Neuromuscular Treatments for Speech and Swallowing: A Tutorial

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Despite the proliferation of oral motor therapies, much controversy exists regarding the application and benefit of neuromuscular treatments (NMTs) such as strength training for alleviating dysarthria and/or dysphagia. Not only is limited empirical support available to validate the use of NMTs, but clinicians may also lack the foundational information needed to judge the theoretical soundness of unstudied treatment strategies. This tutorial reviews the theoretical foundations for several NMTs, including active exercises, passive exercises, and physical modalities. It highlights how these techniques have been used to address neuromuscular impairments in the limb musculature and explores potential applications to the speech and swallowing musculature. Key issues discussed in relation to active exercise are the selection of treatment targets (e.g., strength, endurance, power, range of motion), specificity of training, progression, and recovery. Factors influencing the potential effectiveness of passive exercises and physical modalities are presented, along with discussion of additional issues contributing to the controversy surrounding oral motor therapies.

Key Words: dysarthria, dysphagia, motor treatment, neuromuscular treatment, oral motor treatment

At least two strategies are available to clinicians selecting management techniques for specific individuals: The approach that is advocated by evidence-based practice is to refer to research reports describing the benefits of a particular treatment. The question asked in this case is, "Is this treatment beneficial?" In the absence of adequately documented clinical efficacy, clinicians may select treatments based on theoretical soundness. The question asked in this case is, "*Should* this treatment be beneficial?" This second method of treatment selection has potential for success if the clinician has a clear understanding of both the nature of the targeted impairment and the therapeutic mechanism of the selected treatment technique.

One treatment approach that lacks the empirical support necessary for evidence-based practice is the use of oral motor techniques to improve speech and/or swallowing activity. Moreover, selecting these techniques based on theoretical soundness may be difficult for clinicians who have an incomplete understanding of how common neuromuscular dysfunctions (e.g., altered tone, weakness) affect movement or how motor-based treatments act to influence underlying impairments. The ability to critically evaluate information in this area is essential in light of the apparent popularity of oral motor workshops, therapy guidebooks, and commercially developed therapy "kits."

The purpose of this article is to help clinicians make informed judgments about the potential benefit of neuromuscular treatments (NMTs) for specific impairments contributing to dysarthria and dysphagia. A review of neuromuscular impairments is presented, followed by a detailed discussion of the physiological impacts of NMT, with special attention given to how these treatments would be expected to affect neuromuscular impairments commonly observed in dysarthria and/or dysphagia. Finally, the current state of empirical support for the use of NMT is presented along with further discussion of issues contributing to the controversy surrounding these techniques.

Neuromuscular Impairments

Weakness

Weakness is defined as a reduced ability to produce force. A related concept is *fatigue,* which refers to weakness that becomes evident during sustained force production or over repeated trials. Weakness may result from a variety of conditions, including damage to the lower motor neuron or neuromuscular junction (as in flaccid dysarthria) and upper motor neuron (as in spastic dysarthria), as well as general depression of function that may accompany illness or mental fatigue. In addition to reducing force of movement, weakness may also disrupt speed and range of movement.

1058-0360/03/1204-0400

Weakness in the oral–pharyngeal systems is commonly assessed perceptually as the client attempts to move against resistance provided by the clinician, but it may also be objectively identified using instrumentation. Weakness in the peripheral structures is generally easier to observe; laryngeal and pharyngeal weakness is typically inferred from reduced range of motion of these structures.

The impact of weakness on speech and swallowing activity is not well understood. Although weakness often accompanies dysarthria and dysphagia (Chigara, Omoto, Mukai, & Kaneko, 1994; Clark, Henson, Barber, Stierwalt, & Sherrill, 2003; Dworkin & Aronson, 1986; Dworkin, Aronson, & Mulder, 1980; Dworkin & Hartman, 1979; Gentil, Perrin, Tournier, & Pollak, 1999; Langmore & Lehman, 1994; Logemann, 1998; Murdoch, Attard, Ozanne, & Stokes, 1995; Murdoch, Spencer, Theodoros, & Thompson, 1998; Solomon, Lorell, Robin, Rodnitzky, & Luschei, 1995; Solomon & Stierwalt, 1995; Stierwalt, Robin, Solomon, Weiss, & Max, 1995; Thompson, Murdoch, & Stokes, 1995), predicting the nature or degree of functional limitation from the severity of weakness has not been possible (e.g., Clark et al., 2003).

Disrupted Muscle Tone

Tone refers to the tendency of muscle tissue to resist passive stretch. Several neuromuscular substrates are thought to be involved in the regulation of tone. Muscle spindles within the muscle respond to fiber lengthening by eliciting a "stretch reflex" that causes the muscle to contract, resulting in the perceived resistance to passive movement. The Golgi tendon organ may inhibit this reflex during slow or volitional movements. Sensitivity or excitability of the stretch reflex is further influenced by neural input from both cortical and subcortical structures.

Tone may be disrupted by a variety of neuromuscular insults. Damage to the lower motor neuron prevents normal function of the efferent component of the stretch reflex, resulting in hypotonia, which is often observed in flaccid dysarthria. Damage to the upper motor neuron is thought to interrupt inhibitory signals and often results in hyperexcitability of the stretch reflex and hypertonia. Hypertonia of this type, which is more evident at high movement velocities, is termed *spasticity,* and is associated with spastic dysarthria. Lesions of subcortical structures such as the substantia nigra and basal ganglia may also affect tone. *Rigidity,* another form of hypertonia, is associated with hypokinetic dysarthria. Hyperkinetic dysarthria resulting from damage to the basal ganglia control circuit may be accompanied by *variable tone.*

Disrupted tone in speech and swallowing musculature may be difficult to recognize. In the limb system, tone is assessed perceptually by gauging the amount of resistance in a muscle when the examiner passively extends and flexes the limb. In the speech and swallowing musculature, relatively few articulators are accessible for passive movement by an examiner. Another complicating factor is the relative lack of agonist/antagonist relationships in the oral/pharyngeal/laryngeal muscle groups. It may be difficult to judge the amount of resistance offered by a single muscle group when the perceived resistance may include the tonic response of another, overlapping muscle group. Furthermore, the presence and distribution of muscle spindles vary across orofacial muscle groups (Barlow, 1999). Specifically, only the jaw-closing muscles exhibit the pattern of stretch reflexes observed in the limbs (Cooper, 1960; Neilson, Andrews, Guitar, & Quinn, 1979). Lip, tongue, and jaw-opening muscles are either devoid of muscle spindles or lack a clear pattern of stretch reflexes (Anderson, 1956; Cooper, 1953; Neilson et al., 1979). Further contributing to the difficulty in assessing tone is the fact that little, if any, data are available regarding the normal range of tone for the various muscle groups.

In light of these issues, it is not surprising that the impact of disrupted tone on speech and swallowing activity has not been widely studied. Nonetheless, some reasonable inferences might be drawn from the limb literature and based on the performance patterns associated with various forms of dysarthria. The effects of hypotonia, most commonly associated with lower motor neuron dysfunction, may be difficult to distinguish perceptually from those of weakness (Van der Meche & Van der Gijn, 1986). Spasticity is often most obvious in the laryngeal musculature where a bias towards hyperadduction contributes to the strained–strangled vocal quality associated with spastic dysarthria (Duffy, 1995). Rigidity, such as that observed in hypokinetic dysarthria, results in movements that are slow and/or of reduced range. Clinical manifestations of rigidity include breathiness and/or low vocal intensity as well as short phrases necessitated by reduced respiratory flexibility (Brookshire, 2003). Variable tone may contribute to irregular articulatory breakdowns and voice stoppages observed in hyperkinetic dysarthrias.

