four Sepedi speakers with acquired dysarthria. These speech samples consisted of 20 CVCV words with HL tone variation produced first in three- and then in six- /seven-syllable utterances (resulting in a total of 40 words). The speech samples were analysed acoustically using *Praat* software. To achieve the first aim, the following acoustic measures were obtained from the 40 words produced by participants: (1) Mean fundamental frequency (F_0) of syllable 1 (S1) and syllable 2 (S2), (2) Change in F_0 across words from the highest F_0 point of S1 to the lowest F_0 point of S2, (3) Changes in F_0 within S1 and S2. To achieve the second aim of the study, the change in F_0 across words in short utterances was compared to the change in F_0 across words in longer utterances for the typical speakers and speakers with dysarthria. All of the data obtained was skewed and therefore median values for individual and group data were compared within and across participants to achieve both aims of the study. The conclusions drawn from the results are presented in the ensuing sections.

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1.1 A comparison of tone variation between typical speakers and speakers with dysarthria

1.1.1 Conclusions regarding the groups

- The dysarthria group retained the ability to produce tone variation across the context of an entire word. They also indicated maintained ability to lengthen and tense the vocal folds to produce a high tone within the context of the first syllable.
- In contrast, the dysarthria group may have been unable to suitably grade the relaxation of the vocal folds within the context of S2 to produce a low tone, as indicated through significantly greater change in F_0 within the second syllable than in the case of the control group. The speakers with dysarthria may have presented with fatigue or decreased breath support, resulting in exaggerated F_0 changes during the production of S2.

1.1.2 Conclusions regarding the individual control speakers

- All control speakers produced S1 with a higher mean F_0 than S2, as was appropriate for the HL tone pattern ascribed to the target words. Only one control speaker (C1) did not produce S1 with a significantly higher mean F_0 than S2.
- For both the change in F_0 across words and the change in F_0 within S1, participant C1 produced *significantly smaller* changes in F_0 than the control group as a whole and C5 produced *significantly greater* F_0 changes than the control group as a whole. C3 produced a *significantly smaller* F_0 change than that of the control group within S1. These trends in the F_0 changes of control speakers suggest that unique patterns of tone variation exist in typical speakers.
- Only two out of the five control speakers (C2 and C4) consistently produced the F_0 changes necessary for tone variation similarly to the control group as a whole. As indicated by the variability of the F_0 changes found for the control speakers, it is possible that tone variation within typical Sepedi speakers is a phonetic feature which normally varies from person to person, even if an individual's speech is

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typical and intelligible. This conclusion is supported by the 100% intelligibility scores that were achieved by all of the control speakers on the *STSI.*

1.1.3 Conclusions regarding the individual speakers with dysarthria

- All speakers with dysarthria were successfully able to produce S1 of the target words with a higher mean F_0 than S2, as was appropriate for the words' HL tone pattern. These results indicate that the speakers with dysarthria, just like typical speakers, were able to differentiate between high and low tones in bisyllabic words. As in the case of the control speakers, only one speaker with dysarthria (P4) produced S1 with an *insignificantly* higher mean F_0 than S2. The fact that there were speakers from both groups who did not produce a significant difference in the relative F_0 values for the two syllables suggests that this may have been due to normal speaker differences which were also observed in the typical speakers.
- For certain acoustic measures, the individual speakers with dysarthria differed significantly from the control group and for other acoustic measures, no significant differences were found. Individual trends were also noted in the magnitude of tone variation of the individual speakers with dysarthria. Participants P1 and P3 showed *greater* F_0 changes compared to the control group for all of the acoustic measures. Participants P2 and P4 showed *smaller* F_0 changes compared to the control group for all of the acoustic measures. As typical speakers also varied in their abilities to produce F_0 changes within and across words, the differences observed in the tone variation of speakers with dysarthria were possibly due to the normal speaker differences also observed in typical speakers.
- Due to the unique patterns of tone variation observed in the typical speakers and speakers with dysarthria, the reduced intelligibility scores obtained by the individuals with dysarthria, varying from 48% to 78% on the *STSI,* could not be ascribed to impaired tone variation.

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1.2 Change in F_0 across the words in short compared to longer utterances in typical speakers and speakers with dysarthria

- For both the control and the dysarthria groups, significantly greater tone variation was found in short utterances than in longer utterances. The tone variation of individual control speakers generally followed control group trends in short compared to longer utterances.
- Although significantly greater tone variation was observed in short compared to long utterances for the dysarthria *group as a whole,* the difference in tone variation between the two utterance lengths was not significant for the *individual* speakers with dysarthria.
- The role of increased utterance length in decreasing F_0 variation was *greater* for the control group than the dysarthria group.

1.3 Summarised conclusion

In summary, tone variation may not be affected to the same extent as other aspects of speech in Sepedi speakers with dysarthria. Out of the four aspects of tone variation compared between control speakers and speakers with dysarthria, significant differences in F_0 changes between the two speaker populations were only found in the greater lowering of F_0 within S2 for the dysarthria group, indicating possible difficulties in the graded relaxation of the vocal folds required. Individual differences in F_0 changes were found for both typical speakers and speakers with dysarthria, indicating that unique tone variation patterns may exist for all speakers.

For both control and dysarthria groups, greater tone variation was observed in short compared to longer utterances. However, the role of increased utterance length in lessening F_0 variation was greater for the typical speakers than for the individuals with dysarthria.

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2. Implications of the study

This study's findings have several implications for clinical practice. These implications include the following:

- Insignificant differences were found in most of the F0 changes compared between typical speakers and speakers with dysarthria. The fact that tone variation may be less affected by dysarthria in Bantu languages than other aspects of speech production bears implications for goal setting by clinicians. For certain speakers with dysarthria where voice production is not significantly compromised, the focus on therapy to improve speech intelligibility should rather be on improved articulation than on tone variation.
- In the current study, speakers with dysarthria differed more significantly from typical speakers in their lowering of F_0 within S2 than in their raising of F_0 within S1. These results imply that speakers with dysarthria could *more accurately tense* the vocal folds *than produce graded relaxation* in them. This may bear implications for the manner in which the neuromotor control of changes in voice pitch is addressed in intervention with speakers having dysarthria.

3. Limitations and recommendations for future research

The current study had a few limitations that should be considered in the interpretation of the study's findings, as well as when making recommendations for future research.

- The small sample sizes of the control and experimental groups in the current study do not allow for generalization of the results to all typical Bantu language speakers (specifically speakers of Sepedi) and speakers with dysarthria. Both typical speakers and speakers with dysarthria are heterogeneous populations and consist of people of different backgrounds and exposure to Bantu languages. Future studies should compare the tone variation of control and dysarthria groups using larger sample sizes to confirm that the results obtained are generalizable.
- The ages of control and experimental participants could not be controlled for in the current study. Due to the fact that ageing has an effect on the mobility of the larynx (Kent et al., 1992), age may need to be kept constant in future studies to control for the effect of age on the extent of tone variation.

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- The results of the current study suggest that male speakers with dysarthria may present with smaller F_0 changes in their speech than their female counterparts. Similar findings were reported in studies by Ng (2001) and Kent and colleagues (1992). Larger groups of male compared to female speakers with dysarthria can be used as participants in future research to determine if smaller F_0 changes are consistently found in male compared to female speakers with dysarthria.
- All of the speakers with dysarthria in the current study presented with mixed dysarthria. Although it was confirmed through communication with the speakers' treating physicians that the speakers had neurological lesions, a lack of evidence was present to confirm the *site* of their lesions. The types of dysarthria could therefore not be linked to speakers' tone variation ability in the current study. This aspect should be investigated in future research, as it is possible that different sites of lesion may impact upon tone variation differently.

4. Final conclusions

Despite the limitations highlighted above, this study constitutes a noteworthy explorative investigation of the lexical tone variation ability of Bantu language speakers with acquired dysarthria. This study was the first to attempt investigating tone variation across *bisyllabic words* and determining *intra-syllabic* F_0 changes. It was also the first to compare speakers' tone variation in utterances of *varying length.* For these reasons, there is value in the current study's findings, conclusions, and recommendations.

5. Summary of Chapter 4

In this chapter, the conclusions and implications of the current study were presented and the study's limitations and recommendations for future research were discussed.

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Appendix A: Table presenting an overview of past research

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Table: A summary of studies conducted into tone and prosodic variation in speakers with neuromotor speech disorders

Study	Tone or Intonation?	Aims	Participants	Procedures	Analysis Software	Significant findings
Ng (2001)	STUDIED TONE	To conduct acoustic analysis of contour tones produced by adult Cantonese speakers with dysarthria due to Cerebral Palsy (CP), compared to typical speakers.	19 adult Cantonese L1 speakers with dysarthria due to CP, compared to 18 controls.	Acoustic analysis to determine F_0 at different time points across the voiced segments of 11 monosyllabic Cantonese words.	Soundscope/16 2.17	(1) Speakers with dysarthria had significantly higher mean F_0 than control speakers. (2) Speakers with dysarthria had a final drop of overall F_0 from the fourth to the last time point of the voiced segment. (3) Overall F_0 at the final time point of male speakers with dysarthria was significantly lower than all the other time points (4) Overall variation in F_0 in the male speakers with dysarthria group was significantly higher than the control group. (5) Overall F_0 variation in the female speakers with dysarthria group was not significantly higher than the control group. (6) Qualitative analysis showed that abnormal F_0 patterns were observed in some of the speakers with dysarthria.

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Patel & Campellone (2009)	STUDIED INTONATION	To understand acoustic and perceptual cues to contrastive stress in speakers with dysarthria and typical speakers.	12 L1 American English speakers with dysarthria due to CP and 12 age- and gender-matched controls. 48 L1 American English listeners	Acoustic analysis derived the F_0, intensity and duration for 5 phrases consisting of 4 monosyllabic words. Perceptual analysis: Listeners listened to sentences produced by both speakers with dysarthria and controls. They had to say whether they felt the stress was produced on the 1st, 2nd, 3rd or 4th word in the phrase or whether the phrase was produced neutrally.	Praat	(1) Both groups used increased F_0, intensity and duration to mark contrastive stress. Speakers with dysarthria relied more heavily on durational cues. (2) Speakers with dysarthria showed slowed overall production of the sentences compared to controls. (3) Despite errors in contrastive stress by speakers with dysarthria, listeners were still generally able to identify their contrastive stress patterns in sentences.
Ma, Whitehill, & So (2010)	STUDIED INTONATION	To investigate intonation contrasts produced by speakers with Parkinson's Disease (PD).	14 Cantonese speakers with hypokinetic dysarthria due to PD. 20 4th Year students in Speech and Hearing Sciences from the University of Hong Kong acted as listeners.	Perceptual task: Listeners were required to listen to sentences and decide whether they were questions or statements. Acoustic analysis: F_0, intensity and duration were measured at equally distributed time points.	Praat	(1) High identification accuracy by listeners for statements produced by speakers with PD. (2) Listeners' identification accuracy for questions varied among speakers with PD. (3) Average F_0 and change in F_0 of the final syllable are especially important for the identification of the statement-question contrast. (4) In cases where the F_0 signal is ambiguous,

						durational cues may be used by speakers with PD to signal question-statement contrasts.
Khouw & Ciocca (2007)	STUDIED TONE	To determine which part of the vocalic segment provides the most information about tone identity.	10 typical Cantonese L1 adolescents 30 L1 Cantonese listeners	Acoustic analysis: Used to determine the F_0 at various time points across the vocalic segment of 4 sets of monosyllabic Cantonese words (6 words per set). Perceptual task: Listeners asked to determine the tone heard for each word	Praat	(1) In both production and perception tasks, it was found that change in F_0 across the latter segments of the vowel play a role in specifying the tones. (2) Two dimensions of F_0 change were found to be important in differentiating tone: a) Direction of the F_0 change b) Magnitude of the F_0 change (3) Average F_0 also played a role in specifying tones.
Jeng, Weismer, & Kent (2006)	STUDIED TONE	**(1)**To evaluate tone intelligibility in three groups of speakers with CP and controls. **(2)**To report the F_0 contour characteristics of tone production amongst these speakers. **(3)** To interpret the relationship between tone intelligibility and specific aspects of F_0 contour characteristics	30 L1 Mandarin speakers with CP (10 spastic, 10 athetoid and 10 mixed). Participants covered a wide range of severity. 10 Mandarin L1 matched participants served as a control group. 36 Mandarin L1 listeners	Perceptual task: Listeners were asked to write down what word they heard for each of the 78 monosyllabic words produced by the speakers. Acoustic analysis: F_0 was determined for the words, across various time points	C-speech	(1) Mean tone intelligibility for speakers with dysarthria was 73%, compared to 91% for controls. (2) Speakers with dysarthria maintained some tonal contrast ability, but with less distinction than the contrasts of typical speakers. (3) F_0 data was more variable for speakers with dysarthria than controls.

