EFFECTS OF STRENGTH TRAINING ON NEUROMUSCULAR FACIAL REHABILITATION

By

Emily S. Perry

A thesis submitted in partial fulfillment of
the requirements for the degree of

MASTER OF ARTS IN SPEECH AND HEARING SCIENCES

WASHINGTON STATE UNIVERSITY
Department of Speech and Hearing Sciences

MAY 2010

To the Faculty of Washington State University:

The members of the Committee appointed to examine the thesis of EMILY S. PERRY find it satisfactory and recommend that it be accepted.

Nancy Potter, Ph.D., Chair

Jon Hasbrouck, Ph.D.

Amy Meredith, Ph.D.

ACKNOWLEDGMENT

"No one ever achieved anything from the smallest object to the
greatest unless the dream was dreamed first." Laura Ingalls Wilder (Pope, 2006)

First and foremost, I want to thank my parents for their continual encouragement, support, and prayers during this research project. They were the first to inspire me to dream big, and words cannot express my gratitude. Whatever the opportunities or challenges I have faced, they have always upheld my highest potential. Thank you, dad and mom. I love you.

I am grateful to Dr. Nancy Potter, who served as the committee chair of my thesis and inspired this research project. Thanks to her dedication, time, energy, enthusiasm, and faith, this project took flight. This incredible learning experience has been an honor. Thank you, Dr. Potter.

I would like to thank my classmate and friend Kayla Rambo for serving as co-data collector, control subject, and fellow graduate student researcher during this project. Most of all, I am grateful for her support and confidence in me. Her smiles were delightful to see each session. Thank you, Kayla.

Thank you to my remaining thesis committee members, Dr. Jon Hasbrouck and Dr. Amy Meredith, for their feedback and investment in my thesis and education. I am also grateful to all of the professors who have supported me on my journey through school to become a speech therapist. A special thanks to Dr. Ella Inglebret for loan of her office during the research study. Thank you, Doug Stevens, for your support and encouragement. Thank you all.

I am grateful to Dr. Erich Luschei for his investment in this project. I was honored to meet personally with Dr. Luschei at the start of this project, and his continual mentorship, support, and advice have played a significant part in shaping my research design. For all you have done, thank you, Dr. Luschei.

Much thanks to Dr. Arthur DiMarco and Eastern Washington University Department of Dental Hygiene for supplying dental whitening trays for the Perry Device. Thank you for your investment in collaborative research.

I extend my gratitude to Dr. Robert Short, who offered valuable statistical assistance during the data analysis of this research project. Thank you, Dr. Short.

Special thank goes to Mrs. Barbara Warriner, my high school English professor. It was under her persistent molding, shaping, editing, and encouraging that my budding writing skills were refined. She promised when we completed her British Literature English class we would be proficient at writing term papers. I wrote all the way through college on the skills and abilities she taught us. Thank you, Mrs. Warriner.

Finally, I owe heartfelt thanks to all of the family and friends who have supported my endeavors. To my brother Scott, his wife Charissa, and kids Emma, Eli, and David, thank you for your enthusiasm and prayers. To my roommate, Katrina Wheeler, thank you for sticking with me during graduate school. To Mrs. Barbara Merz, thank you for your constant encouragement and prayers. To my classmates, thank you for your friendship, advice, and enthusiasm. To Mrs. Cheryl Lindsley, thank you for whetting my appetite for writing and literature. There is not adequate space in which to offer proper thanks to all of the friends, family, advisors, and colleagues who have made an impact on me during graduate school. For those whose names do not appear here, I offer a heartfelt thank you.

Most of all, I believe it is God who brought me where I am today. The unhelmeted motorcycle accident I was in at age ten should have crippled or killed me. The vehicle which hit

Danny and I was going at least fifty miles per hour and hit us head on. I was told in recent years if it were not for Danny shielding me with his body, I would not be alive today. As it was, my injuries were near-fatal. But through the healing power of God, thanks to many prayers, thanks to time, and thanks to excellent physical, occupational, speech therapists, teachers, and counselors, as well as family and friends who always held me to my highest potential, I am in a place today where I can return the favor. I am a speech therapist, and the honor is extraordinary.

Pope, Y. (2006). *Prairie Wisdom.* Kansas City: Andrews McMeel Publishing.

EFFECTS OF STRENGTH TRAINING ON NEUROMUSCULAR FACIAL REHABILITATION

Abstract

by Emily S. Perry, M.A.
Washington State University
May 2010

Chair: Nancy Potter

Purpose: Neuromuscular facial rehabilitation (NMR) using electromyographic (EMG) biofeedback has been reported to retrain muscles of facial expression by targeting increased symmetry and movement (Cronin & Steenerson, 2003, Diels & Combs, 1997; May & Schaitkin, 2000). Since denervation is a serious consequence of facial nerve damage, the present study posits that strength training may be necessary prior to EMG rehabilitation to augment blood flow and oxygen exchange and stimulate angiogenesis (growth of new capillaries) and arteriogenesis (enlargement of pre-existing vessels) for improvement in muscle performance (Yang et al, 2008). **Methods:** The present study examined effects of strength training in a single participant (P_1; author) with right side facial nerve paresis, thirteen years post-onset, resulting from a motorcycle accident. The six and a half week, twice per day protocol targeted maximum strength training in areas served by the obicularis oris superioris (OOS), orbicularis oris inferioris (OOI), zygomaticus (ZYG), and buccal musculature (BM) using the Iowa Oral Pressure Instrument (IOPI). Lip retraction was measured using the Perry Appliance, overlay-grid, and Facial Nerve Grading System (FNGS-2). Pre- through post-therapy data from P_1's affected side was compared to P_1's non-affected side and an age- and gender-matched control participant (P_2).

Results: A significant maximum strength increase occurred in P_1's right BM, and right and left OOS and OOI after six weeks of facial strengthening exercises. No significant change occurred in P_1's non-affected side for the remaining facial regions, or in any of P_2's facial regions. No significant increase in lip retraction occurred for either participant. Inter-rater reliability was highest for the Perry Appliance, followed by the overlay-grid and FNGS-2.

TABLE OF CONTENTS

Page

CHAPTER

LIST OF TABLES

LIST OF FIGURES

Dedication

He [God] has made everything beautiful in His time. Ecclesiastes 7:14

My life has been filled with both joy and sorrow. This thesis—an incredible joy—was spurred on by one of those tremendous sorrows: the 1996 motorcycle accident and loss of my twelve-year old step-brother, Danny. This was not the first sorrow I would face, nor would it be the last; yet it was out of this tragedy that the present research study came, and thus the hope of facial nerve rehabilitation for other individuals with facial nerve damage. I believe it is by the grace of God, the support of others, hard work, and perseverance that I have reached where I am today: a place where I can see the potential in others and draw it out, just as others once did for me. Therefore, it is my great honor to dedicate this project to Danny, my hero and friend.

It is also my honor to dedicate this project to my late father, Ken Perry, who instilled in me the virtues of hard work, dedication, and faith. His example spurred me on to love reading, writing, learning, and teaching. Although his early death of cancer at the time I was eight was sudden, his legacy continues. I am thankful for his investment in my life, and owe him my deep gratitude.

CHAPTER ONE

INTRODUCTION

The motor branch of the facial nerve (CN VII) is a complicated and intricate entity which begins to form in the embryo by the end of the third week of gestation (Vlastou, 2006). The signal for a voluntary smile is expressed by the facial nerve, beginning with a conscious desire to smile, which begins in the non-motor cerebral cortex (Terry, 2001). The signal travels to the premotor cortex, where motor impulses are generated and transmitted to the motor cortex and on to the facial nerve nucleus, located in the pons. Fibers pass through the pons to emerge at the junction of the pons and medulla as the facial nerve. From there, the signal moves along the facial nerve on the surface of the middle cerebellar peduncle before entering the skull, where it courses through the temporal bone in an outward, tortuous route. Most fibers exit at the stylomastoid foramen. The facial nerve then passes through the soft tissue of the face and neck, through the substance of the parotid gland, and across the external carotid artery. Just behind the mandible ramus, the facial nerve divides into two primary branches, the temporofacial and cervicofacial branches, which further subdivide and terminate on the motor endplates of the muscles of expression, including the obicularis oris superior, obicularis oris inferior, buccinator, risorius, and zygomaticus muscles.

The muscles of facial expression play a critical role in communication, facial recognition, and the interpersonal transfer of emotions (Byrne, 2004). Facial expression is related to social interaction, social intelligence, communicative roles, expressing intentions and goals, and recognizing and interpreting intentions and goals of others (Stuart & Byrne, 2004). Six basic emotional expressions, seen in individuals in different cultures as well as in individuals who are blind include: disgust, fear, joy, surprise, sadness, and anger. The ability to produce facial expression has been positively correlated with peer-acceptance in children. Physiological damage or disturbance resulting in facial nerve paralysis can be distressing and debilitative, affecting facial expression, functional abilities such as speech and lip closure, and quality of life (Coulson, O'Dwyer, Adams, & Croxson, 2004).

Although a relatively rare condition (approximately 30 per 100,000), facial nerve paralysis can result from a variety of causes: infection, physical trauma, surgical trauma, other congenital or acquired disorders, and, most commonly, Bell's palsy (Cha, Hong, Park, & Yeo, 2008). Recovery from facial nerve damage may be partial or complete, depending on the etiology, site, and extent of the injury (House & O'Conner, 1987).