Weakness and disrupted tone are not the only neuromuscular impairments affecting speech and swallowing activity (see Duffy, 1995, for a more thorough review). However, the current discussion is limited to these deficits, which are the targets of the NMTs to be reviewed.

Neuromuscular Treatments

Many of the strategies to be reviewed have not historically been a significant component of speech or swallowing intervention. Rather, the strategies have been more widely used by physical and occupational therapists in the rehabilitation of the trunk and limbs. Because the oral/pharyngeal/laryngeal systems differ from the limbs in significant ways, the rationale and/or application of the treatments may not perfectly generalize to the speech and swallowing musculature. These issues are highlighted throughout the review. Three main categories of NMTs are reviewed: active exercises, passive exercises, and physical agent modalities. Several treatments affect motor function in more than one way, and some neuromuscular impairments are addressed by more than one treatment. In recognition of this overlap, two summary tables are be provided. Table 1 lists the treatments addressing identified neuromuscular impairments, whereas Table 2 provides greater detail regarding the purpose of each treatment and describes potential applications to the speech/swallowing musculature.

TABLE 1. Neuromuscular impairments, common assessment procedures, and treatment strategies.

Neuromuscular Impairment	Definition	Assessment Procedure	Treatment Strategies
Disrupted tone (hypertonicity, hypotonicity)	*Tone* refers to the muscle's resistance to passive stretching. *Hypotonicity* is characterized by reduced resistance of passive stretch. It is likened to "floppiness" in the limb system. *Hypertonicity* is characterized by increased resistance to passive stretch. Hypertonicity can be manifest at specific rates of stretch (e.g., spasticity results in increased resistance to fast stretch) or at specific muscle lengths.	Often assessed perceptually by judging the resistance of an articulator to passive stretch	Hypotonicity Active exercises Strength training Endurance training Power training Passive exercise Tapping[a] Quick stretch[a] Modalities Cold[a] Vibration[a] Electrical stimulation Hypertonicity Active exercises Slow stretch[a] Passive exercise Slow stretch & PROM[a] Deep massage Modalities Cold[a] Vibration[a]
Weakness	*Weakness* refers to a reduced ability to exert force.	Strength may be assessed perceptually by having the patient attempt to produce force against resistance provided by the examiner. Strength may be assessed instrumentally in a variety of ways, with the instrument usually recording the amount of force or pressure exerted by an articulator.	Active exercises Strength training Endurance training Power training Modalities Cold Heat Electrical stimulation

Note. PROM = Passive range of motion.

[a] These techniques may have limited effect on the lip and tongue musculature, where the typical pattern of muscle spindles and stretch reflexes are lacking.

Active Exercises

Active exercise is perhaps the most frequently used NMT in the field of speech-language pathology, with many treatment programs and commercially produced intervention materials capitalizing on active exercise strategies as methods for improving speech production and/or swallowing function (e.g., Boshart, 1998; Gangale, 2001; Mackie, 1996a, 1996b; Pehde, Geller, & Lechner, 1996; Strode & Chamberlain, 1997). The two main types of active exercises to be discussed are strength training and stretching.

Improving Strength and Endurance. Because weakness is one of the more easily identified motor impairments, and because developmental (e.g., cerebral palsy) and acquired (e.g., such as those following stroke or progressive neuromuscular disease) dysarthria and dysphagia are often accompanied by weakness (Chigara et al., 1994; Clark et al., 2003; Dworkin & Aronson, 1986; Dworkin et al., 1980; Dworkin & Hartman, 1979; Gentil et al., 1999; Langmore & Lehman, 1994; Logemann, 1998; Murdoch et al., 1995, 1998; Solomon et al., 1995; Solomon & Stierwalt, 1995; Stierwalt et al., 1995; Thompson et al., 1995), it is not surprising that strength training is a common therapeutic strategy. However, the potential benefit of classic oral motor exercise is influenced by a number of complex factors. In the following sections, several strength training principles that are well established in the exercise physiology literature (e.g., Frontera, Dawson, & Slovik, 1999; Savage, 1998) are reviewed along with potential application of the principles to training of the speech and swallowing musculature. To provide clinicians with a model for critically evaluating published or presented strength training programs, two such programs (Kuehn, 1991; Rosenfeld-Johnson, 1999) are reviewed, highlighting how they integrate the principles discussed.

Principles of Strength Training.

1. Goals. One of the primary goals of strength training is to increase the amount of tension or force a muscle can produce. The amount of force produced during single bursts or contractions is typically considered an index of strength. A second goal of strength training is to increase endurance, which is the amount of force that can be sustained over longer periods of time.[1] A third goal of strength training is to increase power, which is the speed at

[1]Endurance may be discussed in other terms, as well. For example, Robin, Goel, Somodi, and Luschei (1992) defined endurance as the length of time that an individual can sustain a given force.

TABLE 2 (p. 1 of 2). Treatment strategies, therapeutic mechanisms, and predicted applications to the speech and/or swallowing musculature.

Treatment	Neuromuscular Impairment or Function Targeted	Therapeutic Mechanism	Application to the Speech/Swallowing Musculature	Reported Investigations
Strength training	Weakness	Strength is increased as additional motor units are recruited and through muscle hypertrophy as the muscles are progressively overloaded during training.		
Strength	Ability to produce large forces in short bursts (Type II motor units)		High levels of force are not generally used during speech; however, high levels of strength may be necessary to produce fast movements, particularly in the tongue.	Bigenzahn, Fischman, & Mayrhofer-Krammel (1992) Dworkin & Hartman (1979) Gommerman & Hodge (1995) Harris & Murry (1984) Kuehn (1991) Kuehn & Wachtel (1994) Neumann (1993) Shaker et al. (1997) Solomon & Stierwalt (1995)
Endurance	Ability to produce small sustained or repeated forces (Type I motor units)		May be particularly relevant for swallowing and/or for patients who have to speak over extended periods	Lorell et al. (1993)
Power	Ability to produce force at high speeds		May be particularly relevant to address the high movement velocities required for speech	
Slow stretching and range of motion (active or passive)	Hypertonicity and resulting contractures	Slow stretching influences the behavior of muscle spindles, inhibiting the stretch reflex, therefore reducing muscle tone.	The lips and tongue are not likely to benefit.[a] Jaw-closing muscles may benefit.[b]	Dworkin (1978) Fujiu & Logemann (1996) Lazarus, Logemann, & Gibbons (1993)
Quick stretch	Hypotonicity	Quick stretch stimulates the muscle spindles to elicit the stretch reflex, resulting in increased muscle tone.	The lips and tongue are not likely to benefit.[a] Jaw-closing muscles may benefit.[b]	
Massage	Disrupted tone			
Effleurage	Hypertonicity	Superficial stroking results in both central and peripheral relaxation.	Potential for inducing relaxation in accessible musculature	Sullivan, Blumberger, Lachowicz, & Raymond (1997)
Tapotement (tapping)	Hypotonicity	Tapping on the belly of muscle stimulates the muscle spindle activating the stretch reflex, resulting in increased tone.	The lips and tongue are not likely to benefit.[a] Jaw-closing muscles may benefit.[b]	
Heat	Pain related to muscle spasm	Heat increases threshold for pain; thus, functional range of motion may be increased as muscle spasms resulting from pain are decreased.	Pain secondary to muscle spasm is not common in the speech and swallowing musculature, so application of heat to treat neuromuscular impairments may be limited.	
Cold	Hypertonicity	Cold temporarily reduces nerve conduction velocity, thus inhibiting the stretch reflex.	The lips and tongue are not likely to benefit.[a] Jaw-closing muscles may benefit.[b]	

TABLE 2 (p. 2 of 2). Treatment strategies, therapeutic mechanisms, and predicted applications to the speech and/or swallowing musculature.