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Ma, Whitehill, & Chueng (2009)	STUDIED INTONATION	**(1)**To characterise the prosodic impairment in Cantonese speakers with hypokinetic dysarthria associated with PD. **(2)**To determine the effects of different types of speech stimuli on the perceptual rating of prosody.	10 Cantonese L1 speakers with hypokinetic dysarthria 12 4th Year undergraduate students on Speech and Hearing Sciences from the University of Hong Kong acted as listeners.	Perceptual analysis: Listeners were asked to listen to sentences, passages and monologues as produced by speakers with dysarthria and to identify 10 prosodic parameters therein, reflecting the 5 dimensions of speech prosody (loudness, pitch, duration, voice quality and degree of reduction).	N/A	The most severely affected prosodic characteristics were harshness, monopitch and monoloudness. These were followed by breathy voice and prolonged intervals.
MacPherson, Huber, & Snow (2011)	STUDIED INTONATION	To examine the effect of PD on the intonational markings of final and non-final syntactic boundaries and to determine whether the effect of PD on intonation is sex-specific	16 Speakers with dysarthria due to PD. 16 age- and gender-matched controls.	Participants read a passage at comfortable pitch, rate, and loudness. Nuclear tones from final and non-final syntactic boundaries in clauses and lists were extracted. Measures of F_0 were made on each tone contour, using acoustic analysis.	Praat	Individuals with PD demonstrated impaired differentiation of syntactic boundary finality versus non-finality through contour direction.
Ciocca, Whitehill, & Ma (2004)	STUDIED TONE	To explore the relationship between F_0 characteristics and the intelligibility of level tones produced by Cantonese speakers with dysarthria.	4 L1 Cantonese speakers with dysarthria 1 L1 Cantonese typical speaker 5 expert L1 Cantonese listeners	Single, monosyllabic words were produced by participants. Perceptual analysis: Listeners had to identify the lexical tone of each word (not just identify the intended word).	N/A	Tones produced by speakers with dysarthria were more poorly identified than that of controls.
Wong & Diehl (1999)	STUDIED TONE	To determine how disruptive reduced pitch range is on tone perception	2 L1 Cantonese speakers were used: 1 with hypokinetic dysarthria due to PD and 1 typical speaker.	Participants were asked to produce 6 words; first in isolation, and then preceded by a carrier phrase 3 times.	Unknown	(1) Pitch range and tonal space were more restricted in the speaker with PD

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			7 L1 Cantonese listeners.	Acoustic analysis: Participants' pitch ranges were determined by calculating the difference between the highest and lowest pitch points. Highest and lowest pitch points for target words within each condition were also measured to determine the tonal space. This specifies the pitch space where tones occur. Perceptual analysis: 7 Listeners asked to identify the isolated word/ last word in a sentence.		(2) It was more difficult to identify the tones produced by the speaker with PD.

Appendix B: Ethical clearance letters

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Faculty of Humanities
Research Ethics Committee

29 August 2014

Dear Prof Vinck

Project:	**Syllabic tone variation by Sepedi speakers with dysarthria**
Researcher:	**R Malan**
Supervisor:	**Prof A van der Merwe**
Department:	**Speech-Language Pathology and Audiology**
Reference:	**29070092**

Thank you for the application that was submitted for ethical review.

The application was **approved** by the **Research Ethics Committee** on 28 August 2014, pending permission from the following:

- Written permission is outstanding from the hospitals and clinics as well as the Department of Health.

Please note that data collection may not commence prior to these outstanding permissions and final approval by this Committee. To facilitate the administrative process, please respond to Ms Tracey Andrew, Room HB 7-27, at your earliest possible convenience.

Sincerely

Prof. Karen Harris
Acting Chair: Research Ethics Committee
Faculty of Humanities
UNIVERSITY OF PRETORIA
e-mail: karen.harris@up.ac.za

Research Ethics Committee Members: Dr L Blokland; Prof M-H Coetzee; Dr JEH Grobler; Prof KL Harris (Actign Chair); Ms H Klopper; Dr C Panebianco-Warrens; Dr C Puttergill; Prof GM Spies; Dr Y Spies; Prof E Taljard; Dr P Wood

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GAUTENG PROVINCE
HEALTH
REPUBLIC OF SOUTH AFRICA

OUTCOME OF PROVINCIAL PROTOCOL REVIEW COMMITTEE (PPRC)

Researcher's Name (Principal investigator)	Ms. Roxanne Malan
Organization / Institution	University of Pretoria
Research Title	Syllabic Tone Variation by Sepedi Speaking with Dysarthria
Contact number	Tel: 012 997 7834 Mobile: 078 803 1992 Email: malanroxanne@gmail.com
Protocol number	P040914
Date submitted	28/08/2014
Date reviewed	November 2014
Outcome	APPROVED
Date resubmitted	N/A
Date of second review	N/A
Final outcome	APPROVED

It is a pleasure to inform that the Gauteng Health Department has approved your research on "Syllabic Tone Variation by Sepedi Speaking with Dysarthria. The Provincial Protocol Review Committee kindly requests that you to submit a report after completion of your study and present your findings to the Gauteng Health Department.

Approves / not approves

Dr R Lebethe
Acting DDG: Clinical Services
Date 10/12 2014

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Kuyasheshwa! Gauteng Working Better

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243 Pretorius Street, Cnr. Thabo Sehume & Pretorius Street, Manaka Building, Pretoria 0001 South Africa.
Tel: +27 12 406 0237
Enquiries: Mr. Peter Silwimba.
e-mail: peter.silwimba@gauteng.gov.za

TSHWANE RESEARCH COMMITTEE

CLEARANCE CERTIFICATE

Meeting: N/A

PROJECT NUMBER: 02/2015

Title: Syllabic tone variation of Sepedi speakers with dysarthria
Researcher: Roxanne Malan
Co-Researcher:
Supervisor: Prof S Van der Merwe
Department: Speech-Language Pathology and Audiology

DECISION OF THE COMMITTEE

Approved

NB: THIS OFFICE REQUESTS A FULL REPORT ON THE OUTCOME OF THE RESEARCH DONE

Date: 25/02/15

....
Mr. Peter Silwimba
Chairperson Tshwane Research Committee
Tshwane District

....
Mr. Pitsi Mothomone
Chief Director: Tshwane District Health
Tshwane District
2015-02-25

NOTE:	Resubmission of the protocol by researcher(s) is required if there is departure from the protocol procedures as approved by the committee.

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Appendix C: Consent letters to research committees and institutions

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Letter to a representative of the Gauteng Provincial Health Department

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Faculty of Humanities
Department of Speech-Language Pathology and Audiology

2 July 2014

Dear Ms Khumalo

Study on syllabic tone variation by Sepedi speakers with dysarthria

I am currently a Masters' student at the University of Pretoria enrolled for the degree, M Communication Pathology, specializing in Speech-Language Pathology. I am interested in conducting a study to investigate the ability of first-language Sepedi speakers with dysarthria (a neuromotor speech disorder) to vary syllabic tone on words consisting of a consonant-vowel-consonant-vowel (CVCV) structure. My study requires a sample of adults who have confirmed diagnoses of a neurological lesion by a neurologist and who present with dysarthria as confirmed by a speech-language therapist. Additionally, participants are required to be first-language Sepedi speakers.

The study will require each participant to take part in a once-off research session whereby they will be required to name 30 scenarios observed in pictures shown to them twice. Their productions will be recorded using an Olympus digital voice recorder. All research sessions will be conducted in an isolated, quiet room at the identified health care institutions to minimize the effect of environmental noise on the data collected. After the research session is complete, the researcher will analyse the 60 words produced by each participant through the use of a computerised acoustic analysis program to investigate the tone variation of the speakers.

The study will pose no discomfort or risks to participants' wellbeing. Participation will be voluntary and participants will be allowed to withdraw from the project at any time, without penalty. All data obtained from the study will remain strictly anonymous and confidential and the study will benefit participants, science and society as a whole by allowing a better understanding of the effect that dysarthria has on individuals' ability to vary tone during speech production. To ensure that accurate data is obtained, I shall require access to patient files at the identified institutions to confirm that research participants have been diagnosed by a neurologist. I kindly request that you allow me the opportunity to conduct my research at health care institutions falling under the Gauteng Department of Health, including academic, regional and district hospitals.

Thank you for your consideration. Should you have any queries, feel free to contact me at 078 803 1992 or at malanroxanne@gmail.com.

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jeannie.vanderlinde@up.ac.za
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Yours sincerely

Ms Roxanne Malan
Masters' student

Prof. Anita van der Merwe
Research supervisor

pp

Mrs Mia le Roux
Research co-supervisor

Mrs Jeannie van der Linde
Research co-supervisor

Prof B Vinck
HEAD: Department of Speech-Language Pathology and Audiology

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Letter to the head of the Tshwane Research Committee

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Faculty of Humanities
Department of Speech-Language Pathology and Audiology

2 July 2014

Dear Mr Silwimba

Re: Study on syllabic tone variation by Sepedi speakers with dysarthria

I am currently a Masters' student at the University of Pretoria enrolled for the degree, M Communication Pathology, specializing in Speech-Language Pathology. I am interested in conducting a study to investigate the ability of first-language Sepedi speakers with dysarthria (a neuromotor speech disorder) to vary syllabic tone on words consisting of a consonant-vowel-consonant-vowel (CVCV) structure. My study requires a sample of adults who have confirmed diagnoses of a neurological lesion by a neurologist and who present with dysarthria as confirmed by a speech-language therapist. Additionally, participants are required to be first-language Sepedi speakers.

The study will require each participant to take part in a once-off research session whereby they will be required to name 30 scenarios observed in pictures shown to them twice. Their productions will be recorded using an Olympus digital voice recorder. All research sessions will be conducted in an isolated, quiet room at the identified health care institutions to minimize the effect of environmental noise on the data collected. After the research session is complete, the researcher will analyse the 60 words produced by each participant through the use of a computerised acoustic analysis program to investigate the tone variation of the speakers.