In humans, spontaneous recovery of facial paralysis can occur up to eighteen months post-onset, although the potential for successful reinnervation diminishes sharply after 6-8 months (May & Schaitkin, 2000). It is not definitive that the degree of muscle fiber atrophy is linked to the ability of muscle fibers to reinnervate successfully. If nerve damage occurs close to the muscle, a high percentage of muscle fibers can reinnervate. However, as the lesion becomes more distant, the efficiency of reinnervation decreases. According to Vlastou (2006) "It is well-documented that denervation of any skeletal muscle for over a year will lead to irreversible atrophy of the motor endplates, and therefore to an inability to reestablish the nerve-muscle synapses and their function" (p. 280). Animal studies have shown the longer the period of denervation, the fewer the muscle fibers that can be successfully reinnervated (May & Schaitkin, 2000). For example, within a month after denervation, rat muscles lose 70% of mass and 90% of maximum contractile force. However, the rate of regeneration varies considerably between different species. In the long-term denervated facial musculature of humans, macrovasculature declines substantially. A tenfold decrease in capillarity and muscle fiber ratio occurs in the first twelve months of denervation. Also, collagen fibers deposit around capillaries and muscle fibers after denervation, which may limit the ability of satellite cells to reproduce and/or restore muscle fibers which have atrophied.

Aberrant redirection of facial nerve axons during reinnervation can lead to synkinesis, a condition in which voluntary contraction of a muscle causes an adjacent muscle to simultaneously and involuntarily contract on the side of the facial nerve damage (e.g. voluntary lip retraction during a smile causing involuntary eye closure; Duffy, 2005). The arrangement of motor fibers from the brainstem to the muscles is diverse, with some axons from the upper division terminating in the muscles of the lower face and vice versa (May & Schaitkin, 2000). After injury, fifty or more axonal sprouts may form from a single interrupted neuron. Therefore, some degree of synkinesis is understandable following facial nerve damage. Synkinesis may also be due to defective myelin and resultant "short circuiting" or jumping of impulses from one axon to another.

Results are mixed as to whether age is a prognostic factor in recovery rates in individuals with facial nerve damage. Cha, Hong, Park, & Yeo (2008) reported that recovery rates depended on the cause of facial nerve paralysis rather than the age of injury, with no statistically significant difference between adults and children. In contrast, Kiziltan, Uzun, Kiziltan, & Savrun (2005) reported that young age-of-onset of peripheral facial nerve palsy was associated with more prominent neuronal excitability changes in the developing central nervous system.

Traumatic facial nerve damage is the third most common cause of facial paralysis and is evaluated by location, type of injury, treatment selection, and prognosis (Cha, Hong, Park, & Yeo, 2008; House & O'Conner, 1987). Injury classification is based on the course of the fracture line in relation to the long axis of the petrous portion of the temporal bone (Miller, 1967). Lesions may be supranuclear, nuclear, occur at the cerebellopontine angle, or occur in the internal auditory and facial canals. Temporal bone fractures are most commonly classified as longitudinal (affecting the external auditory canal, tympanic membrane, and ossicular chain); transverse (affecting the cochlea, labyrinth, and facial nerve); and, mixed (Yetiser, Hidir, & Gonul, 2008). Injuries may be caused by motor vehicle accidents, falls, gunshot wounds, and head trauma. The most common types of lesions include compression, torsion, tearing, crushing, and sectioning (House & O'Conner, 1987).

Johann Friedreich Dieffenback (1794-1847), one of the fathers of modern facial plastic surgery, said "The chronically paralyzed face, due to destruction of the facial nerve, is untreatable. The unsuccessfulness of the treatment in these cases stimulated me to find a surgical way to treat these distorted faces" (Van de Graaf & Nicolai, 2008, p. 476). Treatment of facial paralysis was largely nonsurgical until the end of the nineteenth century and included medicines, ointments, and electrotherapy. The first individual to operate on the facial nerve to restore muscle function was Sir Charles Balance, in 1895.

Presently, if spontaneous recovery is incomplete, treatment of facial nerve damage may include surgical procedures, such as cross-facial nerve grafts or muscle transfers, or non-surgical procedures such as electrical stimulation or rehabilitative exercise programs (Cha, Hong, Park, & Yeo, 2008; Harrison, 1990; May & Schaitkin, 2000). The use of electrial stimulation, thought to maintain muscle viability, is controversial in the rehabilitation of facial nerve damage and may exacerbate synkinesis by reinforcing abnormal movement patterns (Diels, 2000). Exercise programs including mime therapy, resistance exercises, or facial neuromuscular retraining (NMR) exercises with or without electromyographic (EMG) biofeedback are more accepted non-surgical approaches (Cha, Hong, Park, & Yeo, 2008; Cronin & Steenerson, 2003; Diels &

Combs, 1997; Harrison, 1990; May & Schaitkin, 2000). In EMG biofeedback, dual-channel surface electrodes are placed over the facial muscles (e.g. the targeted muscle and the synkinetic muscle, or symmetrically targeted muscles). The participant is then given visual and/or auditory biofeedback of muscle electrical potentials while they attempt to develop selective muscle control, increase functional facial movements, increase symmetry, and decrease synkinesis. For example, in synkinesis, one electrode is placed over the muscle to be contracted. Another electrode is placed on the same side of the face over the muscle exhibiting synkinesis. The participant then observes the cursor movement and slowly contracts and holds the target muscle, while simultaneously relaxing the synkinetic muscle. The cursor on the graph representing voluntary movement should rise, while the cursor on the graph representing synkinetic movement should remain static or decrease as the patient learns to inhibit abnormal movements.

Exercise improves blood flow and oxygen exchange, stimulating angiogenesis (growth of new capillaries) and arteriogenesis (enlargement of pre-existing vessels), leading to improvement in muscle performance (Yang et al, 2008). Mime therapy is an approach to the rehabilitation of facial nerve damage which emphasizes facial symmetry through the practiced use of emotional expression exercises (Beurskens & Heymans, 2003). Grisolia & Ferrary (2007) introduced an intraoral muscle resistance device, combined with facial muscle retraining, which allowed for exercise and facial symmetry at rest by opposing contraction of contralateral muscles. This device was effective in improving facial symmetry in one patient with traumatic facial nerve palsy two years post head trauma due to a motor vehicle accident.

Facial neuromuscular retraining (NMR) is proposed to address learned nonusage (May & Schaitkin, 2000). It is theorized that learned nonusage occurs when the initial facial palsy leads to altered movement patterns which become habituated—even after nerve regeneration occurs.

This theory advocates for NMR to rediscover the old, normal movement patterns. NMR for facial nerve paralysis is a therapeutic treatment often combined with EMG biofeedback (Cronin & Steenerson, 2003; Diels & Combs, 1997; May & Schaitkin, 2000). This technique is individualized to each patient's needs in order to facilitate symmetrical movement and inhibit synkinesis. The primary goals of this technique are to restore function and expression, in order to improve health, self-esteem, acceptance by others, and quality of life. Based on the philosophy of neural plasticity and designed to inhibit synkinesis, NMR targets flaccid paralysis by means of slow execution, small movements, and symmetry.

General treatment techniques for NMR, as needed per individual patient, include: 1) education, 2) muscle relaxation or stimulation, 3) mirror exercise, 4) surface EMG biofeedback, 5) passive hold techniques, and 6) visual feedback cues (May & Schaitkin, 2000).

The general philosophy of NMR—though with variation across studies and reports—has been applied to individuals with facial nerve damage resulting from a) head trauma, with reported increase in strength of the facial muscles (Booker, Rubow, & Coleman, 1969); b) surgical trauma, with reported increases in facial function (Balliet, Shinn, & Bach-y-Rita, 1981) and muscle activity (Daniel & Guitar, 1978); c) Bell's palsy, with reported increases in symmetry (Manikandan, 2007); and, d) mixed participant pools, with reported increases in symmetry and facial function, as well as decreased synkinesis (Corral-Romero & Bustamante-Balcaracel, 1982; Cronin & Steenerson, 2003; Ross, Nedzelski, & McLean, 1991). Although individual studies show increased facial symmetry due to therapy for Bell's palsy, the Cochrane database, a database of systematic reviews which summarize and interpret the results of well-designed controlled trials in the medical and healthcare fields, showed no evidence of either significant benefit or harm, concluding more randomized controlled trials are needed (Teixeira, Soares, Vieira, & Prado, 2009).

EMG biofeedback has served as a prominent component of facial NMR paired with client education (Balliet, Shinn, & Bach-y-Rita, 1981; Booker, Rubow, & Coleman, 1969; Cronin & Steenerson, 2003; Daniel & Guitar, 1978; Ross, Nedzelski, & McLean, 1991). EMG biofeedback can be used to increase tension, facilitating movement, or to promote relaxation of undesirable movements. Application of surface EMG biofeedback has been shown to produce improved facial expression, movement, and symmetry, as well as inhibiting synkinesis in individuals with facial nerve paralysis. EMG biofeedback is not necessarily required to facilitate successful NMR (Ross, Nedzelski & McLean, 1991). Facial nerve recovery can occur with visual feedback training via a mirror, with or without EMG biofeedback. Degrees of improvement from NMR are participant-specific. One patient eleven years post-injury demonstrated moderate synkinesis in six muscle groups pre-treatment, facial movements of 41%, and House-Brackmann Facial Nerve Grading Scale (FNGS-2; Vrabec, 2009) Grade IV; post-treatment, the patient demonstrated mild synkinesis in two muscle groups, facial movements of 80%, and FNGS-2 Grade II (Cronin & Steenerson, 2003).

