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The Effect of Botulinum Toxin Type A on Speech Intelligibility in Oromandibular Dystonia

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THE EFFECT OF BOTULINUM TOXIN TYPE A ON SPEECH INTELLIGIBILITY IN OROMANDIBULAR DYSTONIA

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by

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Abstract

Speech intelligibility of 10 individuals with OMD was measured before and after receiving BoNT-A injections. Intelligibility was assessed using the PIT (single-word intelligibility), SIT (sentence intelligibility), and a conversational speech task. Five listeners rated the speech intelligibility of these three intelligibility tasks via orthographic transcription and visual analogue scaling (VAS) techniques. BoNT-A was not associated with significant differences in speech intelligibility. Further analysis revealed a significant difference on the PIT VAS intelligibility ratings based on order of presentation, suggesting that listeners rated the first half of words on the PIT (words 1-29) as more intelligible than the second half of words (words 30-57). There was also a significant difference in SIT transcription intelligibility scores based on sentence length, suggesting that listeners rated shorter sentences with higher intelligibility than longer sentences. This research will contribute to a small body of literature on speech intelligibility in OMD.

Keywords: speech intelligibility, oromandibular dystonia, botulinum toxin A, motor speech disorders, dysarthria, hyperkinetic dysarthria, speech production measurement, speech perception

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1 Introduction

1.1 Dystonia

Dystonia is defined as a neuromuscular disorder characterized by prolonged muscle contractions, causing repetitive movements and abnormal posturing (Brin & Comella, 2004; Jankovic, 2005; Shanker & Bressman, 2012). Dystonic contractions have been observed to be slower than those of tic disorders (Comella, 2005). There are currently no definitive tests or imaging techniques used to diagnose dystonia (Comella, 2005).

Dystonia can be classified in three different ways: distribution, age of onset, and etiology (Brin & Comella, 2004). It may be classified based on the distribution of body areas affected. There are five main categories, namely, focal, segmental, hemidystonia, multi-focal, or generalized. Focal dystonia is the most common category and is characterized by contractions of a single body region (Shanker & Bressman, 2012). Segmental dystonia results when more than one adjacent body regions are affected. Multi-focal dystonia occurs in non-adjacent distribution of affected regions. Hemidystonia is a subcategory of multi-focal dystonia which affects the arm and leg of the same side of the body. Lastly, generalized dystonia refers to the involvement of one two or more segments of the entire body, typically either the other leg or the trunk (Shanker & Bressman, 2012; Thyagarajan, 1999).

Dystonia can develop at any stage of the lifespan, from childhood to adulthood. Early onset primary dystonia, which occurs before the age of 20, has a mode of 9 years old, while late onset primary dystonia, which occurs after the age of 20, has a mode of 45 years old (Defazio, Abbruzzese, Livrea, & Berardelli, 2004; Shanker & Bressman, 2012). Age of onset is related to

disease spread making age of symptom onset an important determiner of prognosis. Typically, the earlier the age of onset, the higher the probability that dystonic symptoms will spread towards other regions of the body (Albanese et al., 2006).

When classifying based on etiology, dystonia can be either primary or secondary. If the condition is characterized by the absence of other clinical symptoms other than the dystonia itself and no identifiable cause has been found, it is known is primary or idiopathic dystonia (Brin & Comella, 2004). This means that the patient must not have any history of neurological abnormalities or genetic history that could lead to dystonia. In contrast, if the condition is symptomatic of drug use or disease, it is classified as secondary dystonia (Kaji, 2003; Thyagarajan, 1999). Drug-induced dystonia can be classified as either acute or tardive. Acute drug-induced dystonia occurs within a few days of antipsychotic treatment and can be treated with anticholinergic or antihistaminic drugs (Raja, 1998; van Harten, Hoek, & Kahn, 1999). Tardive drug-induced dystonia is associated with long-term use of antidopaminergics and is potentially irreversible (Raja, 1998; Tan & Jankovic, 2000; van Harten, Hoek, & Kahn, 1999). Examples of drugs associated with tardive dystonia are antiemetics such as droperidol, metoclopramide, prochlorperazine, and promethazine, psychotropics such as amoxapine, and neuroleptics, such as haloperidol and phenothiazines (Claxton, Chen, & Swope, 2007). Hemidystonia is usually secondary (Thyagarajan, 1999). Diseases that can result in secondary dystonia are Parkinson's disease, multiple sclerosis, encephalitis, Huntington's disease, and stroke (Shanker & Bressman, 2012). Spinocerebellar ataxia type 8 (SCA8) has also been associated with oromandibular and lingual dystonia (Ushe & Perlmutter, 2012).

Although the exact cause of dystonia is unknown, it has been recognized as a disease involving basal ganglia (Kaji, 2003; Tsui, 2005; Shanker & Bressman, 2012). Additionally, the

DYT1, genes have been noted to play a role in the onset of dystonia (Tsui, 2005, Tagliati, Pourfar, & Bressman, 2005).

The basal ganglia refer to a group of nuclei in the central nervous system that plan and execute motor movements (Mink, 2003). Lesions isolated to the putamen and globus pallidus of the basal ganglia are the most frequently associated with dystonia (Bhatia & Marsden, 1994). The extent of basal ganglia involvement in dystonia remains poorly understood; however, it has been hypothesized that dystonia results from reduced firing of neurons within the globus pallidus interna (GPi) . This decreased activity of GPi neurons leads to incomplete inhibition of competing motor movement patterns. Reduced inhibition of these surrounding motor patterns can lead to the involuntary contraction of neighbouring muscles (Mink, 2003).

The DYT1 gene has been implicated in causing the greatest number of primary dystonias that have been genetically researched (Tagliati et al., 2005). A deletion of a GAG sequence in DYT1 leads to dystonia (Tagliati et al., 2005). The DYT1 gene encodes torsinA, a protein that is involved in vesicle fusion and cytoskeletal dynamics (Tagliati et al., 2005).

1.2 Oromandibular Dystonia and Hyperkinetic Dysarthria

Oromandibular dystonia (OMD) is a focal dystonia affecting the mouth and face regions (Tan, 2004). It consists primarily of forceful involuntary muscular contractions of the face and tongue. These contractions may either be sustained or repetitive. Other terms for OMD are orofacial-buccal dystonia, jaw dystonia, lingual dystonia, cranial dystonia, and adult-onset facial dystonia (Schneider & Hoffman, 2011). In some cases, OMD occurs with blepharospasm, or involuntary contractions of the eyelids. This condition is called Meige's syndrome.

Because OMD involves contraction of the facial muscles, it may produce difficulty in mastication and swallowing (Bhidayasiri, Cardoso, & Truong, 2006; Lee, 2007). It may also lead to difficulties in opening and closing the mandible, and controlling the tongue and lips. These difficulties may lead to dysarthria, a cluster of speech disorders caused by neurological damage (Tan, 2004). Dysarthria is a disruption in speech movements, involving disturbances to muscle tone, reflexes, rate of speech, and accuracy (Freed, 2000). Dysarthria may or may not occur with other language disturbances.

There are several different types of dysarthria; however, the kind most associated with oromandibular dystonia is hyperkinetic dysarthria. Hyperkinetic dysarthrias refer to a heterogeneous group of motor speech disorders that are characterized by involuntary muscle movements (Duffy, 2013). Hyperkinetic dysarthrias may affect the respiratory, phonatory, resonatory, and articulatory aspects of speech, and may also affect prosody (Duffy, 2013). Hyperkinetic dysarthria, as a singular term, however, identifies a specific type of involuntary muscle movement that affects speech production (Duffy, 2013). The speech of patients with hyperkinetic dysarthria typically contains irregular breathing patterns, imprecise articulation, and abrupt changes in pitch, rate, and loudness (Darley, Aronson, & Brown, 1969b). These speech characteristics may contribute to a reduction in speech intelligibility, but do not all necessarily occur together in every type of hyperkinetic dysarthria. In other words, hyperkinetic dysarthria may be associated with different dysarthric profiles depending on the associated movement disorder. For example, in addition to OMD, hyperkinetic dysarthria is associated with Huntington's chorea, spasmodic dysphonia, and voice tremor, all of which present with unique and distinctive speech characteristics. Chorea involves motor unsteadiness and quick, unpredictable muscle movements (Duffy, 2013). The distinctive speech features encountered in

hyperkinetic dysarthria of chorea are articulatory, prosodic, and phonatory in nature and include imprecise consonants, prolonged intervals, variable rate, and inappropriate silences (Darley et al. 1969a). In hyperkinetic dysarthria associated with dystonia, the most affected aspects of speech are primarily articulatory in nature, and include imprecise consonants, distorted vowels, and irregular articulatory breakdowns (Duffy, 2013). The muscle movements of OMD are distinct from those of chorea. Dystonic muscle movements are slower than in chorea, and have been characterized as following a waxing and waning pattern (Duffy, 2013). Dystonia and chorea differ in the rhythm, range, and force of their muscular movements (Darley et al. 1969b). Specifically, the rhythm of individual muscle movements in dystonia involves slow involuntary movements, while those of chorea involve both quick and slow movements. Additionally, the muscle movements in dystonia can be characterized as having a reduced to normal range, while those in chorea present with reduced to excessive movements. Lastly, the force of muscle movements in dystonia is considered normal, while that of chorea is considered reduced to excessive (Darley et al., 1969b). Spasmodic dysphonia is also associated with hyperkinetic dysarthria. Spasmodic dysphonia refers to a group of voice disorders resulting from dystonic movements of laryngeal muscles (Duffy, 2013). Unlike chorea and OMD which primarily involve articulatory difficulties, spasmodic dysphonia refers to a group of voice disorders involving strained, jerky, and breathy voice qualities and (Duffy, 2013). The perceptual aspects of speech that are most affected by hyperkinetic dysarthria of spasmodic dysphonia are primarily phonatory, respiratory, and resonant in nature and involve strained, squeezed, and effortful voice quality, breathy or aphonic segments, and inappropriate silences (Duffy, 2013). These qualities differ from the characteristics of voice tremor, which is another example of a voice disorder associated with hyperkinetic dysarthria. It is distinct from, but sometimes associated with,

movement disorders such as dystonia (Duffy, 2013). Hyperkinetic dysarthria of voice tremor is characterized by pitch and loudness variability and shaky or jerky voice quality (Duffy, 2013). Additionally, tremor of neighbouring muscles, such as the jaw, lips, and tongue may be present during phonation (Duffy, 2013).

1.3 Subtypes of OMD and Muscle Involvement

OMD can occur with various severities and clinical presentations. It is characterized according to the affected muscles and its physical manifestation in a patient. OMD is most commonly categorized as jaw-closing, jaw-opening, jaw-deviation, tongue protrusion, tongue elevation, lip protrusion, and lip retraction (Bakke, Larsen, Dalager, & Møller, 2013, Kleopa & Kyriakides, 2003; Muller et al*.,* 2002). One type of OMD can be secondary to another type of OMD. The affected muscles will likely determine the type of OMD a patient will have. Observations of patients' abnormal muscle posturing can inform clinicians in identifying the subtype of OMD (Cultrara, Chitkara, & Blitzer, 2004).

Jaw-opening dystonia primarily involves abnormal activity of the anterior digastric and external pterygoids, while the genioglossus, and geniohyoid muscles play a secondary role in jaw-opening activity (Cultrara et al., 2004). Involvement of the platysma has also been reported to be associated with jaw-opening OMD (Bhidayasiri, Cardoso, & Truong, 2006). Therefore, if these muscles present with dystonic symptoms, the patient will likely present with jaw-opening OMD. Alternatively, jaw-closing OMD involves the masseter, temporalis, and internal pterygoid muscles, and can lead to jaw-clenching and grinding of teeth (Bhidayasiri et al., 2006; Cultrara et al., 2004). The involvement of the external pterygoid muscles has been associated with jaw-deviation and jaw-protrusion OMD (Bhidayasiri et al., 2006; Cultrara et al., 2004). Lingual

dystonia, specifically tongue protrusion, commonly involves the hyperactivity of the extrinsic tongue muscles, specifically the genioglossus, hypoglossus, chondroglossus, styloglossus, and palataglossus (Bhidayasiri et al., 2006; Esper, Freeman, & Factor, 2010). The hyoglossus has been implicated in depression of the tongue (Bhidayasiri et al., 2006). Lip protrusion dystonia involves the depressor anguli oris and depressor labii inferioris muscles (Kleopa & Kyriakides, 2003). The orbicularis oris pars labialis muscle is involved in lip retraction dystonia (Muller et al., 2002).

1.4 Treatment of OMD

OMD is among the most challenging types of dystonia to treat (Jankovic, 2004). Because of the various clinical presentations and severities of OMD, it has become a challenge among clinicians to properly diagnose this condition (Balasubramaniam, Rasmussen, Carlson, Van Sickels, & Okeson, 2008). Currently, there is no gold standard for diagnosing OMD, but it has been reported that early detection and a thorough understanding of the anatomy and physiology of the face and mouth area is crucial in proper diagnosis (Balasubramaniam et al., 2008). Use of psychological evaluations have also been suggested to identify potential psychogenic causes (Balasubramaniam et al., 2008).

The use of sensory tricks, or *gestes antagonistes*, is not considered a long-term treatment for OMD but nonetheless has been reported to provide temporary relief of dystonic symptoms and postures (Baik, Park, & Kim, 2004; Bakke et al., 2013; Esper et al., 2010; Felicio et al., 2010). The tactile stimulation that comes from sensory tricks modifies the hyperactive muscle activity and reduces dystonic postures (Bakke et al., 2013). It has been suggested that the relief of dystonic symptoms occurs through the activation of different sensory pathways (Giladi, 1997).

Examples of commonly employed sensory tricks for OMD include chewing gum, touching the lips or chin, biting a toothpick or straw, and humming.

There are many available clinical treatments for OMD. These include pharmacological treatments, dental appliances, and chemodenervation using botulinum toxin type A. In rare cases, surgical intervention is also possible. The most common oral medications for OMD are anticholinergic drugs such as trihexylphenidyl, dopaminergics, dopamine receptor blockers, carbamezapines, and baclofen (Tsui, 2005). Oral baclofen has been shown to be commonly used in OMD (Tan, 2004; Tsui, 2005; Jankovic, 2005), and has been reported to be effective in 20% of patients with OMD (Tsui, 2005). In general, treatment of OMD using pharmaceuticals has been reported to be unremarkable and reports of side effects have been high (Cultrara, et al., 2004, Jankovic, 2004; Tsui, 2005).

A bite-block is an example of a dental appliance that can be used for the treatment for OMD. Bite-block therapy was used by Dworkin (1996) with the goal of controlling orofacial hyperkinetic muscle activity in two individuals with Meige's syndrome. A bite-block is a small piece of dental compound that has been molded to fit the patient's dental anatomy. Use of the bite-block was found to have successfully improved dystonic symptoms in patients and improved speech intelligibility. Specifically, patients reported the use of the bite-block helped stabilize jaw-clenching and twisting movements. Unfortunately, this form of treatment has no carry-over effects because baseline symptoms immediately returned after removal of the bite-block (Dworkin, 1996).

A recent study by Schneider & Hoffman (2011) investigated the use of a dental appliance in a 60 year old female patient with OMD. This patient presented with hyperkinetic dysarthria

associated with oromandibular and lingual dystonia. Additionally, this patient also presented with difficulty articulating sounds involving mandibular opening and back-of-tongue elevation. The patient was found to be unresponsive to pharmacological treatments. It was found that the use of a maxillary acrylic resin appliance improved the patient's symptoms of dystonia, however, this improvement was not found to be permanent. Symptoms were found to have returned within three months of use. Despite the current lack of literature explaining this finding, it was hypothesized by the investigators that the change in relative position of the articulators may have caused the decline in OMD symptoms, which later recurred once the nervous system has become accustomed to the positioning (Scheider & Hoffman, 2011).

It was the introduction of botulinum toxin in the 1980s that revolutionized the treatment of OMD. Botulinum toxin has been a potent tool in the treatment of disorders involving uncontrollable muscle contractions. It is delivered to affected muscles via subcutaneous intramuscular injection to block neurotransmitter release (Fishman, 2005). Botulinum toxin A (BoNT-A), known commercially as Botox ® (Allergan, Inc. Irvine, CA, USA), has been used in the treatment of blepharospasm, involuntary jaw opening, and OMD (Batla, Stamelou, & Bhatia, 2012; Bhattacharyya & Tarsy, 2001; Cultrara et al., 2004). Improvement of symptoms due to BoNT-A therapy has been known to last about 8 – 16 weeks (Clark, 2003). Not only is botulinum toxin effective in alleviating symptoms of dystonia, but research has also shown that use of botulinum toxin is effective in improving the quality of life with patients with OMD, including the subdomains of social support and physical health (Bhattacharyya & Tarsy, 2001). Similarly, it has also been found that BoNT-A injections are effective at improving domains of activity and participation, as well as improving social, emotional, and vocational aspects of general well-being (Dykstra, Adams, & Jog, 2007). Investigating consequences on the subjective

well-being in individuals with dysarthria is important because it has been suggested that even mild-moderate cases of dysarthria can have significant negative effects on an individuals' self-esteem and self-image (Dykstra et al., 2007). Measuring patients' perception of their disability in combination with objective assessments may contribute to developing a holistic measure of their condition (Dykstra et al., 2007).

There are several commercially available preparations of BoNT-A. Some commonly used preparations include Botox® (Allergan, Inc. Irvine, CA, USA), Dysport® (Ispen Ltd., Slough, Berkshire, UK), and Xeomin® (Merz Pharmaceuticals, Frankfurt, Germany). Xeomin® differs from Botox® and Dysport® in that it is the first BoNT-A preparation lacking in complexing proteins that do not have therapeutic purposes (Frevert, 2009). Differences in potency and dosage of commercially available types of BoNT-A have been compared by Bhidayasiri et al. (2006). Botox® and Xeomin® appear to have equal potency and efficacy (Frevert, 2009) and it has been suggested that Botox® and Xeomin® are exchangeable following a 1:1 conversion ratio (Dressler, 2009). The recommended starting dose for Botox® is smaller than that of Dysport® as a single unit of Botox® is reported to be three to five times as potent as a single unit of Dysport® (Huang, Foster, & Rogachefsky, 2000). For jaw-closing OMD, a dosage of about 50 units of Botox or 100 units of Dysport® has been recommended for the masseter and temporalis (Bhidayasiri et al., 2006). In cases of jaw-opening OMD, a recommended starting dose to the muscles of the submental complex is 20 units of Botox® or 90 units of Dysport® (Bhidayasiri et al., 2006). Subsequent dosages are adjusted according to the patient's response.

