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Full Length Research Paper

Effects of NMES on pharyngeal muscle group synergy while swallowing

Larry Barnes

West Texas A&M University, WTAMU Box 60757, Canyon, Texas 79116, USA.
E-mail: lbarnes@mail.wtamu.edu. Tel: 806-651-5108.

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The act of swallowing is an extremely complicated event involving multiple muscle groups engaged in complex synergies. Traditionally, dysphagia therapy has focused on muscle strengthening and range of movement. However, recent evidence suggests that specific and shared muscle synergies play a critical role in the coordinated movements required in swallowing. This study investigated the overall effects of muscle strength versus synergy on the swallow events of an elderly woman. A single-subject repeated measures research design was implemented. The quantitative relationships between neuromuscular electronic stimulation (NMES) and duration of the swallow event implicate a modular change in synergy within targeted muscle groups. Outcomes suggest that muscle synergy serves as the primary motor task in actuating a safer swallow. Implications on dysphagia therapy are discussed.

Key words: Dysphagia, electrical stimulation, surface electromyography (sEMG), synergy.

INTRODUCTION

Traditional therapy for remediating neuromuscular dysfunction involved muscle strengthening exercises with a goal of both increasing muscle vigor as well as range of motion. These therapy exercises have met with limited outcomes depending upon the type of etiological insult. However, recent studies suggested that strength and range of motion may have a lesser effect in remediation of muscular activity than previously thought. Evidence indicated muscle synergies may have a longer lasting and more immediate effect on optimal motor behavior.

It has been theorized that the building blocks of optimal motor action are the muscle synergies elicited by dedicated neural networks (Nielsen et al., 2005). Synergies are defined as stereotypical coordinated patterns of two or more muscle groups resulting in a combined effect that is greater than the individual effects. Muscle patterns underlying the control of specific natural behaviors are composed of discrete combinations of synergies, that is, motor behaviors are represented as both spatial and temporal coordinated movements (D'Avella et al., 2003). The summation of a small number of motor synergies can generate optimal motor action (Chhabra and Jacobs, 2006). Motor controllers coordinate the symphony of synergies needed to actuate behaviors that are thought to be modular in organization (D'Avella and Bizzi, 2005). Modular organization is a system of movements built from a structurally limited number of building blocks, that is, synergies. Modules as short latency responses are fed by bundles of neural networks. Feedback from these neurophysiologic structures plays a central role in the configuration of motor synergies (Jing et al., 2004).

Jing et al. (2004) were able to isolate specific neurons associated with the behaviors of deglutition and examine their role in the construction of movement with behavior-specific and behavior-independent modules. Their findings revealed that individual inter-neurons are multifunctional, some exciting modules toward specific goals and others exciting modules toward complex motor actions. Modular organization associated with deglutition may function to reduce the degrees of freedom by specifically controlling groups of muscles designed for specific tasks. This finding was corroborated by the research of Chhabra and Jacobs (2006) when they suggested that synergies as spatial movements are more a reflection of the motor task goals than the details of the neuromuscular structure.

It is theorized then that the task of swallowing can be spatially and temporally measured to determine the synergies involved in specific motor behaviors. One biofeedback tool used to measure synergistic properties associated with motor action is electromyography (EMG). Previous studies found elicited EMG patterns recorded from contracted muscle groups to comprise of smaller subgroups of muscles demonstrating varied activity indicative of synergies (Saltiel et al., 2001). More recently, researchers have used cluster analysis of EMG onset and offset patterns to identify specific synergies of targeted muscle groups (Drew et al., 2008).

Additional research examined the EMG patterns associated with the arbitrary inputs of muscle group activity (Ravichandran and Perreault, 2005). Results revealed the EMG readouts to be a complicated mixture of synergies and corresponding inputs. Thus, EMG graphs recording motor actions generated by modular organization depict a small number of temporal and spatial motor synergies.

This study theorized that through elicitation of targeted muscle groups, EMG feedback would record not only the resulting strength of the muscle groups, but the specific latencies of temporal motor synergies involved. A comparison of muscle group strength with synergy patterns were analyzed to depict motor paradigms associated with optimal movements necessary for swallowing. The purpose of this study was to determine if neuromuscular electronic stimulation (NMES) demonstrated a positive effect on muscle synergy as indicated by decreased latency of a swallow event.

MATERIALS AND METHODS

This study examined the findings of a single subject test involving NMES as a therapeutic model for dysphagia treatment. A single-subject repeated measures research design was implemented. The quantitative relationships between NMES and duration of the swallow event would implicate a modular change in synergy within targeted muscle groups.

