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Effects of Real-Time iEMG Biofeedback on Facial Muscle Activation Patterns in a Child with Congenital Unilateral Facial Palsy

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ABSTRACT

Purpose: Experimental findings are limited concerning efficacious procedures for facial reanimation following persistent idiopathic facial paresis. The use of integrated electromyography (iEMG) for real-time biofeedback has potential clinical applications for reanimation of the face in select cases. The purpose of this exploratory case study was to examine the efficacy of real-time iEMG biofeedback for promoting facial reanimation in a preadolescent child with congenital and persistent idiopathic unilateral facial paresis.

Method: Hydrogel surface electrodes placed bilaterally in bipolar pairs (differential recording) were used to record and display calibrated iEMG signals sampled from four select muscle groups within the midface and lower perioral face of a child (age 3 years, 6 months) with congenital idiopathic unilateral facial paresis. Muscle activation patterns were digitized and displayed for the child to track while performing repeated facial gestures (smile, pucker) during eleven weekly biofeedback sessions.

Results: Overall, the child demonstrated active engagement with the visual waveform display during the repeated production of 'smile' and 'pucker' facial gestures. Computerized measures of iEMG amplitude for the midface muscle recording site increased significantly during smile production on the paretic side of this child's face as a function of biofeedback therapy session number. Significant changes in amplitude of iEMG activation patterns were related to biofeedback session number, and muscle group. Mixed modeling results indicated that the electromyogram amplitude increased in a linear pattern during the visits ($p = .009$ for face, $p = .065$ for lip). The amplitude increased faster in the left (intact) side than in the right (paralyzed) side; however, this difference in change was not statistically significant. Clinical examination following the biofeedback therapy noted functional changes in the face, including the appearance of facial dimpling, greater oral angle retraction during smile, and enhanced extraocular posture and greater movement of the right eyelid.

Conclusions: These findings illustrate the potential utility of non-invasive, real-time iEMG biofeedback for restoration of facial muscle patterning and reanimation during repeated production of 'smile' gestures in a young child with congenital and persistent idiopathic unilateral facial paresis. Moreover, this child's medical care team noted improvements in facial activity after completing the iEMG biofeedback regimen, demonstrating the potential benefit of this intervention.

Keywords: Electromyogram Biofeedback; Congenital Unilateral Facial Palsy; Facial Muscle Activation, Reanimation

Introduction

Facial paralysis or paresis is a rare condition that affects approximately 25-30 per 100,000 individuals per year in the United States (Bleicher, et al. [1]) and is further confounded by varying etiologies, symptoms, and subtypes (de Freitas, et al. [2]). Deficits in facial animation create variable difficulties for individuals, including diminished functional movements (e.g., speech, eating, sucking, eye closure, blowing, conveying emotions, etc.). The functional deficits that arise from diminished movements may impact an individual's ability to engage in daily activities and communicate with others. Therefore, treatment options are necessary to increase reanimation and quality of life for individuals with facial palsies.

Etiology of Facial Palsy

There is a multitude of muscles and branches of the facial nerve (CN VII) that participate in facial kinematics, and their coordination is dependent on proper functioning of all elements. Therefore, facial paralysis or paresis may result from varying etiologies. Of these etiologies, idiopathic facial paralysis is the most common (e.g., Bell's palsy, paralysis without a known cause) comprising 60-75% of cases. Trauma of CN VII or damage to its nucleus is reported to cause 2-5% of cases in population studies Cha et al., 2008 [3]. Infection or disease (e.g., Epstein-Barr virus) account for many of the cases of Bell's palsy, which is due to the unknown etiology at the onset of diagnosis and then identification of the infection later. Other causes include genetic syndrome (e.g., Moebius syndrome) present in 1/150,000 births, developmental anomalies of CN VII (Jemec, et al. [4]; Nordjoe, et al. [5]), cancer (e.g., meningioma at the cerebellopontine angle) 5-6% of cases of CPA meningiomas result in facial palsy (Sam, et al. [6]), and brainstem stroke (Aranha, et al. [7]; Deep, et al. [8]; Kim, et al. [9]; Kouri, et al. [10]; Vogelnik & Matos [11]). For facial palsies with a known cause, one can identify a course of treatment such as surgery, medication, or therapy (Álvarez-Argüelles, et al. [12]; Sam, et al. [6]), however in others with idiopathic facial paralysis, there is a less direct path to intervention that allows for reanimation of the facial nerve.

Similarly, on how facial paralysis can have etiologies ranging from congenital to acquired (Corral-Romero & Bustamante-Balcárcel, [13]; Kasahara, et al. [14]), symptomology also differs based on etiology and can vary in degrees of paralysis and function. Individuals with facial paralysis may present with bilateral or unilateral paralysis due to varied causes (Hamizan, et al. [15]; Jemec, et al. [4]; Messana, et al. [16]). For instance, diffuse damage to the brainstem may present in bilateral facial paralysis if both nuclei are affected, whereas infection to CN VII may present unilaterally. Symptomology and presentation of facial paresis is important for intervention procedures. Furthermore, etiology can also predict the longevity of symptoms. For example, patients who manifest Bell's palsy often recover facial movement within weeks to months. Alternately, other causes such as meningioma or developmental anomaly typically do not result in short-term recovery of facial movement (Deep, et al. [17]; Sam, et al. [18]).

Treatment Strategies for Patients with Facial Palsy

As previously mentioned, due to the variable presentation and symptomology, idiopathic facial paralysis presents a further issue regarding reanimation procedures. Many case studies identifying individuals with persistent idiopathic facial paralysis do not report consistent and noninvasive procedures for reanimation (Nordjoe, et al. [5]). The most common types of treatment for varying etiologies are given in Table 1. Many of these treatments are specific to known causes and not sufficient for treating persistent idiopathic facial paralysis. Although it appears that some medications were effective for reanimation of idiopathic cases, they are not effective for persistent idiopathic cases and should not be deemed reliable and consistent procedures for this population.

Overall, there is an increased need for a more consistent procedure to better treat various facial paralyses and symptomologies. Furthermore, a procedure has little validity until a valid and reliable measure is established to identify and report characteristics of the facial paralysis as well as changes that may occur over the course of treatment. One of the common clinical measures for defining facial paralysis involves facial grading systems (FGS) to classify and subjectively score movement capabilities during facial gestures (i.e., smile, etc.) (Duarte-Moreiera, et al. [19-

22]). Many scoring systems such as the Sunnybrook FGS and the House-Brackmann FGS involve rating of the face and comparison of affected and unaffected sides resulting in qualitative reports reflected as Likert scales or grades (House & Brackmann, et al. [19, 23-24]). Other forms of measurement include photogrammetry which involves the comparison of orofacial flesh points estimated from still images (Filho, et al. [25-26]). These qualitative scales to grade the degree and location of facial paralysis at baseline and after intervention are often inconsistent and influenced by human error. Therefore, it is important that a physiologically based intervention for facial reanimation be paired with an objective and reliable form of measurement. One such instrumental technique that may yield quantification of facial movement is electrophysiology (i.e., surface electromyography - sEMG) during a visuomotor tracking paradigm which will allow the clinician-investigator to explore the correlation between facial muscle activation patterns during baseline evaluation, and repeated-measures during the course of therapeutic biofeedback to retrain facial muscle activation patterns.