Currently, there is no clinical standardization on the use of BoNT-A (Huang, Foster, & Rogachefsky, 2000). It is recommended that treatment be specific to the needs and symptoms of

each individual patient. The effects of BoNT-A is dependent on the location of injection, concentration, and volume of solution used (Huang, Foster, & Rogachefsky, 2000).

In rare cases where patients are found to be nonresponsive to pharmacological treatments or botulinum toxin and are experiencing significant functional disability, surgical treatments are available (Balasubramaniam et al., 2008; Tsui, 2005). In a recent study by Balasubramaniam et al. (2008), botulinum toxin B (BoNT-B) was administered to a patient who presented with sustained jaw-opening OMD and also demonstrated immunoresistance to BoNT-A . Pharmacological treatments proved to be ineffective for this patient. BoNT-B was administered as an experimental treatment after having received all other possible options. BoNT-B had demonstrated limited effectiveness in comparison to BoNT-A, and after BoNT-B injections the patient suffered low grade fever, mild facial paralysis, and dysphagia that resolved after several days. After BoNT-B was proven to be ineffective for this individual, the patient received a lateral pterygoid myotomy. The procedure was shown to have relieved all dystonic symptoms and the patient remained symptom-free for over 12 months.

1.5 Botulinum Toxin Type A

Botulinum toxin (BoNT) is regarded as the most lethal of substances (Jankovic, 2004; Simpson, 2004). In the early 1980's, it was discovered that BoNT-A had applications for medical interventions (Dressler & Saberi, 2005). BoNT is produced by bacteria *Clostridium botulinum, Clostridium baratii,* and *Clostridium butyricum* (Simpson, 2004) and can occur in seven different serotypes: A, B, C, D, E, F, and G. All of these serotypes act to inhibit the release acetylcholine from nerve terminals; however, they differ in regard to their target proteins and potencies

(Dressler & Saberi, 2005). Of the seven existing serotypes, Botulinum toxin type A (BoNT-A) is the most studied for medical use and is considered to be an effective treatment for spasticity, pain, and focal dystonias including blepharospasm, spastic dysphonia, and cervical dystonia (Aoki, 2003; Giladi, 2004; Jankovic, 2004; Snow et al., 1990). BoNT-A is comprised of neurotoxins as well as auxiliary non-toxic proteins. The neurotoxin component of BoNT-A can be separated into a heavy chain and a light chain, while the non-toxic proteins of BoNT-A are the haemagglutinin complex and the non-haemagglutinating proteins (Dressler & Saberi, 2005).

Mechanism of action. When the motor neuron depolarizes the axon terminal, acetylcholine is released into the synaptic cleft. The release of acetylcholine is produced by the soluble N-ethyl-maleimide-sensitive factor attachment protein receptor (SNARE) complex. However, when BoNT-A is injected into the target muscle, it binds to the plasma membrane and travels across the endosome membrane through receptor-mediated endocytosis (Simpson, 2004). Inside the cytosol, the heavy chain docks to glycoprotein structures found on cholinergic nerve terminals and the light chain binds to the SNARE complex. BoNT-A specifically cleaves synaptosome-associated proteins of 25kDa (SNAP25) of the SNARE complex (Dressler & Saberi, 2005). The cleaving action of the light chain prevents docking and fusion of acetylcholine vesicles. This results in chemical denervation, paralysis, muscle atrophy, and local weakness (Giladi, 1997).

When BoNT-A is injected into a striate muscle, the effects have been known to last for two to three months (Dressler & Saberi, 2005). When antibodies against BoNT-A are formed, noticeable reduction in duration of action and therapeutic effect occur (Dressler & Saberi, 2005; Jankovic, 2004). The mechanisms for the development of antibodies are still unknown (Jankovic, 2004). The variation in duration of effect varies between patients receiving therapy for the same

condition (Dressler & Saberi, 2005). If a patient is treated at regular intervals with consistent dosage, duration of action is expected to be stable (Dressler & Saberi, 2005).

Certain aspects of the mechanism of action of BoNT-A are still poorly understood. Evidence suggests that serotype A (BoNT-A) has the most sustained duration of action, although the precise cellular mechanism that leads to the termination of action of the toxin is still unknown (Simpson, 2004). Additionally, it has been suggested that the mechanism of action of BoNT-A treatment may be more complicated than originally hypothesized. One aspect of BoNT-A therapy that the literature has yet to explain is the apparent dual-phase clinical response to BoNT-A treatment: an early response observed within a few hours of injection, and a late response which occurs gradually between a period of one to six weeks (Giladi, 1997). Shortly after BoNT-A is injected in the target muscle; decrease of miniature endplate potentials (MEPPs) is observed (Giladi, 1997). A late response to BoNT-A treatment is also observed in the period between the time of BoNT-A injection and the actual clinical improvement which has been suggested to vary from one to six weeks or more (Giladi, 1997).

It is generally understood that the clinical improvement in dystonic symptoms associated with BoNT-A treatment is caused by the weakness of the target muscle. However, evidence suggests a weak relationship between the actual muscle weakness and beneficial effects (Giladi, 1997). It has been reported that patients with blepharospasm request reinjection despite remaining muscle weakness, citing that spasms and discomfort re-emerge despite remaining weakness (Giladi, 1997). Similarly, the observed reduction in pain which takes place before the decrease in muscle contractions suggests that BoNT-A treatment has a more complex mode of action in managing pain than simply preventing acetylcholine release at the neuromuscular junction (Aoki, 2003).

1.6 Speech Intelligibility

Speech intelligibility can be defined as the understandability of speech (Yorkston, Dowden, & Beukelman, 1992). It is the correspondence between the message produced by a speaker and the percentage of that message correctly understood by the listener (Yorkston, Strand, & Kennedy 1996; Schiavetti, 1992). Intelligibility is the single most practical index in assessing competence or severity of dysarthric speech because individuals with dysarthria tend to assess their disability from a functional perspective (Subtelny, 1977; Yorkston, Beukelman, & Bell, 1988; Weismer & Martin, 1992). Speech intelligibility is said to be perfect if the listener has correctly identified all of the words deliberately produced by the speaker. In contrast, if the listener fails to identify any of the words that the speaker had intended to produce, the speaker would have an intelligibility rating of zero. Therefore, speech intelligibility is the measurement of interaction between a speaker, a transmission system, and a listener (Schiavetti, 1992). Thus, all three components must be taken into consideration to measure speech intelligibility (Schiavetti, 1992; Weismer & Martin, 1992).

1.7 Speech Intelligibility Tasks

One vital aspect to be considered is how to accurately measure speech intelligibility. Intelligibility can be measured across different tasks: phoneme intelligibility, single-word intelligibility, sentence intelligibility, and conversational intelligibility.

Measuring intelligibility in different tasks can provide different kinds of information to the researcher or clinician. Phonetic intelligibility testing can provide information about intelligibility by identifying the nature of articulatory patterns and types of articulation errors

made by individuals with dysarthria (Yorkston, Dowden, & Beukelman, 1992). Phonetic error profiles can be generated from specific single word intelligibility tests (i.e., Phonetic Intelligibility Test or PIT) (Kent, Weismer, Kent, & Rosenbek, 1989). The phonetic error profile which results from this assessment of intelligibility can provide information about phonetic contrast errors, and error proportions (Weismer & Martin, 1992). These variables may then be used in a regression model to predict intelligibility (Weismer & Martin, 1992). For example, Kent and his colleagues (1989) designed a single-word intelligibility task which aimed to identify specific speech-related difficulties, to obtain quantitative data to analyze different speech features (i.e., vowels, fricatives, stops, etc.), to be sensitive to speech characteristics of different clinical populations, and to obtain results that can be related back to other tests of articulation. The test words in Kent and colleagues' (1989) intelligibility test were selected in order to allow for the study of 19 phonetic contrasts and acoustic correlates that are believed to impact intelligibility. These contrasts are front-back vowels, high-low vowels, long-short vowels, voiced-voiceless consonants, alveolar-palatal fricatives, other fricative places of articulation (ex., sigh-thigh), fricative-affricate, stop-fricative, stop-affricate, stop-nasal, glottal-null, initial consonant-null, final consonant-null, final consonant-null, initial cluster-singleton, final cluster-singleton, [r]-[l], and [r]-[w]. The Phoneme Intelligibility Test (PIT) (Yorkston, Beukelman, & Tice, 1999) is commonly used for measuring phoneme intelligibility. The PIT is administered by having listeners select from four options comprised of one target word and three foil words, which differ from the target by a single phoneme. Because phoneme intelligibility provides information about the types of articulatory errors produced, it may also be beneficial in measuring the change in these patterns over time or as a result of intervention (Yorkston et al. 1992).

Measuring intelligibility in single-words can be appropriate for speakers with severe dysarthria (Yorkston, Beukelman, & Bell, 1988). These speakers may not be capable of conversational speech or the production of longer utterances which are more physiologically demanding (Yorkston et al. 1992). Sentence intelligibility provides a more naturalistic speech sample and it can also provide information on speech rate as well as intelligibility, which, when considered together, can serve as an indicator of an individual's overall speech efficiency (Yorkston et al. 1992; Yorkston et al. 1988). One of the tests most widely used in the dysarthric intelligibility literature for measuring both single word and sentence intelligibility is the Assessment of Intelligibility of Dysarthric Speech (AIDS; Yorkston & Beukelman, 1981), which later became known as the Computerized Assessment of Intelligibility in Dysarthria (CAIDS; Yorkston, Beukelman, & Traynor, 1988). Most recently, the Sentence Intelligibility Test (Yorkston, Beukelman, & Tice, 2011) has been developed from the CAIDS for measuring sentence intelligibility.

In a landmark study by Yorkston & Beukelman (1978), intelligibility was measured using different perceptual tasks for single-words and sentences including transcription, a forced-choice paradigm, and sentence completion. Relationships among intelligibility scores of these tasks were then measured. It was found that each of the three techniques rank-ordered dysarthric speakers in the same way, although the actual intelligibility scores derived from each task varied from one another. This suggests that the task of the speakers and the task of the listeners contribute to variation in intelligibility scores. More recently, consistent findings have been suggested by Kempler & Van Lancker (2002) who provided evidence that the speakers' task may have an effect on their intelligibility. In this study, dysarthric participants with Parkinson's disease were tested on five different speech tasks: spontaneous speech, repetition, reading,

repeated singing, and spontaneous singing. It was found that participants were less intelligible when producing spontaneous speech.

While both single word and sentence intelligibility tasks provide measures of an individual's functional ability or severity (Yorkston et al. 1992), neither of these measures is capable of providing information as to why intelligibility is so poor, and therefore does little to help clinicians develop strategies for improvement of intelligibility.

Walshe, Miller, Leahy, & Murray (2008) found that individuals with dysarthria had different perceptions of their intelligibility compared to their results on a standardized intelligibility test (i.e., Assessment of Intelligibility of Dysarthric Speech). This finding challenges the validity of using intelligibility scores as a basis for intervention or treatment planning, as it has been suggested that evaluation of intelligibility is not comprehensive if the therapist neglects to consider perceptions of the client (Walshe, et al., 2008).

Intelligibility can also be assessed in conversation via the production of spontaneously generated speech. The speech sample can be elicited by asking an open ended question and allowing the speaker to respond. These conversational or spontaneously generated speech samples have the highest face validity compared to phoneme, single-word, and sentence intelligibility measures because the majority of everyday communication occurs spontaneously; therefore, speech elicited in conversational tasks is the most naturalistic (Kent, Weismer, Kent, & Rosenbek, 1989). Conversational speech samples have been used clinically in the assessment of intelligibility in dysarthria. For example, the Frenchay Dysarthria Assessment (Enderby, 1983) measures speech intelligibility using word, sentence, and conversational speech tasks. In this assessment, approximately five minutes of spontaneous speech is elicited, and is graded on

the following five levels: no abnormality, speech is abnormal but intelligible, speech is severely distorted, occasional words are recognizable, and speech is totally unintelligible.

One potentially valuable aspect of using conversational intelligibility tasks is that the context provided in the speech sample has been shown to be beneficial to understanding speech, particularly in individuals with mild-moderate dysarthria, because it enables listeners to use top-down processing to understand a speech sample (Dykstra et al., 2007; Hustad, 2007; Tjaden & Wilding, 2011; Yorkston & Beukelman, 1978). Additionally, a vast majority of everyday speech occurs conversationally, therefore measuring speech intelligibility using a conversational task may provide the most accurate picture of an individual's intelligibility within the context of his/her daily communicative functioning. Although context has been shown to be advantageous in individuals with mild dysarthria, Yorkston & Beukelman (1978) found that context provided no additional intelligibility benefit to a subset of speakers with very severe dysarthria. It was suggested that because the speech signal was heavily degraded in these speakers, the role of context was overshadowed. Consistent findings by Hustad (2007) also support this suggestion. However, despite the advantages in face validity for conversational tasks, structured speech tasks are more widely used in the speech intelligibility literature (Tjaden & Wilding, 2011). This is likely because structured tasks enable researchers to provide intelligibility scores with more accuracy. In addition, the consistency in content of structured tasks is advantageous in comparing findings of different intelligibility studies, and measures between and within speakers (Tjaden & Wilding, 2011).

Aside from the difficulty in comparing findings of different intelligibility studies that use conversational speech tasks, there are other challenges in measuring speech in conversation. The first challenge relates to objectivity. Since conversational speech is the most naturalistic

compared to other intelligibility tasks, measuring intelligibility in conversation becomes less objective (McHenry, 2011). Conversational speech cannot be measured using objective techniques because content is spontaneously created and therefore there is no objective means by which to score intelligibility in terms of proportion of words correctly understood. Content in the speech sample will vary even if the topic of conversation is the same because individuals are asked to generate their own responses. A second challenge relates to the possibility of phonetic and phonemic analyses. The analysis of phonemes in conversational tasks becomes problematic because of the open nature of responses (Kent et al., 1989). A third challenge relates to severity of symptoms. Analysis of conversational speech intelligibility becomes particularly challenging in participants with severely impaired speech as these individuals may not be capable of producing lengthy utterances. Thus, testing methods that suit certain individuals or types of dysarthria might not be appropriate for others (Kent et al., 1989).

1.8 Measurement of Speech Intelligibility

Intelligibility can also be measured using different perceptual rating procedures – the most common of procedures are direct magnitude estimation (DME), visual analogue scaling (VAS) and orthographic transcription.

Scaling procedures such as DME are considered subjective measures of intelligibility (Hustad, 2006) where listeners are asked to provide a rating of various speech parameters in order to provide a direct assessment of the qualities of a given speech sample. Direct magnitude estimation is a ratio scaling task which does not limit listeners to fit their ratings of intelligibility within a set range of values (Schiavetti, 1992). Instead, this procedure allows each listener to rate intelligibility as a ratio in proportion to other speech samples in a given set (Schiavetti, 1992).

DME may be sensitive to other factors that influence speech production, such as voice quality and prosody, and may therefore provide a more holistic evaluation of speech production (Weismer & Laures, 2002). DME can be completed either with or without a modulus. A modulus is an arbitrarily selected speech sample against which subsequent samples are rated proportionally (Schiavetti, 1992). Any number can be assigned to a modulus, but 10 or 100 tend to be the most commonly assigned value (Schiavetti, 1992). If a speech sample is considered to be more intelligible than the modulus, it would then be assigned a proportionally higher value than the modulus. Alternatively, if the speech sample is perceived to be less intelligible than the modulus, it will be given an intelligibility rating below the modulus value. The modulus is typically chosen to represent midrange speech intelligibility; although, it may also be chosen from the lower or higher ranges of intelligibility (Schiavetti, 1992). Careful consideration of the modulus is necessary as different moduli can affect intelligibility ratings of a fixed set of speech samples (Weismer & Laures, 2002). In the Weismer study (2002), it was found that DME ratings were directly influenced by the identity of the modulus, even if all four moduli were considered by expert judges to fall within "midrange intelligibility". This suggests that direct comparison of findings of various speech intelligibility studies using a DME paradigm is challenging because moduli are rarely ever the same between two studies, and therefore speech intelligibility ratings in various studies are likely affected depending on the modulus used (Weismer & Laures, 2002). Alternatively, DME can be done without a modulus. This type of procedure is called free-modulus DME. In this case, the listener is asked to begin with any number to assign to the first speech sample, and rate the subsequent speech samples using ratios that represent perceived magnitudes of intelligibility (Schiavetti, 1992). A free-modulus paradigm has been suggested to be used to prevent interaction between the selected modulus and intelligibility values; however,

this has been reported to be both uncomfortable for listeners as well as impractical for researchers because resulting intelligibility ratings are not directly meaningful (Weismer & Laures, 2002). A free-modulus paradigm has its advantages in that it allows for comparison of DME scores across different intelligibility studies (Tjaden & Wilding, 2011). It has been suggested that intelligibility ratings from free-modulus DME for structured speech tasks may serve as an accurate indication of spontaneous speech in speakers with dysarthria (Tjaden & Wilding, 2011)

VAS is another example of a subjective measure of intelligibility. In VAS, listeners are asked to rate a speech sample along a continuum according to how intelligible they perceive it to be. Minimum and maximum values along this continuum are fixed; therefore, listeners are confined to provide responses within a fixed set of values. A problem with VAS and other percentage estimates of intelligibility is that intelligibility scores are not consistent between listeners (dos Santos Barreto & Zazo Ortiz, 2008; Yorkston & Beukelman, 1978). In other words, there is a large variation of intelligibility scores using percentage estimates, and it is only by averaging these individual scores do they resemble the intelligibility values as measured by transcription tasks (Yorkston & Beukelman, 1978). These findings are consistent with those of Hustad (2006) who found that percentage estimates of intelligibility are not consistent between listeners. A notable difference is that Hustad (2006) had also suggested that percentage estimates were significantly lower than transcription scores, which differs from Yorkston & Beukelman (1978) who found that transcription and percentage estimation lead to intelligibility scores that approximate one another.

It is possible that listeners may be taking into account other important aspects of speech production such as speech rate, naturalness, and acceptability while rating a VAS or percentage

estimate task. These other aspects of speech production would not be captured by a transcription task. Therefore, it is possible that VAS and other percentage estimates provide more holistic measures of speech production and intelligibility, while orthographic transcription may primarily be sensitive to the articulatory deficit associated with speech disorders.

Orthographic transcription is an objective measure of intelligibility involving a word identification task wherein the listener is asked to write down each word produced by the speaker. The transcriptions provided by the listener are then compared to the actual words the speaker intended to produce. A percentage of correctly transcribed words is calculated relative to the total number of words produced by the speaker. A higher percentage of accurate transcriptions correspond to more intelligible speech. The SIT is an example of a test involving orthographic transcription, along with the AIDS and CAIDS from which the SIT was derived. Additionally, the Phoneme Intelligibility Test (PIT; Yorkston et al., 2011) may be administered using a forced-choice paradigm or via orthographic transcription.