The House-Brackmann Facial Nerve Grading Scale (FNGS-2) is considered the “gold standard” for assessing facial nerve damage (Vrabec, 2009). To score the severity of facial nerve impairment using the FNGS-2, a participant is videotaped while making a series of facial movements: forehead wrinkle, gentle eye closure, open mouth smile, snarl, and lip pucker. A grader, who has completed training on the FNGS-2, then rates the movement in each of four regions; brow, eye, nasolabial fold, and oral commissure using a score of 1 - 6 according to the degree of movement (Table 1). Normal movement is given a score of 1, movement at more than

75% of normal is given a score of 2, movement between 50-75% of normal is given a score of 3, obvious movement that is less than 50% of normal is given a score of 4, trace movement is given a score of 5, and no movement is given a score of 6. The grader also rates secondary movement (synkinesis) by giving a global score across the entire face on a scale of 0 – 3, with 0 indicating no synkinesis, and 3 indicating disfiguring synkinesis. After analysis of facial movement, the movement scores of each region and secondary movement are summed to produce a total score of 4 – 24. This total score is converted to a grade of I to VI on the following scale: Grade I: 4, Grade II: 5 – 9, Grade III: 10 – 14, Grade IV: 15 - 19, Grade V: 20 - 23, and Grade VI: 24 (Table 2). Grade I represents normal function in all areas. Grade II represents mild dysfunction. Grade III represents moderate dysfunction. Grade IV represents moderately severe dysfunction. Grade V represents severe dysfunction. Grade VI represents total paralysis.

Although non-surgical approaches using EMG biofeedback have been shown to be efficacious, little is known about optimal strategies for increasing and measuring physiological support of the oral muscles, including strength or endurance (Duffy, 2005). Strength is increased by overloading the muscle to increase the size and number of muscle fibers or to increase neural control. Strength increases can be achieved using low-resistance/high-repetition exercises, or high-resistance/low-repetition exercises. Better muscle growth may be developed using high-resistance/low-repetition exercises, since tension within a muscle facilitates muscle growth. Low-repetition is defined as 5-10 repetitions, with rest between sets. For maximal muscle growth, high resistance muscle activity should exceed that of normal activities, but not so great as to cause exhaustion.

Increasing strength may facilitate an increase in functional facial movement. In the limb literature, six weeks of strength training was shown to increase leg strength in children with spastic cerebral palsy who at baseline had a 20-50% decrease in strength (Damiano & Abel, 1998). The increased limb strength resulted in a greater capacity to walk faster in the children with cerebral palsy.

When muscle atrophy is present, a logical progression may be to increase muscle mass and capillarity by strength training as a stand-alone treatment, simultaneous with, or prior to NMR with EMG biofeedback. Increasing strength may facilitate facial NMR and increased functional facial movement. Muscles must have sufficient strength to perform their basic functions, plus a reserve of excess strength (Duffy, 2005). The reserve allows for contraction over time, and contraction against resistance. Weak muscles cannot contract to the desired levels, sometimes even for brief periods. Facial expression requires both brief and sustained contraction of facial muscles, often against resistance. For example, a smile involves contraction of opposing muscles from opposite sides.

According to Duffy (2005), the following principles need to be considered when developing a strengthening program: 1) Recovery and regeneration in the nervous system are possible following injury, 2) Neuromuscular regeneration after injury requires volitional muscle use, 3) Muscle use leads to neural adaptation or plasticity within the nervous system 4) Drill is essential, 5) Feedback is crucial for motor learning, and 6) Training should be as specific as possible.

Although infrequent, there have been reported individual cases where function has been partially restored in facial muscles after years of paralysis (Beurskens & Heymans, 2003; Corral-Romero & Bustamante-Balcaracel, 1982; Cronin & Steenerson, 2003). The present study examines the effects of strengthening facial muscles as a stand-alone treatment in a patient 13-

years post-onset with unilateral facial nerve damage using the Iowa Oral Performance Instrument (IOPI), described in the Method's section. Research questions addressed are:

- Can facial muscle strength be increased 13 years post-injury as measured by the IOPI?
- By exercising the affected side of the face, is there an increase in facial strength in the non-affected side, and/or is there an increase in maximum tongue strength?
- By exercising the affected side of the face, does maximum lip excursion increase on the affected side during non-speech activities?

CHAPTER TWO

METHOD

Participants

The primary participant (P_1; author) was a 23 year old female speech language pathology graduate student who, at age ten years, sustained injuries as an unhelmeted passenger in a motorcycle accident, resulting in a right temporal bone fracture with traumatic brain injury (TBI) and cranial nerve VII palsy causing right-side facial droop with synkinesis affecting the right eyelid, eyebrow, and forehead. Temporal bone decompression surgery was performed following the injury. P_1 received speech therapy addressing language and memory in the year following the accident, but did not receive therapy for speech production or orofacial movement. Significant facial recovery was reported in the year following the accident, with slow improvement noted in subsequent years. At baseline of the present study, facial expression was assymetrical, with reduced lip strength and excursion on the right side, noted during the functional tasks of speaking, smiling, whistling, and maintaining lip seal during balloon blowing, static liquid hold (holding liquid in the oral cavity), and dynamic liquid hold (swishing). P_1 exhibited synkinesis on the right (affected) side, including involuntary eye closure during a voluntary smile; an involuntary smile during voluntary eye closure, an involuntary forehead wrinkle during a voluntary smile; an involuntary smile during a voluntary forehead wrinkle, and an involuntary forehead wrinkle during lip pucker.

The control participant (P_2) was an age- and gender-matched speech language pathology graduate student without facial nerve damage and no facial paralysis.

Procedure

P_1 performed a facial exercise program on only her right (affected) side. P_2 did not participate in the facial exercise program. Both P_1 and P_2 took weekly strength measurements for both the right and left facial regions. Both P_1 and P_2 participated in measurement of lip retraction and facial movement measures at baseline and after week 7. The exercise program, originally scheduled for twelve weeks, was terminated after six and a half weeks. Final data collection was taken on the scheduled day of week 7.

Facial Exercise Program

For neuromuscular facial strength rehabilitation the standard tongue bulb (an air-filled silicone bulb) was used with the Iowa Oral Performance Instrument (IOPI; Figure 1). The IOPI, originally purposed to measure tongue and hand strength (Clark, Henson, Barber, Stierwalt, & Sherrill, 2003; Crow & Ship, 1996; Palmer et al, 2008), measures strength indirectly in kilopascals (kPa) through the pressure readout on an LED display. In the present study, the IOPI tongue bulb was placed between the lip or cheek and maxilla or mandible in four separate muscle regions: upper right lip, targeting the obicularis oris superior (OOS); lower right lip, targeting the obicularis oris inferior (OOI); right buccal region, targeting the buccinator and risorius (BM); and right superior lateral sulcus, targeting the zygomaticus (ZYG). To determine exact placement of the tongue bulb, a custom dental whitening tray was made for the maxillary teeth. A millimeter tape measure was attached to the dental whitening tray using superglue with the 5 cm mark of the tape measure attached to the dental whitening tray between the front incisors. The whitening tray-tape measure combination was named the Perry Appliance (Figure 2).

To complete the exercise program, while looking in a mirror, P_1 placed the tail of the IOPI at a pre-determined millimeter mark on the Perry Appliance, as described in the following measurement section.

The bulb was compressed in a specific rotary sequence: OOS, ZYG, BM, OOI, with maximum strength, and held for 2-3 seconds with a 5 second rest between trials. Ten trials per region were performed twice daily, morning and evening, six days a week, for six and a half weeks.

Maximum Strength Measurements

Strength measurements were taken at baseline, and weekly for weeks 1 to 7 for both P_1 and P_2. The IOPI standard tongue bulb was placed between the lip or cheek and maxilla or mandible in nine separate regions. The tail of the tongue bulb was placed at 5 cm on the Perry Appliance for the right upper lip and 5 cm for the left upper lip (OOS), 5 cm on the Perry Appliance for the right lower lip and 5 cm for the left lower lip (OOI), 7.5 cm on the Perry Appliance for the right buccal region and 2 cm for the left buccal region (BM), 8 cm on the Perry Appliance for the right superior lateral sulcus region and 2 cm for the left superior lateral sulcus region (ZYG). For the tongue, the tail of the standard tongue bulb was placed just posterior to the upper incisors.

During each measurement session, the IOPI and a mirror were set on a desk. The participant whose facial strength was being measured sat at the desk. While looking in a mirror, the participant would compress the standard tongue bulb in a specific sequence: right OOS, left ZYG, right ZYG, left OOI, right BM, left OOS, right OOI, and left BM, with maximum strength, and hold for 2-3 seconds. Three sequences were performed, resulting in three trials per region. P_1's left side and tongue strength measurements served as intra-participant controls. P_2's right and left side and tongue measurements served as inter-participant controls and were used to examine if participation in weekly data collection sessions resulted in increased facial strength.

Lip Retraction Measurements

Lip retraction during a maximum smile was collected at baseline and weekly for P_1 and pre- and post-study for P_2. Lip retraction was measured using three different methods: 1) the Perry Appliance 2) the overlay-grid, and 3) the FNGS-2 Grade.

To record maximum lip retraction for the Perry Appliance and the overlay-grid, participants were instructed to "Smile as wide as you can." A digital camera (Fujifilm A850) was mounted on a VCT-1500L Sony tripod (44 cm tall), which was placed on a desk 75 cm tall, while the camera was positioned 31 cm from the head of the tripod to the participant's nose. Marks were made on the floor and desk in the data collection room to maintain consistent chair and equipment placement in order to maintain the above distance relationship. Digital photographs (from week 1 and week 7; Figure 3) were taken of P_1 and P_2 from three angles for accurate reading of the Perry Appliance 1) with the head turned to both the left and right sides at an approximate 45 degree angle (looking into a consistent corner of the room), and 2) a face-forward view. Three digital photos per participant per side were taken each session. The photo of the right-side facial view showing the greatest retraction at the oral commissure for each condition was selected for analysis.