The subject was a 68 year-old Caucasian female with no prior diagnosis of neurological dysphagia. She was experiencing symptoms, typical of age related swallowing difficulties. These symptoms included decreased laryngeal elevation, effortful swallowing, slower than normal rates of oral-pharyngeal phase and voluntary multiple swallows to clear pharynx. In addition, she was presented with no diagnosis or prior treatment of dementia or psychosis, no skin allergies, a non-modified diet per oral intake and the ability to tolerate direct therapy for 1 h sessions.

The NMES stimulator consisted of a dual channel output configuration with dual intensity potentiometers: 0 to 25 mA. Pulse rate was fixed with duration of 700 ms. The unit was operated by two AA (1.5 V) batteries providing rectangular symmetric biphasic output waveforms. As the current flowed in waveform from the stimulator, it caused a depolarization of the peripheral motor nerve in its path. This in turn elicited the desired muscle contraction. Single use surface electrodes, alcohol swabs to clean the skin prior to each treatment and adhesive tape to affix the electrodes were used in the sessions.

Electrode placement consisted of two placed vertically in relation to each other superior to the laryngeal notch and two placed vertically in relation to each other inferior to the laryngeal notch. A template was used to insure consistent placement from one session to another. Approximately 2 to 3 cm separated each pair of electrodes. The electrodes located immediately superior and inferior to the laryngeal notch were placed approximately 1 cm from the base of the notch.

Treatment sessions began with a gradual increase in stimulation of both channels simultaneously while asking for continuous feedback from the subject. Subject reported sequentially feeling a "tingling" sensation followed by a "burning" sensation and culminating with a "grabbing' sensation. The "grabbing" sensation along with an audible swallow served as clinical indicators that a therapeutic level of muscle contraction was achieved. Each session recorded higher levels of stimulation as the subject's tolerance level increased, with the highest output reaching 22 mA. During the stimulation process, the subject consumed a meal of the same caloric need and consistency as prescribed by her current dietary order. Stimulation occurred during the entire course of the meal, lasting approximately 45 min per session. The subject received treatment five days a week for five weeks.

Strength of the supra- and infra-hyoidal muscle groups and the duration of the pharyngeal phase of swallowing were determined by surface electromyography (sEMG) immediately before and immediately after each NMES treatment. Measures were recorded during swallowing of a standardized 20 cc water volume. sEMG was measured during the complete swallowing cycle. Three swallowing cycles of 20 cc each was recorded during every pre-prandial and post-prandial test session. The average of the three measurements was used to represent the pre-prandial and post-prandial swallowing muscle strengths and swallow event duration.

The sEMG required the placement of two surface triodes. One triode targeted and recorded from the suprahyoid muscle group and the other from the infrahyoid muscle group. A template was used to insure consistent placement from one session to another. At approximately 600 cycles per second, the sEMG detected and recorded the action potentials of targeted muscle groups as measured in micro volts. In addition, the sEMG unit recorded in milliseconds the time lapsed from the moment targeted muscle groups transmitted action potentials to the point in which they ceased. The averaged action potentials and duration of pharyngeal phase swallow were tabulated into a data table.

RESULTS

A Pearson *r* correlation was calculated to determine a statistical relationship between NMES duration and both action potential and duration. Both muscle groups demonstrated a nonlinear relationship to days of treatment. Figures 1 and 2 illustrate a quadratic polynomial regression for each muscle group's relationship to days of treatment. With these polynomial regressions, the supra-hyoid and infra-hyoid muscle groups exhibited a statistically significant correlation coefficient (r) of 0.40 and 0.66, respectively. However, the final action potential readings indicated no difference in degree when compared with baseline readings.

Figure 3 illustrates the linear regression ($r = 0.96$) of swallow duration during the five week treatment process and a two week follow up period. This regression indicated a positive correlation between length of treatment and shortened pharyngeal phase of swallow.

Figure 4 illustrates the differences in seconds between baseline duration of supra-hyoid and infra-hyoid activity during swallowing of a standardized 20 cc water volume and duration following the fifth week of treatment. Duration signifies the time required from initial point of muscle group activation (action potential) to point of