Despite the procedural differences among these measurement paradigms, there is some evidence that these different measurement methods can produce similar estimates of intelligibility. Tjaden & Wilding (2011) have found moderate correlations between intelligibility ratings of free-modulus DME and orthographic transcription tasks. This suggests that these two intelligibility measures may be measuring the same construct (i.e., speech intelligibility) in similar ways. These findings were similar to those of Yorkston & Beukelman (1978), who found that using equal-appearing interval scales and percentage estimates provided similar overall intelligibility ratings to those derived from orthographic transcription.

1.9 Factors that Impact Speech Intelligibility

In addition to procedural differences, other variables must be taken into consideration when measuring intelligibility. An example of this is listener's perception. Hustad (2007) had listeners complete confidence ratings in addition to intelligibility measures and it was found that listeners tended to underestimate their ability to understand impaired speech. These findings were consistent with previous research where listeners' percentage estimates of intelligibility were lower than orthographic transcription scores (Hustad, 2006). A potential explanation for this observation was that listeners were not confident in their ability to understand the speech samples, so they gave lower estimates (Hustad, 2007).

Walshe and colleagues (2008) conducted a study investigating factors that affect listeners' perception of intelligibility of dysarthric speech. Specifically, the researchers were interested in looking at whether listeners' experience listening to dysarthric speech and listeners' gender affected their perceptions of intelligibility. No statistically significant gender effects were found. Furthermore, strong agreement was found between intelligibility ratings of speech-language therapists and naïve listeners. This suggests that speech –language pathologists are not more critical than naïve listeners, which is somewhat contrary to the findings of Beukelman & Yorkston (1980) who stated that speech-language pathologists tend to overestimate intelligibility scores in comparison to naïve listeners. It is noteworthy to mention that a potential source of this discrepancy is the differences in intelligibility measures used between these two studies. Walshe et al. (2008) used a DME paradigm, whereas Beukelman & Yorkston (1980) used a transcription task.

Various speech production dimensions have also been examined in regard to their relationship with speech intelligibility. De Bodt, Huici, Hernandez-Diaz, & Van de Heyning (2002) evaluated the roles of articulation, voice quality, nasality, and prosody, on overall speech intelligibility. The authors found that articulation and prosody were the two dimensions with the largest contribution to intelligibility.

1.10 Rationale for the Current Study

There is currently minimal research investigating speech intelligibility in oromandibular dystonia. One of the first studies that examined speech intelligibility in this population was done by Dworkin (1996), when testing bite-block therapy on two individuals with Meige's syndrome. Not only did these two participants report functioning at near-normal levels when the bite-block was in place, but both participants immediately produced intelligible speech at near-normal levels and improved their articulatory precision. A limitation to this study was that exact improvements to intelligibility were not quantified objectively. It was only reported by the researchers that intelligibility had noticeably improved during use of the bite-block, but the specific nature of these improvements were not discussed.

Dykstra and colleagues (2007) provided preliminary evidence from a case study that BoNT-A resulted in improvements in speech intelligibility in an individual with lingual dystonia. Lingual dystonia is a type of OMD, where dystonic symptoms are limited to the muscles of the tongue. This case study found that BoNT-A was effective in alleviating symptoms of OMD and that BoNT-A improved the speech intelligibility of an individual with lingual dystonia. These findings form the rationale of the current study. It is hypothesized that BoNT-A may produce

differential effects on speech intelligibility in a larger subset of individuals with various presentations of OMD.

The purpose of this study is to evaluate the speech intelligibility of individuals with OMD before and after BoNT-A injections.

Three main objectives will be examined in this study. These objectives are:

1. To evaluate differences in speech intelligibility in single-word, sentence, and conversational tasks pre- and post-BoNT-A injections.
2. To compare single-word intelligibility ratings and sentence intelligibility ratings based on order of presentation for the single word intelligibility task (words 1-29 and words 30-57) and sentence length (5-11 words and 12-15 words) for the sentence intelligibility task.
3. To evaluate the relationship between orthographic transcription and visual analogue scaling intelligibility scores, and to evaluate how single-word, sentence, and conversational intelligibility scores relate to one another in OMD.

It is anticipated that this research will provide preliminary data on the effects of BoNT-A on speech intelligibility in individuals with various presentations of OMD and contribute to a small, but growing body of research in this field.

Chapter 2

2 Method

2.1 Participants

Participants. Ten participants (n=10) diagnosed with OMD were recruited to participate in this study. In total there were 6 males and 4 females (age range: 44-80 years; mean age: 66.9 years), with an average OMD onset of 13.8 years. Participants were recruited from the Movement Disorders Clinic, London Health Sciences Centre at London, Ontario and were seen by neurologist, Dr. Mandar Jog. These participants were recruited because they were diagnosed with OMD, were receiving therapeutic BoNT-A (Botox® or Xeomin®) injections, demonstrated reduced speech intelligibility and had no other speech or hearing impairments. Table 1 contains specific data for each participant. This table includes information about the participant's age, sex, disease duration, duration of BoNT-A use, frequency of injection, type of OMD, and injection sites.

Table 1. Demographic information of participants with OMD.

Participant ID	Sex	Age	OMD Duration (years)	Years receiving BoNT-A	Frequency of injection (in months)	Type of OMD	Injection site and type of BoNT-A
1	M	69	4	3	3	Meige's (jaw closure, lingual)	orbicularis oris: 10u total h/s (Xeomin®)
2*	F	78	2	3m	3	Jaw opening	R&L lateral pterygoid: 30u total, R&L digastric: 40u, f/s (Botox®)
3	F	60	10	8	3	Lingual	Genioglossus: 15u total, R&L

							digastric: 40u total, f/s (Botox®)
4*	M	44	3	1	3	Meige's (labial, jaw closure)	R&L masseter: 40u total, medial pterygoid, 40u total, f/s (Botox®)
5	F	69	21	21	3	Lingual, labial, jaw closure	R&L pterygoid: 30u total, R&L digastric: 10u total, f/s (Xeomin®)
6	M	78	13	11	3	Labial, jaw closure	Orbicularis oris: 60u total, R&L masseter 40 units total, f/s (Botox®)
7	M	56	4	4	3	Jaw opening, jaw closure, lingual	R&L lateral pterygoid: 140u total, R&L digastric: 40u total, tongue: 30u total, f/s (Botox®)
8	M	80	23	22	3	Meige's (jaw opening, jaw closure)	R&L lateral pterygoids: 120u total, R&L digastric: 30u total, f/s (Xeomin®)
9	M	68	8	3	3	Jaw closure	R&L masseter: 30u total, medial pterygoid: 30u total, f/s (Botox®)
10	F	67	50	4	3	Meige's (labial)	R&L digastric: 10u total, R&L pterygoid: 20u total, f/s, orbicularis oris: 5u, h/s (Botox®)

R = right; L = left; u = units; f/s = full strength; h/s = half strength; * = de-novo

The experimenter explained the nature of the study as well as provided each participant with a letter of information (Appendix A) and a consent form (Appendix B) to sign prior to participating in the study. Each participant was also informed that they would be asked to return for a second visit as a continuation of the study. Participants provided written consent prior to beginning the second experimental session. This study was approved by the Health Sciences Research Ethics Board at Western University (Appendix C).

Listeners. Five naive individuals (n=5) were recruited to participate in this study as listeners. These listeners were undergraduate or graduate level students with a mean age of 21 years (age range: 20-23 years). All listeners were native English speakers, had no speech, hearing, or neurological impairments, and had no familiarity with dysarthric speech or the objectives of this research project. Additionally, all listeners passed a 30dB HL hearing screening bilaterally at 500, 1000, 2000 and 4000 Hertz (Hz) before participating in the listening task.

2.2 Apparatus

Speech recordings. Only participants with OMD participated in this part of the study. Participants were tested over two sessions: the first experimental session, which will be referred to as the "pre-BoNT-A" condition, occurred immediately before participants received their routinely scheduled therapeutic BoNT-A injections. The pre-treatment condition occurred approximately three months after participants' last BoNT-A injections, with the exception of two of the 10 participants who were de-novo patients. The second experimental session, which will be referred to as the "post-BoNT-A" condition, occurred approximately 4-6 weeks after participants received their BoNT-A injections to correspond to peak therapeutic effectiveness

(Blitzer & Sulica, 2001). Each experimental session was comprised of a set of speech intelligibility tasks that included single-word, sentence, and conversational intelligibility measures.

During each experimental session lasting approximately 20 minutes, each participant was tested in a quiet treatment room. Each participant wore a headset microphone (AKG C520) to record his or her speech. The headset microphone was the primary recording source of obtaining measures of speech intelligibility. The microphone was placed 6 cm from the participant's mouth. The microphone was connected to a digital audio recorder (Zoom H4n). This digital audio recorder recorded the participant's speech at a 16 bit and 44 kHz sampling rate. Participants were instructed to speak using a natural speaking voice and volume.

2.3 Materials

Speech intelligibility tasks. ***Single-word intelligibility*****.** A measure of single-word speech intelligibility was obtained from each participant in both pre- and post- BoNT-A conditions using the Phoneme Intelligibility Test (PIT) (Yorkston et al., 2011). The PIT is comprised of a list of 57 single words that are randomly generated by a computer program. Each stimulus word is one syllable in length and follows a consonant-vowel-consonant (CVC) structure. Each participant was required to read a randomly generated word list which was unique from that of the other participants. No two participants received an identical word list. The same word list was read by participants during the first experimental session (i.e., pre-BoNT-A condition) and in the second experimental session (i.e., post-BoNT-A condition) in order to provide an accurate measure and comparison of change in intelligibility due to BoNT-A injections. Each participant

was instructed to read all 57 words from the PIT presented on a standard 8 ½" x 11" piece of white paper in 18 point Times New Roman font (see Appendix D).

***Sentence intelligibility*.** Speech intelligibility in sentences was measured using the Sentence Intelligibility Test (SIT) (Yorkston et al., 2011). The SIT is comprised of 11 randomly generated sentences ranging from 5-15 words in length. Each participant was required to read a randomly generated list of sentences unique from the other participants. No two participants were assigned the same list of sentences. The same list was read by participants during the first experimental session (i.e., pre-BoNT-A condition) and in the second experimental session (i.e., post-BoNT-A condition) in order to provide an accurate measure of change in intelligibility due to BoNT-A injections. Each participant was instructed to read aloud all 11 sentences from the SIT presented on a standard 8 ½" x 11" piece of white paper in 18 point Times New Roman font (see Appendix E).

***Conversational intelligibility*.** Conversational intelligibility was measured by asking each participant to talk about a familiar topic for approximately five minutes while being audio recorded. The following are examples of questions that were used to elicit conversational speech:

1. "What do you do for a living?"
2. "What sorts of hobbies do you have?"
3. "Tell me about your last vacation?"

Secondary questions relevant to the original questions were used to encourage further conversation from the participants. Each participant was asked different questions in the pre-BoNT-A and post-BoNT-A conditions. From the five minutes of conversation recorded, each participant's recorded utterances were edited into a single spontaneous conversational excerpt

ranging in length from 30-45 seconds in duration. Conversational excerpts were randomized and compiled into playlists generated by Windows Media Player that were used as the listener speech stimuli.

All ten participants were asked to complete the three speech intelligibility tasks in the same order over both experimental sessions. That is, the SIT was administered first, followed by the PIT, and lastly, the conversational speech task.

Speech sample editing. All speech samples from each intelligibility task (i.e., single-word, sentence, and conversation) were edited in order to equalize volume to an intensity of 65dB using Praat (Boersma & Weenink, 2013). Speech samples were randomized and edited into playlists consisting of all the single word, sentence, and conversational tokens of each participant for both pre-BoNT-A and post-BoNT-A conditions using Windows Media Player.

Speech recordings from the conversational intelligibility task were edited into excerpts lasting 30-45 seconds in duration. Each excerpt was chosen as an exemplar of conversational speech containing the least amount of dysfluencies, hesitations, or interruptions. These conversational excerpts were used as speech stimuli for the perceptual judgement tasks.

2.4 Procedure

Participants with oromandibular dystonia. Informed consent was first obtained, after which each participant with OMD was asked to complete the SIT, PIT, and conversational intelligibility tasks while seated comfortable in a quiet treatment room. Each participant was informed that he or she would be requested to return for a second testing session 4-6 weeks after receiving his/her scheduled BoNT-A injections. During the second testing session, the same

three intelligibility tasks were repeated using the same randomly generated lists of single words and sentences for each participant. Participants were seated comfortably at a writing desk with copies of PIT and SIT tasks placed in front of them. The examiner was seated beside them in the testing room during experimental sessions to ensure that set-up of equipment was consistent among participants. All participants wore a headset microphone (AKG C520) attached to a digital audio recorder (Zoom H4n).

Listener perceptual judgement tasks. Listening sessions were held in a quiet laboratory wherein free-field presentation of speech samples were played at a comfortable listening level via M-Audio speakers (AV 40) placed approximately 0.6 metres (24 inches) away from listeners. Only the experimenter and the listener were present in the room during each listening session. Listeners completed one session in which they perceptually rated speech intelligibility during the presentation of participant speech stimuli corresponding to single-word, sentence, and conversational intelligibility tasks recorded pre- and post-BoNT-A conditions. For single-word (PIT) and sentence intelligibility (SIT) measures, listeners completed two perceptual tasks: orthographic transcription and visual analogue scaling. For conversational intelligibility measures, listeners completed a visual analogue scaling task only.

Orthographic transcription: For the orthographic transcription task, listeners were given a pen and paper and orthographically transcribed each speech token (i.e., PIT words and SIT sentences) to the best of their ability. An intelligibility score for each participant was determined by calculating the percentage of words correctly transcribed by each listener. A mean intelligibility score for each participant was calculated by taking the average of each listener's corresponding intelligibility score in either single-word or sentence intelligibility tasks. The

mean intelligibility scores represented either single-word or sentence intelligibility tasks measured by orthographic transcription and was used for subsequent statistical analyses.

Visual analogue scaling*:* For the visual analogue scaling task, listeners were given a response sheet with a line 100mm in length corresponding to each item to be rated. This 100mm line had anchors labeled "0% intelligible" on the left and "100% intelligible" on the right side of the line (Appendix F). Listeners listened to each speech sample (i.e., PIT single words, SIT sentences, conversation) and indicated the level of intelligibility or "understandability" of each speech sample by placing an "|" mark along the 100mm line corresponding how intelligible they perceived the speech sample to be. "Speech intelligibility" was measured as the distance in millimeters from the left end of the scale where the listeners marked an "|" and was expressed as a percent (i.e., 83 mm = 83% perceived intelligibility). For the PIT (single-word intelligibility) task, listeners provided two VAS ratings: the first rating after presentation of the first half of the 57 words (words 1-29) and again after the presentation of the second half of the 57 words (words 30-57). These two VAS ratings were averaged to calculate the overall single word intelligibility score. These two VAS ratings were also analyzed separately to determine if there were changes in intelligibility due to speaker fatigue. For the SIT (sentence intelligibility) task, listeners also provided two VAS ratings: the first rating after presentation of the first half of the 110 words that comprise the SIT (sentences 5-11) and again after the presentation of the second half of the 110 words (sentences 12-15). These two VAS ratings were averaged to calculate the overall sentence intelligibility score. These two VAS ratings were also analyzed separately to determine if there were changes in intelligibility due to speaker fatigue or due to the demands of increased sentence length. For the conversational intelligibility measure, listeners used visual analogue scaling as

previously described above, and judged intelligibility based on a single VAS rating corresponding to the single conversational excerpt obtained from each participant.

Intelligibility scores for VAS measures were determined according to percent intelligibility ratings generated by each listener. A mean percent intelligibility score for each participant was calculated by taking the average of each of the five listener's corresponding percent intelligibility score based on single-world, sentence, and conversational tasks. The mean percent intelligibility scores obtained via VAS representing single-word, sentence, and conversational intelligibility tasks were used for subsequent statistical analyses.

Order of presentation of intelligibility tasks was counterbalanced across listeners to avoid order effects. Within each intelligibility task, order of presentation of speech samples was randomized so that no two listeners were presented with speech samples in the same order.

2.5 Statistical analyses

Three objectives were investigated in this study. The first objective aimed to evaluate the differences in speech intelligibility based on single-word, sentence, and conversational tasks pre- and post- BoNT-A treatment. The second objective examined single-word and sentence intelligibility in greater detail by comparing intelligibility ratings of words presented in the first half of the PIT (words 1-29) with the second half of the PIT (words 30-57) and shorter sentences (5-11 words in length) with longer sentences (12-15 words in length). The final objective examined relationships among single-word, sentence, and conversational intelligibility scores in OMD from orthographic transcription and visual analogue scaling measures. These objectives will be addressed using the statistical analyses outlined below.

2.5a) Objective 1: Evaluating differences in speech intelligibility based on single-word, sentence, and conversational tasks pre- and post-BoNT-A injection.

A single-factor repeated-measures MANOVA was conducted. There was one within group variable "Time" with two levels [pre-BoNT-A, post-BoNT-A]. Intelligibility scores comprised the three dependent variables: [single-word, sentence, conversation]. Two separate MANOVA analyses were conducted. The first analysis was based on visual analogue scaling scores. The second analysis was based on orthographic transcription scores. The second analysis contains only two dependent variables [single-word, sentence intelligibility] because no orthographic transcription measures were obtained for the conversational intelligibility task.

2.5b) Objective 2: Comparison of single-word and sentence intelligibility ratings based on order of presentation of single words and sentence length.

To examine the effect of order of presentation of single words (based on the PIT) and sentence length (based on the SIT) on speech intelligibility, a 2-factor repeated measures MANOVA was conducted. The within group variables were "Time" and "Order". "Time" was comprised of two levels: [pre-BoNT-A, post-BoNT-A]. "Order" was also contained two levels: "First half" represented the first half of the PIT (words 1-29) and the SIT (5-11 words) and "Second half" represented the second half of the PIT (words 30-57) and the SIT (12-15 words).

The two dependent variables in this analysis were orthographic transcription and visual analogue scaling.

2.5c) Objective 3: Examining the relationships among single-word, sentence, and conversational intelligibility scores pre- and post- BoNT-A.

For the orthographic transcription intelligibility ratings (expressed as a percentage score), Pearson product-moment correlations were calculated in order to examine the relationships between the two methods of intelligibility (i.e., single word, sentence) conducted in this study. Separate correlational analyses were conducted for the pre-treatment and post-treatment conditions.