Table 1: Clinical efficacy for various etiologies of facial palsy.

Reanimation Procedure	Etiologies	Effectiveness	Citation
Anti-inflammatory medications	Epstein Barr Virus	Complete recovery in 4/5 cases; 1 persistent	Vogelnick & Matos (2017)
	Pontine stroke	Asymmetry remains @ 1 yr	Kouri, et al. (2018)
	Bell's palsy	Complete recovery after 1 mo	Viteri, et al. (2015)
Steroid Medications	Bell's palsy	2 wk recovery	Khair & Ibrahim (2018)
	EBV	2 mo recovery	Álvarez-Argüelles et al. (2019)
	Idiopathic bilateral facial palsy	Recovery @ 9 mos	Messana et al. (2018)
Facial Exercises	Bell's palsy	Increased FGS score	Aranha, et al. (2017)
	Intraventricular hemorrhage	Decreased asymmetry	Filho, et al. (2015)
Surgery	Meningioma at cerebellopontine angle	No improvement	Sam, et al. (2017)

Biofeedback

Biofeedback measures are proven to increase awareness of movements and provide a method for increasing volitional control (Corral-Romero & Bustamante-Balcárcel [27]). Biofeedback occurs in many forms including use of a video game to increase volitional control of a muscle (Maia et al. [28]) and EMG output paired with auditory feedback (Arpa & Ozcakir [29]). Researchers have sought to identify the effectiveness of biofeedback procedures in decreasing synkinesis, increasing reanimation following paralysis due to nerve dysfunction, and reanimation following paralysis due to muscle dysfunction (Duarte-Moreiera, et al. [19,2,22]). Given trained participants, biofeedback has yielded effective results in reanimation of orofacial structures (de Freitas, et al. [3]). However, there is vast heterogeneity in the procedures that researchers use, and the reanimation results due to facial nerve deficits (Duarte-Moreiera, et al. [19]). Furthermore, little research has been conducted on iEMG biofeedback procedures for young children with congenital and persistent facial paralysis.

Study Aim

The goal of the clinical study was to assess the efficacy of real-time iEMG visual biofeedback during repeated 'smile' gesture productions over an 11-week treatment regimen for a 3-year, 6-month-old child with a congenital form of idiopathic hemifacial paralysis.

Methods

A 3-year, 6-month-old female presented to the Barkley Speech Language and Hearing Clinic (BSLHC) at the University of Nebraska with congenital right facial paresis. Written informed consent was obtained from the parents according to the University of Nebraska Institutional Review Board approval. The parents and the medical record indicated that the unilateral right side facial paresis was congenital of unknown etiology as depicted in Figure 1. Facial paralysis presented at birth following an uncomplicated pregnancy and delivery. The participant exhibited an asymmetric cry and difficulty with feeding that was first reported by the obstetrician. Subsequently, she was referred to several specialists including an otolaryngologist, a pediatric plastic surgeon, and a neurologist. The participant underwent MRI with and without contrast at 13-months of age. Images revealed otomastoiditis yielding opacification of the right mastoid and middle ear which prevented effective evaluation of the right facial nerve course at that time. Etiology of the opacification was suspected to be recent otitis media. The diagnoses concluding this visit were Bell's palsy, unspecified mastoiditis of the right ear, and chronic sinusitis. Two

months following neuroimaging, the participant visited a pediatric plastic surgeon who reported a complete right facial paralysis with slight movement near the oral commissure. One month later, a neurologist visit revealed no other cranial nerve deficits apart from right facial palsy. Upon presentation to BSLHC, mobility was most noticeably impaired in the right mid-face, with reduced eye closure and corneal reflex on her right side and limited levator function in the upper lip during smile as shown in Figure 2. Parent interview indicated this child exhibited typical cognition, language, social interactions, and acquisition of developmental milestones. Oral motor examination revealed normal tongue and jaw strength and speed with alternating and sequential motion tasks. Limited lip range of motion on affected right side was apparent when protruding, retracting, and puckering the lips during alternating motion tasks.

Figure 1: Participant presentation of facial palsy. From left to right: at birth, 6-weeks, 3-months, and 6-months of age.

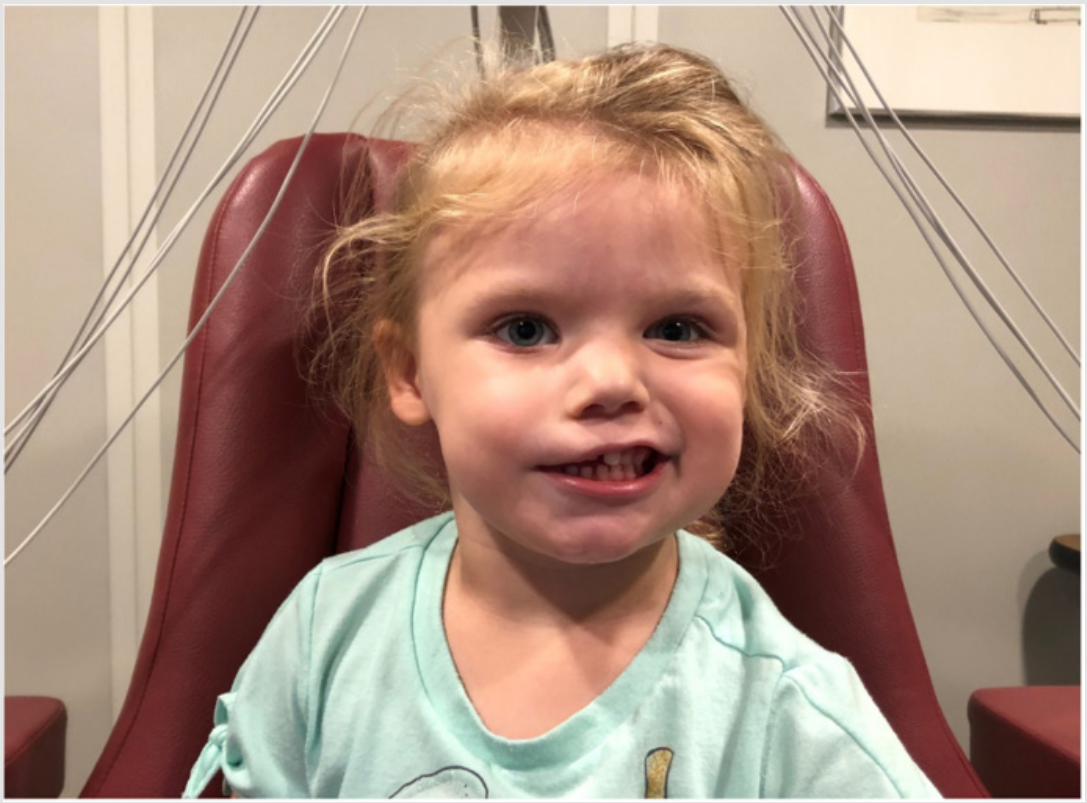

Figure 2: Participant presenting right facial paralysis during "smile" gesture.