Facial Movement Measurements

To measure the FNGS-2 Grade, the camera (Fujifilm A850) was positioned in the same manner as for the lip retraction measurement, with the camera setting selected. P_1 and P_2 were video recorded from a face-forward view with the camera 31 cm from the head of the tripod to the participant's nose while at rest, and while performing five facial movements: forehead wrinkle, gentle eye closure, open mouth smile, snarl, and lip pucker.

Five additional volunteers (graduate students in speech language pathology) served as graders and rated photos of the Perry Appliance and overlay-grid (described below; from week 1 and week 7), and videos for the FNGS-2 Grade (from baseline and week 7) presented in randomized order. The graders completed a training session for the three measures in which graders watched a demo video of a volunteer and a demo photo of P1 and were instructed in how to properly rate each measurement.

For the Perry Appliance, graders were shown photos from weeks 1 and 7 of both P_1 and P_2 in randomized order, and graders were instructed to record the last millimeter mark they could see.

An overlay grid composed of one-millimeter square boxes was constructed using PowerPoint and superimposed onto the photographs from weeks 1 and 7 of both P_1 and P_2 (Figure 4). The graders counted the number of millimeter-square boxes visible with white in them for both P_1 and P_2. This measurement was performed in order to determine if the visible tooth area exposed below the upper lip increased over the course of the facial exercise program.

For the FNGS-2, graders watched videos from baseline and week 7 for P_1 and P_2 in a random order, and filled out the FNGS-2 rating sheet. Graders were instructed to circle the rating that best represented the movements of the participant on the video. Their scores were totaled and the overall grade was assigned.

Data Analysis

A three-way repeated measures analysis of variance (ANOVA) was used to examine the effects of trial for maximum strength of OOS, OOI, ZYG, BM, and tongue. A univariate

ANOVA was used to examine lip retraction using the Perry Appliance, overlay-grid, and the FNGS-2 Grade; a Fleiss Kappa was used to examine inter-rater reliability. A statistical alpha level of .05 was set to determine significance for all measurement comparisons.

CHAPTER THREE

RESULTS

The duration of the present study, originally planned for a twelve weeks, had to be terminated after six and a half weeks due to painful neck spasms experienced by P_1. The neck spasms were likely due to the frequency and intensity of the facial exercises.

Maximum Strength Measurements

Obicularis Oris Superior Region (OOS)

Analysis of variance for maximum strength of the obicularis oris superior region showed a significant time by participant interaction, $F(2,4) = 11.85$, $p < .05$. Further looking at within participant contrasts showed a significant effect of time $F(1,2) = 31.51$, $p < .05$, indicating that P_1 demonstrated a statistically significant improvement in maximum strength for the right and left regions (Figure 5; Table 3).

Obicularis Oris Inferior Region (OOI)

Analysis of variance for maximum strength of the obicularis oris inferior region showed a significant time by participant interaction, $F(2,4) = 20.66$, $p < .01$. Further looking at within participant contrasts showed a significant effect of time $F(1,2) = 39.82$, $p < .05$, indicating that P_1 demonstrated a statistically significant improvement in maximum strength for the right and left regions (Figure 6; Table 3).

Buccal Region (BM)

Analysis of variance for maximum strength of the buccal region showed significant main effects between participants, $F(1,2) = 28.28$, $p < .05$ and between sides, $F(1,2) = 70.44$, $p < .05$. There was a signicant two-way interaction of side by participant, $F(1,2) = 82.00$, $p < .05$, and a signicant three-way interaction of side by time by participant $F(2,4) = 22.47$, $p < .01$. The three-way interaction was further analyzed using an independent test of participants. In P_1, there was a significant time by side interaction $F(2,4) = 24.14$, $p < .05$, indicating that there was an improvement over time in P_1's right (affected) side, but not for P_1's left (non-affected) side or either side of P_2 (Figure 7; Table 3).

Zygomaticus Region (ZYG)

Analysis of variance for maximum strength of the zygomaticus region showed no significant main effects or interactions (Figure 8; Table 3).

Tongue Strength

Analysis of variance for maximum tongue strength showed significant main effects between participants, $F(1,2) = 64.22$, $p < .05$. There was no significant effect of time, indicating tongue strength did not change over time for either P_1 or P_2 (Figure 9).

Lip Retraction/Facial Movement Measurements

Analysis of variance for maximum lip retraction using the Perry Appliance did not show a significant change over time $F(1,16) = 3.2$, $p = .09$, for P_1's right side.

Analysis of variance for maximum lip retraction using the overlay-grid showed the tooth area exposed below the upper lip during a maximum smile on P_1's right side increased by 50%, but did not reach levels of significance over time, $F(1,16) = .12$, $p = .74$.

Analysis of variance for facial movement using the FNGS-2 did not show a significant change over time, $F(1,16) = .17$, $p = .69$.

Inter-rater Reliability of Lip Retraction/Facial Movement Measurements

A Fleiss Kappa was used to examine inter-rater reliability for the five graders. Graders showed a 99.9% agreement for the Perry Appliance, a 97.3% agreement for the overlay-grid, and 85.5% agreement for the FNGS-2 Grade.

CHAPTER FOUR

DISCUSSION

Facial nerve damage and resulting muscle atrophy were once called “untreatable” (Van de Graaf & Nicolai, 2008, p. 476). Results of the present study show maximum facial strength can be increased after long-standing facial nerve damage, as evidenced in P_1 thirteen years post-injury, supporting limited previous studies showing benefit from NMR (Booker, Rubow, & Coleman, 1969; Cronin & Steenerson, 2003). In this investigation, significant maximum strength increases occurred in P_1’s right and left OOS and OOI and right BM after six and a half weeks of strengthening exercises.

The structural characteristics of the obicularis oris muscle (identified as OOS and OOI for the ease of data collection) accounted for significant increases in maximum strength of both PI’s right and left lip muscles. The obicularis oris has been characterized as both a single muscle surrounding the mouth opening, and as paired upper and lower muscles (Seikel, King, & Drumright, 2005). Results support the OOS and OOI as interconnected muscles, in contrast to the zygomaticus and buccal muscles, of which the right and left sides are completely independent.

All affected facial regions in P_1 showed a pattern towards improvement in maximum strength over the course of the study. P_1 did not experience exhaustion of the facial muscles during the facial exercise program. However, the proposed twelve-week exercise program’s duration was shortened to six and a half weeks when P_1 experienced painful neck muscle spasms, as a result of the intensive facial exercises. It is unclear whether the frequency or intensity of the exercise program leading to muscle spasms is participant-specific (related to P_1’s initial motorcycle accident and head injury), or applicable to the other individuals with facial nerve damage. It is also unclear as to whether the maximum strength measures for P_1's ZYG region would have reached statistical significance if the exercise program had continued for the original twelve-week duration.

During the course of the entire study, P_1's left (non-affected) BM was significantly stronger than her right (affected) region or either of P_2's BM regions. This may be due to over-use of P_1's non-affected region post-accident, due to the contralateral facial palsy. However, variability of facial strength is also cited in previous research on facial strength of normal individuals (Neely & Pomerantz, 2002). At baseline, the strength of P_1's right BM region was 44% of her left BM region. As a result of the exercise program, the strength of P_1's right BM region increased to 71% of her left BM region.

P_1 also displayed greater tongue strength as compared to P_2. Variability in tongue strength among individuals has also been reported by researchers (Youmans, Youmans, & Stierwalt, 2009). The maximum strength of P_1's unaffected side and P_2's left and right sides did not increase significantly over the course of the study, although slight increases and slight decreases pre and post-study for P_2 and weekly variation were seen for both P_1 and P_2.

Prior to this study, it was not known if weekly maximum strength measurements would increase strength in both P_1 and P_2. The results of this study indicate participation in weekly measurement sessions was not sufficient to significantly increase facial strength, whereas exercise targeting specific facial regions led to a significant increase in facial strength in P_1. P_1 and P_2 did not demonstrate improvement in strength of non-exercised muscle regions throughout the study. Therefore, any increases in strength could be considered the result of P_1's exercise program. Also, maximum strength of the tongue, which served as a control, did not increase significantly across the study for either P_1 or P_2.

The present study introduced a novel use of the IOPI. The IOPI offered an objective, fast, and clinically applicable method for recording and tracking progress in facial strength training. The IOPI was developed for measuring and monitoring oral strength and endurance, primarily in the tongue (Clark, Henson, Barber, Stierwalt, & Sherrill, 2003; Crow & Ship, 1996; Palmer et al, 2008). The standard tongue bulb of the IOPI was also effective for facial strength training, offering visual biofeedback and motivation for the user.

The increase of maximum facial strength due to exercise in a patient with long-standing nerve damage supports the premise that exercise improves blood flow and oxygen exchange, stimulating angiogenesis (growth of new capillaries) and arteriogenesis (enlargement of pre-existing vessels), which leads to improvement in muscle performance (Yang et al, 2008). Increased strength may also be due to neuromuscular regeneration and/or correction of "learned nonusage" (May & Schaitkin, 2000).