Treatment	Neuromuscular Impairment or Function Targeted	Therapeutic Mechanism	Application to the Speech/Swallowing Musculature	Reported Investigations
Neuromuscular electrical stimulation (NMES)	Weakness and hypotonicity	Electrical currents elicit muscle contractions. When combined with overload and progression, NMES can result in increased strength related to muscle hypertrophy.	Several muscles of the face, palate, and throat are accessible for NMES. Because NMES stimulates motor units in a way dissimilar to volitional contraction, carryover to volitional movement outcomes may be limited. This technique might be best reserved for patients unable to produce volitional contractions.	Freed, Freed, Chatburn, & Christian (2001) Park, O'Neill, & Martin (1997)
Vibration	Hypertonicity, hypotonicity	Vibration stimulates the muscle spindle eliciting the stretch reflex of the agonist (increasing tone), and inhibiting the stretch reflex of the antagonist (decreasing tone).	The lips and tongue are not likely to benefit.[a] Jaw-closing muscles may benefit.[b] The application of vibration may damage the skin of the face, and is not recommended.	Grant (1982)

[a]The lips and tongue lack the typical pattern of muscle spindles and stretch reflexes, and thus are not likely to be influenced by treatments targeting muscle spindles.
[b]The jaw-closing muscles are rich with muscle spindles and display active stretch reflexes, and thus may be particularly amenable to treatments targeting muscle spindles.

which force is produced (Moffroid & Kusick, 1975). Strength, endurance, and power may all be targeted with a variety of strength training activities.

2. *Overload*. Increases in strength, endurance, and power result from two primary physiological changes: hypertrophy of muscle fibers and recruitment of additional motor units. Both of these physiological changes occur only in response to overload, or when a muscle is taxed beyond its typical workload in terms of force or time requirements (Trombly, 1983).

3. *Specificity of Training*. The effects of strength training, similar to the effects of other forms of training, are highly specific to the trained behavior (Jones, McCartney, & McComas, 1986; Schmidt & Lee, 1998; Schmidt & Wrisberg, 2000).

A discussion of how the principle of specificity applies to the various aspects of strength training may be best introduced by a review of motor unit concepts. The term "motor unit" refers to the motoneuron and the muscle fibers it innervates (Barlow, 1999). Every muscle fiber is innervated by a single motoneuron, although some motoneurons innervate many individual muscle fibers. Motor units are selected or "recruited" by the motor planning/programming system during specific movements. For any given movement, the specific motor units recruited—and hence, muscle fibers contracted—are determined by such factors as the direction, force, form, and duration of the movement, with the efficiency of recruitment improving with learning or practice (Barlow, 1999; Schmidt & Lee, 1998).

With respect to active exercises, two main groups of motor units are of interest: slow-twitch (Type I) and fast-twitch (Type II; Brooke & Kaiser, 1970). Type I units tend to be small, develop small tensions, and be resistant to fatigue. Type II units are further classified as fast fatiguable (FF) or fast resistant (FR; Barlow, 1999; Burke, Levine, & Zajac, 1971). FF motor units produce large tensions but are susceptible to fatigue. FR motor units have intermediate characteristics: They produce moderate tensions and are resistant to fatigue, so they will sustain the ability to produce force longer than FF motor units will. Generally, Type I units are recruited first, particularly for slow movements or those requiring small forces. As movements require increased speed or force, the larger Type II FR units are recruited, followed by Type II FF units. The recruitment of motor units is also based on several additional characteristics of the movement, contributing to specificity of training. These characteristics are summarized in Table 3 and described in detail below.[2]

Force. Exercises completed with low levels of resistance typically increase endurance, whereas high-resistance exercises increase strength (Kisner & Colby, 1996). When exercise is discontinued before reaching the point of fatigue, little transfer is observed between low- and high-resistance training. In contrast, exercises completed to the point of fatigue tend to recruit both Type I and Type II motor units, thus improving both strength and endurance (de Lateur, 1996).

Contraction Velocity. The speed at which a muscle can produce tension or force is referred to as power. Producing

[2]Only those contractile characteristics most applicable to the speech and swallowing musculature are discussed. Additional properties subject to specificity of training are discussed in Kisner and Colby (1996).

TABLE 3. Strength training parameters.

Parameters	Definitions and Options
Force/intensity	The resistance to movement or the amount of force required. Progressively increasing intensity increases strength. If intensity is maintained at maximum, the greatest changes will be observed in strength, but not endurance. At midrange intensities, strength training also improves endurance.
Speed/rate/velocity	The speed at which the movement is carried out. Contraction velocity is a training-specific parameter such that exercise speeds should closely match the speed of the desired movement outcome.
Duration	The amount of time the muscle contraction is held. Increasing the amount of time a muscle contraction is held or the number of times the contraction is completed may increase strength and/or endurance. At high intensities, strength will be improved. At low intensities, endurance will be improved. At moderate intensities, both strength and endurance will be improved.
Dynamics	The relationship between muscle length and tension. In isometric contractions, tension is increased while muscle length is held constant. In isotonic contractions, tension remains constant as muscle length shortens or lengthens.
Frequency	The number of training sessions scheduled per unit of time, influenced by the amount of time allowed for recovery between training sessions.
Progression	The systematic increasing of resistance, contraction velocity, and/or duration.

greater force while maintaining rate of contraction increases power, as does increasing contraction speed while force is held constant (Kisner & Colby, 1996). Because contraction velocity is a training-specific factor, the method of targeting power should be selected based on the speed of contraction required for the desired outcome behavior. Targeting contraction velocity in this way is particularly relevant for speech production. That is, speech is characterized by movements of low to moderate forces (relative to maximum forces measured during nonspeech tasks) and high velocities (Barlow & Burton, 1990). Thus, if increased power is the goal of strength training, those exercises that increase contraction velocity are likely to have the greatest carryover to speech movements.

Dynamics. Strength training exercises can be categorized as isotonic or isometric. Isotonic contractions are those in which the muscle changes in length while maintaining approximately the same tension. When performing a bicep curl, the muscles flexing the elbow are performing isotonic contraction. In contrast, isometric contractions are those where the muscle stays the same length but changes tension. During a bicep curl, the muscles gripping the hand weight are performing isometric contraction. Specificity of training applies to the dynamics of exercise, because strength gained for isometric contraction is not necessarily observed during isotonic contraction (de Lateur, Lehmann, & Fordyce, 1968).

The principles of goal selection, overload, and specificity of training are applicable to the treatment of weakness of the speech and swallowing musculature. Determining whether strength, endurance, power, or some combination of these will be targeted requires careful assessment, an issue that is addressed in detail in the Discussion section. Given that speech movements are characterized by low forces at high velocities, it may often be more appropriate to target power than to target strength. Endurance, particularly for maintaining low forces at high speeds over repeated movements, may also be a relevant target.

An additional factor related to target selection is that, unlike in the limb system, where it is relatively easy to isolate single muscle groups, the speech and swallowing musculature is characterized by considerable interaction, with muscle groups overlapping both in structure and in function (Barlow, 1999). Because of this, it may be necessary to identify functional muscle groups (e.g., lingual retractors, laryngeal elevators), as opposed to individual muscles, as exercise targets.