The participant engaged in exploratory intervention sessions which began in June 2019 and consisted of facial imitation (pictures, clinician modeling), muscle exercises, somatosensory stimulation of the affected face (pneumotactile TAC-Cell arrays), and electromyographic (EMG) monitoring of bilateral facial muscle groups. By September of 2019, it was decided to provide the child with EMG biofeedback to facilitate facial muscle activity patterns during a variety of gesture productions. EMG biofeedback sessions occurred within 15-minute sessions one time per week. During these sessions, she participated in three facial gesture exercises, including 'smile', 'kiss', and 'frown'. The 'frown' expression was faded due to child's emotional response, and a sequenced 'smile-kiss' expression was added. Three times per week, the participant was exposed to 20 minutes of pneumotactile facial stimulation in randomized blocks at saltatory velocities ranging from 5 to 105 cm/sec. Concurrent with pneumotactile stimulation, the participant also practiced facial expressions with prompting.

Electromyography. Hydrogel surface electrodes (Kendall H124SG, 8 mm Ag/AgCl disc) were placed bilaterally in bipolar pairs (differential) to record from muscle groups of the midface (maxillary levators) and lower face (perioral) as shown in (Figures 3 & 4). Biopotentials were conditioned by GRASS P511 amplifiers (Gain=20,000, Butterworth BP 30-1000Hz) and digitized in real time (4,000 samples/sec, 16 bits, 5V ADC, AD Instruments PowerLab-16 [Colorado Springs, Colorado, USA]). The digitized EMG signals for each of the four facial muscle recording sites were processed (rectified and integrated [200 ms time constant] in real time. An expanded view of iEMG signals for affected and control mid-face electrode placements is shown in APPENDIX I. The iEMG signals from the affected side were displayed in real time on a 16" HD color display monitor. During these sessions, the participant was presented with clinician models of the target gesture and visuals depicted in (Figure 5). The stimulus visuals were presented to the participant for 20 repetitions of each expression. The presentation schedule is shown in Table 2.

Figure 3: Participant with hydrogel surface electrodes during an EMG biofeedback session.

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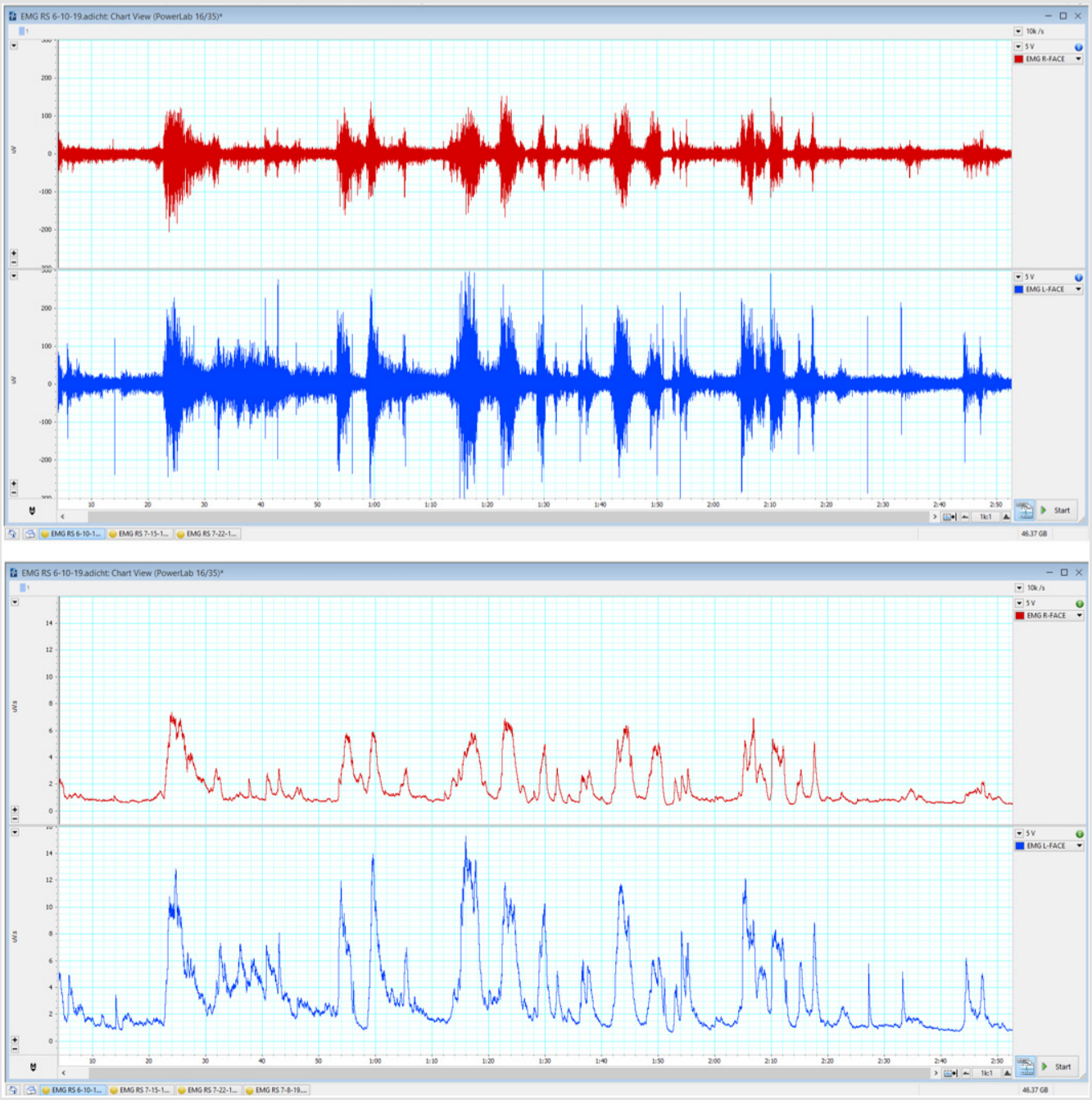

Appendix I: Expanded view of electromyographic records from the affected (red) and non-affected (blue) mid-face facial muscles. Raw unprocessed EMG records are shown in the top panel, and the rectified and integrated EMG (time constant = 200 ms) display used for real time biofeedback on a 17″ HD display monitor is shown in the bottom panel.