The study will pose no discomfort or risks to participants' wellbeing. Participation will be voluntary and participants will be allowed to withdraw from the project at any time, without penalty. All data obtained from the study will remain strictly anonymous and confidential and the study will benefit participants, science and society as a whole by allowing a better understanding of the effect that dysarthria has on individuals' ability to vary tone during speech production. To ensure that accurate data is obtained, I shall require access to patient files at the identified institutions to confirm that research participants have been diagnosed by a neurologist. I kindly request permission to conduct my research at community health centres and local clinics in the Tshwane region.

Thank you for your consideration. Should you have any queries, feel free to contact me at 078 803 1992 or at malanroxanne@gmail.com.

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Yours sincerely

Ms Roxanne Malan
Masters' student

Prof. Anita van der Merwe
Research supervisor

pp

Mrs Mia le Roux
Research co-supervisor

Mrs Jeannie van der Linde
Research co-supervisor

Prof B Vinck
HEAD: Department of Speech-Language Pathology and Audiology

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Letter to facility managers of institutions

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Faculty of Humanities
Department of Speech-Language Pathology and Audiology

2 July 2014

Dear Sir/ Madam

Re: Study on syllabic tone variation by Sepedi speakers with dysarthria

I am currently a Masters' student at the University of Pretoria enrolled for the degree, M Communication Pathology, specializing in Speech-Language Pathology. I am interested in conducting a study to investigate the ability of first-language Sepedi speakers with dysarthria (a neuromotor speech disorder) to vary syllabic tone on words consisting of a consonant-vowel-consonant-vowel (CVCV) structure. My study requires a sample of adults who have confirmed diagnoses of a neurological lesion by a neurologist and who present with dysarthria as confirmed by a speech-language therapist. Additionally, participants are required to be first-language Sepedi speakers.

The study will require each participant to take part in a once-off research session whereby they will be required to name 30 scenarios observed in pictures shown to them twice. Their productions will be recorded using an Olympus digital voice recorder. All research sessions will be conducted in an isolated, quiet room at the identified health care institutions to minimize the effect of environmental noise on the data collected. After the research session is complete, the researcher will analyse the 60 words produced by each participant through the use of a computerised acoustic analysis program to investigate the tone variation of the speakers.

The study will pose no discomfort or risks to participants' wellbeing. Participation will be voluntary and participants will be allowed to withdraw from the project at any time, without penalty. All data obtained from the study will remain strictly anonymous and confidential and the study will benefit participants, science and society as a whole by allowing a better understanding of the effect that dysarthria has on individuals' ability to vary tone during speech production. To ensure that accurate data is obtained, I shall require access to patient files at the identified institutions to confirm that research participants have been diagnosed by a neurologist. If possible, I shall also require an isolated, quiet room at your facility to conduct research sessions. I kindly request permission to conduct my research in your institution.

Thank you for your consideration. Should you have any queries, feel free to contact me at 078 803 1992 or at malanroxanne@gmail.com.

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Yours sincerely

Ms Roxanne Malan
Masters' student

Prof. Anita van der Merwe
Research supervisor

Mrs Mia le Roux
Research co-supervisor

Mrs Jeannie van der Linde
Research co-supervisor

Prof B Vinck
HEAD: Department of Speech-Language Pathology and Audiology

Appendix D: Consent letters to participants

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Faculty of Humanities
Department of Speech-Language Pathology and Audiology

2 July 2014

Dear Sir/ Madam

Participation in study: Syllabic tone variation in Sepedi speakers with dysarthria.

I am currently a Masters' student at the University of Pretoria enrolled for the degree, M Communication Pathology, specializing in Speech-Language Pathology. I am interested in conducting a study to investigate the speech characteristics of first-language Sepedi speakers with dysarthria (a speech disorder).

What will be expected of you should you agree to participate?

You will be required to take part in a once-off research session. Firstly, you will be asked questions regarding your background information and then I will listen to the clarity of your speech to ensure that all participants with dysarthria have a similar degree of speech impairment and that all participants without dysarthria have no other communication disorders. Thereafter, you will be shown 30 pictures, whereby you will be required to name the scenario occurring in each picture. You will be shown each picture twice so that in total, you produce 60 words, preceded by the phrase "I say…" Your productions will be recorded in a quiet room at the clinic or hospital where you attend speech therapy. Recordings will be conducted using an Olympus digital voice recorder. An interpreter will be present during the research session, should any instructions or procedures need clarification in Sepedi.

What will happen with the recorded data?

After the session is complete, I shall analyse your productions using a computer-based acoustic analysis program. These findings will be discussed in a research article and Masters' dissertation.

Potential risks or discomfort

The study will pose no discomfort or risks to your wellbeing as the research entails no methods which have the potential to be physically or psychologically harmful.

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Benefits

The study will benefit science and society as a whole by allowing a better understanding of the speech characteristics of first-language Sepedi speakers with dysarthria.

Your rights

Participation in the study will be voluntary and you will be allowed to withdraw from the project at any time, without penalty.

Confidentiality and anonymity

All data obtained from the study will remain strictly anonymous and confidential and should you withdraw from the study at any time, all data pertaining to you will be destroyed. No names will be used during the study; codes will be assigned to all data collected from participants.

If you have any questions or concerns, please feel free to contact the researcher on 078 803 1992 at any time.

Yours sincerely

Ms. Roxanne Malan
Masters' student

Prof. Anita van der Merwe
Research supervisor

Mrs Mia le Roux
Research co-supervisor

Mrs Jeannie van der Linde
Research co-supervisor

Prof. Bart Vinck
Head: Department of Speech-Language Pathology and Audiology

I have read the above information and understand all aspects involved in the study. I understand that my identity will be protected and that I shall be allowed to withdraw from the study at any time without penalty. I hereby give my voluntary consent to participate in the study.

Participant's signature: ____________________

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Department of Speech-Language Pathology and Audiology

2 July 2014

Madume Morena/ Mohumagadi

Re: Syllabic tone variation by Sepedi speakers with dysarthria.

Ke morutwana wa Masters ko Unibesity ya Pitoria, ke ingwadiseditše degree ya Communication Pathology, specializing in Speech-Language Pathology. Kgahlego yaka ke go nyakišiša kgonagalo ya batho ba ba bolelago leleme la Sepedi gomme ba na le phokolo ya dysarthria (a speech disorder).

Go nyakega eng go wena ge o dumela go tsea karolo?

Byalo ka karolo ya nyakišišo, nka rata go sekaseka bokgoni bja diboledi tša leleme la Sepedi bao ba fokolang ka dysarthria le diboledi tša Sepedi gomme ba sa fokole ka dysarthria go fapafapanya modumo mantsweng kamoka. Ka go dira bjalo, o tlo kgopelwa go tšea karolo mo nyakišišong ga tee fela. Sa pele, o tlo botšišwa dipotšišo mabapi le semelo sa gago gomme nna ke tlo theeletša gore o bolela botse ga kakang, go netefatša gore batšeakarolo ba go ba le dysarthria ba na le bothata ba polelo ba go swana naa, le gore bao ba senang dysarthria a ba na bothata ba polelo naa. Morago ga fao, o tla bontšhwa dinepe tše 30, mo o tla kgopelwang go fa mehlala gotšwa senepeng sengwe le sengwe. O tla bontšhwa senepe se tee ga bedi, gore kaofela o ntšhe mantswe a 60, a etellwa pele ke mmolelwana wo "nna kere..." Dikgatišo tša lena di tla gatišwa ka gare ga kamora ya go hloka lešhata ko kliniking goba sepetlele mo le tokišo ya polelo. Dikgatišo di tla diriwa, go šomišwa Olympus digital voice recorder. Toloki e tla be e le gona ka nako ya nyakišišo, gore e thuše ka tlhatollo ka Sepedi.

Go tla direga eng ka ditsweletswa tseo di gatisitswego?

Ka morago ga ge re feditše, ke tla sekaseka ditšweletšwa tša gago re šumiša computer-based acoustic analysis program go lekola kelo ya godimo le fase ya modumo ya mantšwe. Go kgona ga gago go išha mantšwe godimo le fase go tla bapetšwa magareng ga diboledi tšeo di nago le dysarthria le diboledi tša go sebe le dysarthria. Go tlo bolelwa ka diphihlelelo tše go Masters' dissertation.

Kgonego ya dikgobalo

Tshekatsheko ye e ka se gobatše bophelo bja gago ka ge dinyakišišo di sena mekgwa ye e ka gobatšang nama goba psychology ya gago.

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Dikholego

Tsekatsheko ye e tla hola science le setšhaba ka kakaretšo ka go kwišiša mekgwa ya polelo bokaone.

Ditokelo tša gago

Go tšea karolo dithutong tše, ke go ithaopa gomme o tla dumelelwa go lesa projeke nako efe kapa efe, ka ntle le kotlo.

Sephiri le phumolo ya leina

Digatišwa kamoka go tšwa dithutong tše di tla ba tša sephiri le leina la gago le ka se phatlalatšwe, gomme ge o ka tlogela thuto ye, digatišwa kamoka tša gago di tlo senywa. Ga go maina ao a tlogo šomišwa nakong ya thuto. Digatišwa kamoka tša batšeakarolo di tla fiwa di-code.

Ge o na le dipotšišo goba ditlhobaelo, o lokologile gore o ka letšetša monyakišiši mo go 078 803 1992, nako efe kapa efe.

Wa lena,

Ms. Roxanne Malan
Masters' student

Prof. Anita van der Merwe
Research supervisor

pp M. Khlaveia
Mrs Mia le Roux
Research co-supervisor

Mrs Jeannie van der Linde
Research co-supervisor

Prof. Bart Vinck
Head: Department of Speech-Language Pathology and Audiology

Ke badile mantšwe a a ngwadilwego ka godimo gomme ke kwišiša ka botlalo mahlakore kamoka ao a amanang le thuto ye, le gore ke ka lebaka la eng thuto ye e le bohlokwa. Ka fao ke ithaopa go tšea karolo thutong ye. Ke kwišiša gore boitshupo e tla tšhireletswa e bile ke dumelewa go tlogela nako e nngwe le enngwe mo nyakišišong ntle le go bonwa molato. Participant's signature: ____________________

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Appendix E: Background questionnaire

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Background Information

Participant number: _______ **Date:** ______________

Facility: __________________ **In-patient / Out-patient**

Identifying information

Gender: Male/ Female

Date of birth: _____________

Age: _________

Home language: _________________

Hours per day speaking home language: _________________

Hours per week speaking home language: _________________

How long has the above been the case? __________________

Other languages: _________________

How often do you speak these other languages? __________________

Residential area: _________________

Current medical status

Primary diagnosis: ____

Diagnosed by: ____

Co-morbid conditions and /or other illnesses: _______________________________

Date of neurological incident: ____

Cause of neurological incident: ____

Scan available? Yes / No

Current communication disorders: ____

Current medications: ____

Current therapy received: ____

Participant history:

Highest level of education obtained: ______________________________________

Occupation: ____

Past medical conditions: ____

Past communication disorders: ____

Past medication: ____

Past therapy received: ____

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Smoker: Yes / No

If yes, how many cigarettes smoked per day? ________________________________

Alcohol consumption: Yes / No

If yes, how many units consumed per day? __________________________________

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Appendix F: Copies of picture cards

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Bona (to see)

I see with my eyes.