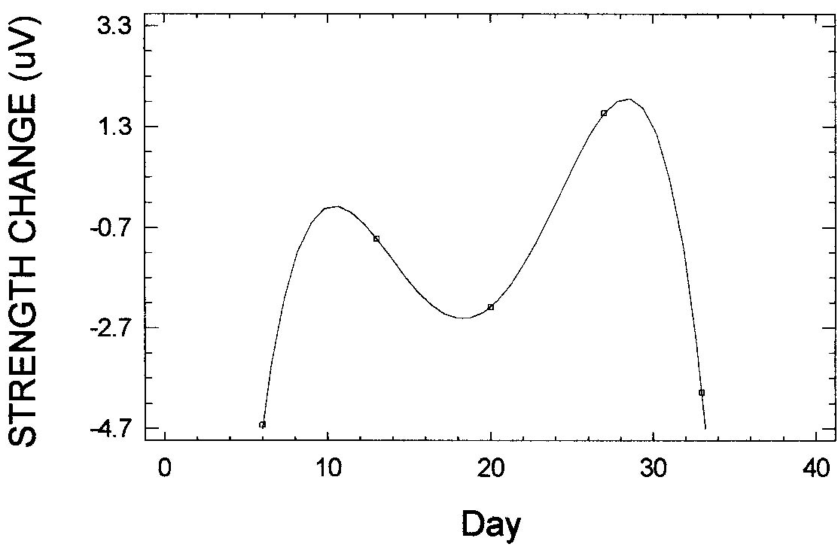

Figure 1. Differences between mean weekly strengths of post-prandial minus pre-prandial measurements for suprahyoid muscle group.

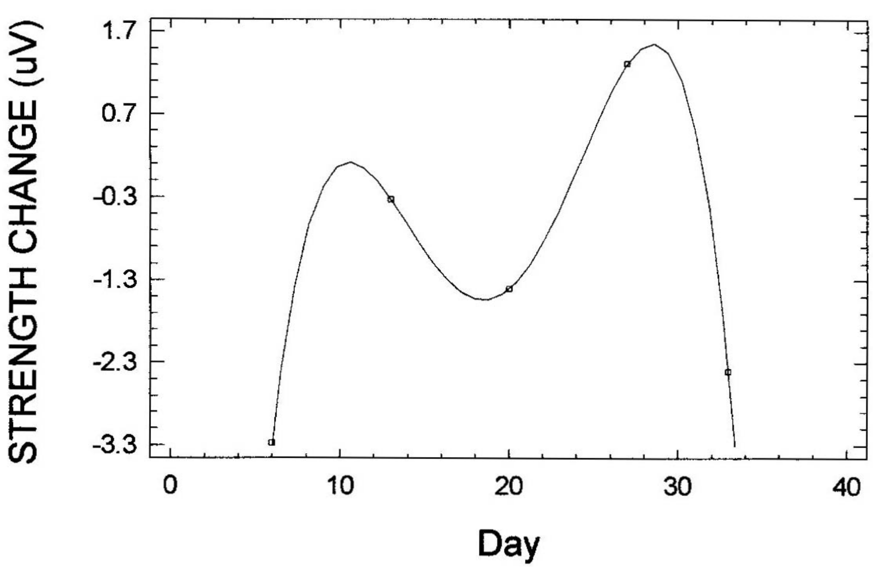

Figure 2. Differences between mean weekly strengths of post-prandial minus pre-prandial measurements for infrahyoid muscle group.

completion (cessation of action potential) during the swallow. Both groups of muscles demonstrated a decrease in action potential duration during the swallow. The upper graph of Figure 4 identifies repeated peaks of action potential resulting from the subject's repeated pre-prandial attempts to swallow. This caused duration of targeted muscle activity during the swallow event to extend well beyond that typically observed in pharyngeal phase of swallowing. The lower graph of Figure 4 identifies the decrease in multiple swallow attempts and duration differences of approximately 3 s (3000 ms).

DISCUSSION

Decreases in swallow duration were not dependent upon changes in muscle strength. Decreases in muscle strength simultaneous with decrease in duration of swallow events rule out muscle strength as the agent. This cut against the conventional wisdom that therapy targeting muscle strength had the primary impact on swallow efficiency. Issues of duration are better argued from the point of synergistic movement of the anatomy implicated in this study. The pre- prandial difficulties

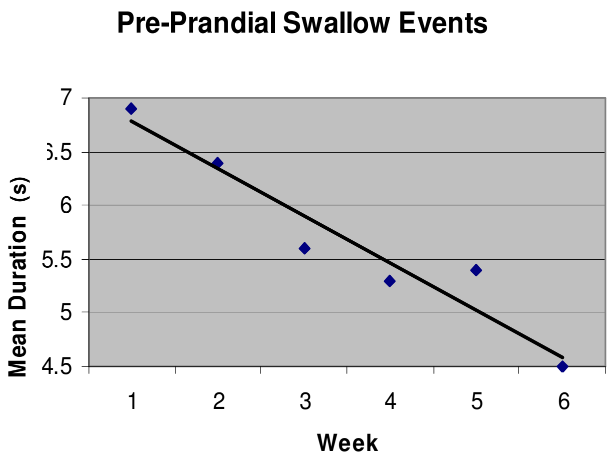

Figure 3. Linear regression (r = 0.96) of swallow duration during five week treatment process and the two week follow up period.