A limitation of the present study occurred in regards to measurement of maximum lip retraction: digital photos were taken for the baseline measurement (week 0) for a face forward view only and not a lateral view. Lip retraction from baseline to week one appeared to show improvement. However, after analysis, it was evident that in order to adequately measure and analyze maximum lip retraction using the Perry Appliance, images were needed from approximate 45 degree angles of both the affected and non-affected sides for P_1 and both sides for P_2; therefore, the baseline photographs were excluded from analysis. Analysis of lip retraction from week one to week seven was not significant. It may be that significant change occurs during the first week of exercises; or perhaps the length of the study did not allow for sufficient change. Also, although the Perry Appliance measured horizontal increase of lip retraction, it was determined post-study it was not sensitive to vertical change. When a millimeter-square grid was overlaid on the photos of P_1's smiles, results indicated a vertical increase in cross-sectional area below the upper lip of approximately 50% over six and a half weeks. In order to reach statistical significance in a single-participant study, P_1 would have needed to increase in cross-sectional area by 100%. A recommendation from the present study is a vertical millimeter grid should be added to the existing Perry Appliance. In future studies examining maximum lip retraction and elevation, it may be more effective to have the participant retract the lip only on the affected side, eliminating contralateral contraction effects of the non-affected side during a smile, resulting in greater retraction and elevation of the affected side, and perhaps more accurate measures of improvement due to exercise.

P_1 reported increased ability to express emotion due to increased facial strength, with a concomitant increase in quality of life; also, family, friends, peers, and faculty reported noticeable improvements in P_1's smile and facial expression. This study did not include objective or subjective measures of quality of life pre- and post-study.

Several methods were used to measure changes in facial range of motion, including the Perry Appliance, the overlay grid, and the FNGS-2. Inter-rater reliability among raters in the present study was highest for the Perry Appliance, followed by the overlay grid, and finally the FNGS-2 Grade. Previous research of the FNGS-2, considered the “gold standard” for reporting recovery of facial function among otolaryngologists, has shown that the FNGS-2 has limited inter-rater reliability, and is not sensitive between Grades 3 and 4, with 64% agreement (Vrabec, 2009). FNGS-2 ratings among graders in the present study were not sensitive between Grades 3 and 4. The Perry Appliance and overlay-grid provide reliable, objective measures (99.9% and 97.3% agreement, respectively) along or in addition to the FNGS-2 for reporting recovery of facial function.

Functional gains reported by P_1 included: 1) increased ability to whistle a single note post-study (15.99 seconds at 64.3 dB compared to baseline of 15.00 seconds at 60.4 dB), and the ability to whistle simple tunes, 2) increased ability to hold and swish liquid without spill from the labial seal, and 3) increased lip seal during sleep, as evidenced by decreased drooling on pillow.

Possible risk factors for facial strengthening include increased synkinesis and neck spasms. Due to facial exercises, synkinesis in P_1 was reportedly increased and attenuated, described by P_1 as increased involuntary forehead wrinkle during a voluntary smile. The reported synkinesis caused P_1's forehead frown line to deepen where few creases had been before, leading to improved facial expression of a "scowl", per P_1's report. Increased synkinesis was likely due to the effortful nature of the quick and forceful facial movements in this exercise program. Gross facial exercises may reinforce synkinesis (Diels & Combs, 1997; Diels, 2000). In order to minimize any negative effects of synkinesis, further investigation should determine whether to include NMR with EMG biofeedback following strength training of the facial musculature. Participants in NMR focus on slow execution, small movements, and symmetry (Diels & Combs, 1997; VanSwearingen & Brach, 2003). Also, in order to inhibit synkinesis, clients are instructed to determine synkinetic patterns, and slowly and progressively initiate primary (voluntary) movements while relaxing the synkinetic (involuntary) area of movement, in order to disassociate the aberrant neural patterns. Applying both facial strengthening exercises and NMR techniques to facial nerve rehabilitation would strengthen facial NMR.

Other recommendations are as follows. First, the IOPI bulb was hardest to position securely in P_1's mouth in the OOI position, due to the slippery nature of the bulb against the mucosal lining of the lip and gum. A graded texture on the IOPI bulb may aid in consistent and stable positioning; or, a lower dental whitening tray with an attached tape measure for friction may also aid in stable placement. The Perry Appliance on the maxillary teeth minimized slippage during OOS, BM, and ZYG measurements. P_1 used an open-mouth posture to compress the IOPI bulb in the OOI position. This was likely compensatory due to muscle weakness.

Further research is needed to investigate the physical and emotional aspects of strength training prior to facial NMR using EMG biofeedback in individuals with traumatic facial nerve damage, Bell’s Palsy, congenital facial palsy, surgical trauma, and other types of facial nerve damage. Normative data is needed on typical facial strength of various individuals, both with and without facial nerve damage. Further research should include a quality of life scale to measure overall personal benefit from strength training (Dutt et al, 2002; Gatehouse, Robinson, & Browning, 1996; Sood et al, 2000). Techniques for more effective measurement of functional measures such as swishing liquid, whistling, and blowing a balloon are needed. A participant rating scale may be more effective in this area.

The findings from this preliminary investigation suggest strength training may be an effective component in rehabilitation of individuals with traumatic facial nerve damage, even in patients with long-standing facial nerve damage. Replication of the current study with a larger group of participants is necessary to determine the following: 1) if these results can be generalized to other individuals with traumatic facial nerve damage as well as the larger population with facial nerve damage, 2) if neck pain is a general symptom of intensive facial exercises or is participant-specific, and 3) if a duration of twelve weeks for intensive facial strengthening exercises would lead to greater strength gains and statistically significant improvements in participants with facial nerve damage.

Acknowledgements

Many thanks to Dr. Arthur DiMarco and Eastern Washington University Department of Dental Hygiene for supplying dental whitening trays for the Perry Appliance, to Dr. Robert Short for assistance with data analysis, to Dr. Erich Luschei for his recommendations and support of this project, and to Dr. Ella Inglebret for use of her office during data collection.

REFERENCES

Balliet, R., Shinn, J.B., Bach-y-Rita, P. (1981). Facial paralysis rehabilitation: retraining selective muscle control. *Int. Rehab. Med.*, 4, 2, 67-73.

Beurskens, C.H.G., Heymans, P.G. (2003). Positive effects of mime therapy on sequelae of facial paralysis: Stiffness, lip mobility, and social and physical aspects of facial disability. *Otology & Neurotology*, 24, 677-81.

Booker, H.E., Rubow, R.T., Coleman, P.J. (1969). Simplified feedback in neuromuscular retraining: An automated approach using electromyographic signals. *Archives of Physical Medicine & Rehabilitation*, 621-625.

Byrne, P.J. (2004). Importance of facial expression in facial nerve rehabilitation. *Current Opinion in Otolaryngology & Head and Neck Surgery*, 12, 332-335.

Cha, C.I., Hong, C.K., Park, M.S., and Yeo, S.G. (2008). Comparison of Facial Nerve Paralysis in Adults and Children. *Yonsei Med J*, 49, 5, 725-734.

Clark, H.M., Henson, P.A., Barber, W.D., Stierwalt, J.A.G., Sherrill, M. (2003). Relationships among participantive and objective measures of tongue strength and oral phase swallowing disorders. *American Journal of Speech-Language Pathology*, 12, 40-50.

Corral-Romero, M.A., Bustamante-Balcharcel, A. (1982). Biofeedback rehabilitation in seventh nerve paralysis. *Ann Oto*, 91, 166-168.

Coulson, S.E., O'Dwyer, N.J., Adams, R.D., Croxson, G.R. (2004). Expression of emotion and quality of life after facial nerve paralysis. *Otology & Neurotology*, 25, 6, 1014-1019.

Cronin, G.W., Steenerson, R.L. (2003). The effectiveness of neuromuscular facial retraining combined with electromyography in facial paralysis rehabilitation. *Otolaryngology-Head and Neck Surgery*, 128, 534-538.

Crow, H.C., Ship, J.A. (1996). Tongue strength and endurance in different aged individuals. *The Journals of Gerontology*, 51A, 5, 247-250.

Damiano, D.L., Abel, M.F. (1998). Functional outcomes of strength training in spastic cerebral palsy. *Arch Phys Med Rehabil*, 79, 119-125.

Daniel, B., Guitar, B. (1978). EMG biofeedback and recovery of facial and speech gestures following neural anastomosis. *Journal of Speech and Hearing Disorders*, 43, 9-20.

Diels, H.J., (2000). Facial paralysis: Is there a role for a therapist? *Facial Plastic Surgery*, 16, 361-364.

Diels, H.J., Combs, D. (1997). Neuromuscular retraining for facial paralysis. *Otolaryngologic Clinics of North America*, 30, 5, 727-743.

Duffy, J.R. (2005). *Motor Speech Disorders: Substrates, Differential Diagnosis, and Management, Second Edition.* St. Louis: Elsevier Mosby.

Dutt, S.N., McDermott, A.L., Jelbert, A., Reid, A.P., Proops, D.W. (2002). The Glascow benefit inventory in the evaluation of patient satisfaction with the bone-anchored hearing aid: Quality of life issues. *The Journal of Laryngology & Otology, 116*, 7-14.

Elliott, J.M. (2006). Physiotherapy treatment of Bell's palsy: A case report. *NZ Journal of Physiotherapy*, 34, 167-171.

Gatehouse, S., Robinson, K., Browning, G.G. (1996). Measuring patient benefit from otorhinolaryngological surgery and therapy. *Ann Oto Rhinol Laryngol, 105,* 415-422.

Grisolia, F.M., Ferrary, T. (2007). Development of an intraoral device for facial muscle retraining and its clinical application. *Acta Odontol. Latinoam.,* 20, 1, 49-54.

Harrison, D.H. (1990). Current trends in the treatment of established facial palsy. *Annals of the Royal College of Surgeons of England*, 72, 94-98.

House, J.W., O'Conner, A.F., (Eds.). (1987). *Handbook of Neurotological Diagnosis.* New York: Marcel Dekker.

Kiziltan, M.E., Uzun, N., Kiziltan, G., Savrun, F.K. (2005). The influence of age in peripheral facial palsy on brainstem reflex excitability. *Neurol India,* 53, 3, 318-322.