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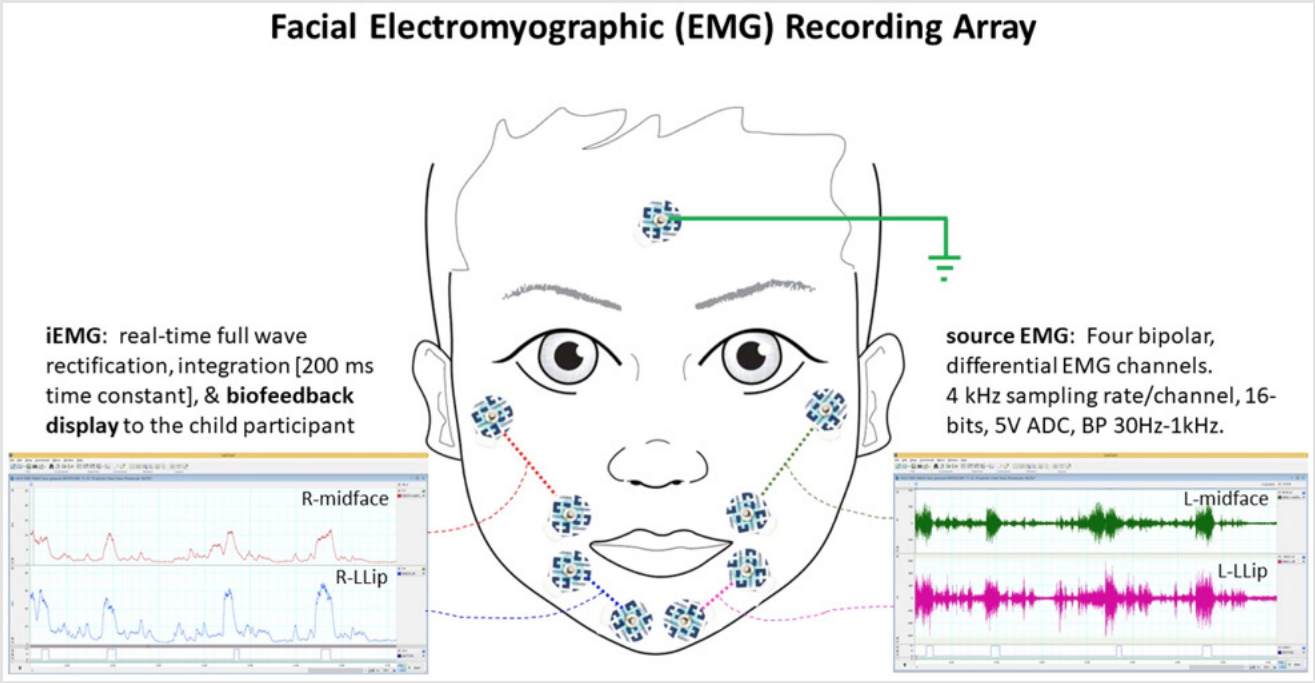

Figure 4: Diagram of participant and the facial electromyographic recording array for real-time biofeedback. The array included 8 mm hydrogel surface electrodes configured as bipolar channels over the

a) right midface (R-midface),

b) right lower lip (R-LLip),

c) left midface (L-midface), and

d) left lower lip (L-LLip).

An example of integrated EMG (iEMG) is shown in the left panel for muscles in the affected face, and an example of source (unprocessed) EMG is shown in the right panel for the unaffected side of the face.

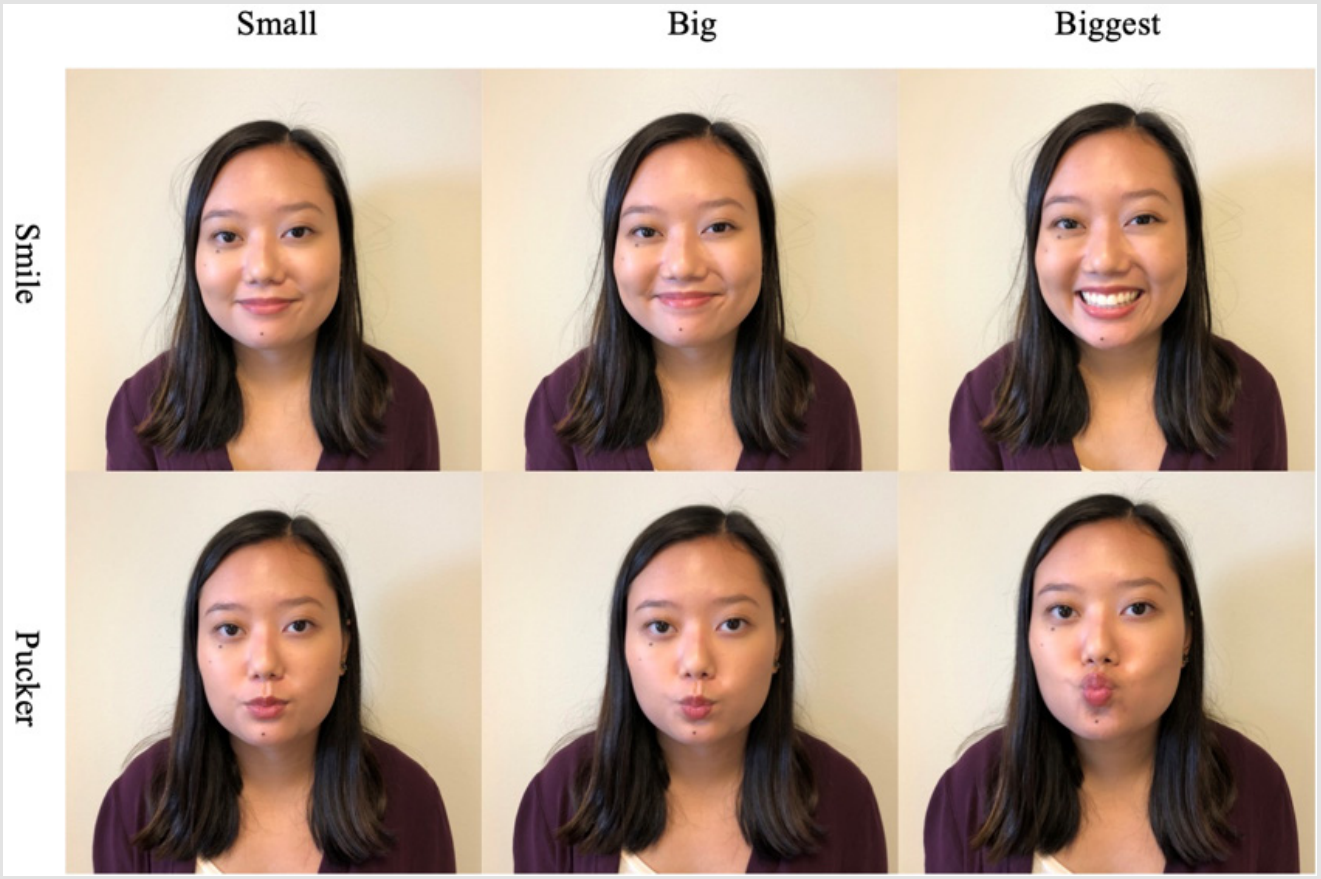

Figure 5: Stimulus prompt pictures presented to the participant by gesture type (i.e., smile and pucker) and gesture size (i.e., small, big, biggest).

Table 2: Presentation schedule of stimulus prompt pictures and participant expressions.

Expressions Produced in Order	First 9 Expressions	Last 11 Expressions
'smile'	1) small, 2) big, 3) biggest expressions produced consecutively (x3)	All 11 'smile' expressions produced at biggest amplitude
'pucker'	1) small, 2) big, 3) biggest expressions produced consecutively (x3)	All 11 'pucker' expressions produced at biggest amplitude
'Smile-kiss'	All 20 expressions produced with 'smile-kiss' alternation at largest amplitude	

The child participant was instructed to view the iEMG waveform on the color display with direct verbal prompts presented in between each expression. Additional verbal prompts and models were provided to demonstrate facial gestures associated with 'little', 'big', and 'bigger' smiles. When the participant produced expressions in natural contexts, her attention was directed to the iEMG biofeedback display, and her behavior was reinforced with positive reinforcement from the clinician. Following each session, the iEMG signals were post-processed to calculate the area under the iEMG waveforms over the duration of each biofeedback session using an absolute, non-resetting integral function expressed as μV.seconds. A normalized iEMG value was subsequently calculated for each muscle site and expressed as μV.seconds/second.