Ke bona ka mahlo.

1. Go bona
2. Monna o a bona.

Dula (to sit)

The man sits on the floor.

Monna o dula mo fase.

1. Go dula
2. Monna o a dula.

(Example card)

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Fela (to finish)

The beer is getting finished.

Bjala bo a fela.

1. Go fela
2. Meetse a a fela.

Thopa (to win)

I win a prize.

Ke thopa sefoka.

1. Go thopa
2. Monna o a thopa.

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Bopa (to mould/fashion with clay)

I shall mould a pot with clay.

Mosadi o bopa pitša.

1. Go bopa
2. Monna o a bopa.

Faga (to add meal to a pot of water and stir it)

When you make porridge, you add meal to the pot of water and stir it.

Mosadi o faga pitša.

1. Go faga
2. Monna o a faga.

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Goba (to bark)

The dog barks.

Mpša e a goba.

1. Go goba
2. Mpša e a goba.

Mona (to suck)

The baby is sucking his fingers.

Ngwana o mona menwana.

1. Go mona
2. Monna o a mona.

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Kgoka (to bind)

The man binds the oxen.

Monna o kgoka dikgomo.

1. Go kgoka
2. Monna o a kgoka.

Nyanya (to suckle)

The baby suckles from his mother’s breast.

Ngwana o nyanya letswele la mmagwe.

1. Go nynanya
2. Ngwana o a nyanya.

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Bata (to flatten by pounding)

The builders pound the floor before they make it smooth.

Baagi ba bata lebato pele ba le ritela.

1. Go bata
2. Monna o a bata.

Fega (To hang/ suspend)

Mother hangs the clothes.

Mma o fega diaparo.

1. Go fega
2. Monna o a fega.

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Kala (to weigh on a scale)

The nurse weighs the children at the clinic.

Mooki o kala bana mo kliniking.

1. Go kala
2. Monna o a kala.

Kgala (to reprimand/ warn/ prevent from doing)

If the child is being naughty, we reprimand her.

Ge ngwana a seleka re a mo kgala.

1. Go kgala
2. Monna o a kgala.

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Phaka (To park)

The man parks the car.

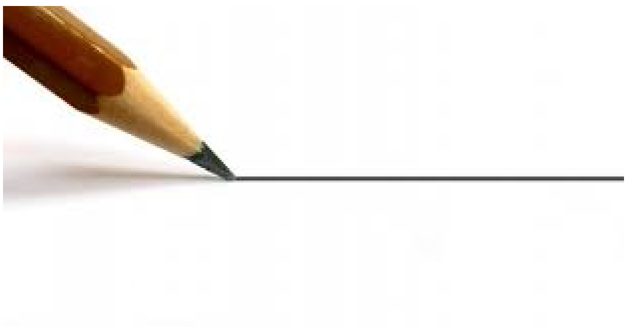
Monna o phaka koloi.

1. Go phaka
2. Monna o a phaka.

Thala (to draw)

I draw a line on the paper.

Ke thala mothalo mo pampiring.



1. Go thala
2. Monna o a thala.

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Tima (to extinguish/ put out a fire)

The man extinguishes a fire.

Monna o tima mollo.

1. Go tima
2. Monna o a tima.

Gama (to milk a cow)

The man milks the cow.

Monna o gama kgomo.

1. Go gama
2. Monna o a gama.

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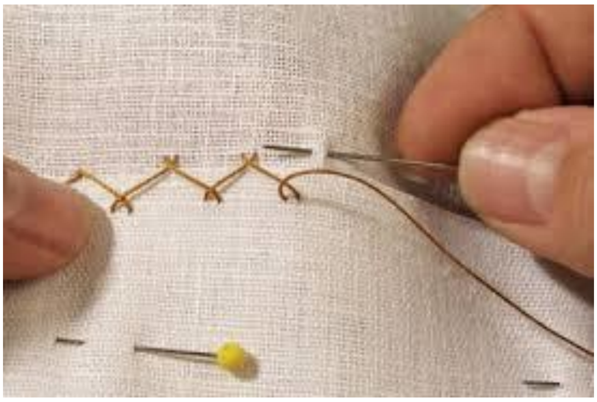
Roka (to stitch)

The man stitches shoes.

Monna o roka dieta.



1. Go roka
2. Monna o a roka.

Loma (to bite)

The dog bites.

Mpša e a loma.

1. Go loma
2. Mpša e a loma.

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Rata (to love)

The man loves his children.

Monna o rata bana ba gagwe.

1. Go rata
2. Monna o a rata.

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Appendix G: Consent forms to pilot study participants

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Denkleiers • Leading Minds • Dikgopolo tša Dihlalefi

Faculty of Humanities
Department of Speech-Language Pathology and Audiology

2 July 2014

Dear Sir/ Madam

Pilot study on syllabic tone variation by Sepedi speakers with dysarthria

Thank you for agreeing to participate in my pilot study. The purpose of the pilot study is to identify flaws in the test stimuli and data collection procedures utilised in the study, and to correct them in order to ensure that all participants will complete my main study with ease. As stated in the consent form provided, the study should pose no discomfort or risks to your wellbeing. Participation will be voluntary and you will be allowed to withdraw from the project at any time, without penalty. All data obtained from the study will remain strictly confidential and the study will benefit participants, science and society as a whole by allowing a better understanding of the speech characteristics of first-language Sepedi speakers with dysarthria. Once you have completed the procedure, I kindly request that you answer the following questions:

1. Were the instructions regarding how to complete the study clear and easily understandable? If not, please indicate which aspects could be improved upon.

2. Were there any unclear or ambiguous pictures included in the study? If so, please indicate which pictures they were.

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3. Are there any words that were elicited during the study which you feel are not commonly used by first-language Sepedi speakers?

4. Do you wish to make any additional commentary regarding the study?

Thank you for taking part in my pilot study. Your insight will be valuable in ensuring that the data obtained from the main study will be representative of the Sepedi-speaking and dysarthric populations.

Yours sincerely

Ms. Roxanne Malan
Masters' student

Prof. Anita van der Merwe
Research supervisor

pp Mrs Mia le Roux
Research co-supervisor

Mrs Jeannie van der Linde
Research co-supervisor

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Appendix H: Instructions to participants

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Instructions given to participants during each data collection session

Thank you for agreeing to participate in my study. The interpreter and I will both be present during the entire session. Do not hesitate to stop us at any time if you have questions or if you feel uncomfortable continuing with data collection. We are going to conduct this session in three parts, which I shall explain to you as we proceed:

PART 1 (Researcher labels part: Background information)

Please answer the following questions related to your background information as fully as possible. *(See background questionnaire).*

PART 2 (Researcher labels part: Indication of speech clarity)

Here are four lists of Sepedi words. Choose one of the four lists, without letting me or the interpreter see.

Firstly, read each of the words from the list to yourself quietly for practice. When you are done, indicate this with a nod of your head.

Now you are going to read the word list aloud. When I say the number of a word, please read the corresponding word aloud. Try to say each word clearly, so that listeners will understand what you are reading. We shall be recording your responses.

You now have a four-minute rest period.

PART 3 (Researcher labels part: Picture cards)

I am going to show you 21 picture cards, the first one is an example. *(Show example).* Each picture card contains a Sepedi word and its English translation, as well as the word in English and Sepedi sentences to clarify the meaning of the word. A picture is also present to further clarify the meaning of the word. *(The researcher points to what she is describing).* Note that the picture and sentences are only there to explain the meaning of the word and are not directly linked to what you have to say. For example, even if a woman appears in the picture, you should still say “Monna o a…” (“The man is…”). *(Point to example as explanation).*

For each picture card, the interpreter will read phrase number one below the picture aloud and will then count with her fingers (1-2-3-4-5). When she points to you, say the phrase one aloud. The interpreter will then read phrase 2 aloud and will count with her fingers (1-2-3-4-5). When she points to you, you must say phrase 2 aloud. (*Indicate all this with example flash card).*

You can first go through all the picture cards to give you an idea of what words and phrases you will have to say. When you are done, show me by nodding your head.

Now we are going to start. You can take a 30 second break after every three picture cards. I will indicate this to you. We shall be recording your responses.

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Appendix I: Raw data of the individual control and experimental participants

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Raw data: Mean F_0 of S1 and S2 for C1

Word	Translation	Mean F_0 S1	Mean F_0 S2
Short utterances			
Bata	To flatten by pounding	194.471	-
Bona	To see	187.926	260.068
Bopa	To mould/ fashion with clay	209.236	222.074
Fala	To scrape clean	200.673	184.316
Fega	To hang/ suspend	210.097	273.427
Fela	To finish	196.304	182.623
Gama	To milk a cow	204.199	218.438
Goba	To bark	204.599	162.253
Kala	To weigh with a scale	185.824	143.100
Kgala	To bind	205.346	226.482
Kgoka	To reprimand/ warn/ prevent from doing	229.929	217.785
Loma	To bark	202.650	204.824
Mona	To suck	209.099	185.545
Nyanya	To suckle	196.568	209.385
Phaka	To park	197.988	504.603
Rata	To love	196.246	165.668
Roka	To stitch	220.177	161.249
Thala	To draw a line	212.714	177.310
Thopa	To win	180.028	-
Tima	To put out/ extinguish a fire	221.973	178.683
Long utterances			
Bata	To flatten by pounding	181.693	-
Bona	To see	173.885	195.737
Bopa	To mould/ fashion with clay	184.998	-
Fala	To scrape clean	195.748	186.640
Fega	To hang/ suspend	187.916	-
Fela	To finish	178.729	166.776
Gama	To milk a cow	187.919	155.146
Goba	To bark	176.093	426.514
Kala	To weigh with a scale	186.876	177.369
Kgala	To bind	194.340	188.880
Kgoka	To reprimand/ warn/ prevent from doing	192.485	198.112
Loma	To bark	185.018	182.942
Mona	To suck	192.042	174.664
Nyanya	To suckle	186.408	199.737
Phaka	To park	188.661	-
Rata	To love	178.123	-
Roka	To stitch	181.471	206.724
Thala	To draw a line	194.951	175.933
Thopa	To win	185.918	-
Tima	To put out/ extinguish a fire	203.494	196.959

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Raw data: Aspects of tone variation in short and long utterances for C1