Finally, it is important to match the contraction characteristics of the exercise to the desired movement outcome. Force, speed, and duration of movement will be specified according to the target of strength, power, and/or endurance. Identifying contraction dynamics for speech and swallowing movements may prove challenging because of the complex interaction among muscle groups. For example, it is likely that while many of the lingual muscles are producing isotonic contractions during tongue-tip elevation, some stabilizing muscle groups may be performing isometric contraction. By matching the exercise as closely as possible to the desired movement outcome, specificity will be maximized—even when clear descriptions of the movement are lacking.

Two final training parameters are relevant to strength training: exercise frequency and exercise progression. When planning exercise frequency, adequate recovery time must be provided between exercise sessions. During recovery, glycogen and oxygen stores are replenished and waste products are removed from the muscle (Kisner & Colby, 1996). Unfortunately, no data are available regarding typical recovery time for the speech/swallowing musculature, or about how neuromuscular insult affects recovery time.

Exercise progression for the limb musculature has been described in a variety of ways. Periodically assessing strength and training at a specified percentage of this measured maximum (e.g., 50%, 75%, 100%) is one way to progress training (DeLorme, 1951). Another progression strategy is to increase the number of repetitions, particularly at high intensities. Increasing either the number of repetitions per set or the number of sets per session will improve both strength and endurance if completed to the point of fatigue. Progression may also be accomplished by increasing repetitions and intensity simultaneously (de Lateur, 1996).

A final way to progress in training is to increase speed of contraction. Beginning with relatively high resistance, a metronome can be used to regulate and systematically increase contraction speed (Hellebrandt & Houtz, 1958). This method may be particularly appropriate for strength training to improve speech production, because it targets movement velocity/power to a greater extent than do the other progression methods.

Evaluating Strength Training Programs. Reference to strength training is common in textbooks addressing dysarthria and dysphagia associated with neuromuscular dysfunction (e.g., Dworkin, 1991; Duffy, 1995; Logemann, 1998) and in therapy guidebooks (e.g., Gangale, 2001; Mackie, 1996a, 1996b; Marshalla, 2000; Pehde et al., 1996; Strode & Chamberlain, 1997). However, few publications detail the principles guiding the described techniques, and precise goals or progression schemes are not regularly included. Clinicians may nonetheless carefully examine the exercise descriptions to infer this information and then evaluate the technique within the framework of established strength training principles. Two treatment programs are analyzed here as examples.

The first exercise program, although typically prescribed for structural rather than neuromuscular impairment, was selected for review because it serves as an example of a "model" strength training program designed after the principles reviewed here (Liss, Kuehn, & Hinkle, 1994). The program, described in detail in Kuehn (1991), uses continuous positive airway pressure (CPAP) to provide resistance for strength training of the velopharyngeal musculature to address hypernasal speech. The CPAP apparatus includes a nasal mask that produces a controlled amount of air pressure. When the velum elevates to close off the velopharyngeal port during the production of oral phonemes, it must do so against this positive air pressure.

Kuehn's (1991) protocol capitalizes on specificity of training because the exercises are conducted during speech. Thus, by design, the exercise sessions precisely match the desired movement outcomes with respect to speed, duration, and dynamics. Additionally, intensity and frequency of exercise are systematically increased over the course of treatment (i.e., overload and progression). For example, Kuehn described a case study where the client began exercising for 10 min at a time against 3 cm water pressure, 3 weeks later was exercising for 26 min against 5 cm water pressure, and at the end of the 8-week treatment protocol was exercising for 24 min against 7 cm water pressure. This strength training program is one that possesses the theoretical soundness to suggest it *should* be beneficial for individuals with neuromuscular impairment along with a beginning literature to support that it *is* beneficial, at least for individuals with cleft palate (Kuehn, 1991; Kuehn et al., 2002; Kuehn & Wachtel, 1994).

The second treatment program reviewed here is that of Rosenfeld-Johnson (1999). In her therapy manual, Rosenfeld-Johnson described a strengthening program that uses drinking straws to target specific muscle contractions and articulatory postures. Rosenfeld-Johnson (1999) suggested that the program is particularly suited for promoting tongue retraction for articulatory productions of lingual consonants. The program achieves progression by varying straw and liquid characteristics. For example, the straws differ according to diameter, length, and resistance to gravity, although the liquid is varied along a continuum of viscosity. The program also progresses from small sips, to larger sips, and then to multiple sips.

Comparing the movement parameters of the exercise (straw drinking) to the desired movement (articulation of lingual consonants, specifically /r/) is complicated by the lack of a clear kinematic description of the lingual movements associated with straw drinking. Assuming that the direction of lingual movement during straw drinking roughly matches that of production of /r/, other contraction properties may then be considered. Forces produced during straw drinking are likely to be higher than those produced during speech, and the duration of movement is more sustained, particularly during prolonged sucks. Although articulation movements involve primarily isotonic contractions, the described exercises may involve both isometric and isotonic contractions, depending on the amount of resistance (e.g., trying to suck against a great deal of resistance could produce an isometric contraction, while repetitive sucking against low resistance would produce isotonic contractions). By modifying various exercise parameters, this program may target strength, endurance, and/or speed of contraction. However, because the exercise differs from the desired movement outcome in several ways, specificity of training is not maintained and less transfer from practice to the desired outcome would be expected than if the exercises were conducted using the same movement pattern or goal as the desired outcome (Schmidt & Lee, 1998).

The descriptions and analyses above are intended to serve as examples of how clinicians might approach the critical review of treatment programs purporting to address weakness of the speech and swallowing musculature. However, reviewing programs for theoretical soundness is only one way of evaluating the potential benefit of described techniques. Moreover, such evaluation should not take the place of studying the available literature examining outcomes of the treatment methods. A more thorough discussion of the empirical support for strength training and other NMT strategies is included in the Discussion section.

It is relevant to consider additional short-term and long-term effects of exercise on muscle physiology. An obvious but seldom mentioned effect of strength training is fatigue. After exercise sessions and until recovery has occurred, muscles cannot produce or sustain the forces observed before exercise. For most individuals, the weakness associated with exercise-induced fatigue is temporary, with strength being regained and increased with repeated overload. However, some disease processes, such as those associated with amyotrophic lateral sclerosis and multiple sclerosis, prevent or significantly impede the recovery process. Thus, for some patients, strength training serves to functionally decrease strength levels without realizing any long-term benefit of increased strength. For such individuals, conservation of energy is generally recommended over strength training (Yorkston, Miller, & Strand, 1995).

A second impact of strength training is increased muscle tone. For individuals with spasticity (as with spastic dysarthria) or rigidity (as with hypokinetic dysarthria) who exhibit baseline hypertonia, strengthening exercises further increase tone and may result in discomfort and reduced range of motion.[3] Thus, such exercises are usually contraindicated for these patients. Instead, stretching exercises and other NMTs designed to reduce tone are often recommended (Duffy, 1995).

Stretching

Moving a limb or articulator through its full range of comfortable movement is termed range of motion (ROM). This can be accomplished both actively (AROM) and passively (PROM). A related activity is stretching, which occurs when the articulator is moved beyond the range of typical or comfortable movement. Like ROM, stretching can be either passive or active.