Statistical Processing: Ordinary least square (OLS) regression was conducted using Minitab v18.1 (Minitab, [30]) to characterize the relation between the normalized iEMG and session number. Paired-sample t-test was used to test for differences between the affected (right face) and non-affected (left face) muscle groups, including right versus left midface, and right versus left lower perioral face. Mixed modeling was performed using SAS 9.4 (SAS, [31]) to examine the rate of change in amplitude of the child's integrated electromyograms during biofeedback training over the 11 visits (i.e., time effect) as well as the difference in change rate between the right and left side of the face (i.e., time-by-location

interaction). The model was fitted separately for midface and lip iEMG data and accounted for the correlations among repeated measurements.

Results

The following data were accumulated from a series of EMG and biofeedback sessions that took place one time per week at 11:00 in the morning in the Communication Neuroscience Laboratory for the 'smile' expression. Two EMG baseline control sessions plus nine EMG biofeedback sessions were recorded over a period of 13 weeks from September 4th to November 22nd of 2019. The total minutes of EMG data recording across all eleven sessions equaled 80.5 minutes (4,828 seconds). The average EMG data recording session was 7.3 minutes (439 seconds). The integrated EMG data across the 11 visits are shown in Table 3. File_len is the length of the digitized data file in seconds. The following columns demonstrate the EMG measurements for the right midface, right lip, left midface, and left lip. These measurements are reported as integrated EMG over session length and normalized to integrated EMG per second.

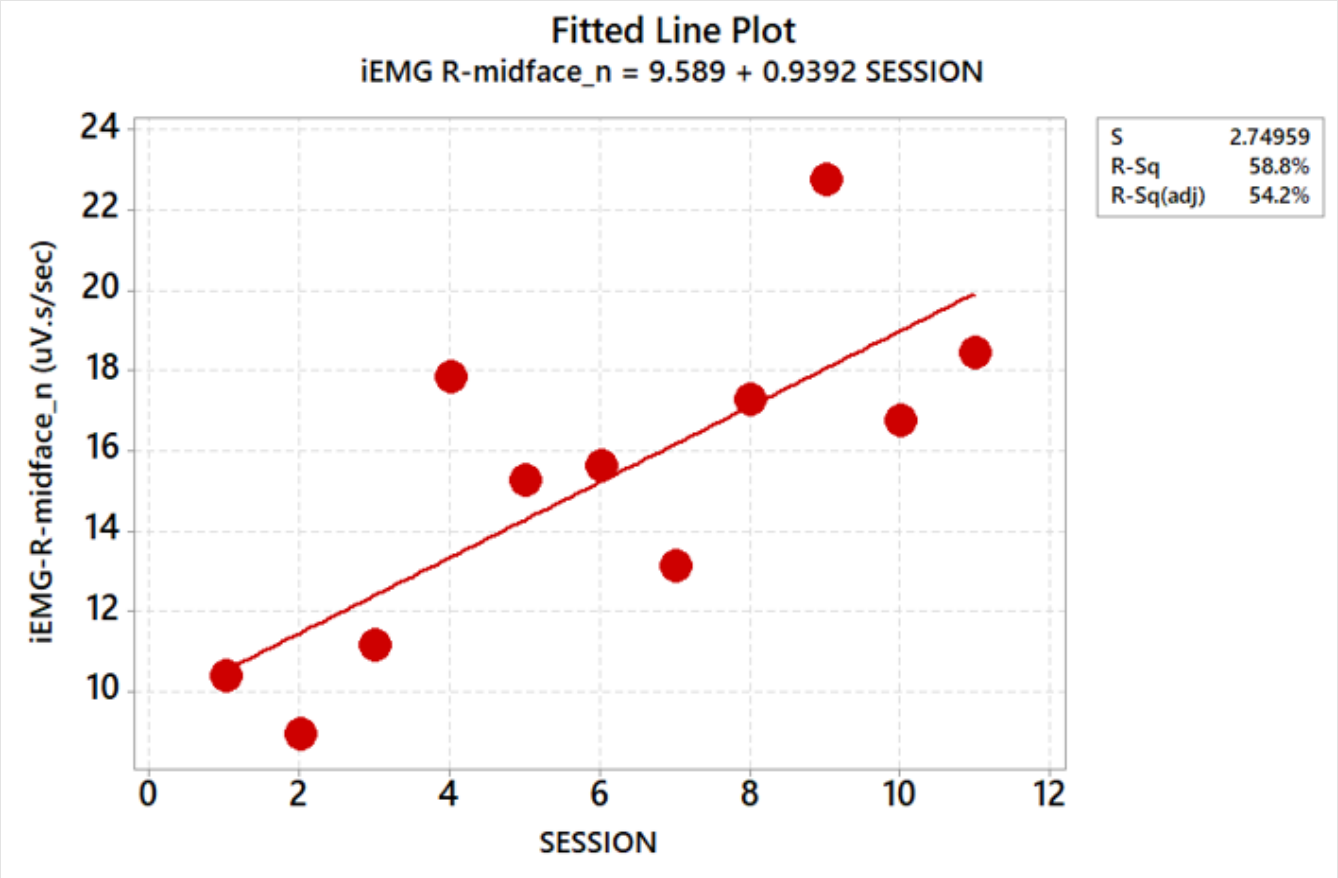

Figure 6: Normalized iEMG for R-midface during 'smile' biofeedback gestures as a function of session.