Word	Utterance	Translation	Change in F_0 across word (Hz)	Change in F_0 within S1 (Hz)	Change in F_0 within S2 (Hz)
Short utterances					
Bata	Go bata	To flatten by pounding	-	20.263	-
Bona	Go bona	To see	0.261	31.579	342.045
Bopa	Go bopa	To mould/ fashion with clay	5.658	35.718	5.878
Fala	Go fala	To scrape clean	45.225	38.332	15.829
Fega	Go fega	To hang/ suspend	51.456	27.326	270.338
Fela	Go fela	To finish	39.660	21.685	20.473
Gama	Go gama	To milk a cow	1.377	12.354	32.225
Goba	Go goba	To bark	59.928	37.23	40.228
Kala	Go kala	To weigh with a scale	105.932	6.711	115.083
Kgala	Go kgala	To bind	7.49	7.67	219.745
Kgoka	Go Kgoka	To reprimand/ warn/ prevent from doing	42.053	38.205	9.179
Loma	Go loma	To bark	18.096	19.643	15.699
Mona	Go mona	To suck	42.086	14.791	35.644
Nyanya	Go nyanya	To suckle	1.379	21.641	13.396
Phaka	Go phaka	To park	279.262	14.531	27.307
Rata	Go rata	To love	49.029	24.208	27.935
Roka	Go roka	To stitch	62.154	29.087	54.356
Thala	Go thala	To draw a line	62.154	31.823	18.909
Thopa	Go thopa	To win	-	43.014	-
Tima	Go tima	To put out/ extinguish a fire	42.402	26.282	19.013
Long utterances					
Bata	Monna o a bata	The man flattens by pounding	-	20.263	-
Bona	Monna o a bona	The man sees	1.491	15.398	-
Bopa	Monna o a bopa	The man moulds clay	-	24.416	-
Fala	Monna o a fala	The man scrapes clean	30.148	23.831	7.176
Fega	Monna o a fega	The man hangs	-	14.211	-
Fela	Meetse a a fela	The water is finished	23.164	6.081	16.820
Gama	Monna o a gama	The man milks	107.401	17.906	94.637
Goba	Mpša e a goba	The dog barks	229.896	17.131	24.806
Kala	Monna o a kala	The man weighs with a scale	16.694	10.508	7.841
Kgala	Monna o a kgala	The man reprimands	16.722	13.534	4.335
Kgoka	Monna o a kgoka	The man binds	11.001	12.272	13.796
Loma	Mpša e a loma	The dog bites	12.073	6.793	15.466
Mona	Monna o a mona	The man sucks	44.319	12.149	37.596
Nyanya	Ngwana o a nyanya	The baby suckles	0.778	9.830	11.799
Phaka	Monna o a phaka	The man parks	-	20.824	-
Rata	Monna o a rata	The man loves	-	10.821	-
Roka	Monna o a roka	The man stitches	20.445	10.646	0.48
Thala	Monna o a thala	The man draws a line	41.702	22.484	15.185
Thopa	Monna o a thopa	The man wins	-	198.074	-
Tima	Monna o a tima	The man extinguishes a fire	13.453	218.286	195.164

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Raw data: Mean F_0 of S1 and S2 for C2

Word	Translation	Mean F_0 S1	Mean F_0 S2
Short utterances			
Bata	To flatten by pounding	179.93	-
Bona	To see	204.369	153.577
Bopa	To mould/ fashion with clay	220.573	222.074
Fala	To scrape clean	205.811	158.897
Fega	To hang/ suspend	210.097	273.427
Fela	To finish	196.304	182.623
Gama	To milk a cow	203.034	145.810
Goba	To bark	218.808	148.811
Kala	To weigh with a scale	224.735	143.618
Kgala	To bind	208.549	152.908
Kgoka	To reprimand/ warn/ prevent from doing	242.840	243.265
Loma	To bark	194.457	142.573
Mona	To suck	196.129	153.769
Nyanya	To suckle	196.300	154.092
Phaka	To park	200.636	-
Rata	To love	187.234	-
Roka	To stitch	198.154	-
Thala	To draw a line	210.230	158.778
Thopa	To win	234.556	235.112
Tima	To put out/ extinguish a fire	214.336	159.125
Long utterances			
Bata	To flatten by pounding	148.598	-
Bona	To see	166.069	147.091
Bopa	To mould/ fashion with clay	162.659	-
Fala	To scrape clean	156.047	122.486
Fega	To hang/ suspend	163.830	-
Fela	To finish	157.596	130.844
Gama	To milk a cow	173.812	149.877
Goba	To bark	168.682	146.155
Kala	To weigh with a scale	168.416	141.228
Kgala	To bind	169.466	142.362
Kgoka	To reprimand/ warn/ prevent from doing	212.399	215.629
Loma	To bark	162.142	135.209
Mona	To suck	161.431	139.559
Nyanya	To suckle	177.202	159.749
Phaka	To park	162.280	-
Rata	To love	152.279	-
Roka	To stitch	150.681	-
Thala	To draw a line	168.105	148.082
Thopa	To win	180.754	144.192
Tima	To put out/ extinguish a fire	180.341	147.353

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Raw data: Aspects of tone variation in short and long utterances for C2

Word	Utterance	Translation	Change in F_0 across word (Hz)	Change in F_0 within S1 (Hz)	Change in F_0 within S2 (Hz)
Short utterances					
Bata	Go bata	To flatten by pounding	-	29.966	-
Bona	Go bona	To see	73.255	44.748	14.843
Bopa	Go bopa	To mould/ fashion with clay	94.983	67.053	22.536
Fala	Go fala	To scrape clean	45.225	39.520	13.357
Fega	Go fega	To hang/ suspend	51.456	59.804	21.859
Fela	Go fela	To finish	39.660	149.602	22.308
Gama	Go gama	To milk a cow	82.642	51.931	18.973
Goba	Go goba	To bark	94.200	58.896	300.838
Kala	Go kala	To weigh with a scale	350.351	327.517	7.408
Kgala	Go kgala	To bind	74.294	30.224	14.359
Kgoka	Go Kgoka	To reprimand/ warn/ prevent from doing	36.841	13.681	76.785
Loma	Go loma	To bark	80.212	57.719	18.767
Mona	Go mona	To suck	70.174	38.570	32.527
Nyanya	Go nyanya	To suckle	66.778	31.979	17.509
Phaka	Go phaka	To park	-	56.805	-
Rata	Go rata	To love	-	361.317	-
Roka	Go roka	To stitch	-	38.936	-
Thala	Go thala	To draw a line	62.154	51.378	24.642
Thopa	Go thopa	To win	-	22.942	26.308
Tima	Go tima	To put out/ extinguish a fire	42.402	44.680	34.143
Long utterances					
Bata	Monna o a bata	The man flattens by pounding	-	22.713	-
Bona	Monna o a bona	The man sees	31.377	29.795	5.542
Bopa	Monna o a bopa	The man moulds clay	-	24.418	-
Fala	Monna o a fala	The man scrapes clean	30.148	35.906	21.882
Fega	Monna o a fega	The man hangs	-	32.093	-
Fela	Meetse a a fela	The water is finished	23.164	37.805	4.587
Gama	Monna o a gama	The man milks	36.139	16.583	7.742
Goba	Mpša e a goba	The dog barks	43.757	35.638	6.419
Kala	Monna o a kala	The man weighs with a scale	40.355	30.865	6.682
Kgala	Monna o a kgala	The man reprimands	21.327	25.305	9.923
Kgoka	Monna o a kgoka	The man binds	43.533	31.611	29.697
Loma	Mpša e a loma	The dog bites	33.881	30.438	12.433
Mona	Monna o a mona	The man sucks	28.695	17.935	11.145
Nyanya	Ngwana o a nyanya	The baby suckles	28.695	17.264	7.250
Phaka	Monna o a phaka	The man parks	-	19.879	-
Rata	Monna o a rata	The man loves	-	27.300	-
Roka	Monna o a roka	The man stitches	-	83.518	-
Thala	Monna o a thala	The man draws a line	41.702	28.357	13.086
Thopa	Monna o a thopa	The man wins	-	65.248	7.779
Tima	Monna o a tima	The man extinguishes a fire	13.453	27.532	24.296

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Raw data: Mean F_0 of S1 and S2 for C3

Word	Translation	Mean F_0 S1	Mean F_0 S2
Short utterances			
Bata	To flatten by pounding	175.593	148.628
Bona	To see	187.609	160.107
Bopa	To mould/ fashion with clay	187.733	255.406
Fala	To scrape clean	191.992	145.690
Fega	To hang/ suspend	187.566	147.068
Fela	To finish	186.816	145.794
Gama	To milk a cow	172.173	150.291
Goba	To bark	191.784	158.715
Kala	To weigh with a scale	189.398	141.834
Kgala	To bind	230.056	101.938
Kgoka	To reprimand/ warn/ prevent from doing	208.595	151.928
Loma	To bark	201.394	157.266
Mona	To suck	185.162	148.689
Nyanya	To suckle	128.902	96.733
Phaka	To park	201.102	161.824
Rata	To love	188.326	152.037
Roka	To stitch	180.499	143.586
Thala	To draw a line	196.623	147.970
Thopa	To win	206.583	152.557
Tima	To put out/ extinguish a fire	210.068	155.536
Long utterances			
Bata	To flatten by pounding	169.813	147.105
Bona	To see	162.492	154.409
Bopa	To mould/ fashion with clay	170.321	140.986
Fala	To scrape clean	172.529	146.634
Fega	To hang/ suspend	169.942	146.136
Fela	To finish	175.776	150.850
Gama	To milk a cow	168.591	147.714
Goba	To bark	168.087	140.779
Kala	To weigh with a scale	175.131	147.430
Kgala	To bind	174.898	150.381
Kgoka	To reprimand/ warn/ prevent from doing	182.401	219.567
Loma	To bark	177.647	151.377
Mona	To suck	164.421	141.694
Nyanya	To suckle	174.070	155.551
Phaka	To park	187.040	162.002
Rata	To love	169.940	146.121
Roka	To stitch	166.074	150.001
Thala	To draw a line	155.535	145.657
Thopa	To win	177.145	143.955
Tima	To put out/ extinguish a fire	190.073	154.421

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Raw data: Aspects of tone variation in short and long utterances for C3

Word	Utterance	Translation	Change in F_0 across word (Hz)	Change in F_0 within S1 (Hz)	Change in F_0 within S2 (Hz)
Short utterances					
Bata	Go bata	To flatten by pounding	56.094	45.056	21.009
Bona	Go bona	To see	52.368	42.686	18.009
Bopa	Go bopa	To mould/ fashion with clay	55.789	34.019	4.964
Fala	Go fala	To scrape clean	62.549	45.237	9.806
Fega	Go fega	To hang/ suspend	58.568	39.335	3.963
Fela	Go fela	To finish	57.128	43.228	10.170
Gama	Go gama	To milk a cow	42.082	37.703	15.390
Goba	Go goba	To bark	72.454	69.300	22.879
Kala	Go kala	To weigh with a scale	284.746	18.147	67.862
Kgala	Go kgala	To bind	411.507	324.044	86.896
Kgoka	Go Kgoka	To reprimand/ warn/ prevent from doing	77.304	28.151	16.846
Loma	Go loma	To bark	76.531	51.932	22.342
Mona	Go mona	To suck	62.735	43.284	14.210
Nyanya	Go nyanya	To suckle	52.514	45.000	12.101
Phaka	Go phaka	To park	63.650	37.877	12.558
Rata	Go rata	To love	57.233	45.780	8.572
Roka	Go roka	To stitch	55.246	25.096	12.528
Thala	Go thala	To draw a line	63.453	50.815	5.696
Thopa	Go thopa	To win	77.408	50.279	10.113
Tima	Go tima	To put out/ extinguish a fire	73.478	47.205	19.079
Long utterances					
Bata	Monna o a bata	The man flattens by pounding	30.964	16.660	12.180
Bona	Monna o a bona	The man sees	13.693	16.937	4.172
Bopa	Monna o a bopa	The man moulds clay	45.956	23.811	10.749
Fala	Monna o a fala	The man scrapes clean	37.763	20.368	14.516
Fega	Monna o a fega	The man hangs	37.424	27.627	3.653
Fela	Meetse a a fela	The water is finished	39.280	17.201	19.552
Gama	Monna o a gama	The man milks	28.850	8.959	9.241
Goba	Mpša e a goba	The dog barks	44.932	15.092	21.299
Kala	Monna o a kala	The man weighs with a scale	41.302	14.896	27.482
Kgala	Monna o a kgala	The man reprimands	36.009	18.161	9.179
Kgoka	Monna o a kgoka	The man binds	60.609	20.796	377.686
Loma	Mpša e a loma	The dog bites	38.728	15.031	16.023
Mona	Monna o a mona	The man sucks	37.625	15.473	20.859
Nyanya	Ngwana o a nyanya	The baby suckles	37.733	21.270	19.199
Phaka	Monna o a phaka	The man parks	46.755	22.019	17.137
Rata	Monna o a rata	The man loves	38.008	24.381	8.834
Roka	Monna o a roka	The man stitches	24.829	15.305	4.108
Thala	Monna o a thala	The man draws a line	17.974	14.547	7.774
Thopa	Monna o a thopa	The man wins	55.645	9.113	5.670
Tima	Monna o a tima	The man extinguishes a fire	49.721	6.048	28.231