Stretching can either decrease or increase tone, depending on the speed of the stretch. If muscle fibers are stretched quickly, a stretch reflex is elicited resulting in increased muscle tone. The clinical application of this technique is discussed in the Passive Exercises section. Slow stretching, in contrast, causes an inhibition of the stretch reflex and serves to decrease tone. When muscle tone is reduced, both PROM and AROM may be increased. AROM exercises and stretching may also be an effective means of preventing tissue adhesions (e.g., restrictive scar tissue) and contractures related to hypertonicity (Kisner & Colby, 1996).

The lips and tongue are most often targeted when stretching, and AROM exercises have been described as speech treatments (Duffy, 1995; Dworkin, 1991). However, because these muscle groups lack the typical pattern of stretch reflexes, using slow stretch to inhibit the stretch reflex in these articulators seems neither necessary nor appropriate. The jaw-closing muscles, which have a dense distribution of muscle spindles and clearly observable stretch reflexes, may be more responsive to AROM and stretching techniques, although no studies were identified addressing this issue.

In reviewing the reported application of stretching and AROM exercises in the speech and swallowing musculature, one finds that these techniques have been used less widely to inhibit stretch reflexes (i.e., to reduce tone) than as a variation of strength training (i.e., to increase tone). A relatively well-documented example is that of the "Mendelsohn maneuver" (e.g., Lazarus, Logemann, & Gibbons, 1993), which is intended to improve laryngeal elevation during swallowing. This technique, which is performed during a swallow, requires the patient to maintain the larynx in an elevated position for a period of several seconds. The exercise has characteristics both of stretching, since the target is one of range rather than force, and of strength training, since the laryngeal posture must be sustained against the resistance of gravity. This particular technique, although using a stretching motion, meets many of the criteria for a theoretically sound strength training program, including specificity of training and overload.

Other, although less systematic, examples of using stretching and AROM activities for the purpose of improving strength are the myriad of classic oral motor exercises described in various treatment guidebooks (e.g., Gangale, 2001). Protruding the tongue as far as possible outside the mouth and pursing and retracting the lips (e.g., "ooh" and "eeee") over several repetitions are two examples. Theoretical support for using these generic techniques to either reduce tone or increase strength for the purpose of improved speech and/or swallowing activity cannot be drawn from the strength training or stretching principles reviewed here.

Passive Exercises

By definition, passive exercises are those for which the patient is provided total or nearly total assistance. The two groups of passive exercises to be reviewed here are PROM or stretch and massage.

PROM and Slow Stretch. PROM and passive stretch are similar to AROM and active stretch, with the modification that the articulator is moved by the clinician instead of by the patient. PROM and passive stretch are widely applied in the treatment of the limb systems (Katz, 1996; Pedretti & Early, 2001; Trombly, 1983), with the goals of maintaining the integrity of joints and soft tissues, preventing contractures, maintaining muscular elasticity, improving circulation, and providing sensory input (Kisner & Colby, 1996). PROM does not increase muscle strength and endurance, nor does it prevent muscle atrophy (Kisner & Colby, 1996). When extended to include slow passive stretch, PROM may reduce hypertonicity by inhibiting the stretch reflex. The principles for the application of PROM and passive slow stretch are the same as those described for their active counterparts, with the added caution of being mindful of pain or discomfort because the patient is not in control of the speed or range of movement (Kisner & Colby, 1996; Parry, 1980; Trombly, 1983).

Although passive exercises to treat hypertonicity of the tongue and lips have been described (e.g., Dworkin, 1991; Gangale, 2001), the benefits of these techniques for improved speech or swallowing have not been reported. Further, from a theoretical standpoint, given the lack of typical stretch reflexes in the lips and tongue, it is unlikely that passive stretching would affect the tone of these muscle groups. Additionally, unlike for active stretch and AROM, there are no applications of passive exercises that serve to increase strength.

[3]Carr and Shepherd (1998) argued that strengthening exercises conducted during functional movements may actually *reduce* spasticity by improving neural control. No studies were identified that examined the effect of strength training on tone of the speech and swallowing musculature.

Because active and passive versions of ROM and stretching exercises have similar applications, it is relevant to consider under which conditions each technique should be applied. For the limb musculature, passive exercises are often used when the patient is unable to perform active exercise, as in the case of severe spasticity or weakness, reduced levels of alertness, or impaired ability to follow commands. The implication is that active ROM and stretching are preferred over their passive counterparts if the patient is able to perform the exercises, a principle which is consistent with current models of motor learning (e.g., Schmidt & Lee, 1998).

Passive Quick Stretch. When muscle fibers are quickly lengthened, stimulation of the muscle spindles triggers the stretch reflex, which causes the stretched muscle to contract, thereby increasing muscle tone. When used therapeutically to address hypotonia, quick stretch is generally applied passively (i.e., by the therapist) because weakness often prevents the patient from moving quickly enough to elicit the stretch reflex.

Because the quick stretch is intended to elicit the stretch reflex, it will be effective only for those muscle groups containing muscle spindles and exhibiting stretch reflexes. Thus, although some treatment programs (e.g., Beckman, 1988) use passive quick stretching for the purposes of improving tone of the lips and tongue, there is neither empirical nor theoretical support for this practice. Quick stretch might be expected to increase tone of the jaw-closing musculature, for example, in the case of flaccid dysarthria affecting the trigeminal nerve, but no data exist regarding the benefit of this application for improved speech or swallowing.

Massage. Another passive treatment recommended for improving underlying muscle function is massage. Massage, or the systematic stroking and/or application of pressure, has several general effects on neuromuscular function. Mechanical influences of massage include improving circulation of blood and lymph, increasing oxygenation of tissues, and facilitating waste removal. Additionally, massage reduces or eliminates tissue adhesions as well as loosens and stretches contracted tendons. Massage also affects neuromuscular function by facilitating relaxation both psychologically/emotionally and by reducing muscular tension (Wakim, 1980). Massage may relieve pain and hypomobility associated with muscle spasm and hypertonicity, but it does *not* increase strength or prevent atrophy and hypotonia (Atchison, Stoll, & Gilliar, 1996).

The two types of massage that have been used to treat neuromuscular impairments in the limb system are effleurage (stroking) and tapotement (tapping and vibration; Cyriax, 1980). Superficial effleurage has been used to help reduce spasticity by facilitating both central and peripheral relaxation (e.g., Atchison et al., 1996). With respect to the speech musculature, stroking of the lip, jaw, and superficial throat musculature could be administered externally, whereas the tongue and velum are accessible through the mouth. Effleurage should be used with care in the presence of oral defensiveness or a hypersensitive gag reflex, as well as to avoid potential discomfort that may result if too much pressure were applied, particularly in the laryngeal area. Used appropriately, effleurage would be expected to have the same relaxing effect on the speech and swallowing musculature that has been observed in the limbs. At least one study has reported that massage facilitated short-term reduction of laryngeal muscle tension and improved vocal quality (Sullivan, Blumberger, Lachowicz, & Raymond, 1997), but other descriptions of massage to reduce hypertonicity associated with spastic dysarthria (e.g., Dworkin, 1991; Gangale, 2001) have no empirical support.

Two forms of tapotement have been described for the treatment of neuromuscular impairments. The first type, vibration, is also considered a physical modality, and is discussed in detail in the Vibration section. The second type is tapping. Tapping with the fingertips over the belly of the muscle immediately before or during contraction is thought to stimulate the muscle spindle, thereby increasing the tone of the targeted muscle (McCormack, 1996). As with the other techniques that act on the muscle spindle and stretch reflex, the theoretical application of this technique to the speech and swallowing musculature is limited to the jaw-closing muscles. Interestingly, the lip musculature does exhibit reflexive response to tapping; however, it is unclear how these reflexes contribute to normalization of tone either during stimulation or over time (Barlow, 1999).