Figure 4. Differences in seconds between baseline duration of suprahyoid and infra-hyoid activity.

suffered by the subject could be explained not from the point of muscle weakness but of dysynergistic movement. Muscle weakness serving as an etiological factor can be ruled out given that near baseline strengths were finalized at the end of the therapy while deglutive presentations improved. However, if modules were not functioning efficiently, the asynchronous movement of muscle groups could present similar to what the subject was experiencing.

It is theorized by the data presented from this study that the electrical charges from NMES causing muscle contraction stimulated the modules implicated. This stimulation may have allowed for modifications regarding subsequent motor plans. The plasticity of the brain could accommodate changes in motor output if appropriate sensory input encouraged such changes. This interpretation would support the findings of Chhabra and Jacobs (2006) who suggested that synergies as spatial movements are more a reflection of the motor task goals than the details of the neuromuscular structure, the motor task goal being the efficiency of swallow.

The summation of a small number of motor synergies can generate optimal motor action. This would explain why a focal rather than a diffuse stimulation of the larynx, as was the case in this study, could have such a significant impact on the latency of swallow events. The decrease in swallow duration coupled with the perceptual differences noted by the subject indicated that a more optimal motor action was achieved.

The implications for therapy include direct versus indirect approaches and neuromuscular stimulation versus strengthening exercises. Direct approaches involve therapy activity that occurs during the act of swallowing. It is the act of swallowing combined with NMES in this case that stimulated the implicated modules necessary for motor modification. These modules would not be implicated in indirect therapy approaches. In addition, it was thought that NMES would result in muscle strength. The nullification of this hypothesis (long term effect of NMES on muscle strength was inconclusive) coupled with positive duration changes suggested NMES has a redeeming quality in its effect as a module stimulant. For this reason, except in cases involving flaccidity, neuromuscular stimulation therapies may prove to be more efficient therapy approaches to swallow remediation.

The limited data from a single subject design limits a generalized application of the results. For this reason, additional research is needed in controlling the variable of swallowing duration as related to NMES therapy.

Conclusion

Outcomes suggested that muscle synergy serves as the primary motor task in actuating a safer swallow. Stimulation of the modules implicated in this study was found effective through NMES coupled with direct therapy. The absence of continued muscle strength during the time when swallow latency continued in a regressive pattern rules out strength as the primary cause of motor accentuation. Rather, synergism of the targeted muscle groups is implicated in the decrease of latency of the swallow event. To account for the decrease in latency, reduction in multiple swallows, and patient report of easier swallow, it is speculated that NMES stimulated the individual inter-neurons associated with multifunctional and specific complex motor actions related to deglutition. This finding supports the idea that modular organization associated with deglutition may function to reduce the degrees of freedom by specifically controlling groups of muscles designed for specific deglutition tasks (Jing et al., 2004).

The decreased latency results of the sEMG outcomes of this study support previous research that suggest EMG readouts to be a complicated mixture of synergies and corresponding inputs (Ravichandran and Perreault, 2005). Because synergies are a reflection of motor task goals (Chhabra and Jacobs, 2006) and because the outcomes of this research identified a reduction in the amount of time needed for post-prandial to accomplish a motor task during deglutition, muscle synergy is supported as the primary motor task in actuating a safer swallow.

Modular organization is a system of movements built from a structurally limited number of building blocks, that is, synergies (D'Avella and Bizzi, 2005). Degrees of freedom decrease secondary to the specific control of muscle groups designated for specific motor tasking (Jing et al., 2004). Ruling out muscle strength as a contributing factor, this study corroborated the limited degrees of freedom concept by demonstrating through more efficient (time related) deglutition that specific motor tasking through stimulation can effect positive change.

There are several implications from this study related to therapy. First, targeting of specific muscle groups for stimulation is important to actuate a synergistic change. Decreasing the degree of freedom specific to motor tasking requires a careful and deliberate placement of NMES electrodes. Second, therapist utilizing NMES should look beyond muscle strength as an outcome measure related to efficacy. The findings of this study supported previous research (Chhabra and Jacobs, 2006) suggesting physiology (synergy) as opposed to structural changes (muscle strength) serve as the primary motor task in actuating a safer swallow.

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