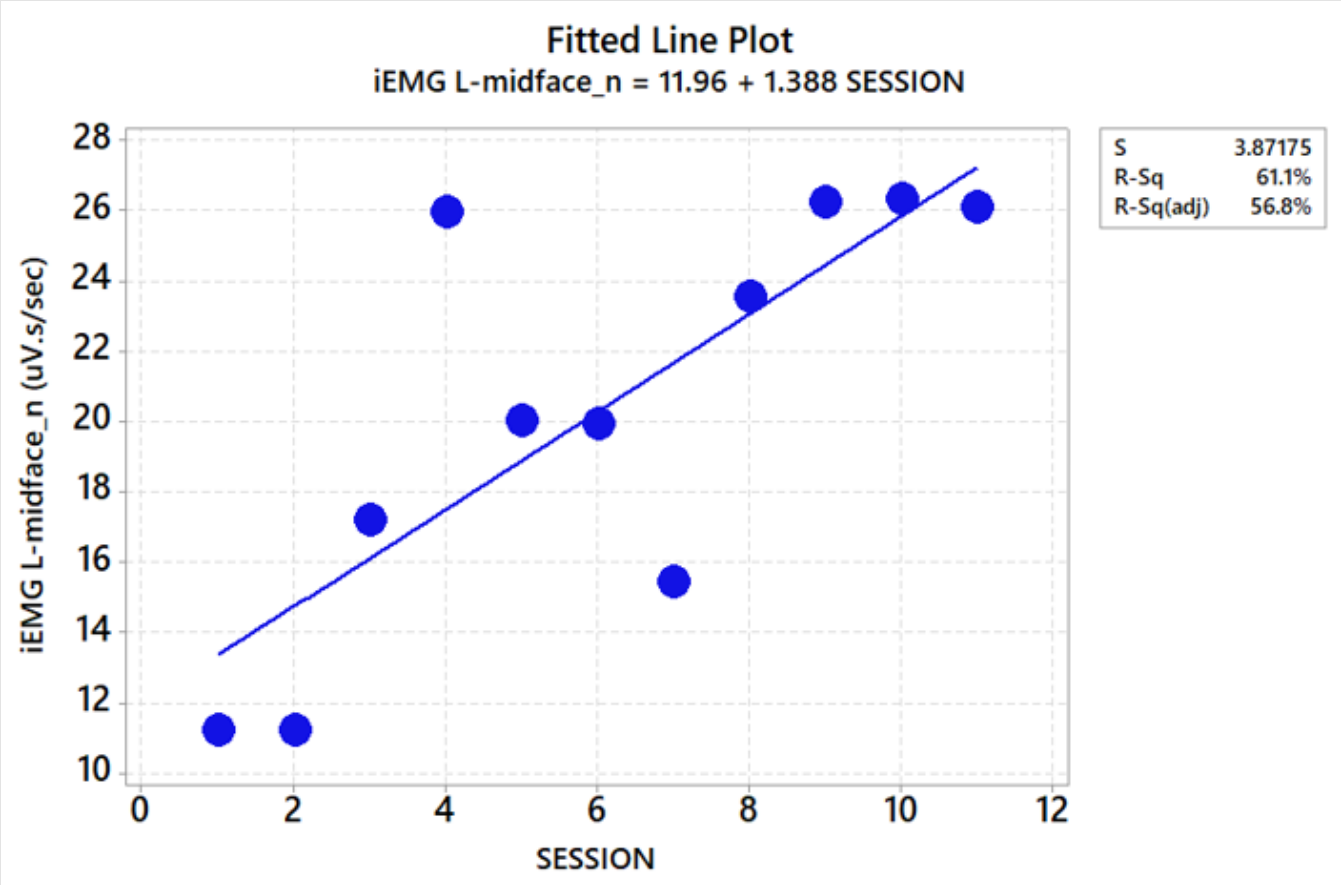

Figure 7: Normalized iEMG for the non-affected L-midface during 'smile' biofeedback gestures as a function of session.

The raw EMG waveform was full wave rectified resulting in only positive measurements. An envelope was created from the rectified waveform and this envelope was filtered and smoothed using a 0.2 sec time constant. The area under the iEMG envelope was measured using a non-resetting absolute integral to calculate the total μV.s over each session recording. The first column for each muscle group in Table 3 reports the total muscle bioelectric energy expressed as an integral (μV.s) that the participant produced for each digitized record. Since individual sessions vary in duration, iEMG data records were subsequently normalized and expressed as μV.s/sec. Therefore, the second column for each muscle group in Table 3 represents the normalized iEMG value as a function of session (visit) number. The results of OLS regression revealed that the paretic R-midface iEMG amplitude was significantly related to session (visit) number [F (1, 9) = 12.83, p =.006, adjusted R2 = 54.2%] with a predicted positive growth in iEMG of 0.9392 μV.s/sec for each session (Figure 6). Compared to baseline (sessions #1 and #2), the child participant showed a doubling of R-midface iEMG muscle activity to approximately 20 μV.s/sec (predicted Y) over the 9 subsequent treatment sessions. The iEMG for the non-affected L-midface also shows a highly significant positive relation to session number [F(1, 9) = 14.14, p =.004, adjusted R2 = 56.8%] (Figure 7). The predicted y-value (iEMG) at the 11th session was more than double in magnitude compared to session 1 (11.19 μV.s/sec compared to 26.09 μV.s/sec, respectively). The L-midface iEMG manifest a steeper slope compared to the affected R-midface iEMG (1.388 μV.s/sec versus 0.9392 μV.s/sec).

The iEMG for the paretic R-lip perioral face is not significantly related to session number [F(1, 9) = 3.01, p = .117, adjusted R2 = 16.8%] (Figure 8). The predicted y-value (iEMG) at the 11th session is somewhat higher in magnitude compared to session 1 (31.38 μV.s/sec compared to 44.16 μV.s/sec, respectively), but this apparent difference is not significant which is consistent with large variation in the data and a small R-square of 16.8%. This is consistent with less significant change compared to the L-lip perioral face (2.101 μV.s/sec versus 1.47 μV.s/sec). The iEMG for the non-affected L-lip perioral face shows a highly significant positive relation to session number [F(1, 9) = 11.11, p = .009, adjusted R2 = 50.3%] (Figure 9). The predicted y-value (iEMG) at the 11th session is triple in magnitude compared to session 1 (14.97 μV.s/sec compared to 45.28 μV.s/sec, respectively). The L-lip perioral iEMG manifest a steeper slope compared to the affected R-lip perioral iEMG (2.101 μV.s/sec versus 1.47 μV.s/sec).

Table 3: iEMG (μV.s) and normalized iEMG data (μV.s/sec) calculated for the 'smile' motor expression task across all muscle recording sites and visits. *Visits during which baseline EMG data were recorded.

Visit	file_len (secs)	iEMG R-midface (μV.s)	iEMG R-midface normalized (μV.s/sec)	iEMG R-LIP (μV.s)	iEMG R-LIP normalized (μV.s/sec)	iEMG L-midface (μV.s)	iEMG L-midface normalized (μV.s/sec)	iEMG L-LIP (μV.s)	iEMG L-LIP normalized (μV.s/sec)
*1	345	3576.5	10.37	10825.9	31.38	3859.9	11.19	5164.3	14.97
*2	350	3120.2	8.92	8958.2	25.59	3923.4	11.21	7707.8	22.02
3	391	4356.5	11.14	9820.4	25.12	6729	17.21	10790.5	27.6
4	845	15083	17.85	28249.1	33.43	21931.8	25.95	34929.2	41.34
5	554	8442.2	15.24	29263.6	52.82	11086.2	20.01	22063.4	39.83
6	416	6495.9	15.62	15798.4	37.98	8296.1	19.94	13786.6	33.14
7	465	6103.3	13.13	12050.1	25.91	7171.8	15.42	12363	26.59
8	455	7853	17.26	15473.9	34.01	10720.6	23.56	15347.8	33.73
9	405	9214.1	22.75	20772.7	51.29	10619.3	26.22	15063.8	37.19
10	367	6147.3	16.75	13525.3	36.85	9665.4	26.34	15353.5	41.84
11	235	4336.7	18.45	10378.1	44.16	6132.1	26.09	10639.9	45.28