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Raw data: Mean F_0 of S1 and S2 for C4

Word	Translation	Mean F_0 S1	Mean F_0 S2
Short utterances			
Bata	To flatten by pounding	131.222	97.626
Bona	To see	128.273	95.72
Bopa	To mould/ fashion with clay	133.461	92.877
Fala	To scrape clean	131.577	101.465
Fega	To hang/ suspend	142.884	97.873
Fela	To finish	138.385	98.839
Gama	To milk a cow	124.397	95.628
Goba	To bark	126.359	99.203
Kala	To weigh with a scale	127.289	94.796
Kgala	To bind	135.634	86.229
Kgoka	To reprimand/ warn/ prevent from doing	226.915	-
Loma	To bark	130.232	104.918
Mona	To suck	131.847	100.276
Nyanya	To suckle	128.902	96.733
Phaka	To park	130.932	-
Rata	To love	125.903	91.183
Roka	To stitch	131.298	98.698
Thala	To draw a line	124.488	91.598
Thopa	To win	141.62	100.144
Tima	To put out/ extinguish a fire	156.547	101.231
Long utterances			
Bata	To flatten by pounding	104.385	-
Bona	To see	107.913	86.138
Bopa	To mould/ fashion with clay	120.89	96.267
Fala	To scrape clean	108.728	90.011
Fega	To hang/ suspend	108.982	91.296
Fela	To finish	117.735	93.095
Gama	To milk a cow	105.25	86.045
Goba	To bark	106.986	90.52
Kala	To weigh with a scale	104.513	84.279
Kgala	To bind	115.024	89.631
Kgoka	To reprimand/ warn/ prevent from doing	138.216	142.781
Loma	To bark	109.18	94.792
Mona	To suck	113.328	92.554
Nyanya	To suckle	112.263	95.095
Phaka	To park	108.479	241.56
Rata	To love	103.689	-
Roka	To stitch	110.894	89.178
Thala	To draw a line	109.306	87.406
Thopa	To win	119.258	90.25
Tima	To put out/ extinguish a fire	124.342	97.129

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Raw data: Aspects of tone variation in short and long utterances for C4

Word	Utterance	Translation	Change in F_0 across word (Hz)	Change in F_0 within S1 (Hz)	Change in F_0 within S2 (Hz)
Short utterances					
Bata	Go bata	To flatten by pounding	46.804	31.083	3.946
Bona	Go bona	To see	48.730	37.496	11.633
Bopa	Go bopa	To mould/ fashion with clay	134.740	117.704	9.940
Fala	Go fala	To scrape clean	66.490	39.252	6.657
Fega	Go fega	To hang/ suspend	65.422	31.112	8.585
Fela	Go fela	To finish	55.259	26.193	7.855
Gama	Go gama	To milk a cow	47.572	31.610	14.648
Goba	Go goba	To bark	47.860	43.613	6.440
Kala	Go kala	To weigh with a scale	61.191	43.607	13.963
Kgala	Go kgala	To bind	67.366	34.448	7.387
Kgoka	Go Kgoka	To reprimand/ warn/ prevent from doing	-	418.604	-
Loma	Go loma	To bark	44.106	28.764	11.182
Mona	Go mona	To suck	55.359	27.903	23.325
Nyanya	Go nyanya	To suckle	43.869	20.080	5.627
Phaka	Go phaka	To park	-	45.343	-
Rata	Go rata	To love	40.107	18.366	1.304
Roka	Go roka	To stitch	45.518	28.432	6.343
Thala	Go thala	To draw a line	54.032	34.426	13.661
Thopa	Go thopa	To win	67.109	49.247	12.765
Tima	Go tima	To put out/ extinguish a fire	82.409	53.998	16.686
Long utterances					
Bata	Monna o a bata	The man flattens by pounding	-	14.686	-
Bona	Monna o a bona	The man sees	33.634	24.115	3.430
Bopa	Monna o a bopa	The man moulds clay	31.669	21.485	2.577
Fala	Monna o a fala	The man scrapes clean	27.838	16.723	2.481
Fega	Monna o a fega	The man hangs	26.305	15.418	5.745
Fela	Meetse a a fela	The water is finished	37.203	18.929	5.208
Gama	Monna o a gama	The man milks	30.546	14.774	14.282
Goba	Mpša e a goba	The dog barks	25.230	20.294	5.954
Kala	Monna o a kala	The man weighs with a scale	33.387	19.128	8.182
Kgala	Monna o a kgala	The man reprimands	40.407	32.945	4.137
Kgoka	Monna o a kgoka	The man binds	328.944	319.395	213.632
Loma	Mpša e a loma	The dog bites	21.767	13.187	6.863
Mona	Monna o a mona	The man sucks	38.868	24.874	7.197
Nyanya	Ngwana o a nyanya	The baby suckles	24.299	14.500	7.389
Phaka	Monna o a phaka	The man parks	50.585	22.908	412.538
Rata	Monna o a rata	The man loves	-	17.175	-
Roka	Monna o a roka	The man stitches	28.428	17.142	3.945
Thala	Monna o a thala	The man draws a line	37.966	26.648	6.907
Thopa	Monna o a thopa	The man wins	53.497	36.537	6.580
Tima	Monna o a tima	The man extinguishes a fire	37.953	27.440	7.218

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Raw data: Mean F0 of S1 and S2 for C5

Word	Translation	Mean F_0 S1	Mean F_0 S2
Short utterances			
Bata	To flatten by pounding	215.964	175.774
Bona	To see	224.004	177.517
Bopa	To mould/ fashion with clay	233.682	184.815
Fala	To scrape clean	222.711	158.402
Fega	To hang/ suspend	227.994	181.346
Fela	To finish	209.369	151.496
Gama	To milk a cow	218.873	175.39
Goba	To bark	236.752	176.225
Kala	To weigh with a scale	229.037	162.307
Kgala	To bind	227.756	165.07
Kgoka	To reprimand/ warn/ prevent from doing	229.31	181.595
Loma	To bark	236.182	155.084
Mona	To suck	229.543	171.706
Nyanya	To suckle	220.888	171.364
Phaka	To park	213.226	149.874
Rata	To love	232.482	166.83
Roka	To stitch	228.814	170.411
Thala	To draw a line	234.408	168.581
Thopa	To win	239.038	174.138
Tima	To put out/ extinguish a fire	249.368	178.683
Long utterances			
Bata	To flatten by pounding	198.207	-
Bona	To see	204.477	174.487
Bopa	To mould/ fashion with clay	204.482	130.227
Fala	To scrape clean	222.815	159.431
Fega	To hang/ suspend	190.303	166.493
Fela	To finish	194.132	154.552
Gama	To milk a cow	194.595	175.28
Goba	To bark	205.446	162.721
Kala	To weigh with a scale	197.77	151.247
Kgala	To bind	195.442	154.172
Kgoka	To reprimand/ warn/ prevent from doing	209.925	174.789
Loma	To bark	236.314	158.35
Mona	To suck	201.781	149.361
Nyanya	To suckle	199.175	175.021
Phaka	To park	188.217	143.129
Rata	To love	193.892	-
Roka	To stitch	188.406	85.932
Thala	To draw a line	197.776	150.242
Thopa	To win	210.09	170.648
Tima	To put out/ extinguish a fire	227.605	168.8

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Raw data: Aspects of tone variation in short and long utterances for C5

Word	Utterance	Translation	Change in F_0 across word (Hz)	Change in F_0 within S1 (Hz)	Change in F_0 within S2 (Hz)
Short utterances					
Bata	Go bata	To flatten by pounding	71.828	52.638	30.685
Bona	Go bona	To see	102.468	73.701	57.856
Bopa	Go bopa	To mould/ fashion with clay	102.364	91.763	18.836
Fala	Go fala	To scrape clean	124.682	108.798	12.969
Fega	Go fega	To hang/ suspend	117.854	109.377	23.240
Fela	Go fela	To finish	114.234	101.983	10.785
Gama	Go gama	To milk a cow	84.972	61.729	35.853
Goba	Go goba	To bark	107.518	91.269	18.952
Kala	Go kala	To weigh with a scale	123.830	99.487	23.289
Kgala	Go kgala	To bind	151.040	129.507	22.455
Kgoka	Go Kgoka	To reprimand/ warn/ prevent from doing	114.693	102.199	8.819
Loma	Go loma	To bark	183.153	79.769	115.554
Mona	Go mona	To suck	97.705	67.018	22.376
Nyanya	Go nyanya	To suckle	90.923	75.994	14.907
Phaka	Go phaka	To park	180.419	111.019	76.148
Rata	Go rata	To love	103.106	75.811	13.958
Roka	Go roka	To stitch	104.682	86.860	19.736
Thala	Go thala	To draw a line	122.072	110.806	10.760
Thopa	Go thopa	To win	128.280	120.994	7.070
Tima	Go tima	To put out/ extinguish a fire	128.977	90.339	46.408
Long utterances					
Bata	Monna o a bata	The man flattens by pounding	-	33.358	-
Bona	Monna o a bona	The man sees	54.767	31.190	32.299
Bopa	Monna o a bopa	The man moulds clay	134.404	47.585	85.484
Fala	Monna o a fala	The man scrapes clean	122.004	104.382	16.814
Fega	Monna o a fega	The man hangs	50.497	48.486	4.883
Fela	Meetse a a fela	The water is finished	66.952	44.789	10.640
Gama	Monna o a gama	The man milks	40.103	30.837	19.929
Goba	Mpša e a goba	The dog barks	75.199	56.799	11.196
Kala	Monna o a kala	The man weighs with a scale	133.320	44.004	87.402
Kgala	Monna o a kgala	The man reprimands	97.769	56.013	41.618
Kgoka	Monna o a kgoka	The man binds	88.641	89.140	17.054
Loma	Mpša e a loma	The dog bites	174.136	78.407	104.822
Mona	Monna o a mona	The man sucks	140.955	32.686	105.759
Nyanya	Ngwana o a nyanya	The baby suckles	44.995	29.030	16.983
Phaka	Monna o a phaka	The man parks	92.094	68.440	5.450
Rata	Monna o a rata	The man loves	-	22.831	-
Roka	Monna o a roka	The man stitches	125.570	43.090	18.362
Thala	Monna o a thala	The man draws a line	100.489	76.192	23.324
Thopa	Monna o a thopa	The man wins	88.999	85.484	10.206
Tima	Monna o a tima	The man extinguishes a fire	87.683	45.155	31.824