Physical Modalities

Physical agents or “modalities” include heat, cold, vibration, electricity, sound, and electromagnetic waves such as light and microwaves. Physical agents are applied to “induce a therapeutic response in tissue” (Weber & Brown, 1996, p. 449). The various modalities have different effects on tissue and are thus prescribed for different underlying impairments. Many of the modalities discussed here are used more frequently for impairments unrelated or indirectly related to the motor system per se (e.g., application of heat to relieve pain), but this discussion is limited primarily to the application of modalities to the treatment of neuromuscular impairments.

Heat. Heat, as a physical agent, may be used to reduce muscle spasm and to improve ROM (Michlovitz, 1986a; Weber & Brown, 1996). Because heat elevates thresholds for pain, individuals may be able to stretch farther without pain, improving ROM. This reduced sensitivity to pain may also inhibit muscle spasms triggered by the pain associated with muscle overuse or joint inflammation. Because heat may improve blood flow, muscle strength may also be increased (Edwards et al., 1972). Both superficial and deep tissues may be affected by heat. Superficial tissues are typically heated using hot packs, heating pads, or paraffin baths (Weber & Brown, 1996). Other techniques such as ultrasound or microwave technologies are needed to deliver heat to deep tissues.

Application of heat to treat neuromuscular impairments in the speech and swallowing musculature is not widely described, perhaps because pain related to muscle spasm in this musculature is relatively uncommon. Muscle spasms are observed in some forms of hyperkinetic dysarthria, but it is typically the involuntary movement rather than pain that interferes with normal speech and swallowing movements. If pain related to muscle spasm were shown to contribute to dysarthria and/or dysphagia, heat might be an appropriate therapeutic modality; however, little information is available regarding the therapeutic range for both temperature and duration of heat application in this musculature. Interested clinicians are referred to studies reporting the use of heat to reduce pain associated with temporomandibular joint dysfunction (e.g., Nelson & Ash, 1988; Weinberg, 1980) as a starting point for determining appropriate procedures if this treatment modality is warranted.

Cold. Cryotherapy, or the therapeutic use of cold, has many applications to the treatment of the neuromuscular system (Michlovitz, 1986b; Weber & Brown, 1996). Specifically, cold has been found to be effective in temporarily reducing spasticity by reducing nerve conduction velocities (Hedenberg, 1970; Miglietta, 1973). "Quick icing" may also increase tone by eliciting withdrawal reflexes (McCormack, 1996). Finally, because cryotherapy may increase blood flow, improvements in isometric strength may also be observed (McGown, 1967). Some authors recommend that cold be applied before PROM or passive stretch, to relieve pain and to reduce spasticity (Parry, 1980), as well as after stretching to maintain the therapeutic effects (Kisner & Colby, 1996).

Levine, Kabat, Knott, and Boss (1954) recommended that cold be applied to hypertonic muscles to relieve spasticity. During the period when spasticity is reduced, strengthening exercises can be carried out. This process contrasts with the methods typically prescribed to address spasticity in the speech system, in which strengthening exercises are discouraged (e.g., Duffy, 1995). No studies were identified that examined the effectiveness of applying cryotherapy in isolation or of combining cryotherapy and strength training for individuals exhibiting weakness and hypertonia (e.g., as in spastic dysarthria). As was true for the application of heat, the therapeutic range of temperature, duration, and location of application of cold is unknown for the speech and swallowing musculature.

It is worthy of note that cryotherapy has been used by speech-language pathologists for the purposes of increasing thermotactile sensitivity, specifically to improve the promptness of the pharyngeal phase of swallow. The potential impact of cryotherapy on sensory afferents is beyond the scope of this discussion, but readers are referred to Sciortino, Liss, Case, Gerritsen, and Katz (2003) for a review of this topic.

Electrical Stimulation. Neuromuscular electrical stimulation (NMES), applied to treatment of the motor system, refers to the application of low voltage electrical currents to muscle tissue, causing contraction of muscle fibers. The observed neuromuscular response is influenced by the characteristics of the electrical current used. For example, high frequency stimulation produces the most forceful contractions, but can quickly induce fatigue, whereas lower frequency stimulation produces lower forces but significantly reduces fatigue effects (Mysiw & Jackson, 1996).

In normal healthy adults, NMES does not induce greater gains in physical strength than does volitional exercise (Currier & Mann, 1983). Moreover, the pattern of motor unit recruitment in NMES differs from volitional exercise. During volitional contractions, the smaller, Type I fibers are typically activated first, followed by Type II as additional force is required. During NMES, a greater proportion of the larger, Type II fibers is recruited. Thus, although strength may be gained during NMES, the carryover to functional activities may not be as great as that of active exercises that match the motor unit recruitment pattern of the target outcome movement. Finally, similar to active exercise, NMES induces fatigue and is contraindicated for individuals with neuromuscular conditions negatively affected by fatigue (e.g., myasthenia gravis).

NMES has a variety of applications to the treatment of neuromuscular impairments, including maintaining muscle tone and mass during joint immobilization, preserving function in neuromuscular disease, and stimulating muscle denervated due to cerebrovascular accident or spinal cord injury. In all cases, the best results have been obtained when NMES is paired with resistance training and/or functional activities (Mysiw & Jackson, 1996).

Applications of NMES to the speech/swallowing mechanism have been few, and limited information is available regarding the stimulation parameters appropriate for evoking either high or low force contractions in the various oral, pharyngeal, and laryngeal muscle groups. Perhaps even more relevant for speech targets are the stimulation parameters necessary to evoke high speed contractions. Without reference data describing therapeutic ranges for these variables, it is difficult to determine if described NMES programs should be beneficial for improving strength of the speech and/or swallowing musculature. However, even if or when these parameters are identified for the various muscle groups, given the differences in order of muscle unit recruitment observed in volitional versus electrically stimulated contractions, active exercise would still be predicted to have a greater impact on the desired movement outcome. If this supposition proved true, it is likely that NMES would be reserved for individuals unable to participate in an active exercise program.

Application of NMES to the velar musculature has inconsistent effects (Park, O'Neill, & Martin, 1997; Peterson, 1974). Freed, Freed, Chatburn, and Christian (2001) reported high rates of success in using NMES of the neck muscles to improve swallowing function, but this research has been criticized on several fronts (e.g., Mills et al., 2002). The benefit of NMES of the facial musculature (Stefanakos, 1993) for improved speech and/or swallowing has not been systematically examined. Considering currently available data, there is limited empirical evidence of the benefit of NMES for improved speech or swallowing.

Vibration. Vibration is a modality that targets both the sensory and motor systems. The applications of vibration vary according to a variety of potential parameters. Relevant to the present discussion is the use of high frequency vibration (100–300 Hz) to evoke a tonic vibratory response (TVR; Farber, 1982). The TVR is a reflex resulting from the stimulation of the muscle spindle leading to a contraction of the muscle stimulated. Depression of the antagonist is also accomplished via reciprocal inhibition. Thus, vibration may be used to increase tone or force of contraction of the agonist or decrease tone of the antagonist (Bishop, 1974, 1975).