For the VAS intelligibility ratings (expressed as a percentage score), Pearson product-moment correlations were calculated in order to determine the relationships among the three methods of intelligibility (i.e., single word, sentence, conversation) conducted in this study. Separate correlational analyses were conducted for the pre-treatment and post-treatment conditions.

Chapter 3

3 Results

3.1 Reliability

Speech intelligibility. Inter-rater and intra-rater estimates of reliability were calculated for single-word intelligibility, sentence intelligibility, and conversational speech intelligibility measures both before and after BoNT-A injections. Scores from each listener for each intelligibility task were measured against each other to obtain inter-rater reliability values. All five listeners re-measured 10% of data to determine intra-rater reliability.

The values obtained for inter-rater reliability ranged from 0.794 to 0.960, $p<0.001$. These correlation coefficients demonstrate overall excellent reliability between listeners for the speech intelligibility measures. Cronbach's alpha revealed an intra-rater reliability estimate of 0.987, $p<0.001$, which demonstrates high intra-rater reliability for all speech intelligibility measurements.

Table 2 summarizes the intraclass correlation coefficient and Cronbach's alpha values in obtaining overall inter-rater and intra-rater reliability values. Table 3 summarizes the descriptive statistics and the results of intraclass coefficient analyses used to obtain inter-rater estimates of reliability. Statistical output of the overall inter-rater reliability analysis can be found in Appendix G. Statistical output of the overall intra-rater reliability analysis can be found in Appendix H.

Table 2. Summary of inter-rater and intra-rater estimates of reliability for single-word, sentence, and conversational intelligibility tasks.

	Intra-rater reliability	Inter-rater reliability
Intra-class correlation coefficient (ICC)	0.987 p<0.001	0.900 p<0.001
Cronbach's alpha	0.987	0.915

Table 3. Summary of inter-rater estimates of reliability for single-word, sentence, and conversational intelligibility tasks pre- and post-BoNT-A injections.

	Listener 1	Listener 2	Listener 3	Listener 4	Listener 5	ICC	Cronbach's alpha
PIT trans pre[1]	78.95	75.79	72.98	74.74	80.88	0.948 *p*<0.001	0.961
PIT VAS pre[2]	86.25	76.73	56.43	76.05	82.08	0.794 *p*<0.001	0.927
SIT trans pre[3]	87.72	85.27	89.55	95.36	96.54	0.906 *p*<0.001	0.940
SIT VAS pre[4]	80.08	79.38	72.75	90.93	83.48	0.877 *p*<0.001	0.901
Conv pre[5]	75.80	72.75	68.80	87.70	69.30	0.920 *p*<0.001	0.939
PIT trans post[6]	79.12	74.56	72.80	75.08	82.63	0.956 *p*<0.001	0.969
PIT VAS post[7]	84.23	74.13	70.90	81.53	79.6	0.891 p<0.001	0.912
SIT trans post[8]	89.18	83.90	90.36	91.54	93.27	0.960 p<0.001	0.971
SIT VAS post[9]	81.38	78.85	74.20	93.45	76.78	0.893 p<0.001	0.928
Conv post[10]	74.85	67.05	68.80	91.05	66.70	0.854 p<0.001	0.894

[1]Single-word intelligibility measured by orthographic transcription pre-BoNT-A.

[2]Single-word intelligibility measured by visual analogue scaling pre-BoNT-A.

[3]Sentence intelligibility measured by orthographic transcription pre-BoNT-A.

[4]Sentence intelligibility measured by visual analogue scaling pre-BoNT-A.

[5]Conversational intelligibility pre-BoNT-A.

[6]Single-word intelligibility measured by orthographic transcription post-BoNT-A.

[7]Single-word intelligibility measured by visual analogue scaling post-BoNT-A.

[8]Sentence intelligibility measured by orthographic transcription post-BoNT-A.

[9]Sentence intelligibility measured by visual analogue scaling post-BoNT-A.

[10]Conversational intelligibility post-BoNT-A.

3.2 Objective 1: Evaluating differences in speech intelligibility based on single-word, sentence, and conversational tasks pre- and post-BoNT-A injection.

The primary objective in this study was to investigate whether BoNT-A treatment affected intelligibility in single-word, sentence, and conversational speech tasks in individuals with oromandibular dystonia. This analysis examined speech intelligibility in single-words using the PIT, sentences using the SIT, and in conversation via spontaneous speech recordings. In the single-word and sentence intelligibility tasks, intelligibility was measured via orthographic transcription and visual analogue scaling techniques. The following analyses were conducted to answer the following question: *Does BoNT-A treatment result in a change in speech intelligibility in participants with various presentations of oromandibular dystonia?*

Based on this objective, the following two comparisons were made: S*ingle-word and sentence intelligibility: pre- versus post- BoNT- A treatment (orthographic transcription measurement)* and *Single-word, sentence, conversational intelligibility: pre- versus post- BoNT-A treatment (VAS measurement).* In order to examine the main effect of BoNT-A on speech intelligibility, two single-factor repeated-measures MANOVAs were conducted. We used two

separate multivariate analyses of variance (MANOVAs) to control for multiple comparison bias (Hummel & Sligo, 1971). The first analysis was based on orthographic transcription scores. The second analysis was based on visual analogue scaling scores. For both analyses, there was one within group variable "Time" with two levels [pre-BoNT-A, post-BoNT-A]. The first analysis, using orthographic transcription scores, contained two dependent variables [single-word, sentence intelligibility] because no orthographic transcription measures were obtained for the conversational intelligibility task. The second analysis, using VAS scores, was comprised of three dependent variables: [single-word, sentence, conversation]. In these analyses, intelligibility scores were collapsed across task (PIT, SIT, conversation).

Orthographic transcription. The first analysis which was based on orthographic transcription scores revealed no significant multivariate main effect of "Time" (e.g., pre-BoNT-A, post-BoNT-A) on speech intelligibility (single-word and sentence tasks) based on orthographic transcription, $F(2,8)=.381$, $p=.695$, $\eta^2_{partial} = 0.087$.

Since no significant multivariate effects were detected, the alpha was adjusted for each of the subsequent univariate analyses based on the number of dependent variables (i.e., $^{\alpha}/_{2} = 0.025$ for orthographic transcription). The univariate statistics are presented in Table 4 for orthographic transcription. None of these effects are statistically significant at $\alpha < .025$. Descriptive statistics are presented in Table 5. The detailed results of this single-factor repeated-measures MANOVA analysis are presented in Appendix I.

Table 4. Effect of time on single-word and sentence intelligibility scores measured by orthographic transcription.

	$F(1,9)$	p	$\eta^2_{partial}$
OT[1]			
OT – PIT (single words)	.022	.920	.001
OT – SIT (sentences)	.725	.417	.075

[1]OT: multivariate effect: $F(2,8) = .381$, p=.695, $\eta^2 partial = .0875$, $^{\alpha}/_{2} = .025$

Table 5: Descriptive statistics of intelligibility scores measured by orthographic transcription.

	Pre-BoNT-A Mean (SD)	Post-BoNT-A Mean (SD)
OT - PIT (single words)	76.686 (10.859)	76.375 (14.443)
OT - SIT (sentences)	90.910 (10.397)	89.655 (12.987)

Visual analogue scaling. Similarly, a second single-factor repeated-measures MANOVA was conducted in order to examine the multivariate main effect of "Time" on speech intelligibility (single-word, sentence, and conversation) as measured by visual analogue scaling. This analysis revealed no significant multivariate main effect of "Time" (e.g., pre-BoNT-A, post-BoNT-A) on speech intelligibility (single-word, sentence, and conversation) based on VAS, $F(3,7)$=.873, p=.499, $\eta^2_{partial}$ = 0.272.

Since no significant multivariate effects were detected, the alpha was adjusted for each of the subsequent univariate analyses based on the number of dependent variables (i.e., $^{\alpha}/_{3} = 0.017$ for VAS). The univariate statistics are presented in Table 6 for VAS measures. None of these

effects are statistically significant at $\alpha < .017$. Descriptive statistics for are presented in Table 7. The detailed results of this single-factor repeated-measures MANOVA analysis are presented in Appendix J.

Table 6: Effect of time on single-word, sentence, and conversational intelligibility scores measured by visual analogue scaling.

	$F(1,9)$	p	$\eta^2_{partial}$
VAS[1]			
VAS – PIT (single words)	.693	.427	.072
VAS – SIT (sentences)	.105	.753	.012
VAS – conversation	.010	.923	.001

[1]VAS: multivariate effect: $F(3,7) = .873$, p=.499, $\eta^2 partial = .272$, $^{\alpha}/_{2} = .017$

Table 7: Descriptive statistics of intelligibility scores measured by visual analogue scaling.

	Pre-BoNT-A Mean (SD)	Post-BoNT-A Mean (SD)
VAS - PIT (single words)	75.5 (12.248)	78.075 (13.595)
VAS - SIT (sentences)	81.185 (14.932)	80.930 (15.653)
VAS - conversation	74.870 (21.230)	73.690 (19.087)

Overall, these results, in combination with results of the previous MANOVA using orthographic transcription scores, suggests that BoNT-A injections do not produce significant changes to speech intelligibility, regardless of how intelligibility is measured (e.g., orthographic transcription or VAS).

3.3 Objective 2: Comparison of single-word and sentence intelligibility ratings based on order of presentation of single words and sentence length.

The purpose of this objective was to evaluate single-word and sentence intelligibility in closer detail. Specifically, our aim was to determine if there were any differences in speech intelligibility ratings based on order of presentation of single words or difference in speech intelligibility based on sentence length.

A two-factor repeated measures MANOVA was conducted to evaluate differences in intelligibility ratings based on order of presentation obtained from the PIT and sentence length obtained from the SIT. The two within-subjects factors examined were "Time" which had two levels [pre-BoNT-A, post-BoNT-A] and "Order" which also had two levels [first half of words and sentences, second half of words and sentences]. There were four dependent variables: PIT transcription, PIT VAS, SIT transcription, SIT VAS. Based on this objective, the following comparisons were made: *Speech intelligibility (orthographic transcription and VAS): first half of single-words (1-29) and sentences (5-11 words) vs. second half of single-words (30-57) and longer sentences (12-15 words).* As before, we used a multivariate analysis of variance (MANOVA) to control for multiple comparison bias. No significant multivariate effects were detected (for the interaction or either of the main effects), and so the comparison alpha was adjusted for each of the subsequent univariate analyses (i.e., $^{\alpha}/_{4} = .0125$). These analyses are reported within Table 8.

Within the univariate effects, there were no significant interactions, but a significant effect of "Order" was seen for PIT VAS, $F(1,9) = 11.078$, $p<.0125$, $\eta^2 partial = .552$, and for SIT transcription, $F(1,9) = 11.720$, $p<.0125$, $\eta^2 partial = .566$. SIT VAS approached significance within this effect, $F(1,9) = 7.499$, $p=.023$, $\eta^2 partial = .455$, but was not statistically significant when considering this effect in the context of our adjusted per-comparison alpha. All of these univariate effects are also presented in Table 8. Descriptive statistics are presented in Table 9. These results suggest that order of presentation of single-words and sentence length has a significant effect on intelligibility. Specifically, these results suggest that in a VAS task, listeners rate single-words from the first half of the PIT has more intelligible than words presented in the second half of the PIT. These results also suggest that listeners rate shorter sentences as more intelligible compared to longer sentences in an orthographic transcription task.

Table 8: Univariate effects of "Time" and "Order" on single-word and sentence intelligibility scores measured by orthographic transcription and visual analogue scaling.

	$F(1,9)$	p	$\eta^2 partial$
Interaction Effect[1]			
PIT transcription	2.796	.129	.125
PIT VAS	4.993	.052	.357
SIT transcription	.001	.974	<.000
SIT VAS	.691	.427	.071
Main effect of "Order"[2]			
PIT transcription	.511	.493	.054
PIT VAS	11.078	.009*	.552
SIT transcription	11.720	.008*	.566
SIT VAS	7.499	.023	.455
Main effect of "Time"[3]			
PIT transcription	.022	.899	.002
PIT VAS	.693	.427	.072
SIT transcription	.717	.419	.074
SIT VAS	1.623	.235	.153

[1]Interaction Effect: $F(4,6) = 1.056$, p=.453, $\eta^2 partial = .413$, $^{\alpha}/_{4} = .0125$

[2]Main Effect of "Order": $F(4,6) = 3.342$, p=.091, $\eta^2 partial = .690$, $^{\alpha}/_{4} = .0125$

[3]Main Effect of "Time": $F(4,6) = 1.333$, p=.358, $\eta^2 partial = .471$, $^{\alpha}/_{4} = .0125$

Table 9: Descriptive statistics of single-word and sentence intelligibility scores based on "Order" pre- and post-BoNT-A.

	First half PIT words 1-29 SIT sentences 5-11 Mean (SD)	**Second half** PIT words 30-57 SIT sentences 5-11 Mean (SD)
PIT transcription pre-BoNT-A	75.310 (11.630)	77.990 (10.744)
PIT transcription post-BoNT-A	76.253 (14.145)	76.142 (15.834)
PIT VAS pre-BoNT-A	78.330 (10.233)	72.670 (14.404)
PIT VAS post-BoNT-A	79.310 (12.135)	76.840 (15.174)
SIT transcription pre-BoNT-A	93.501 (9.759)	88.222 (11.636)
SIT transcription post-BoNT-A	92.214 (11.687)	87.000 (14.873)
SIT VAS pre-BoNT-A	84.420 (13.316)	80.950 (16.688)
SIT VAS post-BoNT-A	83.150 (13.585)	78.710(17.758)

3.4 Objective 3: Examining the relationships among single-word, sentence, and conversational intelligibility scores in OMD.

This purpose of this objective was to examine potential relationships between intelligibility scores based on common measurement techniques used in assessing dysarthric speech intelligibility. Specifically, the relationship between VAS and orthographic transcription was examined. In addition, this objective examined the relationships among single word, sentence and conversational speech tasks in order to identify potential consistencies among speech tasks. Therefore, this objective seeks to understand the relationships among different speech

intelligibility tasks, and seeks to understand if VAS and orthographic transcription measure speech intelligibility similarly in this clinical population.

In order to determine and to explore these relationships, two Pearson product-moment correlations were conducted. The first correlational analysis was for all pre-BoNT-A measures, and the second correlational analysis was for all post-BoNT-A measures. For the purposes of this study, a correlation value of 0.75 or greater will be considered a strong correlation, 0.50-0.75 will be considered a moderate correlation, and below 0.50 a mild correlation (Portney & Watkins, 2009).

Pre-BoNT-A. ***Within intelligibility tasks.*** A correlational analysis was conducted for pre-BoNT-A intelligibility measures. It was found that orthographic transcription and visual analogue scaling scores were strongly correlated when measuring the same intelligibility task. Specifically, strong correlations were found between single-word intelligibility orthographic transcription scores (M= 76.650, SD= 10.836) and single-word intelligibility VAS scores (M= 75.50, SD= 12.248) (PIT OT and PIT VAS), $r = 0.760$, $p = 0.011$ and between sentence intelligibility transcription scores (M= 90.909, SD= 10.397) and sentence intelligibility VAS scores (M= 81.185, SD= 14.932) (SIT OT and SIT VAS), $r = 0.901$, $p < 0.001$. These results suggest that there is a strong relationship between orthographic transcription and visual analogue scaling and that these two measurement techniques are likely measuring speech intelligibility in a similar way. These results also suggest a strong degree of predictability between transcription and VAS scores.

Within measurement techniques. Additionally, it was found that intelligibility scores of different tasks were correlated when measured using the same technique (i.e., orthographic

transcription, visual analogue scaling). Strong correlations were found between single-word intelligibility transcription scores (*M*= 76.650, *SD*= 10.836) and sentence intelligibility transcription scores (*M*= 90.909, *SD*= 10.397) (PIT OT and SIT OT), $r = 0.753$, $p = 0.012$ and between single-word intelligibility VAS scores (*M*= 75.50, *SD*= 12.248) and sentence VAS scores (*M*= 81.185, *SD*= 14.932) (PIT VAS and SIT VAS), $r = 0.856$, $p = 0.002$ Furthermore, a moderate correlation was found between sentence intelligibility VAS scores (*M*= 81.185, *SD*= 14.932) and conversational intelligibility scores (*M*= 74.870, *SD*= 21.225) which was also measured by VAS (SIT VAS and CONV), $r = 0.639$, $p = 0.047$. These results suggest that VAS demonstrates consistency in measuring intelligibility across single-word, sentence, and conversational intelligibility and that orthographic transcription is consistent at measuring intelligibility in single-words and sentences. These results also suggest that there is a correlational relationship between single-word and sentence scores, as well as sentence scores and conversational scores when they are measured using the same technique.

Between intelligibility tasks and measurement techniques. Lastly, correlations were found between intelligibility scores across different tasks and different measurement techniques. A strong correlation was found between single-word VAS scores (*M*= 75.50, *SD*= 12.248) and sentence intelligibility transcription scores (*M*= 90.909, SD= 10.397) (PIT VAS and SIT OT), $r = 0.808$, $p = 0.005$; and a moderate-strength correlation was found between single-word intelligibility transcription scores (*M*= 76.650, *SD*= 10.836) and sentence intelligibility VAS scores (*M*= 75.50, *SD*= 12.248) (PIT OT and SIT VAS), $r = 0.728$, $p = 0.017$. These results suggest a consistency in intelligibility scores across different tasks (single-word and sentence intelligibility) as well across measurement technique (OT and VAS). Taken together, these results suggest that significant relationships exist between single-word and sentence

intelligibility. These results are represented as a correlation matrix in Table 10. The detailed results of this correlational analysis are found in Appendix L.

Table 10. Pearson correlation coefficients of single-word, sentence, and conversational intelligibility measures in the pre-BoNT-A condition.

	PIT transcription	PIT VAS	SIT transcription	SIT VAS	CONV
PIT transcription[1]	1	$r = 0.760$* $p = 0.011$	$r = 0.753$* $p = 0.012$	$r = 0.728$* $p = 0.017$	$r = 0.444$ $p = 0.198$
PIT VAS[2]	-	1	$r = 0.808$* $p = 0.005$	$r = 0.856$* $p = 0.002$	$r = 0.382$ $p = 0.275$
SIT transcription[3]	-	-	1	$r = 0.901$* $p = 0.000$	$r = 0.389$ $p = 0.267$
SIT VAS[4]	-	-	-	1	$r = 0.639$* $p = 0.047$
CONV[5]	-	-	-	-	1

[1]Single-word intelligibility orthographic transcription score

[2]Single-word intelligibility visual analogue scaling score

[3]Sentence intelligibility orthographic transcription score

[4]Sentence intelligibility visual analogue scaling score

[5]Conversational intelligibility visual analogue scaling score

Post-BoNT-A. ***Within intelligibility tasks.*** Similarly, a second correlational analysis was conducted for post-BoNT-A intelligibility scores. It was found that orthographic transcription and visual analogue scaling scores were strongly correlated when measuring the same intelligibility task. In this analysis, strong correlations were found between single-word intelligibility transcription scores (M= 76.198, SD= 14.618) and single-word intelligibility VAS scores (M= 78.075, SD= 13.595) (PIT OT and PIT VAS), $r = 0.906$, $p < 0.05$; and between sentence intelligibility transcription scores (M= 89.655, SD= 12.986) and sentence intelligibility

VAS scores (*M*= 80.930, *SD*= 15.653) (SIT OT and SIT VAS), $r = 0.907$, $p < 0.05$. These results add support to the previous finding that orthographic transcription and VAS techniques measure intelligibility in similar ways and that orthographic transcription and VAS scores are predictive of one another.