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Raw data: Mean F_0 of S1 and S2 for P1

Word	Translation	Mean F_0 S1	Mean F_0 S2
Short utterances			
Bata	To flatten by pounding	157.024	-
Bona	To see	167.504	127.452
Bopa	To mould/ fashion with clay	174.296	121.777
Fala	To scrape clean	175.649	258.927
Fega	To hang/ suspend	159.397	-
Fela	To finish	190.512	122.144
Gama	To milk a cow	166.689	117.418
Goba	To bark	178.496	137.012
Kala	To weigh with a scale	177.878	144.706
Kgala	To bind	165.205	139.818
Kgoka	To reprimand/ warn/ prevent from doing	179.725	-
Loma	To bark	180.619	143.313
Mona	To suck	161.642	132.624
Nyanya	To suckle	152.965	140.574
Phaka	To park	148.174	-
Rata	To love	176.146	-
Roka	To stitch	118.15	443.341
Thala	To draw a line	154.02	-
Thopa	To win	177.164	84.867
Tima	To put out/ extinguish a fire	183.236	148.222
Long utterances			
Bata	To flatten by pounding	153.985	-
Bona	To see	133.768	131.437
Bopa	To mould/ fashion with clay	146.98	105.3
Fala	To scrape clean	137.493	82.868
Fega	To hang/ suspend	292.972	-
Fela	To finish	153.003	131.41
Gama	To milk a cow	134.439	141.488
Goba	To bark	154.751	-
Kala	To weigh with a scale	149.212	222.071
Kgala	To bind	122.63	-
Kgoka	To reprimand/ warn/ prevent from doing	120.507	-
Loma	To bark	150.495	121.794
Mona	To suck	150.683	114.916
Nyanya	To suckle	152.946	130.553
Phaka	To park	127.615	-
Rata	To love	132.247	-
Roka	To stitch	140.198	455.475
Thala	To draw a line	82.113	-
Thopa	To win	159.26	-
Tima	To put out/ extinguish a fire	152.536	127.471

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Raw data: Aspects of tone variation in short and long utterances for P1

Word	Utterance	Translation	Change in F_0 across word (Hz)	Change in F_0 within S1 (Hz)	Change in F_0 within S2 (Hz)
		Short utterances			
Bata	Go bata	To flatten by pounding	-	38.309	-
Bona	Go bona	To see	95.334	71.642	32.254
Bopa	Go bopa	To mould/ fashion with clay	66.434	43.448	5.266
Fala	Go fala	To scrape clean	51.065	120.698	25.071
Fega	Go fega	To hang/ suspend	-	40.292	-
Fela	Go fela	To finish	421.379	413.673	30.388
Gama	Go gama	To milk a cow	126.281	61.987	85.498
Goba	Go goba	To bark	59.191	29.589	23.376
Kala	Go kala	To weigh with a scale	71.004	44.284	31.232
Kgala	Go kgala	To bind	68.172	66.569	39.862
Kgoka	Go Kgoka	To reprimand/ warn/ prevent from doing	-	31.958	-
Loma	Go loma	To bark	71.317	50.616	41.443
Mona	Go mona	To suck	56.224	33.186	27.334
Nyanya	Go nyanya	To suckle	65.456	107.160	24.124
Phaka	Go phaka	To park	-	107.912	-
Rata	Go rata	To love	-	23.816	-
Roka	Go roka	To stitch	245.364	114.993	18.273
Thala	Go thala	To draw a line	-	46.084	-
Thopa	Go thopa	To win	127.465	61.684	12.096
Tima	Go tima	To put out/ extinguish a fire	96.413	64.676	34.179
		Long utterances			
Bata	Monna o a bata	The man flattens by pounding	-	30.861	-
Bona	Monna o a bona	The man sees	47.073	48.254	23.110
Bopa	Monna o a bopa	The man moulds clay	52.671	27.339	0.683
Fala	Monna o a fala	The man scrapes clean	80.308	80.130	14.107
Fega	Monna o a fega	The man hangs	-	391.808	-
Fela	Meetse a a fela	The water is finished	63.036	74.806	17.092
Gama	Monna o a gama	The man milks	18.116	73.918	20.665
Goba	Mpša e a goba	The dog barks	-	38.658	-
Kala	Monna o a kala	The man weighs with a scale	48.952	45.685	154.481
Kgala	Monna o a kgala	The man reprimands	-	82.786	-
Kgoka	Monna o a kgoka	The man binds	-	93.841	-
Loma	Mpša e a loma	The dog bites	51.777	36.079	16.054
Mona	Monna o a mona	The man sucks	66.355	36.209	28.469
Nyanya	Ngwana o a nyanya	The baby suckles	45.649	36.349	15.614
Phaka	Monna o a phaka	The man parks	-	9.064	-
Rata	Monna o a rata	The man loves	-	42.546	-
Roka	Monna o a roka	The man stitches	316.297	19.459	12.371
Thala	Monna o a thala	The man draws a line	-	0	-
Thopa	Monna o a thopa	The man wins	-	11.450	-
Tima	Monna o a tima	The man extinguishes a fire	47.958	32.153	21.425

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Raw data: Mean F_0 of S1 and S2 for P2

Word	Translation	Mean F_0 S1	Mean F_0 S2
Short utterances			
Bata	To flatten by pounding	131.671	-
Bona	To see	132.373	122.182
Bopa	To mould/ fashion with clay	136.001	111.661
Fala	To scrape clean	140.425	117.702
Fega	To hang/ suspend	173.482	-
Fela	To finish	141.346	119.328
Gama	To milk a cow	139.114	117.407
Goba	To bark	145.113	120.211
Kala	To weigh with a scale	135.703	-
Kgala	To bind	137.681	-
Kgoka	To reprimand/ warn/ prevent from doing	148.069	122.867
Loma	To bark	145.988	126.37
Mona	To suck	141.262	120.949
Nyanya	To suckle	139.138	132.2
Phaka	To park	137.843	-
Rata	To love	134.785	-
Roka	To stitch	140.21	122.821
Thala	To draw a line	134.624	-
Thopa	To win	140.793	-
Tima	To put out/ extinguish a fire	151.452	123.939
Long utterances			
Bata	To flatten by pounding	127.833	-
Bona	To see	122.813	257.399
Bopa	To mould/ fashion with clay	140.087	121.831
Fala	To scrape clean	128.799	-
Fega	To hang/ suspend	131.627	-
Fela	To finish	141.391	132.441
Gama	To milk a cow	137.121	123.83
Goba	To bark	135.293	109.333
Kala	To weigh with a scale	133.707	-
Kgala	To bind	149.818	115.262
Kgoka	To reprimand/ warn/ prevent from doing	138.072	120.454
Loma	To bark	142.363	129.518
Mona	To suck	134.938	133.262
Nyanya	To suckle	140.888	132.065
Phaka	To park	126.39	121.302
Rata	To love	132.309	-
Roka	To stitch	133.446	124.922
Thala	To draw a line	139.389	122.264
Thopa	To win	128.42	130.897
Tima	To put out/ extinguish a fire	147.166	124.906

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Raw data: Aspects of tone variation in short and long utterances for P2

Word	Utterance	Translation	Change in F_0 across word (Hz)	Change in F_0 within S1 (Hz)	Change in F_0 within S2 (Hz)
		Short utterances			
Bata	Go bata	To flatten by pounding	-	22.482	-
Bona	Go bona	To see	20.434	5.408	14.419
Bopa	Go bopa	To mould/ fashion with clay	36.974	23.641	7.610
Fala	Go fala	To scrape clean	39.665	36.427	10.008
Fega	Go fega	To hang/ suspend	-	403.449	-
Fela	Go fela	To finish	54.792	49.205	11.388
Gama	Go gama	To milk a cow	31.530	24.688	5.696
Goba	Go goba	To bark	42.592	35.090	12.734
Kala	Go kala	To weigh with a scale	-	27.313	-
Kgala	Go kgala	To bind	-	32.363	-
Kgoka	Go Kgoka	To reprimand/ warn/ prevent from doing	40.895	35.770	5.548
Loma	Go loma	To bark	33.367	21.839	15.857
Mona	Go mona	To suck	34.664	27.768	6.153
Nyanya	Go nyanya	To suckle	20.528	13.754	12.464
Phaka	Go phaka	To park	-	21.584	-
Rata	Go rata	To love	-	13.226	-
Roka	Go roka	To stitch	29.677	25.797	6.027
Thala	Go thala	To draw a line	-	39.825	-
Thopa	Go thopa	To win	-	26.778	-
Tima	Go tima	To put out/ extinguish a fire	46.267	32.837	11.657
		Long utterances			
Bata	Monna o a bata	The man flattens by pounding	-	20.692	-
Bona	Monna o a bona	The man sees	124.371	14.283	8.325
Bopa	Monna o a bopa	The man moulds clay	27.596	19.921	1.914
Fala	Monna o a fala	The man scrapes clean	-	6.625	-
Fega	Monna o a fega	The man hangs	-	12.960	-
Fela	Meetse a a fela	The water is finished	20.637	13.536	7.286
Gama	Monna o a gama	The man milks	19.849	14.677	3.260
Goba	Mpša e a goba	The dog barks	46.560	21.740	23.852
Kala	Monna o a kala	The man weighs with a scale	-	28.032	-
Kgala	Monna o a kgala	The man reprimands	329.949	322.001	9.440
Kgoka	Monna o a kgoka	The man binds	31.118	20.248	10.070
Loma	Mpša e a loma	The dog bites	23.102	9.578	13.455
Mona	Monna o a mona	The man sucks	15.665	22.625	26.107
Nyanya	Ngwana o a nyanya	The baby suckles	20.213	13.354	6.196
Phaka	Monna o a phaka	The man parks	11.209	9.706	6.567
Rata	Monna o a rata	The man loves	-	13.759	-
Roka	Monna o a roka	The man stitches	17.566	18.327	3.497
Thala	Monna o a thala	The man draws a line	28.817	22.690	4.822
Thopa	Monna o a thopa	The man wins	4.132	16.845	0.679
Tima	Monna o a tima	The man extinguishes a fire	40.414	18.492	21.533

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Raw data: Mean F_0 of S1 and S1 for P3

Word	Translation	Mean F_0 S1	Mean F_0 S2
Short utterances			
Bata	To flatten by pounding	218.107	204.461
Bona	To see	225.206	199.796
Bopa	To mould/ fashion with clay	218.334	206.058
Fala	To scrape clean	221.835	205.259
Fega	To hang/ suspend	236.852	212.957
Fela	To finish	231.776	210.39
Gama	To milk a cow	200.26	198.049
Goba	To bark	217.95	207.252
Kala	To weigh with a scale	223.951	196.676
Kgala	To bind	220.356	210.608
Kgoka	To reprimand/ warn/ prevent from doing	240.949	218.394
Loma	To bark	246.103	225.818
Mona	To suck	219.128	207.558
Nyanya	To suckle	228.726	197.21
Phaka	To park	216.722	187.876
Rata	To love	231.42	216.629
Roka	To stitch	233.571	254.934
Thala	To draw a line	232.466	210.102
Thopa	To win	203.386	203.138
Tima	To put out/ extinguish a fire	243.307	206.121
Long utterances			
Bata	To flatten by pounding	225.922	205.377
Bona	To see	199.439	185.952
Bopa	To mould/ fashion with clay	226.154	213.349
Fala	To scrape clean	210.448	195.32
Fega	To hang/ suspend	218.995	203.535
Fela	To finish	225.363	208.727
Gama	To milk a cow	206.848	191.721
Goba	To bark	218.62	204.976
Kala	To weigh with a scale	206.775	186.546
Kgala	To bind	223.775	206.029
Kgoka	To reprimand/ warn/ prevent from doing	142.057	203.964
Loma	To bark	233.758	204.22
Mona	To suck	222.303	201.524
Nyanya	To suckle	231.87	202.935
Phaka	To park	218.104	190.991
Rata	To love	218.554	203.27
Roka	To stitch	215.273	195.409
Thala	To draw a line	220.702	193.81
Thopa	To win	221.552	196.971
Tima	To put out/ extinguish a fire	239.213	199.652