The limitations of treatments that act on the muscle spindle apply to vibration. In a study examining the neuromuscular response to vibration, Folkins and Larson (1978) reported the TVR is absent in the lip musculature. In contrast, TVRs have been observed in the jaw-closing and jaw-opening muscles (Hagbarth, Hellsing, & Lofstedt, 1976; Hellsing, 1977). However, several precautions apply to the use of vibration in the jaw and other facial muscles. First, the therapeutic effects of vibration are dependent on selective stimulation of isolated muscles. Given the overlap of muscle fibers in the facial region, isolating muscle groups to stimulate only those fibers targeted for facilitation or inhibition would be very difficult. Furthermore, vibration of the facial skin, particularly in older individuals, is not recommended due to the risk of damage to the skin (Farber, 1982; McCormack, 1996). A final precaution should be noted that vibration is contraindicated for individuals with extrapyramidal or cerebellar lesions—as might be observed in spastic, hypokinetic, hyperkinetic, and ataxic dysarthria—because vibration may exacerbate tremors and irregular muscle tone (McCormack, 1996). The number, variety, and gravity of the precautions surrounding the use of vibration in the oral regions suggest that clinicians should carefully consider other treatment alternatives before using vibration to address underlying disruptions of tone contributing to dysarthria and dysphagia.

Discussion

The goal of this article was to help clinicians critically evaluate the theoretical soundness of treatment programs purporting to address underlying impairments of the neuromuscular system affecting speech and swallowing activity. A review of oral motor treatments, however, would be incomplete without a discussion of the controversy surrounding the use of these techniques. The next sections review the primary issues that fuel the continuing debate regarding whether NMT is appropriate in the management of dysarthria and dysphagia.

The first issue relates to a general philosophy regarding the approach to speech and/or swallowing limitations resulting from neuromuscular impairment. Specifically, one view holds that assessment and treatment of task performance (i.e., speech and/or swallowing) is best accomplished at the task level (e.g., Weismer, 2000). Stated simply, if speech or swallowing activity is the behavior of interest, assess and treat speech or swallowing. An alternate view holds that if underlying impairments in neuromuscular function are contributing to dysarthria or dysphagia, then appropriate identification and remediation of the underlying impairments should improve speech and swallowing function. Fueling this aspect of the debate is the fact that the relationships between neuromuscular impairments and the resulting/accompanying limitations in speech and swallowing performance are not perfectly predictable. Most of the study in this area has involved examining correlations among measures of strength and measures of speech performance (e.g., Dworkin et al., 1980), with fewer studies including other physiological measures such as fine force and position control (e.g., Barlow & Abbs, 1986) or speed of contraction (e.g., Langmore & Lehman, 1994). In general, although differences in mean measures of strength, control, and speed are typically observed between normal speakers and those with neuromuscular impairments (i.e., dysarthria), few studies have reported strong correlations between neuromuscular impairment and speech performance. Additionally, several aspects of neuromuscular function remain virtually unstudied in relation to speech and swallowing performance. Specifically, no studies have included explicit measures of power, although the measures of speed reported in some studies (e.g., Langmore & Lehman, 1994) are similar to power measures. Few studies have included measures of endurance (although see Solomon et al., 1995; Solomon, Robin, & Luschei, 2000, for exceptions). Furthermore, no studies were identified that included dependent or independent measures of muscle tone, although some authors have included tone as a component of the participant descriptions (e.g., Dworkin & Hartman, 1979). Without clearer data describing the relationships between neuromuscular impairments and speech/swallowing performance, it is difficult to identify for whom NMT is warranted.

Contributing most significantly to this aspect of the debate is the assessment and treatment of strength. A key issue is that the relevance of strength differences may be questioned, as it is well documented that individuals use only a small proportion of their potential muscular force during speech (see Kuehn & Moon, 2000, for review). For example, a patient whose tongue strength is reduced to 60% of normal maximum may still be able to produce the forces (e.g., 20% of normal maximum) necessary for speech production (Muller, Milenkovic, & MacLeod, 1985). Luschei (1991) argued that this conceptualization is incomplete, particularly for an articulator like the tongue. Specifically, he contended that the tongue, as a muscular hydrostat, requires considerable muscular strength to move *quickly* (e.g., Dworkin et al., 1980), even if contact forces are not great. In other words, while high forces may not be observed during lingual speech movements, significant power may be necessary to produce the forces at an adequate speed. Thus, strength training for a patient such as this may focus on improving power as opposed to force, with the ultimate goal of improved speed of articulator movement, which would result in articulatory accuracy and intelligibility.

A second factor confounding the relationship between strength and speech/swallowing performance is fatigue. Most studies have measured strength during single maximum contractions by targeting Type II motor units (e.g., Dworkin et al., 1980; Langmore & Lehman, 1994), with fewer studies including measures of endurance or sustained contractions of submaximal force by targeting Type I motor units (e.g., Kuehn & Moon, 2000; Solomon et al., 2000). It may be that the ability to produce adequate force (e.g., 20% of normal maximum) over multiple repetitions is more predictive of speech and swallowing performance in some individuals, although the limited data available have failed to reveal a consistent relationship between endurance and performance in speakers with dysarthria or oral phase dysphagia (e.g., Solomon et al., 1995, 2000; Stierwalt & Clark, 2002).

A final issue relevant to the discussion of the relationship between strength and performance is the potentially different physiological requirements for speech and swallowing. There is evidence that chewing and swallowing require forces greater than those required for speech (Pouderoux & Kahrilas, 1995). Thus, it is possible that reduced strength and/or endurance will have a greater impact on swallowing ability than on speech production.

Taken together, the available data have failed to demonstrate a clear relationship between strength or endurance and speech/swallowing performance, although some researchers (e.g., Luschei, 1991) have contended that potentially important associations may be more complex than those revealed by past studies. Moreover, given the near absence of information regarding the impact of other neuromuscular impairments (e.g., disrupted tone) on speech and swallowing activity, clinicians have limited information available to help determine either (a) which physiological impairments contribute most significantly to limitations in speech and swallowing function, or (b) the severity of impairment necessary to warrant NMT. This significant gap in the knowledge base leads to wariness regarding the use of NMT to address neuromuscular deficits accompanying dysarthria and dysphagia.

A second and related philosophical issue surrounding NMT is the implicit espousal of reductionism. Weismer and Liss (1991) stated that reductionism "implies that all observations at one level of analysis can be reduced to, or predicted from, observations at a different level" (p. 20). As these authors further pointed out, a key result of reductionism in the study of dysarthric speech has been a tendency to examine the behavior (e.g., strength, velocity, range of motion) of a single articulator, even though no articulator behaves in isolation during speech or swallowing. Extended to the issue of NMT, most oral motor treatments address the behavior of individual muscle groups. Isolating muscle groups for strength training may appear to be justified, because it is commonly accepted that individual muscle groups can be differentially affected by neuromuscular impairments (e.g., the jaw muscles in the case of flaccid dysarthria involving the trigeminal nerve). Furthermore, isolating muscle groups in strength training is common practice in sports and fitness training. However, this line of reasoning fails to incorporate the critical principle of specificity of training that applies to active exercise. Moving an articulator (with appropriate force, speed, or range) in isolation is clearly a different task than that required for speech or swallowing activity. Specificity of training predicts that exercises incorporating the desired movement outcome (e.g., speech or swallowing), including the movements of all related articulators, will result in greater functional gain than those targeting isolated movements of a single articulator. The challenge for clinicians wishing to target the performance of individual articulators is to identify and/or develop exercises that overload the impaired muscle groups during functional movements.