Manikandan, N. (2007). Effect of facial neuromuscular re-education on facial symmetry in patients with Bell’s palsy: A randomized controlled trial. *Clinical Rehabilitation*, 21, 338-343.

May, M., Schaitkin, B.M. (2000). *The Facial Nerve: May’s Second Edition*. New York: Thieme.

Miller, H., (1967). Facial paralysis. *British Medical Journal,* 3, 815-819.

Neely, J.G., Pomerantz, R.G., 2002. Measurement of facial muscle strength in normal participants. *The Laryngoscope*, 112, 1562–1568.

Palmer, P.M., Jaffe, D.M., McCulloch, T.M., Finnegan, E.M., Van Daele, D.J., Luschei, E.S. (2008). Quantitative contributions of the muscles of the tongue, floor-of-mouth, jaw, and velum to tongue-to-palate pressure generation. *Journal of Speech, Language, and Hearing Research,* 51, 828-835.

Ross, B.G., Fradet G., Nedzelski J.M. (1996). Development of a sensitive clinical facial grading system. *Otolaryngol Head Neck Surg,* 114, 380-386.

Ross, B., Nedzelski, J.M., McLean, J.A. (1991). Efficacy of feedback training in long-standing facial nerve paralysis. *Laryngoscope,* 101, 744-750.

Seikel, J.A., King, D.W., Drumright, D.G. (2005). *Anatomy & Physiology for Speech, Language, and Hearing, Third Edition.* New York: Thomson Delmar Learning.

Sood, S., Anthony, R., Homer, J.J., Van Hille, P., Fenwick, J.D. (2000). Hypoglossal-facial nerve anastomosis: Assessment of clinical results and patient benefit for facial nerve palsy following acoustic neuroma excision. *Clin. Otolaryngol., 25*, 219-226.

Stuart, R.M., Byrne, P.J. (2004). The importance of facial expression and the management of facial nerve injury. *Neurosurg Q*, 14, 239–248.

Terry, D.A., Pirtle, P.L. (2001). Learning to smile: The neuroanatomic basis for smile training. *Journal of Esthetic and Restorative Dentistry*, 13, 20-7.

Teixeira, L.J., Soares, B.G.D.O., Vieira, V.P., Prado, G.F. (2009). Physical therapy for Bell's palsy (idiopathic facial paralysis). *Cochrane Database of Systematic Reviews*, 3, 1-36.

Van de Graaf, R.C., Nicolai, J.P.A. (2008). On the surgical treatment of facial paralysis in the early nineteenth century. *Plastic and Reconstructive Surgery*, 121, 475-480.

VanSwearingen, J.M., Brach, J.S. (2003). Changes in facial movement and synkinesis with facial neuromuscular reeducation. *Plastic and Reconstructive Surgery*, 111, 2370-2375.

Vlastou, C. (2006). Facial paralysis. *Microsurgery*, 26, 278-287.

Vrabec, J.T., Backous, D.D., Djalilian, H.R., Gidley, P.W., Leonetti, J.P., Marzo, S.J., Morrison, D., Ng, M., Ramsey, M.J., Schaitkin, B.M., Smouha, E., Toh, E.H., Wax, M.K., Williamson, R.A., O-Brien Smith, E. (2009). Facial nerve grading system 2.0. *Otolaryngology–Head and Neck Surgery, 140*, 445-450.

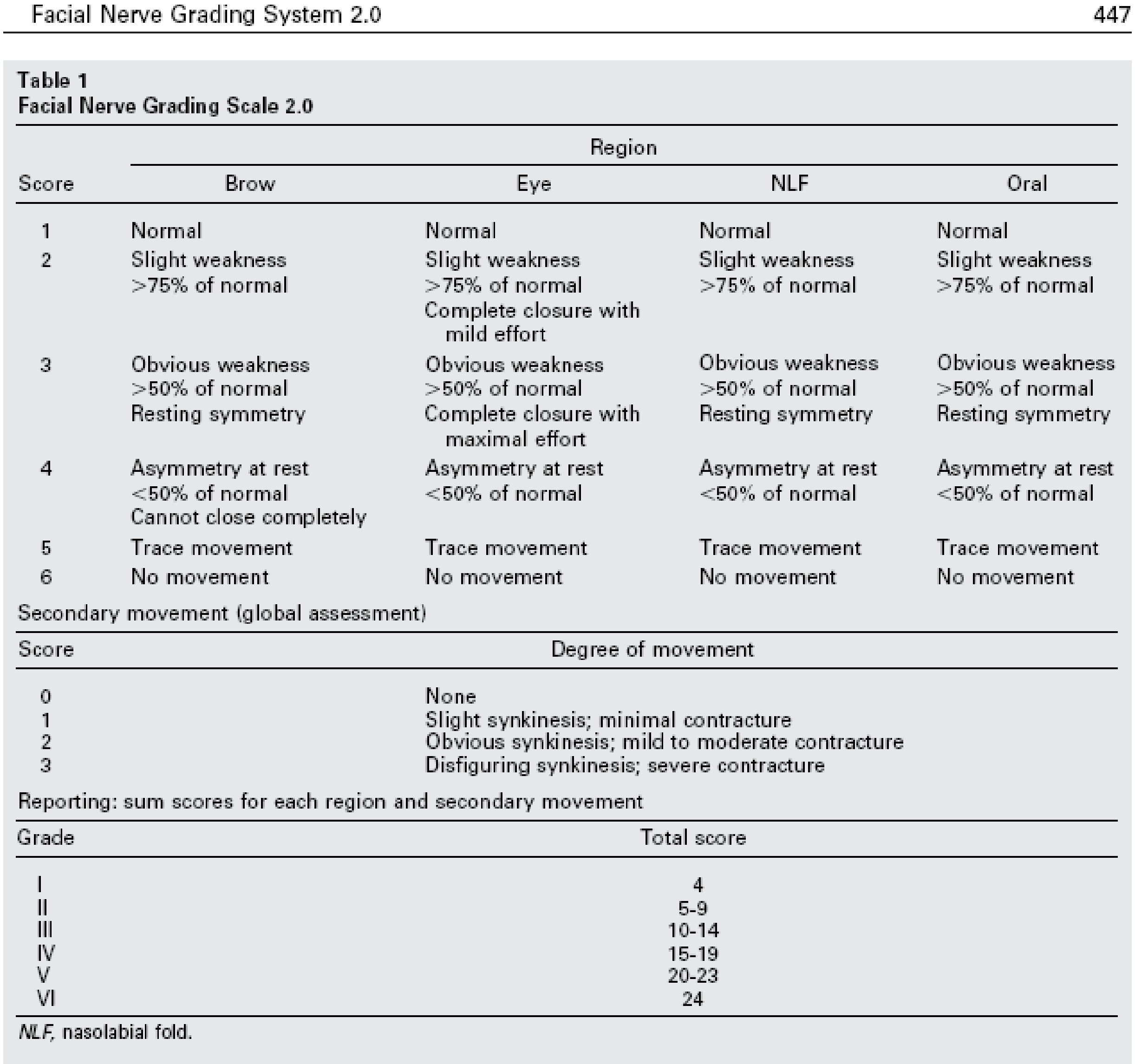
Yang, H.T., Prior, B.M.., Lloyd, P.G., Taylor, J.C., Li Z., Laughlin, M.H., Terjunng, R.L. (2008). Training-induced vascular adaptations to ischemic muscle. *Journal of Physiology and Pharmacology*, 7, 57-70.

Yetiser, S., Hidir, Y., Gonul, E. (2008). Facial nerve problems and hearing loss in patients with temporal bone fractures: Demographic data. *The Journal of Trauma Injury, Infection, and Critical Care.* 65, 1314-1320.

Youmans, S.R., Youmans, G.L., Stierwalt, J.A.G. Differences in tongue strength across age and gender: Is there a diminished strength reserve? *Dysphagia, 24,* 57-65.

TABLES

Table 1. Facial Nerve Grading System 2.0 (Vrabec, 2009)



Facial Nerve Grading System 2.0 447

Table 1
Facial Nerve Grading Scale 2.0

	Region			
Score	Brow	Eye	NLF	Oral
1	Normal	Normal	Normal	Normal
2	Slight weakness >75% of normal	Slight weakness >75% of normal Complete closure with mild effort	Slight weakness >75% of normal	Slight weakness >75% of normal
3	Obvious weakness >50% of normal Resting symmetry	Obvious weakness >50% of normal Complete closure with maximal effort	Obvious weakness >50% of normal Resting symmetry	Obvious weakness >50% of normal Resting symmetry
4	Asymmetry at rest <50% of normal Cannot close completely	Asymmetry at rest <50% of normal	Asymmetry at rest <50% of normal	Asymmetry at rest <50% of normal
5	Trace movement	Trace movement	Trace movement	Trace movement
6	No movement	No movement	No movement	No movement

Secondary movement (global assessment)