Within measurement techniques. It was also found that intelligibility scores of different tasks were correlated when using the same measurement technique. Strong correlations were also found between single-word intelligibility transcription scores (*M*= 76.198, *SD*= 14.618) and sentence intelligibility transcription scores (*M*= 89.655, *SD*= 12.986) (PIT OT and SIT OT), $r = 0.756$, $p = 0.011$ and between single-word intelligibility VAS scores (*M*= 78.075, *SD*= 13.595) and sentence intelligibility VAS scores (*M*= 80.930, *SD*= 15.653) (PIT VAS and SIT VAS), $r = 0.899$, $p < 0.05$. Furthermore, a strong correlation was found between conversational intelligibility scores (*M*= 73.690, *SD*= 19.087) and sentence intelligibility VAS scores (*M*= 80.930, *SD*= 15.653) (CONV and SIT VAS), $r = 0.815$, $p = 0.004$, and a moderate correlation was found between conversational intelligibility scores (*M*= 73.690, *SD*= 19.087) and single-word intelligibility VAS scores (*M*= 78.075, *SD*= 13.595) (CONV and PIT VAS), $r = 0.687$, $p = 0.028$. These results are consistent with findings in the pre-BoNT-A condition and provide evidence that orthographic transcription and VAS techniques measure intelligibility consistently across single-word, sentence, and conversational tasks.

Between intelligibility tasks and measurement techniques. Finally, strong correlations were found between intelligibility scores across different tasks and different measurement techniques. Strong correlations were found between single-word intelligibility transcription scores (*M*= 76.198, *SD*= 14.618) and sentence intelligibility VAS scores (*M*= 80.930, *SD*= 15.653) (PIT OT and SIT VAS), $r = 0.786$, $p = 0.007$; and between single-word intelligibility

VAS scores (*M*= 78.075, *SD*= 13.595) and sentence intelligibility transcription scores (*M*= 78.075, *SD*= 13.595) (PIT VAS and SIT OT), $r = 0.847$, $p = 0.002$. Again, these results suggest a consistency in intelligibility scores across different tasks (single-word and sentence intelligibility) as well across measurement technique (OT and VAS). Taken together, these results provide evidence for significant relationships between single-word and sentence intelligibility. These results are represented as a correlation matrix in Table 10. The detailed results of this correlational analysis are found in Appendix M.

Table 11. Pearson correlation coefficients of single-word, sentence, and conversational intelligibility measures in the post-BoNT-A condition.

	PIT OT	PIT VAS	SIT OT	SIT VAS	CONV
PIT OT[1]	1	$r = 0.906$* $p = 0.000$	$r = 0.756$* $p = 0.011$	$r = 0.786$* $p = 0.007$	$r = 0.535$ $p = 0.111$
PIT VAS[2]	-	1	$r = 0.847$* $p = 0.002$	$r = 0.899$* $p = 0.000$	$r = 0.678$* $p = 0.028$
SIT OT[3]	-	-	1	$r = 0.907$* $p = 0.000$	$r = 0.578$ $p = 0.080$
SIT VAS[4]	-	-	-	1	$r = 0.815$* $p = 0.004$
CONV[5]	-	-	-	-	1

[1]Single-word intelligibility orthographic transcription score

[2]Single-word intelligibility visual analogue scaling score

[3]Sentence intelligibility orthographic transcription score

[4]Sentence intelligibility visual analogue scaling score

[5]Conversational intelligibility visual analogue scaling score

Chapter 4

4 Discussion

4.1 Overview

This study examined the effect of therapeutic BoNT-A injections on the speech intelligibility of 10 participants with various presentations of OMD. Speech intelligibility was assessed in single-word, sentence, and conversational speech production tasks. This study also examined the differences in speech intelligibility ratings in single-words based on order of presentation, as well as in sentences based on sentence length. The final objective of this study identified and described the relationships between intelligibility scores measured by orthographic transcription and visual analogue scaling techniques and examined relationships among single word, sentence and conversational intelligibility tasks.

The following sections in this chapter will discuss the primary findings of the present study and relate the findings of this study to those of previous research. Subsequent sections will discuss the limitations of this study, followed by recommendations for future research. Lastly, clinical and research implications will be discussed.

The overarching goal of this study was to examine the speech intelligibility of participants with oromandibular dystonia in single-word, sentence, and conversational tasks pre- and post- BoNT-A injections in an attempt to gain a better understanding of the impact of therapeutic BoNT-A injections on speech intelligibility due to the dysarthria resulting from OMD. In order to examine speech intelligibility across various intelligibility tasks, the PIT and the SIT created by Yorkston and colleagues (2011), served as the primary measures of

intelligibility in single-words and sentences, respectively. Conversational speech generated from spontaneous responses to open-ended questions was extracted into 30-45 second samples and served as the primary measure of conversational intelligibility.

4.2 Objective 1: Evaluating differences in speech intelligibility pre- and post-BoNT-A injections in single-word, sentence, and conversational tasks.

The first objective of the study investigated the speech intelligibility of participants with various presentations of oromandibular dystonia pre- and post-BoNT-A injections.

Single-word intelligibility. Single word intelligibility was assessed via the PIT. The PIT contains 57 single-words, each one syllable and following a CVC pattern. Participants read the 57 single words aloud while being audio-recorded; the first time before receiving their routinely scheduled BoNT-A injections and the second time approximately 4-5 weeks after receiving his or her injections to correspond to peak therapeutic effect. Participants were given the same word list to read over both testing sessions. Intelligibility was measured using two techniques: orthographic transcription and VAS. Non-significant results were found between pre-and post-BoNT-A single-word intelligibility scores measured by orthographic transcription. Mean transcription intelligibility scores before and after BoNT-A injections were 76.65% (*SD* = 10.836) and 76.198% (*SD* = 14.618), respectively. Additionally, non-significant results were found between pre- and post-BoNT-A single-word intelligibility scores measured by VAS. Mean intelligibility scores pre- and post- BoNT-A injections were 75.5% (*SD*=12.248) and 78% (*SD* = 13.594), respectively. Overall, these results indicate that therapeutic injections of BoNT-A

treatment did not result in a statistically significant change to single word intelligibility in our participants with OMD regardless of measurement technique.

Sentence intelligibility. In addition to single-word intelligibility, sentence intelligibility measurements were also obtained using the SIT. Participants read aloud 11 unique sentences, ranging from 5 – 15 words in length while being audio-recorded; the first time before receiving their routinely scheduled BoNT-A injections and the second time approximately 4-5 weeks after receiving his or her injections to correspond to peak therapeutic effect. Participants were given the same unique sentence list to read aloud over both testing sessions. Intelligibility was measured using two techniques: orthographic transcription and VAS. Non-significant results were found between pre- and post-BoNT-A sentence intelligibility scores measured by orthographic transcription. Mean sentence intelligibility scores measured by orthographic transcription before and after BoNT-A injections was 90.909% (*SD* = 10.397) and 89.654% (*SD* = 12.986), respectively. Additionally, non-significant results were found between pre-and post-BoNT-A sentence intelligibility sores measured by VAS. Mean sentence intelligibility measured by VAS before and after BoNT-A injections was 81.185% (*SD* = 14.932) and 80.930% (*SD* = 15.653), respectively. Similar to results at the single-word task, these results suggest that therapeutic injections of BoNT-A did not result in a statistically significant change to sentence intelligibility in our participants with OMD, regardless of measurement technique (i.e., VAS or orthographic transcription).

Conversational intelligibility. To obtain a measure of conversational intelligibility, participants were engaged in approximately 5 minutes of conversation while being audio-recorded. Thirty to forty-five seconds of spontaneous speech was extracted for analysis. Similar to the protocol for obtaining single-word and sentence intelligibility measures, each participant

had two testing sessions: before receiving their routinely scheduled BoNT-A injections and again approximately 4-5 weeks after receiving his or her injections to correspond to peak therapeutic effect. However, unlike the previous two intelligibility tasks, only VAS measures were obtained because there was no way to verify orthographic transcription responses. Non-significant results were found between pre- and post-BoNT-A conversational intelligibility scores. Mean conversational intelligibility scores before and after BoNT-A treatment was 74.870% (*SD* = 21.230) and 73.690% (*SD* = 19.087). These results indicate that in a conversational intelligibility task, therapeutic injections of BoNT-A did not result in a statistically significant change to conversational intelligibility in our participants with OMD.

In this examination of single-word, sentence, and conversational intelligibility, there were no significant differences in speech intelligibility ratings of our participants with OMD before and after receiving their routinely scheduled therapeutic injections of BoNT-A. This finding is contrary to previous research by Dykstra and colleagues (2007) who found that BoNT-A injections resulted in a significant improvement in the speech intelligibility in an individual with lingual dystonia. Because of the paucity of research relating to the effect of BoNT-A on speech intelligibility in this clinical population, it is difficult to ascertain the exact cause of our opposing findings, however, possible explanations will be discussed.

Our sample of participants with OMD was comprised of 6 males and 4 females, each with OMD as their primary diagnosis and with no comorbidities. Table 1 presents demographic information of participants with OMD. Within our sample, five participants presented with mixed dystonia (e.g., jaw and tongue involvement) and five presented with single-site or focal involvement (e.g., tongue only, jaw only, lip only). Ideally, a subgroup analysis of speech intelligibility based on type and location of OMD (e.g., lingual, jaw opening, jaw closing) would

be an interesting analysis to conduct in order to determine if BoNT-A produced differential effects to intelligibility based on type or location of OMD. However, due to our modest sample size of 10, subdividing participants into smaller and more discrete subgroups would not produce statistical results that could be interpreted in an accurate manner. Still, analyzing the effects of BoNT-A injections on speech intelligibility based on specific presentation of symptoms is warranted in a future study. Previous literature suggests that tongue control is more strongly related to speech intelligibility than jaw or lip control in individuals with a neuromotor disorder (Weismer, Yusuonva, & Bunton, 2012). Additionally, in previous work examining the efficacy of BoNT-A injections on OMD, it has been found that that jaw-opening OMD is less responsive to BoNT-A injections than jaw-closing OMD (Tan & Jankovic, 1999; Teive et al., 2012).

Speech production is unique from other motor movements. It involves a greater variety of muscle types than any other motor system (Kent, 2004). Speech also involves the simultaneous activation of a greater number of muscle fibers than any other mechanical process (Kent, 2000). Smith (2006) conducted a comparison of muscle activity between speech and non-speech tasks (e.g., chewing), and suggested that chewing and breathing are controlled by central pattern generators which are neural networks in the central nervous system responsible for creating patterns of muscle activity necessary for the execution of a motor behaviour. What was observed in the muscle activity in a chewing task was clear pattern of simultaneous activation of jaw-closing muscles such as the masseter, temporalis, and medial pterygoid. The activation of the anterior belly of the digastric, a jaw-opening muscle, followed an opposite pattern and only occurred during the deactivation of jaw-closing muscles. By contrast, the muscle activity involved in speech tasks did not appear to be under the control of central pattern generators. Instead of seeing clear activation patterns, a continuous and co-activated pattern of muscle

activity was observed. Notably, there was very little activation of the masseter and temporalis muscles during speech, as is expected because there is less jaw movement in speech production than there is in chewing. The muscles involved jaw-opening and closing for speech movements were the anterior belly of the digastric and medial pterygoid, respectively. This suggests that the motor movements involved in speech and non-speech tasks are managed by different neural mechanisms. The notion that speech and non-speech tasks are facilitated by different neural mechanisms is consistent with other findings (Ruark & Moore, 1997). Additionally, Weismer (2006) has provided arguments against the use of non-speech oromotor tasks as a measure of motor speech control. Although speech and non-speech tasks are executed by a similar set of muscles, they differ in patterns of muscle control and nature of muscle movement (Weismer, 2006). It has even been suggested that the neural mechanisms responsible for two different verbal tasks, speech and singing, are unique from one another (Kent, 2004). The difference in underlying neural mechanisms of these oromotor tasks could be a reason dystonic symptoms such as severity and frequency of spasms, involuntary movement, and pain were improved due to BoNT-A injections as seen in previous literature (Cultrara et al., 2004; Esper et al., 2010; Teive, et al., 2012), but that these improvements were not extended to speech intelligibility outcomes in the present study.

The motor speech disorder associated with OMD, hyperkinetic dysarthria, is primarily characterized by imprecise consonant articulation, vowel distortion, and irregular articulatory breakdown (Darley, Aronson, & Brown, 1969). In general, dysarthrias are known to have global impacts on speech and can produce many effects on speech production such as intelligibility, prosody, voice quality, and speech rate (Kent, 2000). Some of the findings in the present study may be reflecting the different dimensions of speech production aside from intelligibility that are

affected by hyperkinetic dysarthria. Specifically, in comparing orthographic transcription and visual analogue scores for sentence intelligibility in the present study, it was found that VAS intelligibility scores were much lower than transcription scores. Mean sentence intelligibility scores measured by VAS pre- and post-BoNT-A were 81.185% and 80.930%, respectively. Mean sentence intelligibility scores measured by transcription pre- and post-BoNT-A were 90.909% and 89.654%, respectively. However, in single-word intelligibility tasks, these differences are less consistent. Mean single-word intelligibility scores measured by VAS pre- and post-BoNT-A were 75.5% and 78%, respectively. Mean single-word intelligibility scores measured by transcription pre- and post-BoNT-A were 76.65% and 76.198%, respectively. The lower VAS scores in sentence intelligibility may be reflecting other aspects of speech production affected by hyperkinetic dysarthria such as naturalness, listener effort, and acceptability, which can impact intelligibility scores. These patterns were not reflected in the single-word tasks because presenting listeners with individual words one at time likely did not provide an overall impression of these other aspects of speech production that may contribute to intelligibility. It seems as though VAS measures were likely providing a more holistic measure of intelligibility in comparison to transcription, which was likely only sensitive to articulation. This interpretation may be supported by Yorkston, Beukelman, and Traynor (1988) who suggested that measuring articulatory deficits alone does not provide an indicator of overall speech adequacy. Because of the multidimensional effects of hyperkinetic dysarthria on speech production, it is possible that treatment via BoNT-A injections may not be addressing all of the irregularities in speech production exhibited by participants.

It has been suggested that dysarthrias caused by chronic conditions, as is the case in the current study, cannot be completely cured or resolved by medical intervention (Kent, 2000).

Therefore, relying on BoNT-A treatment exclusively to reduce speech-related deficits caused by OMD may not be an entirely realistic expectation. The treatment of OMD using BoNT-A injections is to primarily improve involuntary dystonic muscles contractions and manage pain (Cultrara et al., 2004; Esper et al., 2010; Teive et al., 2012), not to improve specific speech-related outcomes. Although there is no available cure for OMD, behavioural therapy may be helpful in the management of dystonic symptoms that impair speech intelligibility (Yorkston, 1996). Common behavioural interventions for dysarthria include, but are not limited to, articulation exercises, breath control exercises, rate control exercises, and use of a pacing board (Yorkston, 1996). There is also a demand for a combination of both behavioural and medical interventions; however, the efficacy of combining interventions has not been empirically examined and are thus still poorly understood (Kent, 2000). Furthermore, by combining behavioural interventions with BoNT-A treatment, the management of dystonia and its related symptoms can be customized to each individual based on the subtype of OMD with which they present as well as the severity of symptoms.

4.3 Objective 2: Comparison of single-word and sentence intelligibility ratings based on order of presentation of single-words and sentence length.

A two-factor repeated measures MANOVA revealed a significant main effect of the order of presentation of single-words where listeners rated the first half of words on the PIT (words 1-29) as more intelligible than those in the second half of the PIT (words 30-57). The same two-factor repeated measures MANOVA revealed a significant main effect of sentence length on intelligibility in our participants. More specifically, shorter sentences (5-11 words) were rated as

more intelligible than longer sentences (12-15 words) based on the SIT. These results were consistent across conditions (i.e., pre-, post-BoNT-A), suggesting that the effect of "Order" is more likely due to OMD itself, rather than the result of receiving BoNT-A injections.

These findings may be explained by a speech fatigue effect in speakers. Speakers were not given any breaks between the recording of the first and second half of the PIT or the SIT. It is possible that when the end of each intelligibility task was reached, participants' speech production mechanisms became fatigued which aggravated their dystonic symptoms and lead to a decrease in speech intelligibility ratings for the second half of words on the PIT and for longer sentences on the SIT. In the single-word intelligibility task, the protocol involved having participants read individual words in the order that they were presented on the list. In the sentence intelligibility task, the protocol involved having participants begin reading shorter sentences that progressed in length. Because there was an observed effect based on order of presentation and sentence length on intelligibility scores, it is possible that speakers exhibited a fatigue effect which impacted their speech intelligibility. These findings may supported by those of Dworkin & Aronson (1986) who found that dysarthric subjects who exhibited tongue weakness also demonstrated articulatory difficulties. More recently, in an attempt to determine the impact of fatigue on speech production, Solomon (2000) induced fatigue of tongue muscles in neurologically normal individuals and found that induced fatigue reduced speech precision and even after a recovery period, participants were still not able to perform speech tasks at a baseline level. Although limited data is available regarding the endurance or fatigue of dysarthric subjects during speech production, Kent, Kent, and Rosenbek (1987) have noted the potential clinical importance of determining maximum performance particularly in individuals with

neurologic disorders as a step towards the identification of reduced speech production capacity. A reduced speech production capacity may make speech a demanding process.