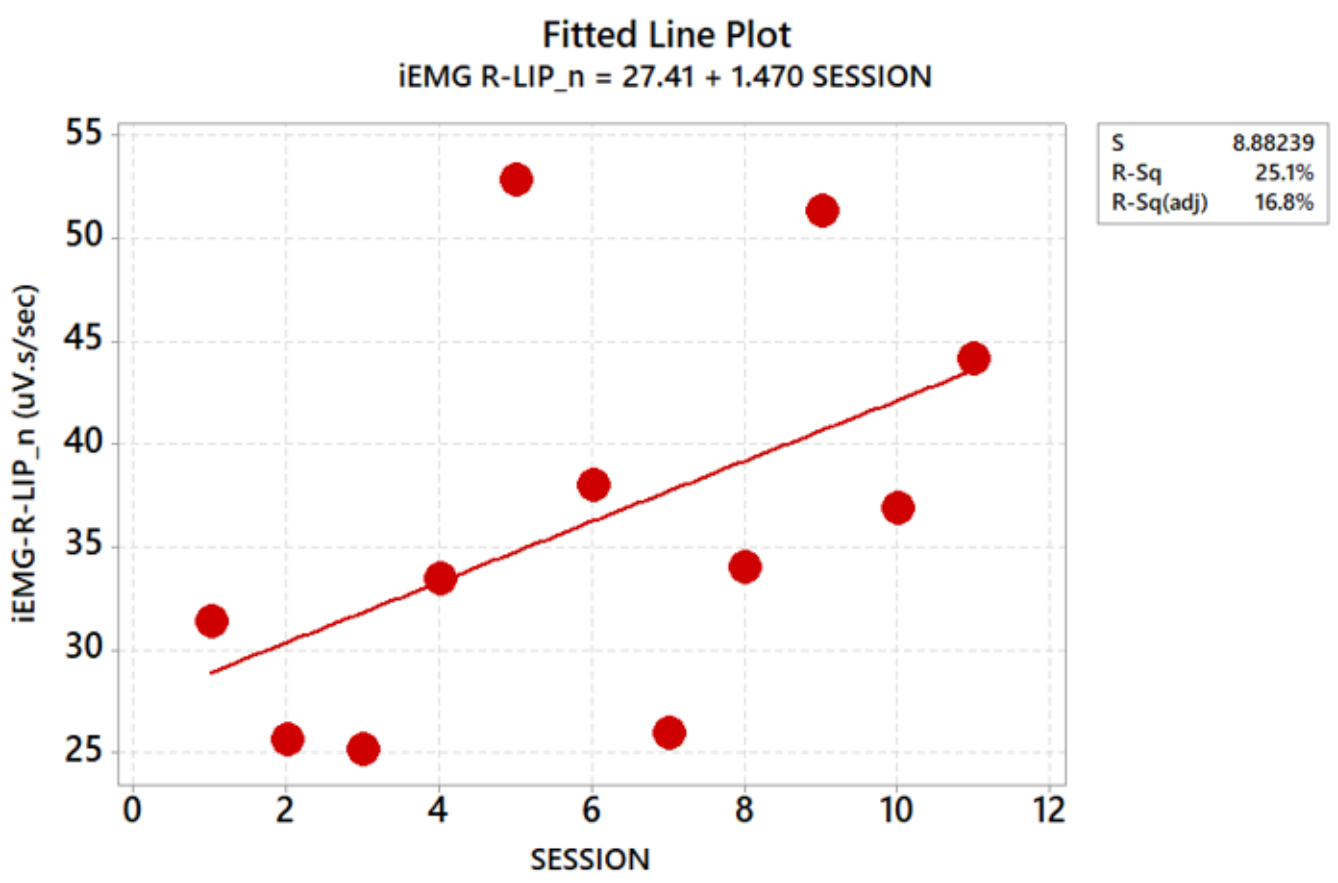

Figure 8: Normalized iEMG for R-lip perioral during 'smile' biofeedback gestures as a function of session.

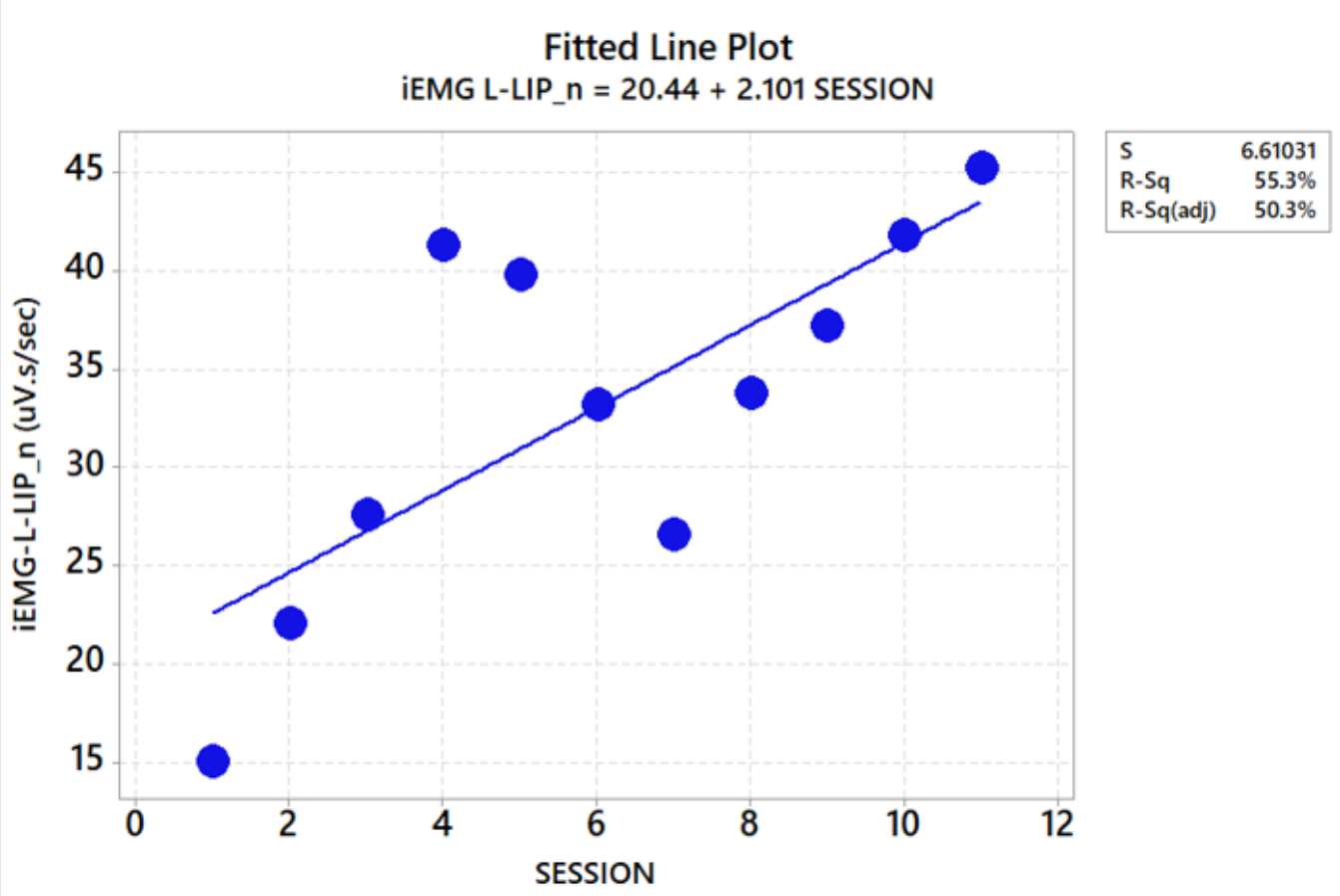

Figure 9: Normalized iEMG for the non-affected L-lip perioral during 'smile' biofeedback gestures as a function of session.