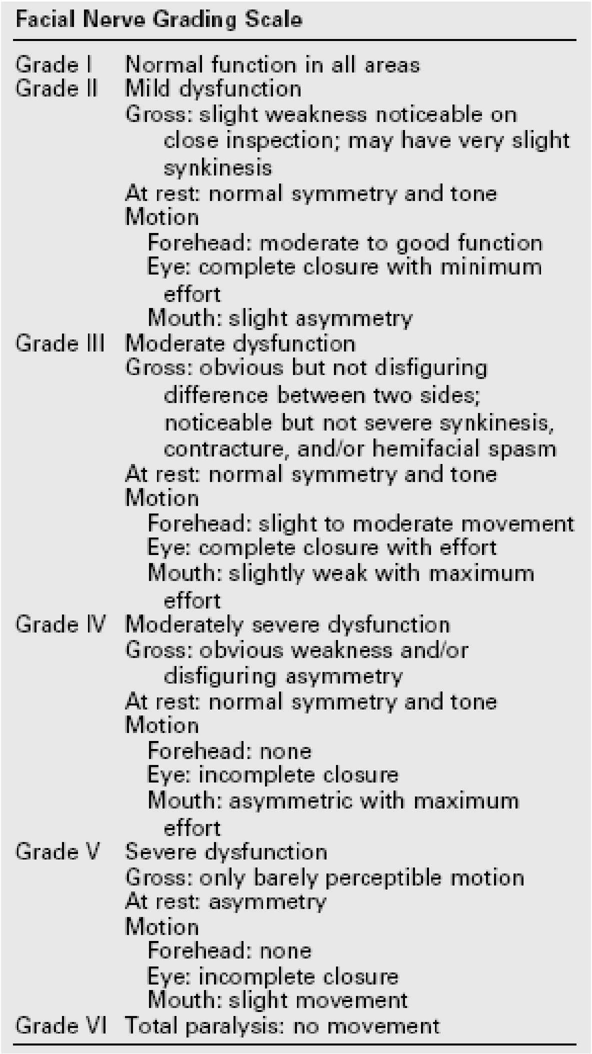
Score	Degree of movement
0	None
1	Slight synkinesis; minimal contracture
2	Obvious synkinesis; mild to moderate contracture
3	Disfiguring synkinesis; severe contracture

Reporting: sum scores for each region and secondary movement

Grade	Total score
I	4
II	5-9
III	10-14
IV	15-19
V	20-23
VI	24

NLF, nasolabial fold.

Table 2. Grading Scale for the FNGS-2 (Vrabec, 2009).



Facial Nerve Grading Scale

Grade I	Normal function in all areas
Grade II	Mild dysfunction Gross: slight weakness noticeable on close inspection; may have very slight synkinesis At rest: normal symmetry and tone Motion Forehead: moderate to good function Eye: complete closure with minimum effort Mouth: slight asymmetry
Grade III	Moderate dysfunction Gross: obvious but not disfiguring difference between two sides; noticeable but not severe synkinesis, contracture, and/or hemifacial spasm At rest: normal symmetry and tone Motion Forehead: slight to moderate movement Eye: complete closure with effort Mouth: slightly weak with maximum effort
Grade IV	Moderately severe dysfunction Gross: obvious weakness and/or disfiguring asymmetry At rest: normal symmetry and tone Motion Forehead: none Eye: incomplete closure Mouth: asymmetric with maximum effort
Grade V	Severe dysfunction Gross: only barely perceptible motion At rest: asymmetry Motion Forehead: none Eye: incomplete closure Mouth: slight movement
Grade VI	Total paralysis: no movement

Table 3. Comparison of maximum strength (kPa) over time for all muscle regions across participants.

		OOS		OOI		BM		ZYG	
Participant	Week	L	R	L	R	L	R	L	R
P_1	Baseline	22	19	17	13	32	14	29	16
	Week 7	35	28	40	40	35	25	32	24
P_2	Baseline	25	25	33	36	21	21	29	25
	Week 7	29	26	23	28	23	23	25	27

FIGURES

Figure 1. Iowa Oral Pressure Instrument (IOPI) with standard tongue bulb on right.

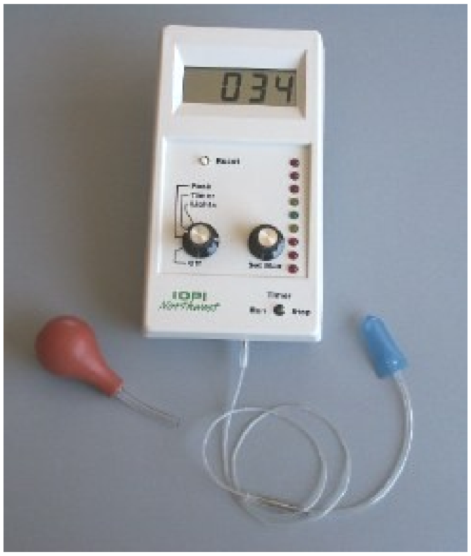


Figure 2. Perry Appliance

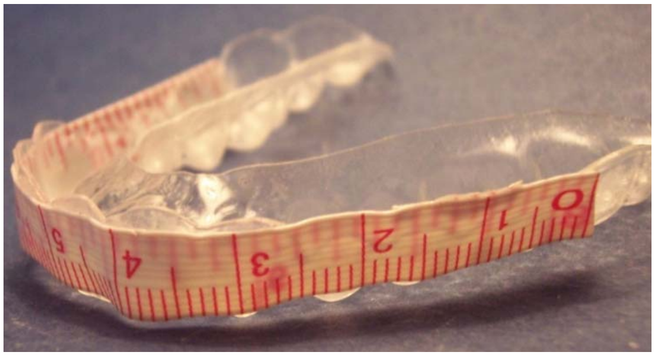


Figure 3. Digital photographs of right-side facial view (from week 1 and week 7) for P_1

Week 1

Week 7

Figure 4. Overlay grid superimposed on digital photograph of P_1.

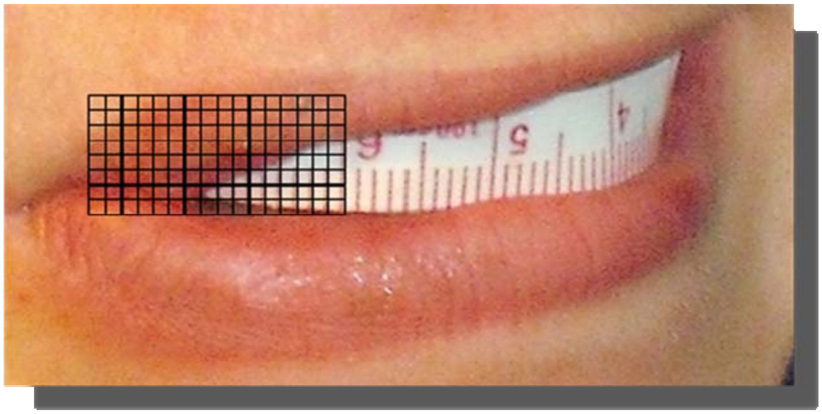


Figure 5. Changes in maximum strength (kPa) of the obicularis oris superior region (OOS) for both participants.

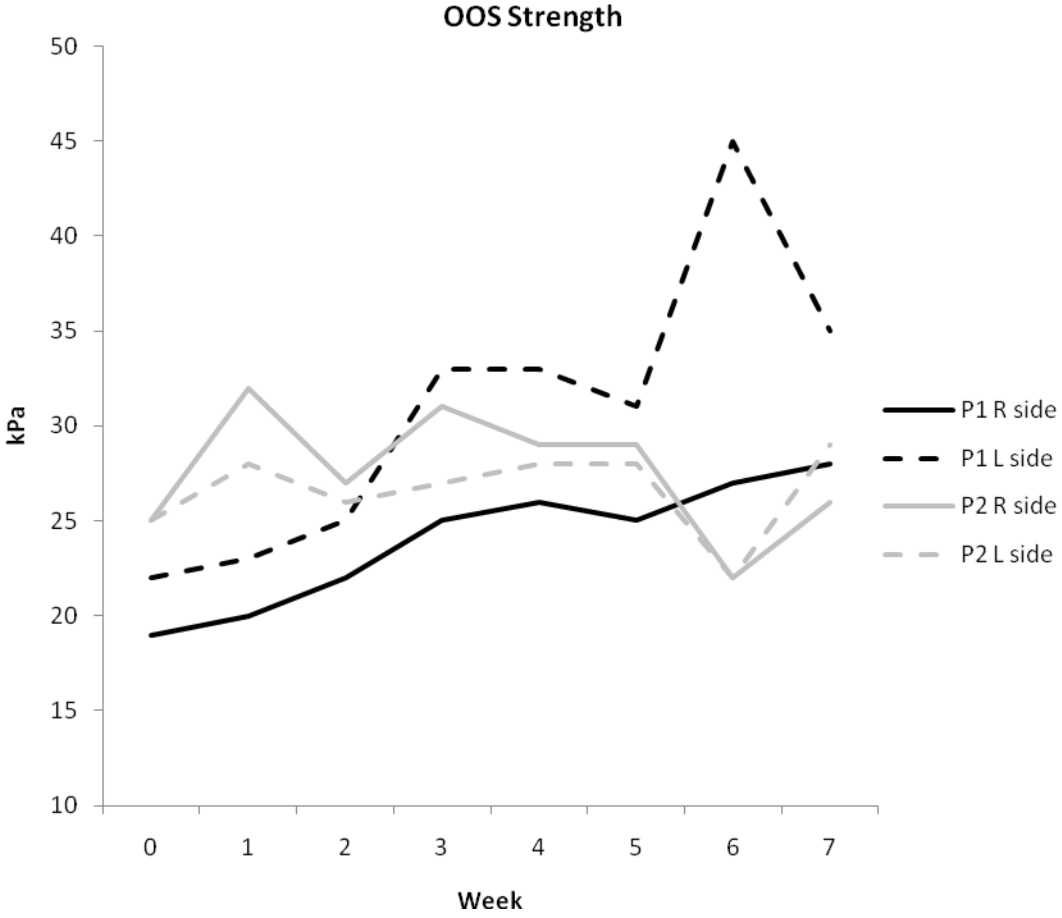


Figure 6. Changes in maximum strength (kPa) of the obicularis oris inferior region (OOI) for both participants.