The significant effect of sentence length in our results is consistent with previous literature (Ansel & Kent, 1992) that suggests that utterance length is a factor that influences intelligibility. A possible explanation for these results is that shorter utterances are more beneficial to the listener. More specifically, shorter utterances contain syntactically simpler sentence patterns making them more easily understood. This could aid the listener in using semantic information from the sentences and filling in words that were less intelligible. Longer sentences are more syntactically complex and therefore it becomes more challenging to take advantage of these semantic cues to increase predictability of the sentence. The SIT task provides listeners with semantic information which has been shown to increase intelligibility, particularly in speakers with mild to moderate dysarthria. The effect of these semantic cues may have been observed in the results of the present study. Specifically, it has been suggested that semantic cues in sentences increase the predictability of the utterance and therefore make use of top-down processing instead of relying on the acoustic signal to determine intelligibility (Yorkston, Strand, & Kennedy, 1996; Yorkston & Beukelman, 1981). In shorter utterances with simple syntactic structures, such as the SIT sentences with 5 – 11 words, it may be easier for listeners to take advantage of semantic information to increase the predictability of the words in each sentence and make use of top-down cognitive processing. Longer sentences which are syntactically more complex, such as SIT sentences with 12-15 words in length, are semantically more difficult to predict, therefore listeners may have found it more challenging to use semantic content in filling spaces in sentences that were difficult to understand and would have to depend more strongly on the acoustic signal itself. Additionally, in cases where speakers have more

severely disordered speech, the majority of the utterance may have been difficult to understand, creating greater challenges for listeners to use top-down processing to compensate for a weak or degraded acoustic signal.

Aside from semantic and syntactic differences that aid the listener, another potential explanation for the discrepancy in intelligibility ratings between shorter and longer sentences is that shorter sentences may be more beneficial for the speaker. Producing shorter sentences requires less energy and effort for speakers, and therefore is a less demanding speech production task in comparison to tasks involving the production of longer sentences. Longer sentences may be more taxing to the speech production mechanism and therefore may be more challenging for speakers with dysarthria to produce. If this is the case, increasing the speech demands of participants may have enabled us to gain some insight on the extent of the impact of OMD on speech intelligibility.

Another factor that might have affected results in the present study is the time of day when speech samples were recorded. Many participants informally shared with the experimenter that their speech was generally worse in the afternoons and evenings. Most of the speech sample recordings occurred in the afternoon. This anecdotal evidence may lend support to the suggestion of a fatigue effect and exacerbation of dystonic symptoms which may have led to a decrease in intelligibility.

Listener fatigue, or the phenomenon in which listeners can become fatigued from transcribing disordered speech, was controlled for by the counterbalanced presentation in which listeners were asked to rate the speech samples. Three of the five listeners were asked to rate the speech samples from shortest sentences to longest sentences, which was also the order in which

the sentences were recorded. The remaining two of the five listeners were presented with speech samples that had shorter and longer sentence groups reversed. In other words, these listeners were presented with sentences that were 12-15 words in length first and were subsequently presented with the shorter sentences of five to eleven words in length. The two listeners who began with the longer sentences gave intelligibility ratings that were consistent with that of the three listeners who began with the shorter sentences, therefore suggesting that listener fatigue was not an explanation as to why longer sentences consistently received lower intelligibility ratings.

4.4 Objective 3: Examining the relationships among single-word, sentence, and conversational intelligibility scores in OMD.

The final objective of this study sought to determine how intelligibility scores derived from different measurement techniques are related to one another and how different intelligibility tasks (i.e., single-word, sentence, conversational) are related to one another. Relationships were examined in the pre- and the post- BoNT-A conditions.

In both pre- and post-BoNT-A conditions, statistically significant correlations were found between orthographic transcription and visual analogue scaling scores when measuring the same intelligibility task. Specifically, significant correlations were found between single-word intelligibility transcription scores and single-word intelligibility visual analogue scaling scores, as well as between sentence intelligibility transcription scores and sentence intelligibility visual analogue scaling scores. These findings suggest that orthographic transcription and visual analogue scaling are measuring intelligibility in a similar way. These findings also suggest that orthographic transcription measures and VAS technique scores are statistically reliable in

measuring intelligibility and are predictive of one another. This finding may be supported by previous work that suggests that intelligibility estimates, when averaged, reflect transcription scores (Yorkston & Beukelman, 1978). Additionally, in both pre- and post- BoNT-A conditions, strong correlations were found between intelligibility scores of different tasks when measured using the same technique. Specifically, strong correlations were found between single-word intelligibility transcription scores and sentence intelligibility transcription scores, as well as between single-word intelligibility visual analogue scaling scores and sentence intelligibility visual analogue scaling scores. Lastly, statistically significant correlations were found between different intelligibility tasks and different measurement techniques in both pre- and post- BoNT-A conditions. Specifically, statistically significant correlations were found between single-word intelligibility transcription scores and sentence intelligibility visual analogue scaling scores, as well as between single-word intelligibility visual analogue scaling scores and sentence intelligibility transcription scores. This suggests that the correlational relationship between single-word and sentence intelligibility tasks remains regardless of measurement technique used. Additionally, it provides further evidence of the reliability between single-word and sentence intelligibility scores (Tjaden & Wilding, 2011). These findings also support findings of Yorkston & Beukelman (1978) who did not find significant differences between single-word and sentence intelligibility scores measured by transcription.

Conversational intelligibility scores appear to have a less consistent relationship with single-word and sentence intelligibility. A statistically significant correlation was found between sentence intelligibility visual analogue scaling scores and conversational intelligibility scores, in both pre- and post-BoNT-A conditions, which provides further evidence of the consistency of intelligibility scores when measured by the same technique. However, no correlations were

found between sentence intelligibility transcription scores and conversational intelligibility scores or between single-word intelligibility transcription scores and conversational intelligibility in both pre- and post- BoNT-A conditions. A simple explanation for this finding may be that the speech production task of the speaker influences intelligibility scores. For example, it was found that spontaneous speech has significantly lower intelligibility than read or repeated speech (Kempler & Van Lancker, 2002). Another possible explanation for the non-significant correlational relationship of other speech intelligibility measures with conversational speech is that participants were given material to read in the single-word and sentence level tasks, but for conversational intelligibility, spontaneous speech was elicited by asking participants an open-ended question (i.e., What do you do for a living?). Perhaps single-word and sentence intelligibility demonstrated stronger correlations because external models or cues (e.g., read speech) were provided which were not provided in the conversational speech condition (e.g., spontaneous speech). External models decrease the demand placed on basal ganglia with regard to the planning and execution of motor speech movements (Kempler & Van Lancker, 2002). Furthermore, not only was there a difference in that external models were provided for single-word and sentence tasks and not for the conversational task, but also there was a difference in the measurement technique used to obtain these scores. The difference in measurement technique (transcription for PIT and SIT, VAS for conversation) may also be a contributing factor to the non-significant correlation and may also lend support to the notion that VAS may be capturing other aspects of speech production, such as speech rate, prosody, and voice quality, that transcription does not account for.

A final possible explanation for the inconsistency of conversational intelligibility results is that differences in intelligibility score are emphasized when the content of the speech samples

differ (Tjaden & Wilding, 2011). The material used to evaluate sentence and conversational intelligibility, which both measure intelligibility of connected speech and make use of contextual information, were inherently different because participants were free to choose whatever words they wanted to in the conversational condition. Additionally, conversational speech was elicited using different questions, therefore making the content of the two speech samples different in the pre-BoNT-A and post-BoNT-A conditions. In the single-word and sentence intelligibility tasks, participants were asked to read identical material for both treatment conditions. Furthermore, these findings are consistent with published studies (Tjaden & Wilding, 2011) that suggest that intelligibility scores derived from validated clinical intelligibility tests cannot be extrapolated to spontaneous speech.

4.5 Limitations of the Current Study

Although this study revealed some interesting findings, it is important to acknowledge some of its methodological limitations. The first methodological limitation relates to the sample size of the current study. The current study examined the speech intelligibility of 10 participants with various subtypes of OMD. This is mainly due to difficulties in participant recruitment. The prevalence of OMD is estimated to be only 68.9 cases/million persons (Nutt, Muenter, Aronson, Kurland, & Melton, 1988). Further, the eligibility criteria for this study involved participants to have primary OMD without any other comorbidities, making data collection in this population particularly challenging. Because of the modest sample size and number of comparisons in our analysis, the current study is likely underpowered. Additionally, the ability to generalize findings is limited. Furthermore, the small sample size prevents further investigation into the differential

effects of BoNT-A injections on speech intelligibility based on the various types/presentations of OMD (e.g., jaw opening, jaw closing, lingual, labial, mixed).

The second limitation relates to the participants BoNT-A injection schedule and the relationship to baseline intelligibility scores. Eight out of 10 participants received BoNT-A injections on a 3-4 month cycle (the remaining two participants were de-novo). The pre-BoNT-A condition corresponded to the final day of each participant's 3-4 month injection cycle. It was the intention that we were seeing participants when BoNT-A had worn off, however, there was no definitive way to determine with certainty that the effects of the previous BoNT-A treatments had diminished completely prior to the next series of injections. Therefore there remains some uncertainty about the baseline intelligibility measurements in the pre-BoNT-A condition. Although the treatment schedule followed by participants in the current study is consistent with previous literature (Tsui, 2005), suggesting that BoNT-A treatments follow a 3-4 month cycle, a future study may seek to extend the injection cycle to 6 months or more to ensure that BoNT-A had a complete "wearing off" effect before obtaining baseline intelligibility measures.

The third limitation relates to the history of BoNT-A treatment of each participant. Only two out of 10 participants with OMD were de-novo. The remaining eight participants had been receiving ongoing therapeutic injections of BoNT-A during the data collection period of the current study. Because of this, the speech samples obtained for the pre- and post-BoNT-A conditions is merely a snapshot of their progress throughout the course of their treatment and not a comprehensive look at how their speech production has been impacted by BoNT-A throughout the history of their treatment for OMD. Therefore, measuring speech intelligibility before and after receiving a single series of BoNT-A injections may have resulted in the limited change in speech intelligibility observed in the results of the current study. This also relates to the second

limitation involving the difficulty in ascertaining that the effects of the previous BoNT-A injections had completely diminished prior to collecting baseline speech recordings. Because the majority of participants had received BoNT-A injections before the inception of this study, the speech samples obtained from these participants may not be a true representation of their speech production pre-injection. As a result, there the possibility remains that the residual effects of previous treatment were present during the recording of the baseline speech samples.

Finally, the fourth limitation of this study relates to the artificial nature of speech recording that is inherent to clinical intelligibility testing. Although we made an attempt to elicit an ecologically valid estimate of speech intelligibility (i.e., the conversational intelligibility task), the recorded speech was collected in a room with no background noise. Our daily conversations rarely occur in complete silence. This could mean that speech recorded in a quiet clinical environment may be produced differently than true day-to-day conversational speech. Therefore, the ability to generalize findings from this study to a real-life setting is limited. Because only 30-45 seconds of spontaneous speech was elicited for this speech task, there is no sufficient evidence to verify that the proposed fatigue effect observed in the sentence intelligibility tasks carried over to conversational speech. A conversational speech sample of 30-45 seconds in duration may not be adequate to tax the speech production mechanism to determine if speech intelligibility changes with sustained speech production over time, potentially due to fatigue.

4.6 Future Directions

The results of the current study provide information and rationale from which further studies can be developed. Further exploration in this area can be pursued by adapting the research design to examine results in greater depth.

The present study intended to study the effects of BoNT-A treatments on the speech intelligibility of individuals with various presentations of oromandibular dystonia. The current study tested participants before and after a single series of BoNT-A injections and examined differences in speech intelligibility between these two testing conditions. A valuable future investigation would be to follow up with participants over a longer period of time beyond the four to six week period used in the current study. A longitudinal approach such as this would allow researchers examine speech intelligibility in more detail to determine potential variability in speech intelligibility over the course of a treatment cycles. Tan & Jankovic (1999) conducted a prospective clinical trial of 162 individuals diagnosed with OMD with a mean follow up period of four years wherein the researchers examined the effects of botulinum toxin A in OMD participants and found that botulinum toxin A treatment caused a significant improvement in both the severity of dystonia and the function of the affected areas. However, the researchers did not appear to measure specific speech-related outcomes that would be relevant to the line of research addressed by the current study. A longitudinal approach has not currently been conducted in the examination of speech intelligibility and other communication-related outcomes in a population with OMD. This approach could potentially provide valuable information to supplement the findings of the current study. If results from longitudinal research determined that BoNT-A injections did improve speech intelligibility over time, this would provide a stronger rationale for the continued use of BoNT-A for individuals with OMD and associated dysarthria. However, if the results were consistent with that of the current study, it may challenge the clinical utility of BoNT-A injections for individuals with OMD whose foremost priority is to improve their intelligibility. Perhaps in this case a more appropriate approach to therapy would entail a combination of behavioural and medical intervention, as suggested by Kent (2000). It

would also be important to solicit feedback from each patient to determine if BoNT-A had a perceived beneficial effect for their dystonia and speech production.

In addition to expanding this research longitudinally, it would be interesting to replicate a future study with a larger number of participants. Having a greater sample size would allow for a more in-depth analysis of the effect of BoNT-A injections on speech intelligibility in OMD based on type and presentation. This information would be important in adding to the limited empirical research on the effects of BoNT-A injections on speech intelligibility, which is of scientific and clinical value. It would also be interesting to replicate this study using de-novo participants only. Testing participants at the start of their treatment and capturing the effects that BoNT-A has on speech intelligibility may produce compelling results. If future research finds an improvement in speech intelligibility in de-novo participants that is not present in participants who had been receiving BoNT-A injections prior to the collection of speech samples, these findings may suggest a cumulative improvement in intelligibility over the course of treatment. Therefore, although it may appear that individuals receiving ongoing BoNT-A injections are not deriving a benefit to speech intelligibility, it may be the case that there was a significant change to speech intelligibility at the beginning of treatment which has since plateaued and is no longer affected by subsequent BoNT-A injections.

Using more naturalistic approaches such as recording speech samples in background noise or by adapting the design of the study wherein both participant and listener are tested together allowing for natural communicative interactions could also lead to some interesting insights on the effectiveness of BoNT-A injections on speech intelligibility. Furthermore, comparing intelligibility ratings of listeners based on familiarity (i.e., naïve listeners vs. caregivers) before and after BoNT-A injections may produce important results. Previous work

has suggested that speaker experience and listener familiarity impacts intelligibility scores (Ansel & Kent, 1992; Tjaden & Liss, 1995a; Tjaden & Liss, 1995b). It is possible that familiar listeners may be more sensitive than naïve listeners at identifying subtle differences in intelligibility after treatment.

Another possible direction for this line of research is to measure qualitatively the impact of BoNT-A injections in speech intelligibility and communicative ability in this population. If it was found that BoNT-A injections improved participants' perception of their speech intelligibility or communicative abilities, this could justify the continued use of this therapeutic option. It would also be important to look holistically at the overall impact of BoNT-A injections. This information could help to determine the overall benefit in the management of other dystonic symptoms such as pain and uncontrollable muscle contractions (Jankovic, 2006) and managing orofacial esthetics (Bhattacharya & Tarsy, 2001), for example. Previous literature has demonstrated that BoNT-A injections in OMD can improve quality of life and help manage dystonic symptoms (Bhattacharyya & Tarsy, 2001; Dykstra, Adams, & Jog, 2007; Tan & Jankovic, 1999; Teive et al., 2012). Perhaps future research can address the impact of BoNT-A treatment on communication-related quality of life and communicative participation in this population. If findings of this future research are positive, perhaps this could imply that there are other aspects of communication beyond intelligibility that BoNT-A treatments are effective at improving.

Finally, measuring listener effort in relation to speech intelligibility may lead to interesting findings. Previous research has suggested that listener effort is sometimes included in definitions of intelligibility, although listener effort and intelligibility should be regarded as separate constructs (Whitehill & Wong, 2006). It would be interesting to examine how listener

effort, which can be measured via VAS, are related to intelligibility scores measured by both VAS and orthographic transcription techniques.

4.7 Research and Clinical Implications

The results of this study adds to the small but growing body of empirical literature on speech intelligibility in oromandibular dystonia and also provides preliminary data on how BoNT-A injections can effect speech intelligibility in individuals with oromandibular dystonia. Developing an understanding of how speech intelligibility is impacted by dystonic symptoms of OMD and BoNT-A injections is essential since BoNT-A is the most widely used treatment for OMD (Jankovic, 2006). If individuals with OMD prioritize the improvement of their speech intelligibility, then it is important to know what the best course of treatment is to ensure optimal communicative outcomes. With continued systematic and empirical study in this area of research, future studies can inform novel assessment and treatment protocols for the improvement of speech intelligibility in OMD.

4.8 Summary and Conclusions

This study was designed to evaluate the effects of BoNT-A injections on speech intelligibility in oromandibular dystonia by measuring speech intelligibility in single-word, sentence, and conversational tasks before and after participants received therapeutic BoNT-A injections. In addition to this research objective, the relationships among intelligibility scores in single-word, sentence, and conversational intelligibility tasks, and relationships between orthographic transcription and visual analogue scaling techniques in pre- and post-BoNT-A conditions were explored.

The first objective of this study revealed no significant differences between speech intelligibility scores for single-word, sentence, and conversational tasks before and after receiving BoNT-A injections, regardless of whether intelligibility scores were measured by orthographic transcription or visual analogue scaling. These results suggest that BoNT-A injections do not affect speech intelligibility, either positively or negatively.

The second objective of this study revealed that in the single-word intelligibility task, listeners rated single-words on the first half of the Phoneme Intelligibility Test as more intelligible than the second half of the test. Stated differently, single words that participants with OMD recorded first resulted in higher intelligibility scores than the latter half of single words of contained on the PIT. In addition, listeners rated shorter sentences (5-11 words in length) as more intelligible than longer sentences (11-15 words in length) based on the SIT. This statistically significant difference was present in VAS scores, and was trending towards significance in orthographic transcription scores. Taken together, these results suggest that as speech tasks become more demanding, dystonic symptoms are exacerbated which negatively impacts speech production. These results also suggest the possibility of a fatigue effect which becomes more pronounced as utterances are lengthened or when the motor demands of speech production have increased.

Finally, the third objective of this study revealed significant correlational relationships between single-word and sentence intelligibility scores as measured by orthographic transcription and visual analogue scaling techniques. Additionally, significant correlations were found between sentence intelligibility scores measured by visual analogue scaling as well as conversational intelligibility scores, which were also measured via visual analogue scaling. However, the relationship between conversational intelligibility scores and that of single-words

is not significant; and the relationship between conversational intelligibility and sentence intelligibility is not consistent. More specifically, conversational and sentence intelligibility are only correlated when both tasks are measured using the same technique, which supports the idea that VAS measures are sensitive to aspects of speech production, such as speech rate, naturalness, and acceptability, that transcription measures do not capture. When sentence intelligibility is measured using orthographic transcription, no correlations with conversational intelligibility are revealed. Two possible explanations for this is that external cues are present at the single-word and sentence levels, but are not present at the conversational level (i.e., where participants have to generate the semantic content of their speech sample) and that the neurological mechanisms facilitating the production of read speech and spontaneous speech are different.