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Raw data: Aspects of tone variation in short and long utterances for P3

Word	Utterance	Translation	Change in F_0 across word (Hz)	Change in F_0 within S1 (Hz)	Change in F_0 within S2 (Hz)
		Short utterances			
Bata	Go bata	To flatten by pounding	46.673	51.017	49.757
Bona	Go bona	To see	66.394	23.461	48.797
Bopa	Go bopa	To mould/ fashion with clay	62.530	42.706	71.128
Fala	Go fala	To scrape clean	45.990	18.716	40.357
Fega	Go fega	To hang/ suspend	57.362	37.591	34.367
Fela	Go fela	To finish	63.057	53.419	49.202
Gama	Go gama	To milk a cow	25.612	21.172	23.579
Goba	Go goba	To bark	60.771	25.012	59.927
Kala	Go kala	To weigh with a scale	49.687	31.623	21.194
Kgala	Go kgala	To bind	26.746	21.752	19.821
Kgoka	Go Kgoka	To reprimand/ warn/ prevent from doing	57.437	37.590	40.028
Loma	Go loma	To bark	60.558	6.892	56.920
Mona	Go mona	To suck	47.870	22.691	44.694
Nyanya	Go nyanya	To suckle	69.665	11.864	15.642
Phaka	Go phaka	To park	55.266	52.547	15.642
Rata	Go rata	To love	59.452	47.246	46.229
Roka	Go roka	To stitch	66.285	58.243	277.502
Thala	Go thala	To draw a line	52.401	23.627	35.471
Thopa	Go thopa	To win	69.068	155.309	40.839
Tima	Go tima	To put out/ extinguish a fire	68.872	21.291	37.688
		Long utterances			
Bata	Monna o a bata	The man flattens by pounding	44.914	18.674	3.396
Bona	Monna o a bona	The man sees	41.997	17.759	36.592
Bopa	Monna o a bopa	The man moulds clay	46.376	9.245	43.020
Fala	Monna o a fala	The man scrapes clean	47.808	14.362	43.352
Fega	Monna o a fega	The man hangs	51.295	35.424	35.383
Fela	Meetse a a fela	The water is finished	50.007	48.979	30.366
Gama	Monna o a gama	The man milks	38.957	10.304	30.074
Goba	Mpša e a goba	The dog barks	38.838	21.706	34.408
Kala	Monna o a kala	The man weighs with a scale	37.839	11.742	23.491
Kgala	Monna o a kgala	The man reprimands	54.822	19.196	55.326
Kgoka	Monna o a kgoka	The man binds	28.056	126.051	26.932
Loma	Mpša e a loma	The dog bites	72.429	70.548	68.547
Mona	Monna o a mona	The man sucks	64.049	38.862	60.906
Nyanya	Ngwana o a nyanya	The baby suckles	66.894	9.550	57.344
Phaka	Monna o a phaka	The man parks	47.406	26.072	26.671
Rata	Monna o a rata	The man loves	41.146	5.732	42.384
Roka	Monna o a roka	The man stitches	48.290	19.253	42.408
Thala	Monna o a thala	The man draws a line	56.684	26.977	39.448
Thopa	Monna o a thopa	The man wins	63.127	45.805	40.683
Tima	Monna o a tima	The man extinguishes a fire	69.459	40.228	31.933

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Raw data: Mean F_0 of S1 and S2 for P4

Word	Translation	Mean F_0 S1	Mean F_0 S2
Short utterances			
Bata	To flatten by pounding	281.183	-
Bona	To see	116.398	93.674
Bopa	To mould/ fashion with clay	110.933	-
Fala	To scrape clean	-	83.468
Fega	To hang/ suspend	116.225	-
Fela	To finish	118.465	-
Gama	To milk a cow	112.853	82.173
Goba	To bark	166.88	500.14
Kala	To weigh with a scale	-	-
Kgala	To bind	215.988	81.274
Kgoka	To reprimand/ warn/ prevent from doing	118.352	-
Loma	To bark	105.746	86.563
Mona	To suck	191.198	81.691
Nyanya	To suckle	111.03	-
Phaka	To park	117.564	-
Rata	To love	-	-
Roka	To stitch	-	-
Thala	To draw a line	-	-
Thopa	To win	113.065	97.515
Tima	To put out/ extinguish a fire	108.353	196.178
Long utterances			
Bata	To flatten by pounding		481.547
Bona	To see	103.164	85.417
Bopa	To mould/ fashion with clay	107.606	494.543
Fala	To scrape clean	86.685	80.007
Fega	To hang/ suspend	107.85	-
Fela	To finish	-	-
Gama	To milk a cow	98.708	82.583
Goba	To bark	100.654	-
Kala	To weigh with a scale	89.025	76.532
Kgala	To bind	103.329	84.048
Kgoka	To reprimand/ warn/ prevent from doing	96.24	-
Loma	To bark	106.832	227.007
Mona	To suck	95.256	-
Nyanya	To suckle	111.622	-
Phaka	To park	-	-
Rata	To love	107.422	-
Roka	To stitch	99.431	362.352
Thala	To draw a line	105.553	-
Thopa	To win	102.952	-
Tima	To put out/ extinguish a fire	103.243	81.817

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Raw data: Aspects of tone variation in short and long utterances for P4

Word	Utterance	Translation	Change in F_0 across word (Hz)	Change in F_0 within S1 (Hz)	Change in F_0 within S2 (Hz)
		Short utterances			
Bata	Go bata	To flatten by pounding	-	447.301	-
Bona	Go bona	To see	32.901	8.821	17.494
Bopa	Go bopa	To mould/ fashion with clay	-	36.686	-
Fala	Go fala	To scrape clean	-	-	2.785
Fega	Go fega	To hang/ suspend	-	7.122	-
Fela	Go fela	To finish	-	28.898	-
Gama	Go gama	To milk a cow	37.577	8.556	4.568
Goba	Go goba	To bark	226.920	132.419	66.997
Kala	Go kala	To weigh with a scale	-	-	-
Kgala	Go kgala	To bind	444.181	424.545	0.383
Kgoka	Go Kgoka	To reprimand/ warn/ prevent from doing	-	20.480	-
Loma	Go loma	To bark	37.941	26.776	15.886
Mona	Go mona	To suck	163.611	150.334	4.790
Nyanya	Go nyanya	To suckle	-	10.798	-
Phaka	Go phaka	To park	-	17.257	-
Rata	Go rata	To love	-	-	-
Roka	Go roka	To stitch	-	-	-
Thala	Go thala	To draw a line	-	-	-
Thopa	Go thopa	To win	25.280	21.180	4.365
Tima	Go tima	To put out/ extinguish a fire	43.251	21.180	4.365
Bata	Monna o a bata	The man flattens by pounding	-	-	33.508
Bona	Monna o a bona	The man sees	33.704	22.345	11.176
Bopa	Monna o a bopa	The man moulds clay	316.922	38.518	92.787
Fala	Monna o a fala	The man scrapes clean	21.655	22.298	2.050
Fega	Monna o a fega	The man hangs	-	22.243	-
Fela	Meetse a a fela	The water is finished	-	-	-
Gama	Monna o a gama	The man milks	20.434	0.599	7.689
Goba	Mpša e a goba	The dog barks	-	30.761	-
Kala	Monna o a kala	The man weighs with a scale	21.754	16.831	3.490
Kgala	Monna o a kgala	The man reprimands	34.291	21.023	8.009
Kgoka	Monna o a kgoka	The man binds	-	32.461	-
Loma	Mpša e a loma	The dog bites	106.617	28.811	3.225
Mona	Monna o a mona	The man sucks	-	14.083	-
Nyanya	Ngwana o a nyanya	The baby suckles	-	22.352	-
Phaka	Monna o a phaka	The man parks	-	-	-
Rata	Monna o a rata	The man loves	-	4.080	-
Roka	Monna o a roka	The man stitches	25.921	32.634	436.793
Thala	Monna o a thala	The man draws a line	-	15.512	-
Thopa	Monna o a thopa	The man wins	-	33.062	-
Tima	Monna o a tima	The man extinguishes a fire	36.460	28.402	6.795

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Appendix J: List of devoiced syllables

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Devoicing of syllables by the control group

CVCV Word	Devoiced syllable	Participants who devoiced syllable
Short utterances		
-bata *(Flatten by pounding)*	S2	C1, C2
-kgoka *(Bind)*	S2	C4
-phaka *(Park)*	S2	C2, C4
-rata *(Love)*	S2	C2
-roka *(Stitch)*	S2	C2
-thopa *(Win)*	S2	C1
Long utterances		
-bata *(Flatten by pounding)*	S2	C1, C2, C4, C5
-bopa *(Bind)*	S2	C1, C2
-fega *(Hang)*	S2	C1, C2
-phaka *(Park)*	S2	C1, C2
-rata *(Love)*	S2	C1, C2, C4, C5
-roka *(Stitch)*	S2	C2
-thopa *(Win)*	S2	C1

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Devoicing of syllables by the dysarthria group

CVCV Word	Devoiced syllable	Participants who devoiced syllable
	Short utterances	
-bata *(Flatten by pounding)*	S2	P1, P2, P4
-bopa *(Bind)*	S2	P4
-fala *(Scrape clean)*	S1 and S2	P4
-fega *(Hang)*	S2	P1, P2, P4
-fela *(Finish)*	S2	P4
-kala *(Weigh with a scale)*	S1 and S2	P2, P4
-kgala *(Reprimand)*	S2	P2
-kgoka *(Bind)*	S2	P1, P4
-nyanya *(Suckle)*	S2	P4
-phaka *(Park)*	S2	P1, P2, P4
-rata *(Love)*	S1 and S2	P1, P2, P4
-roka *(Stitch)*	S1 and S2	P4
-thala *(Draw a line)*	S1 and S2	P1, P2, P4
	Long utterances	
-bata *(Flatten by pounding)*	S1 and S2	P1, P2, P4
-fala *(Scrape clean)*	S2	P2
-fega *(Hang)*	S2	P1, P2, P4
-fela *(Finish)*	S1 and S2	P4
-goba *(Bark)*	S2	P4
-kala *(Weigh with a scale)*	S2	P2
-kgala *(Reprimand)*	S2	P1
-kgoka *(Bind)*	S2	P1, P4
-mona *(Suck)*	S2	P4
-nyanya *(Suckle)*	S2	P4
-phaka *(Park)*	S1 and S2	P1, P4
-rata *(Love)*	S2	P1, P2, P4
-thala *(Draw a line)*	S2	P1, P4
-thopa *(Win)*	S2	P1, P4

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