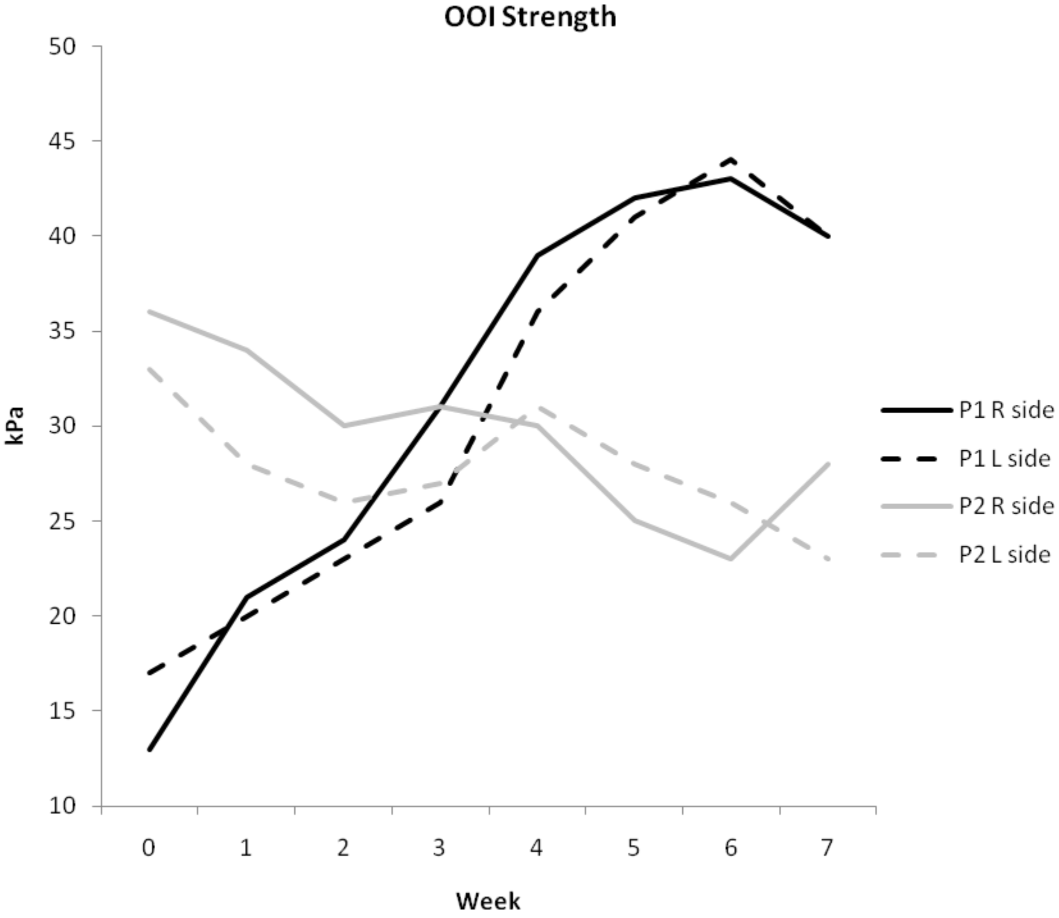


Figure 7. Changes in maximum strength (kPa) of the buccal region (BM) for both participants.

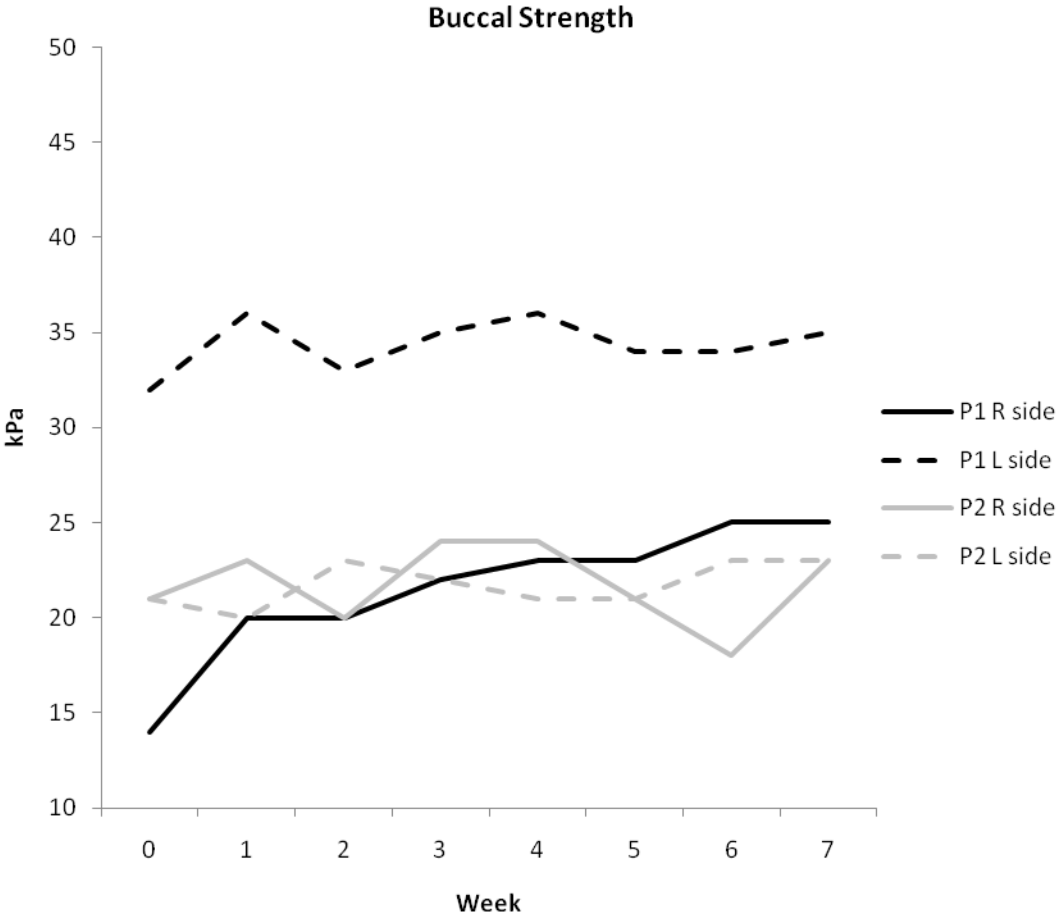


Figure 8. Changes in maximum strength (kPa) of the zygomaticus region (ZYG) for both participants.

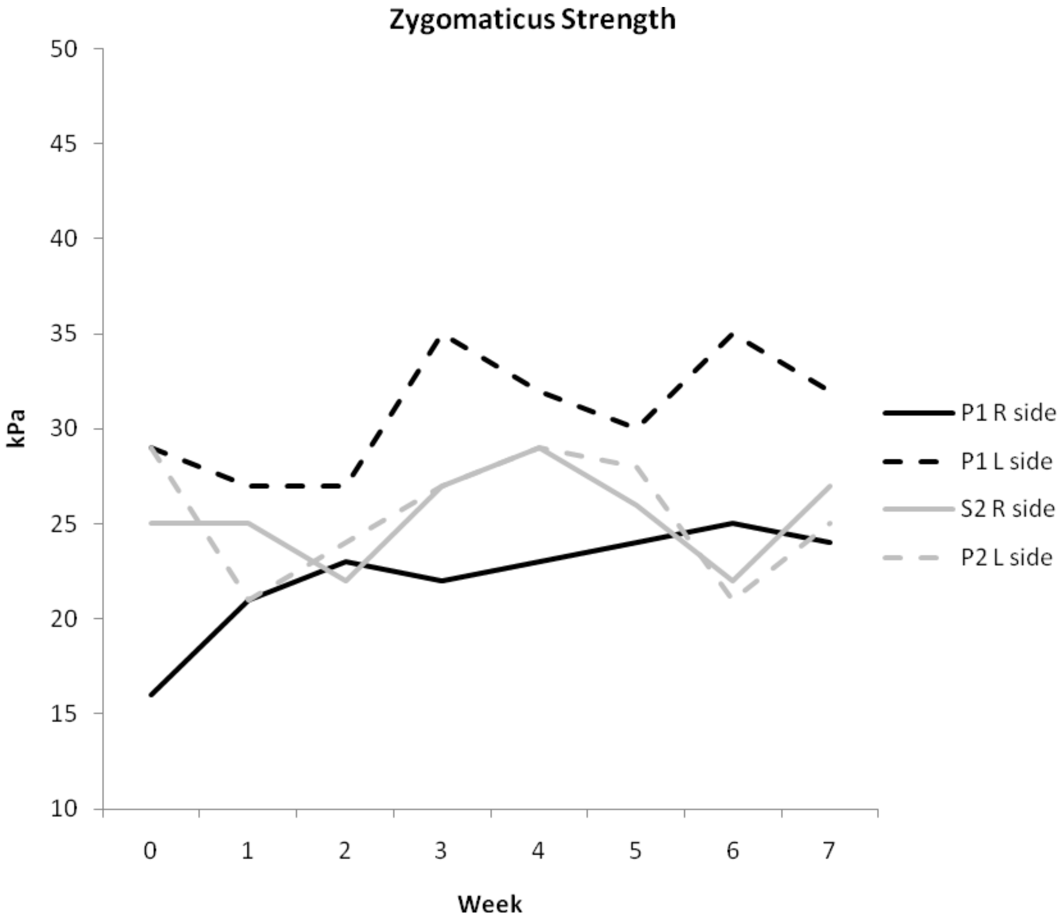


Figure 9. Changes in maximum tongue strength (kPa) for both participants.