This study has revealed novel and potentially valuable information in the study of speech intelligibility in oromandibular dystonia. The results and implications of this research can serve as basis upon which to design future research that investigate the role of BoNT-A in the improvement of speech intelligibility in this population. With further exploration, this information has the potential to contribute to our knowledge of speech intelligibility in oromandibular dystonia. Lastly, the findings from this line of research will contribute to a small but growing body of literature regarding the effect of BoNT-A injections on speech intelligibility in oromandibular dystonia.

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APPENDIX A

Letter of Information

STUDY TITLE
The effects botulinum toxin A on speech intelligibility, levels of speech usage, communication apprehension, self-perceived communication competence, communicative effectiveness, communication-related quality of life and the lived experiences of individuals with oromandibular dystonia.

PRINCIPAL INVESTIGATOR
Allyson Dykstra, Ph.D.
Assistant Professor
School of Communication Sciences and Disorders, Western University

CO-INVESTIGATOR
Dr. Mandar Jog, MD, FRCPC, Professor
Director, Movement Disorders Program
London Health Sciences Centre, University Campus and Western University

INTRODUCTION
This letter of information describes a research study and what you may expect if you decide to participate. You should read the letter carefully and ask the person discussing this with you any questions that you may have before making a decision whether or not to participate. This form contains important information and telephone numbers, so you should keep this copy for future reference. If you decide not to participate in this study, the decision will not be held against you and will not affect your treatment in any way.

You are being asked to participate in this research study because you are an individual with oromandibular dystonia (OMD). The **purpose of this study** is to investigate the effects of oromandibular dystonia on your speech intelligibility (how understandable your speech is), your level of speech usage, your level of apprehension or concern when you are communicating orally, your self-perceived communicative competence, your effectiveness as a communicator in different social settings and your quality of life as it relates to communication. An additional purpose of this study is to compare how the Botox© injections you are receiving to manage your dystonia affects your speech intelligibility, your communicative apprehension, communication effectiveness and communication-related quality of life. We are also interested in learning about your experience of having oromandibular dystonia.

This study will involve 30 participants with OMD. Information about participants will be collected from patient charts and person-to-person interviews by the principal experimenter or another designated member of the research team. This will include information about the participant's date of birth, general medical history, neurological history, and speech and hearing history.

This study will be conducted over two sessions, separated by approximately one month and lasting approximately 40 minutes for the first visit and approximately 2 hours for the second visit. Both visits will involve speech recordings of your voice. During this 10 minute recording period you will be asked to read aloud a series of 57 single words and 11 sentences while being recorded with a microphone. Both visits will also involve completing a series of six questionnaires that will look at how you use your speech

on a daily basis, your level of concern or apprehension when you are communicating orally, your self-perceived competence when communicating, your effectiveness as a communicator in different social situations and your quality of life as it relates to your communication. It is anticipated that completion of the questionnaires will take approximately 30 minutes. The second visit will involve an additional 60-90 minute one-time in-person interview with the researchers into order to learn more about your experiences of living with oromandibular dystonia. During this interview we will ask you to share stories and information about strategies you have used to help you participate in life activities due to having dystonia. We want to hear about strategies that worked well and those that did not work well. In particular, we want to hear about things that make you more or less confident about your participation in activities. We want to hear your recommendations that you would give to other people in similar circumstances. You do not need to answer any questions you do not want to answer. The interview will be audio-recorded. Only the researchers will have access to the recording of the interview. The audio file would be stored on a secure server at Western University.

The first visit will be completed during your scheduled clinic visit at the Movement Disorders Clinic. The second visit will be scheduled approximately one month later to ensure that your Botox© treatment is working optimally.

If you agree to participate you will be able to complete the first visit of the study directly following your scheduled appointment time at the Movement Disorders Clinic in a separate testing room located within University Hospital. For the second visit of the study you will be asked to come to the Principal Investigator's Lab in Elborn College [redacted] at the University of Western Ontario for repeat administration of questionnaires, speech recordings and the in-person interview. While at Elborn College, you will be provided with free parking.

The experimental procedures will require very little physical effort, and there is no known discomfort or risk involved in performing them. You will be seated in a comfortable chair throughout the procedures and during the interview and you will be given rest breaks approximately every five minutes or more frequently if required.

The procedures that will be used during this study are experimental in nature and will not provide any direct benefit to the participant's medical condition, however, it is anticipated that results from this study may provide important information about the effect of oromandibular dystonia on speech intelligibility, one's perception of their apprehension when communicating orally, their level of speech usage, their perception of how effective they are as communicators, and their quality of life as it relates to communication. It may also provide important information about the effect of Botox© on speech intelligibility, communication apprehension, communicative effectiveness and communication-related quality of life. Financial compensation will not be provided upon completion of this study. Parking costs over and above your

regular clinic visit at the Movement Disorders Clinic will not be reimbursed. While at Elborn College, you will be provided with free parking.

Participation in this study is voluntary. You may refuse to participate, refuse to answer any questions, or withdraw from the study at any time with no effect on your future care.

All of the information obtained in this study will be held in strict confidence. Your name and any identifying information will be removed from the data. If the results of the study are published, your name will not be used and no information that discloses your identity will be released or published. Representatives of Western University's Health Sciences Research Ethics Board may contact you or require access to your study-related records to monitor the conduct of the research. You do not waive any legal rights by signing the consent form.

Throughout the study, all confidential information and data will be preserved in a locked filing cabinet in the Principal Investigator's laboratory at Elborn College, Western University. All study materials will be destroyed after 25 years.

If requested, you will be provided with a copy of any publication related to the results of this study when it becomes available.

If you have any questions or would like additional information about this study, please contact Professor Allyson Dykstra at the School of Communication Sciences and Disorders, Elborn College, Western University, London, Ontario, N6G 1H1 (Phone: [redacted] If you have any questions about the conduct of this study or your rights as a research subject you may contact Dr. David Hill, Scientific Director, Lawson Health Research Institute at [redacted]

If you agree to participate in this study, please sign the consent form on the next page.

Sincerely,

Allyson Dykstra, PhD

Assistant Professor

APPENDIX B

Consent Form

STUDY TITLE
The effects botulinum toxin A on speech intelligibility, levels of speech usage, communication apprehension, self-perceived communication competence, communicative effectiveness, communication-related quality of life and the lived experiences of individuals with oromandibular dystonia.

PRINCIPAL INVESTIGATOR
Allyson Dykstra, Ph.D.
Assistant Professor
School of Communication Sciences and Disorders, Western University

CO-INVESTIGATOR
Dr. Mandar Jog, MD, FRCPC, Professor
Director, Movement Disorders Program
London Health Sciences Centre, University Campus and Western University

I have read the Letter of Information, have had the nature of the study explained to me and I agree to participate. All questions have been answered to my satisfaction.

_____	_____	_____
Signature of Research Subject	Printed Name	Date

_____	_____	_____
Signature of Person Obtaining Consent	Printed Name	Date

APPENDIX C

Ethics Approval Notice

Research Western

Use of Human Participants - Ethics Approval Notice

Principal Investigator: Dr. Allyson Dykstra
Review Number: 17190E
Review Level: Delegated
Approved Local Adult Participants: 30
Approved Local Minor Participants: 0
Protocol Title: The effects of botulinum toxin A on speech intelligibility, levels of speech usage, communication apprehension, self-perceived communication competence, communicative effectiveness and communication-related quality of life in individuals with oromandibular dystonia
Department & Institution: Communication Sciences & Disorders, University of Western Ontario
Sponsor:
Ethics Approval Date: August 19, 2011 **Expiry Date:** August 31, 2013
Documents Reviewed & Approved & Documents Received for Information:

Document Name	Comments	Version Date
UWO Protocol		
Letter of Information & Consent		2011/08/11

This is to notify you that The University of Western Ontario Research Ethics Board for Health Sciences Research Involving Human Subjects (HSREB) which is organized and operates according to the Tri-Council Policy Statement: Ethical Conduct of Research Involving Humans and the Health Canada/ICH Good Clinical Practice Practices: Consolidated Guidelines; and the applicable laws and regulations of Ontario has reviewed and granted approval to the above referenced revision(s) or amendment(s) on the approval date noted above. The membership of this REB also complies with the membership requirements for REB's as defined in Division 5 of the Food and Drug Regulations.

The ethics approval for this study shall remain valid until the expiry date noted above assuming timely and acceptable responses to the HSREB's periodic requests for surveillance and monitoring information. If you require an updated approval notice prior to that time you must request it using the UWO Updated Approval Request Form.

Members of the HSREB who are named as investigators in research studies, or declare a conflict of interest, do not participate in discussion related to, nor vote on, such studies when they are presented to the HSREB.

The Chair of the HSREB is Dr. Joseph Gilbert. The UWO HSREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.

[redacted]

Signature

Ethics Officer to Contact for Further Information

[redacted]	[redacted]	[redacted]

This is an official document. Please retain the original in your files.

APPENDIX D

Phoneme Intelligibility Test (PIT) – Single words

Sample word list from the Phoneme Intelligibility Test – Single words

1. herd	30. that
2. taught	31. towed
3. made	32. chat
4. Jan	33. man
5. made	34. mate
6. load	35. lug
7. bat	36. can
8. mule	37. shine
9. Jane	38. meal
10. foil	39. seat
11. mod	40. lodge
12. loin	41. lush
13. loaf	42. maim
14. ham	43. fall
15. boy	44. bee
16. caught	45. time
17. male	46. sat
18. thine	47. tame
19. Tim	48. she'd
20. mood	49. file
21. lobe	50. mop
22. men	51. peat
23. man	52. main
24. Pam	53. ice
25. lung	54. bin
26. mod	55. rug
27. men	56. shine
28. Dan	57. towed
29. dam	

APPENDIX E

Sentence Intelligibility Test (SIT)

Sample sentences from the short version of the Sentence Intelligibility Test

5A. Do you like doing math?

6A. Their house is grey and white.

7A. It was very popular with our fans.

8A. This is a period of transition for me.

9A. You can rent a mower from many garden stores.

10A. The patient managed to fall and break his ankle again.

11A. We saw a mother bear leading her cubs up the hill.

12A. There are no judges to intimidate you, or lawyers making obscure points.

13A. After you've finished answering all the questions, please mail the card to us.

14A. The sun never reaches the ground through the overhead canopy of trees and vines.

15A. It was the exact same feeling you get when your knee gives out on you.

APPENDIX F

VAS Samples

Single-word Intelligibility: VAS

Instructions for listeners:
You will be listening to a series of single words. Following each series of words, you will be required to rate the intelligibility or understandablility of the series. Samples will only be presented once.

Single word series 1:

Intelligibility Rating
Please rate your perception of how intelligible/understandable the series of single words were.

|_____|
0% 100%

Sentence Intelligibility: VAS

Instructions for listeners:
You will be listening to a series of sentences. Following each series of sentences, you will be required to rate the intelligibility or understandablility of the series. Samples will only be presented once.

Sentence series 1:

Intelligibility Rating
Please rate your perception of how intelligible/understandable the series of sentences were.

|_____|
0% 100%

Conversational Intelligibility: VAS

Instructions for listeners:
You will be listening to 20 conversational excerpts ranging in length from 30 to 45 seconds each. Following each conversational excerpt, you will be required to rate the intelligibility or understandablility of each. Samples will only be presented once.

Conversational Excerpt 1:

Intelligibility Rating
Please rate your perception of how intelligible/understandable the phrases in the conversation were.

|_____|
0% 100%

APPENDIX G
Inter-rater Reliability

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.973	.976	5

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0		
		Lower Bound	Upper Bound	Value	df1	df2
Single Measures	.846[a]	.687	.943	37.704	12	48
Average Measures	.965[c]	.916	.988	37.704	12	48

Intraclass Correlation Coefficient

	F Test with True Value 0[b]
	Sig
Single Measures	.000[a]
Average Measures	.000[c]

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. The estimator is the same, whether the interaction effect is present or not.

b. Type A intraclass correlation coefficients using an absolute agreement definition.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

APPENDIX H

Intra-rater Reliability

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.987	.987	2

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0		
		Lower Bound	Upper Bound	Value	df1	df2
Single Measures	.973[a]	.956	.984	76.567	64	64
Average Measures	.987[c]	.978	.992	76.567	64	64

Intraclass Correlation Coefficient

	F Test with True Value 0[b]
	Sig
Single Measures	.000[a]
Average Measures	.000[c]

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. The estimator is the same, whether the interaction effect is present or not.

b. Type A intraclass correlation coefficients using an absolute agreement definition.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

APPENDIX I

Repeated Measures MANOVA: Time (Orthographic Transcription)

Descriptive Statistics

	Mean	Std. Deviation	N
SITpre_tot_ave	90.9090909090 91120	10.39707524036 0687	10
SITpost_tot_ave	89.6545454545 45570	12.98623980382 4155	10
PITpre_tot_ave	76.6502463054 18800	10.83618505465 6324	10
PITpost_tot_ave	76.1979802955 66610	14.61830449249 7483	10

Multivariate Tests[a]

Effect			Value	F	Hypothesis df	Error df
Between Subjects	Intercept	Pillai's Trace	.986	273.228[b]	2.000	8.000
		Wilks' Lambda	.014	273.228[b]	2.000	8.000
		Hotelling's Trace	68.307	273.228[b]	2.000	8.000
		Roy's Largest Root	68.307	273.228[b]	2.000	8.000
Within Subjects	time	Pillai's Trace	.087	.381[b]	2.000	8.000
		Wilks' Lambda	.913	.381[b]	2.000	8.000
		Hotelling's Trace	.095	.381[b]	2.000	8.000
		Roy's Largest Root	.095	.381[b]	2.000	8.000

Multivariate Tests[a]

Effect			Sig.	Partial Eta Squared
Between Subjects	Intercept	Pillai's Trace	.000	.986[b]
		Wilks' Lambda	.000	.986[b]
		Hotelling's Trace	.000	.986[b]
		Roy's Largest Root	.000	.986[b]
Within Subjects	time	Pillai's Trace	.695	.087[b]
		Wilks' Lambda	.695	.087[b]
		Hotelling's Trace	.695	.087[b]
		Roy's Largest Root	.695	.087[b]

Tests of Within-Subjects Effects

Multivariate[a,b]

Within Subjects Effect		Value	F	Hypothesis df	Error df	Sig.
time	Pillai's Trace	.087	.381[c]	2.000	8.000	.695
	Wilks' Lambda	.913	.381[c]	2.000	8.000	.695
	Hotelling's Trace	.095	.381[c]	2.000	8.000	.695
	Roy's Largest Root	.095	.381[c]	2.000	8.000	.695

Multivariate[a,b]

Within Subjects Effect		Partial Eta Squared
time	Pillai's Trace	.087
	Wilks' Lambda	.087
	Hotelling's Trace	.087
	Roy's Largest Root	.087

a. Design: Intercept

Within Subjects Design: time

b. Tests are based on averaged variables.

c. Exact statistic

Univariate Tests

Source	Measure		Type III Sum of Squares	df	Mean Square	F
time	SIT_OT_ave	Sphericity Assumed	7.869	1	7.869	.725
		Greenhouse-Geisser	7.869	1.000	7.869	.725
		Huynh-Feldt	7.869	1.000	7.869	.725
		Lower-bound	7.869	1.000	7.869	.725
	PIT_OT_ave	Sphericity Assumed	1.023	1	1.023	.022
		Greenhouse-Geisser	1.023	1.000	1.023	.022
		Huynh-Feldt	1.023	1.000	1.023	.022
		Lower-bound	1.023	1.000	1.023	.022
Error(time)	SIT_OT_ave	Sphericity Assumed	97.734	9	10.859	
		Greenhouse-Geisser	97.734	9.000	10.859	
		Huynh-Feldt	97.734	9.000	10.859	
		Lower-bound	97.734	9.000	10.859	
	PIT_OT_ave	Sphericity Assumed	428.036	9	47.560	
		Greenhouse-Geisser	428.036	9.000	47.560	
		Huynh-Feldt	428.036	9.000	47.560	
		Lower-bound	428.036	9.000	47.560	

Univariate Tests

Source	Measure		Sig.	Partial Eta Squared
time	SIT_OT_ave	Sphericity Assumed	.417	.075
		Greenhouse-Geisser	.417	.075
		Huynh-Feldt	.417	.075
		Lower-bound	.417	.075
	PIT_OT_ave	Sphericity Assumed	.887	.002
		Greenhouse-Geisser	.887	.002
		Huynh-Feldt	.887	.002
		Lower-bound	.887	.002
Error(time)	SIT_OT_ave	Sphericity Assumed		
		Greenhouse-Geisser		
		Huynh-Feldt		
		Lower-bound		
	PIT_OT_ave	Sphericity Assumed		
		Greenhouse-Geisser		
		Huynh-Feldt		
		Lower-bound		

APPENDIX J

Repeated Measures MANOVA: Time (VAS)

Descriptive Statistics

	Mean	Std. Deviation	N
VASpre_tot_ave	81.1850	14.93213	10
VASpost_tot_ave	80.9300	15.65324	10
PITVASpre_tot_ave	75.500000000000100	12.248446613528053	10
PITVASpost_tot_ave	78.075000000000100	13.594509716957324	10
Conv_pre_total_ave	74.870	21.2295	10
Conv_post_total_ave	73.690	19.0867	10

Multivariate Tests[a]

Effect			Value	F	Hypothesis df	Error df
Between Subjects	Intercept	Pillai's Trace	.979	110.527[b]	3.000	7.000
		Wilks' Lambda	.021	110.527[b]	3.000	7.000
		Hotelling's Trace	47.369	110.527[b]	3.000	7.000
		Roy's Largest Root	47.369	110.527[b]	3.000	7.000
Within Subjects	time	Pillai's Trace	.272	.873[b]	3.000	7.000
		Wilks' Lambda	.728	.873[b]	3.000	7.000
		Hotelling's Trace	.374	.873[b]	3.000	7.000
		Roy's Largest Root	.374	.873[b]	3.000	7.000

Multivariate Tests[a]

Effect			Sig.	Partial Eta Squared
Between Subjects	Intercept	Pillai's Trace	.000	.979[b]
		Wilks' Lambda	.000	.979[b]
		Hotelling's Trace	.000	.979[b]
		Roy's Largest Root	.000	.979[b]
Within Subjects	time	Pillai's Trace	.499	.272[b]
		Wilks' Lambda	.499	.272[b]
		Hotelling's Trace	.499	.272[b]
		Roy's Largest Root	.499	.272[b]

APPENDIX K

Two Factor Repeated Measures MANOVA: Time and Order

Multivariate Tests[a]