In addition to these philosophical issues, several practical concerns have been expressed with regard to NMT. The most frequently mentioned of these concerns is the limited empirical support for the use of NMT in the treatment of dysarthria or neuromuscular dysphagia (e.g., Hodge, 2002).

By far the most widely studied NMT is strength training, although even this strategy has been surprisingly understudied given the apparent popularity of its application (see Table 2). The studies identified in the current review generally reported that strength training was of benefit to some patients with dysarthria and/or dysphagia, particularly when combined with functional level interventions. However, this general conclusion is problematic, primarily because of the design limitations of the reported studies. Many studies (e.g., Bigenzahn, Fischman, & Mayrhofer-Krammel, 1992) included no control condition examining the effects of no treatment or of a different treatment. Other studies have reported on single participants or very low numbers of participants (e.g., Harris & Murry, 1984) and many studies have combined strength training with traditional therapies (e.g., Solomon & Stierwalt, 1995), so the isolated effects of strength training are unknown. Clearly, the current state of literature is inadequate for establishing that strength training is of benefit for improving speech and/or swallowing function in individuals with neuromuscular impairments.

There is a paucity of literature examining the benefit of other NMTs. At least one study describing positive effects on speech and/or swallowing performance was identified for each of the techniques of active stretching, vibration, massage, and NMES. However, each of these studies exhibits design limitations similar to those described above for strength training. Thus, it is impossible to conclude from the available literature that these treatments are appropriate for treating dysarthria and dysphagia accompanying neuromuscular impairments.

Several factors have likely contributed to the current state of empirical support for the use of NMT. The first is the same concern that prompted this article, namely that many of the popular treatment programs do not appear to be based on sound theoretical principles. Most fail to address specificity of training (e.g., Rosenfeld-Johnson, 1999), many do not incorporate plans for progressive overload (e.g., Stefanakos, 1993), and others fail to identify the underlying neuromuscular impairment the treatment is intended to address (e.g., Beckman, 1988). It is not surprising that treatments lacking appropriate theoretical foundation have failed to inspire controlled study.

It is likely that the philosophical issues identified at the beginning of this discussion have also contributed to the limited amount of study that has been conducted in this area. Researchers may feel that time and effort is better spent directly examining speech and swallowing performance. Nonetheless, even those researchers who have devoted time to examining the relationships between neuromuscular impairments, speech, and/or swallowing activity generally have not explored the benefits of NMT.

Another practical issue potentially limiting the effective application of NMT is accurate diagnosis of neuromuscular impairments. Each of the oral motor therapies described in this review is intended to act on specific underlying neuromuscular deficits. Unless such impairments are accurately diagnosed, appropriate NMT cannot be selected. Unfortunately, clinicians may feel as ill equipped to identify neuromuscular impairments as they do for selecting appropriate management strategies. The oral mechanism examination is perhaps the most familiar clinical tool that has the potential to identify neuromuscular impairments. Commonly included in the oral mechanism exam are perceptual judgments of strength and range of motion, particularly of the more peripheral articulators. Unfortunately, the validity and reliability of these subjective ratings are not known, nor have adequate normative data been described to help clinicians distinguish normal from abnormal performance. To address the potential limitations of subjective judgments, several objective measures of strength (e.g., the Iowa Oral Performance Instrument [IOPI]) and range of motion (e.g., labial goniometer) have been developed. However, objective measures also vary in the availability of normative data. Some tools, such as the IOPI, have been well studied in normal speakers as well as in those with dysphagia and/or dysarthria (e.g., Robbins, Levine, Wood, Roecker, & Luschei, 1995; Robin, Goel, Somodi, & Luschei, 1992; Robin, Somodi, & Luschei, 1991; Stierwalt & Clark, 2002), whereas others have no identified published norms (e.g., labial goniometer). These tools also differ in clinical practicality. A labial goniometer can be purchased for less than five dollars and fits in a shirt pocket, whereas a strain gauge system for measuring range or motion or speed of movements may cost thousands of dollars and require a laboratory of analysis equipment. Both portable and stationary tools for measuring strength are available, but the cost of these tools is often prohibitive for clinical practice. It isn't surprising, given these practical limitations, that objective measures have not yet replaced the more commonly used, but potentially less reliable, subjective measures of strength and range of motion.

Muscle tone is an aspect of neuromuscular function that has been largely ignored in standard oral mechanism exams. With the exception of noting facial droop, an indicator of hypotonia and weakness, specific methods for identifying abnormal tone are generally lacking in descriptions of the clinical examinations (e.g., Duffy, 1995). Even tools that do include specific tasks for assessing tone (e.g., Dworkin & Culatta, 1996) rely on subjective ratings with no normative data describing the level of resistance characteristic of normal tone in the speech and swallowing musculature. It is difficult to imagine how clinicians would be expected to effectively address underlying disruptions in muscle tone when it is unclear how such deficits should be identified.

A final issue related to diagnosis is patient selection. Patients who are susceptible to fatigue and/or who have impaired recovery mechanisms (e.g., as in myasthenia gravis or critical medical conditions) should not be subjected to strength training that may exacerbate effects of fatigue without any long term benefit of increased strength. Unless clinicians appropriately select treatments based on the neuromuscular impairments and disease processes displayed by their patients, the potential benefit of NMT is extremely limited.

A third practical concern contributing to the controversy surrounding the use of NMT is that some applications would not be considered skilled treatment and thus do not qualify for reimbursement by most third-party payers. Only when ongoing feedback and/or modification of the task by clinician are required can these techniques qualify for reimbursement (American Speech-Language-Hearing Association, 2001). A related concern is that such treatments may be inappropriately used to the exclusion of treatments directly targeting speech or swallowing activity. This concern has been discussed with respect to both assessment and treatment. As Weismer (2000) pointed out, it is inappropriate to limit assessment observations to the neuromuscular level, because these observations do not describe or even predict speech and/or swallowing performance. Similarly, whereas it remains to be seen whether NMT is of benefit for improving dysarthria and/or dysphagia accompanied by neuromuscular impairments, it is almost certain that such techniques will complement, not replace, treatments directly targeting speech and/or swallowing behaviors.

Conclusions

The information in this article is intended to clarify the physiological foundations of NMT as well as review the issues contributing to the debate surrounding the use of these techniques. It is clear that the empirical support necessary for the inclusion of NMT in evidenced-based practice is lacking. However, provided with adequate information, clinicians may be better able to evaluate the theoretical foundations of described therapies as well as develop new treatments based on neurophysiologic principles. Ideally, clinicians and researchers alike will test the predictions derived from the principles reviewed here, reporting their findings and adding to the very limited literature base addressing the benefit of these treatments. Evidence-based review of specific applications of NMT has begun (Strand & Sullivan, 2001). As research accumulates, these reviews will help establish for whom NMT is most appropriate as well as under what conditions (e.g., time postonset, presence of concomitant deficits). Additionally, it is hoped that educators will consider including information about the physiologic mechanisms of NMT in clinical training so that future clinicians will be better prepared to critically evaluate therapeutic innovations addressing neuromuscular impairments.

Acknowledgments

This tutorial has benefited from the contributions of several individuals. Nancy Pearl Solomon provided clarification of issues related to the physiology of the speech and swallowing systems. I am indebted to Travis Threats, Brenda Kennell, Joe Duffy, and Gary Weismer for their invaluable suggestions for strengthening earlier versions of the manuscript. I also wish to thank Kristie Cothren, who accessed many of the documents cited in this tutorial.

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Received September 11, 2002
Accepted April 4, 2003
DOI: 10.1044/1058-0360(2003/086)

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