The iEMG amplitudes were compared between the affected right-side face to the child's non-affected left side face using paired-sample t-test. There was a significant difference between the right and left midface iEMG levels ($t(10) = 6.11$, $p < .001$), however no difference was found between the right and left lower lip iEMG levels ($t(10) = 1.30$, $p = .222$). Thus, facial motor neuron innervation to the right lower lip was relatively intact compared to the unaffected side. Facial motor neuron innervation to the child's right face was significantly less than the unaffected side. While iEMGs on the affected mid-face electrode placement showed strong therapy-related modulation as a function of session number, there was nonetheless reduced iEMG drive compared to the left (unaffected) side of this child's face. The mixed modeling results indicated that the iEMG amplitude increased in a linear pattern during the visits ($p = .009$ for face, $p = .065$ for lip). The amplitude increased faster in the left (intact) side than in the right (paralyzed) side; however, this difference in change was not statistically significant ($p = .334$ for face, $p = .557$ for lip).

Discussion

Persistent idiopathic facial paralysis often presents variable reanimation given various treatment techniques. In this study, real-time iEMG biofeedback was shown to promote increased levels of muscle activation and observed reanimation in an individual with persistent idiopathic facial paralysis. This quantitative physiological measurement and intervention can be compared to facial grading systems which are subjective in nature (Duarte-Moreiera, et al. [19-22]). The results provide evidence of the positive effects of biofeedback for reanimation of the participant's affected mid-face. Regression analyses revealed the strong positive relation between voluntary iEMG levels among muscle groups in the affected (paralytic) face and session number. On average, our 3-year, 6-month-old female participant achieved a growth in Right mid-face iEMG of 0.9392 μV.s/sec for each session, with more than half of the variance in her EMG production accounted for by this regression function [R2(adj) = 54.2%].

The positive growth in iEMG levels each week of therapy also demonstrated that the treatment effect was greater than chance. On average, our participant achieved a growth in the right lower lip iEMG of 1.470 μV.s/sec for each session, however less than half of the variance in her EMG production could be accounted for by this

regression function [R2 (adj) = 16.8%.]. These findings align with previous studies indicating the efficacy of biofeedback for increasing movement and reanimation following paralysis and the variance in results (de Freitas, et al. [2,28]). During the treatment period, the clinical researchers noted observable changes in the participant's face including the appearance of a dimple on the participant's right side and increased movement such as the ability for the participant to furrow her eyebrows. Additionally, the participant's dentist, who was blind to the research procedure, commented on perceived increases in the participant's facial range of motion.

These observations indicate the subjective yet practical changes which occurred during the treatment period. Upon post-interview 11 months following the final EMG and biofeedback session, the participant's parents indicated that they had not observed any further changes in her facial movement. Per clinician observation, the participant maintains asymmetry when producing expressions and does not have the corneal reflex provided with external stimulants (i.e., snapping near the eye). It should be noted that the participant exhibits eye closure and reflexes when provided with pneumotactile sensory stimulation in the orbital region. However, no objective measures were taken to determine longevity of treatment effects. They also indicate no solidified treatment plan given the global pandemic and subsequent discontinuation of biofeedback sessions and interventions. The participant continues to participate in activities which maintain her quality of life including dance and school. From parent report, medical records, and iEMG analyses it is possible that the participant's orofacial musculature and anatomy has regressed due to a loss/reduction of facial motor nerve input, including atrophy of zygomatic facial muscle groups which are necessary to produce a full smile and oral angle retraction. The extent of orofacial muscular atrophy could be determined using high resolution anatomical MRI. Further neuroimaging was previously recommended by the participant's otolaryngologist following inability to visualize the facial nerve course due to opacification of the mastoid. Increasing the iEMG electrode montage over putative mid-face zygomatic and buccinator muscle groups would be useful to increase the resolution of muscle activation fields. Increasing the number of recording sites and decreasing the size of bipolar iEMG recording fields (interelectrode distance) may provide additional electrophysiological information regarding the participant's specific areas of paresis and yield further comparisons with the unaffected side. Although not appropriate for pediatric applications, the use of 40 μm hook-wire intramuscular electrodes or needle electrodes in adult applications greatly improves the selectivity of muscle recordings to help define the location and extent of intact facial muscle groups impacted by peripheral or central paresis of the facial muscles.

Limitations of this Clinical Study

The present report, based on study of a 3.5-year-old child with idiopathic unilateral facial palsy, demonstrated the therapeutic effects of real-time EMG biofeedback over the course of eleven weekly sessions in a clinical speech physiology laboratory using simple, non-invasive electrophysiological methods to promote the growth in muscle activation levels among affected muscle groups during repetition of functional motor behaviors (i.e., smile, pucker, etc.). Further research is required to investigate the effects of biofeedback across populations using larger sample sizes and inclusion of follow-up measures to quantify the nature of short- and long-term effects on muscle activation patterns produced on the paretic side of the face. Unfortunately, the COVID-19 pandemic prevented further study with this energetic young child. Thus, the electrophysiological data and observations of facial reanimation presented in this report are based on iEMG data sampled during clinical intervention with this child over eleven weekly sessions completed during the Fall semester of 2019. Our goal was to conduct a more comprehensive clinical study with this child using augmented pulsed pneumotactile stimulation and iEMG biofeedback to enhance facial reanimation. We hope to reopen this clinical study with this child, who is now 6 years old and a precocious 1st grader, to map and facilitate functional motor recovery of the affected side of her face.

Hydrogel electrodes provide a very comfortable and stable sensor of electromyographic activity on the face and other muscle systems. However, smaller diameter hydrogel Ag/AgCl snap-lead electrodes are needed for routine monitoring of muscle activation patterns from the relatively small faces of young children. The underlying anatomy of facial musculature and its relation to the integument in perioral and maxillary regions of the face is complex (Chu, et al. [32]). Based on the Bolton skull standards, it is not until approximately age 12 years, that the craniofacial skeleton approaches (within 90%) adult form and scale (Broadbent, Broadbent, Golden, 1975 [33]). Clinical interventions aimed to restore facial animation in patients with congenital anomalies of facial nerve function benefit from a detailed case history, including craniofacial and neuroimaging data to better understand the presence/absence of select facial muscle groups, and delineation of the presence/absence of specific facial nerve branches, and congenital anomalies at or near cranial/facial skeleton foramen which may have contributed to malformation of the peripheral distribution of the facial nerve in this child. This may also determine her candidacy for a more invasive treatment such as a nerve and muscle graft to restore facial kinematics, used in conjunction with EMG biofeedback and somatosensory therapies. This procedure was previously mentioned by the participant's pediatric plastic surgeon and was pending reevaluation after the participant turned five years old. The participant's parents indicated their preference to avoid invasive surgical procedures when noninvasive ones are accessible and potentially efficacious. These demonstrate the range of treatment options available to individuals with facial palsy and

the complex decision-making process that each individual and family units must contemplate.

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Data Availability Statement: The data that support the findings of this study are available from the corresponding author, S.B., upon reasonable request.

Ethics Approval and Patient Consent Statement: The study was reviewed and approved by the University of Nebraska Institutional Review Board. The participant's parents were informed about the experimental procedures, provided informed written consent for their child to participate in the study, and a family member observed each session in the laboratory.

Conflict of Interest: The authors confirm that there are no conflicts of interest associated with this publication and there has been no financial support for this work that could have influenced its outcome.

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