Effect			Value	F	Hypothesis df
Between Subjects	Intercept	Pillai's Trace	.990	142.082[b]	4.000
		Wilks' Lambda	.010	142.082[b]	4.000
		Hotelling's Trace	94.722	142.082[b]	4.000
		Roy's Largest Root	94.722	142.082[b]	4.000
	time	Pillai's Trace	.471	1.333[b]	4.000
		Wilks' Lambda	.529	1.333[b]	4.000
		Hotelling's Trace	.889	1.333[b]	4.000
		Roy's Largest Root	.889	1.333[b]	4.000
Within Subjects	a_vs_b	Pillai's Trace	.690	3.342[b]	4.000
		Wilks' Lambda	.310	3.342[b]	4.000
		Hotelling's Trace	2.228	3.342[b]	4.000
		Roy's Largest Root	2.228	3.342[b]	4.000
	time * a_vs_b	Pillai's Trace	.413	1.056[b]	4.000
		Wilks' Lambda	.587	1.056[b]	4.000
		Hotelling's Trace	.704	1.056[b]	4.000
		Roy's Largest Root	.704	1.056[b]	4.000

Multivariate Tests[a]

Effect			Error df	Sig.	Partial Eta Squared
Between Subjects	Intercept	Pillai's Trace	6.000	.000[b]	.990
		Wilks' Lambda	6.000	.000[b]	.990
		Hotelling's Trace	6.000	.000[b]	.990
		Roy's Largest Root	6.000	.000[b]	.990
Within Subjects	time	Pillai's Trace	6.000	.358[b]	.471
		Wilks' Lambda	6.000	.358[b]	.471
		Hotelling's Trace	6.000	.358[b]	.471
		Roy's Largest Root	6.000	.358[b]	.471
	a_vs_b	Pillai's Trace	6.000	.091[b]	.690
		Wilks' Lambda	6.000	.091[b]	.690
		Hotelling's Trace	6.000	.091[b]	.690
		Roy's Largest Root	6.000	.091[b]	.690
	time * a_vs_b	Pillai's Trace	6.000	.453[b]	.413
		Wilks' Lambda	6.000	.453[b]	.413
		Hotelling's Trace	6.000	.453[b]	.413
		Roy's Largest Root	6.000	.453[b]	.413

a. Design: Intercept

Within Subjects Design: time + a_vs_b + time * a_vs_b

b. Exact statistic

Univariate Tests

Source	Measure		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
time	SIT_OT	Sphericity Assumed	15.735	1	15.735	.717	.419	.074
		Greenhouse-Geisser	15.735	1.000	15.735	.717	.419	.074
		Huynh-Feldt	15.735	1.000	15.735	.717	.419	.074
		Lower-bound	15.735	1.000	15.735	.717	.419	.074
	SIT_VAS	Sphericity Assumed	30.800	1	30.800	1.623	.235	.153
		Greenhouse-Geisser	30.800	1.000	30.800	1.623	.235	.153
		Huynh-Feldt	30.800	1.000	30.800	1.623	.235	.153
		Lower-bound	30.800	1.000	30.800	1.623	.235	.153
	PIT_OT	Sphericity Assumed	2.045	1	2.045	.022	.887	.002
		Greenhouse-Geisser	2.045	1.000	2.045	.022	.887	.002
		Huynh-Feldt	2.045	1.000	2.045	.022	.887	.002
		Lower-bound	2.045	1.000	2.045	.022	.887	.002
	PIT_VAS	Sphericity Assumed	66.306	1	66.306	.693	.427	.072
		Greenhouse-Geisser	66.306	1.000	66.306	.693	.427	.072
		Huynh-Feldt	66.306	1.000	66.306	.693	.427	.072

		Lower-bound	66.306	1.000	66.306	.693	.427	.072
		Sphericity Assumed	197.544	9	21.949			
	SIT_OT	Greenhouse-Geisser	197.544	9.000	21.949			
		Huynh-Feldt	197.544	9.000	21.949			
		Lower-bound	197.544	9.000	21.949			
		Sphericity Assumed	170.782	9	18.976			
	SIT_VAS	Greenhouse-Geisser	170.782	9.000	18.976			
		Huynh-Feldt	170.782	9.000	18.976			
		Lower-bound	170.782	9.000	18.976			
Error(time)		Sphericity Assumed	856.072	9	95.119			
	PIT_OT	Greenhouse-Geisser	856.072	9.000	95.119			
		Huynh-Feldt	856.072	9.000	95.119			
		Lower-bound	856.072	9.000	95.119			
		Sphericity Assumed	860.511	9	95.612			
	PIT_VAS	Greenhouse-Geisser	860.511	9.000	95.612			
		Huynh-Feldt	860.511	9.000	95.612			
		Lower-bound	860.511	9.000	95.612			
a_vs_b	SIT_OT	Sphericity Assumed	275.252	1	275.252	11.720	.008	.566

		Greenhouse-Geisser	275.252	1.000	275.252	11.720	.008	.566
		Huynh-Feldt	275.252	1.000	275.252	11.720	.008	.566
		Lower-bound	275.252	1.000	275.252	11.720	.008	.566
	SIT_VAS	Sphericity Assumed	156.420	1	156.420	7.499	.023	.455
		Greenhouse-Geisser	156.420	1.000	156.420	7.499	.023	.455
		Huynh-Feldt	156.420	1.000	156.420	7.499	.023	.455
		Lower-bound	156.420	1.000	156.420	7.499	.023	.455
	PIT_OT	Sphericity Assumed	16.507	1	16.507	.511	.493	.054
		Greenhouse-Geisser	16.507	1.000	16.507	.511	.493	.054
		Huynh-Feldt	16.507	1.000	16.507	.511	.493	.054
		Lower-bound	16.507	1.000	16.507	.511	.493	.054
	PIT_VAS	Sphericity Assumed	165.242	1	165.242	11.078	.009	.552
		Greenhouse-Geisser	165.242	1.000	165.242	11.078	.009	.552
		Huynh-Feldt	165.242	1.000	165.242	11.078	.009	.552
		Lower-bound	165.242	1.000	165.242	11.078	.009	.552
Error(a_vs_b)	SIT_OT	Sphericity Assumed	211.363	9	23.485			
		Greenhouse-Geisser	211.363	9.000	23.485			
		Huynh-Feldt	211.363	9.000	23.485			
		Lower-bound	211.363	9.000	23.485			

time * a_vs_b	SIT_VAS	Sphericity Assumed	187.732	9	20.859			
		Greenhouse-Geisser	187.732	9.000	20.859			
		Huynh-Feldt	187.732	9.000	20.859			
		Lower-bound	187.732	9.000	20.859			
	PIT_OT	Sphericity Assumed	290.653	9	32.295			
		Greenhouse-Geisser	290.653	9.000	32.295			
		Huynh-Feldt	290.653	9.000	32.295			
		Lower-bound	290.653	9.000	32.295			
	PIT_VAS	Sphericity Assumed	134.245	9	14.916			
		Greenhouse-Geisser	134.245	9.000	14.916			
		Huynh-Feldt	134.245	9.000	14.916			
		Lower-bound	134.245	9.000	14.916			
	SIT_OT	Sphericity Assumed	.010	1	.010	.001	.974	.000
		Greenhouse-Geisser	.010	1.000	.010	.001	.974	.000
		Huynh-Feldt	.010	1.000	.010	.001	.974	.000
		Lower-bound	.010	1.000	.010	.001	.974	.000
	SIT_VAS	Sphericity Assumed	2.352	1	2.352	.691	.427	.071
		Greenhouse-Geisser	2.352	1.000	2.352	.691	.427	.071

		Huynh-Feldt	2.352	1.000	2.352	.691	.427	.071
		Lower-bound	2.352	1.000	2.352	.691	.427	.071
	PIT_OT	Sphericity Assumed	19.461	1	19.461	2.796	.129	.237
		Greenhouse-Geisser	19.461	1.000	19.461	2.796	.129	.237
		Huynh-Feldt	19.461	1.000	19.461	2.796	.129	.237
		Lower-bound	19.461	1.000	19.461	2.796	.129	.237
	PIT_VAS	Sphericity Assumed	25.440	1	25.440	4.993	.052	.357
		Greenhouse-Geisser	25.440	1.000	25.440	4.993	.052	.357
		Huynh-Feldt	25.440	1.000	25.440	4.993	.052	.357
		Lower-bound	25.440	1.000	25.440	4.993	.052	.357
Error(time*a_vs_b)	SIT_OT	Sphericity Assumed	82.823	9	9.203			
		Greenhouse-Geisser	82.823	9.000	9.203			
		Huynh-Feldt	82.823	9.000	9.203			
		Lower-bound	82.823	9.000	9.203			
	SIT_VAS	Sphericity Assumed	30.640	9	3.404			
		Greenhouse-Geisser	30.640	9.000	3.404			
		Huynh-Feldt	30.640	9.000	3.404			
		Lower-bound	30.640	9.000	3.404			

PIT_OT	Sphericity Assumed	62.645	9	6.961			
	Greenhouse-Geisser	62.645	9.000	6.961			
	Huynh-Feldt	62.645	9.000	6.961			
	Lower-bound	62.645	9.000	6.961			
PIT_VAS	Sphericity Assumed	45.857	9	5.095			
	Greenhouse-Geisser	45.857	9.000	5.095			
	Huynh-Feldt	45.857	9.000	5.095			
	Lower-bound	45.857	9.000	5.095			

Appendix L

Pearson Correlation: Pre-BoNT-A

Correlations

		SITpre_tot_ave	VASpre_tot_ave	PITpre_tot_ave
SITpre_tot_ave	Pearson Correlation	1	.901**	.753*
	Sig. (2-tailed)		.000	.012
	N	10	10	10
VASpre_tot_ave	Pearson Correlation	.901**	1	.728*
	Sig. (2-tailed)	.000		.017
	N	10	10	10
PITpre_tot_ave	Pearson Correlation	.753*	.728*	1
	Sig. (2-tailed)	.012	.017	
	N	10	10	10
PITVASpre_tot_ave	Pearson Correlation	.808**	.856**	.760*
	Sig. (2-tailed)	.005	.002	.011
	N	10	10	10
Conv_pre_total_ave	Pearson Correlation	.389	.639*	.444
	Sig. (2-tailed)	.267	.047	.198
	N	10	10	10

Correlations

		PITVASpre_tot_ave	Conv_pre_total_ave
SITpre_tot_ave	Pearson Correlation	.808	.389**
	Sig. (2-tailed)	.005	.267
	N	10	10
VASpre_tot_ave	Pearson Correlation	.856**	.639
	Sig. (2-tailed)	.002	.047
	N	10	10
PITpre_tot_ave	Pearson Correlation	.760*	.444*
	Sig. (2-tailed)	.011	.198
	N	10	10
PITVASpre_tot_ave	Pearson Correlation	1**	.382**
	Sig. (2-tailed)		.275
	N	10	10
Conv_pre_total_ave	Pearson Correlation	.382	1*
	Sig. (2-tailed)	.275	
	N	10	10

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Appendix M

Pearson Correlation: Post-BoNT-A

Correlations

		SITpost_tot_ave	VASpost_tot_ave	PITpost_tot_ave
SITpost_tot_ave	Pearson Correlation	1	.907**	.756*
	Sig. (2-tailed)		.000	.011
	N	10	10	10
VASpost_tot_ave	Pearson Correlation	.907**	1	.786**
	Sig. (2-tailed)	.000		.007
	N	10	10	10
PITpost_tot_ave	Pearson Correlation	.756*	.786**	1
	Sig. (2-tailed)	.011	.007	
	N	10	10	10
PITVASpost_tot_ave	Pearson Correlation	.847**	.899**	.906**
	Sig. (2-tailed)	.002	.000	.000
	N	10	10	10
Conv_post_total_ave	Pearson Correlation	.578	.815**	.535
	Sig. (2-tailed)	.080	.004	.111
	N	10	10	10

Correlations

		PITVASpost_tot_ave	Conv_post_total_ave
SITpost_tot_ave	Pearson Correlation	.847	.578**
	Sig. (2-tailed)	.002	.080
	N	10	10
VASpost_tot_ave	Pearson Correlation	.899**	.815
	Sig. (2-tailed)	.000	.004
	N	10	10
PITpost_tot_ave	Pearson Correlation	.906*	.535**
	Sig. (2-tailed)	.000	.111
	N	10	10
PITVASpost_tot_ave	Pearson Correlation	1**	.687**
	Sig. (2-tailed)		.028
	N	10	10
Conv_post_total_ave	Pearson Correlation	.687	1**
	Sig. (2-tailed)	.028	
	N	10	10

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Curriculum Vitae

Ysabel Domingo

Education

Western University (2012 – present)

- MSc Health and Rehabilitation Sciences - Speech and Language Sciences
- Thesis: The effect of botulinum toxin A on speech intelligibility in oromandibular dystonia
- Supervisor: Dr. Allyson Dykstra

University of Toronto Mississauga (2008 - 2012)

- Honours Bachelor of Science with distinction
- Double major: Biology for Health Sciences and Exceptionality in Human Learning

Research Experience

Research Assistant, Communicative Participation Lab - Western University
(October 2012 – August 2013)

- Transcription of qualitative interviews
- Data collection, entry, and analysis
- Preparation of poster for presentation

Research Assistant, Infant Language and Speech Lab - University of Toronto Mississauga
(August 2010 – August 2012)

- Recruited/scheduled family volunteers to participate in studies
- Responsible for testing infants, training new lab members, coordinating schedules, preparation of recruitment packages, delegate responsibilities to lab members based on their skills, abilities, data collection and entry for studies

Independent Research Project - University of Toronto Mississauga ***(September 2011 - December 2011)***

- Project title: Infants' use of spatial information to segment words from speech in the presence of a single-talker masker
- Supervisor: Dr. Elizabeth Johnson
- Investigated 10 month-olds' ability to use spatial information to segment words in noise using the Headturn Preference Procedure
- Responsible for scheduling and testing participants, literature search, and data analysis

Research Opportunity Program - University of Toronto Mississauga ***(September 2010 - April 2011)***

- Project title: TeleAudiology: Factors relating to future applications
- Supervisors: Dr. Kathy Pichora-Fuller, Dr. Gurjit Singh
- Assessed attitudes of students, seniors, and clinicians about eHealth and teleAudiology services
- Responsible for testing participants, literature search, and data entry

Teaching Experience

Teaching Assistant, HS4702 The Aging Mind ***(January 2014 – April 2014)***

- Responsibilities include holding office hours, grading presentations and exams, proctoring exams, attending lectures

Peer-reviewed Posters and Presentations

- **Oral presentation: Domingo, Y.**, Dykstra, A.D., Adams, S.G., Johnson, A., & Jog, M. "The effect of botulinum toxin type A (Botox) on speech intelligibility in oromandibular dystonia", 16th Research Colloquium in Rehabilitation, McGill University, May 1, 2014.

- **Poster presentation:** Dykstra, A.D., **Domingo. Y**., Adams, S., & Jog, M. (2014, February). The effect of botulinum toxin type A on speech intelligibility and self-ratings of communicative effectiveness by speakers with oromandibular dystonia. Conference on Motor Speech, Sarasota, FLA.

- **Oral presentation: Domingo, Y.**, Dykstra, A.D., Adams, S.G., Johnson, A., & Jog, M. "The effect of botulinum toxin type A (Botox) on speech intelligibility in oromandibular dystonia", Health & Rehabilitation Sciences Graduate Research Forum 2014

- **Poster presentation: Domingo, Y.**, Dykstra, A.D., Adams, S.G., Johnson, A., & Jog, M. "Evaluating the impact of botulinum toxin A injections on speech intelligibility in oromandibular dystonia", Aging, Rehabilitation and Geriatric Care & Faculty of Health Science Symposium, "Partnerships and Possibilities in Health Research", Western University, February 7, 2014.

- **Poster presentation:** Mancinelli, C., **Domingo, Y.**, Dykstra, A.D., Dworschak-Stokan, M.S., & Husein, M. "An examination of speech intelligibility, hypernasality, and self-ratings of communicative effectiveness in adults with velopharyngeal insufficiency", Health & Rehabilitation Sciences Graduate Research Forum 2014.

- **Poster presentation:** Mancinelli, C., **Domingo, Y.**, Dykstra, A.D., Dworschak-Stokan, M.S., & Husein, M. “An exploration of the relationships between speech intelligibility, hypernasality, and self-ratings of communicative effectiveness in adults with velopharyngeal insufficiency”, Aging, Rehabilitation and Geriatric Care & Faculty of Health Science Symposium, “Partnerships and Possibilities in Health Research”, Western University, February 7, 2014.

- **Poster presentation**: **Domingo, Y**., Dykstra, A.D., Jablecki, D., Adams, S.G., Johnson, A., & Jog, M. "An evaluation of speech intelligibility based on technique in Oromandibular Dystonia", Health & Aging Graduate Research Conference "Urban Health and Well-being" McMaster University, March 1, 2013

- **Poster presentation:** Jablecki, D., Dykstra, A.D., **Domingo, Y.,** & Jog, M. "Examining levels of speech intelligibility in an individual with Oromandibular Dystonia", Health & Aging Graduate Research Conference "Urban Health and Well-being" McMaster University, March 1, 2013

- **Poster presentation: Domingo, Y.,** Dykstra, A.D., Jablecki, D., Adams, S.G., Johnson, A., & Jog, M. "A comparison of speech intelligibility measures obtained from three measurement techniques in Oromandibular Dystonia", Health & Rehabilitation Sciences Graduate Research Forum 2013: "Sowing Seeds of Ideas for Fruitful Trees”, Western University, February 6, 2013

- **Poster presentation: Domingo, Y.,** Dykstra, A.D., Jablecki, D., Adams, S.G., Johnson, A., & Jog, M. "Evaluating speech intelligibility based on technique in Oromandibular Dystonia", Aging, Rehabilitation & Geriatric Care Research Centre & Faculty of Health Science Symposium “Research to Action: Technology, Innovation & Health”, Western University, February 1, 2013

- **Poster presentation**: Jablecki, D., Dykstra, A.D., **Domingo, Y.,** Adams, S.G., & Jog, M. "The effect of task on speech intelligibility in Oromandibular Dystonia: A case report.", Aging, Rehabilitation & Geriatric Care Research Centre & Faculty of Health Science Symposium “Research to Action: Technology, Innovation & Health”, Western University, February 1, 2013

Scholarships and Awards

Best Oral Presentation, Masters student

- Health & Rehabilitation Sciences Graduate Research Forum 2014
- Presentation title: The effect of botulinum toxin type A (Botox) on speech intelligibility in oromandibular dystonia.

Western Graduate Research Scholarship ***(September 2012 – present)***

- Value: $10,000/year