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What Is Orofacial Fatigue and How Does It Affect Function for Swallowing and Speech?

Nancy Pearl Solomon, Ph.D., CCC-SLP¹

¹Research Speech-Language Pathologist, Army Audiology and Speech Center, Walter Reed Army Medical Center, Washington, DC.

Abstract

Speech-language pathologists are likely to encounter patients who report symptoms of fatigue, but there are few clinical procedures to assess this phenomenon. Furthermore, it is difficult to determine whether fatigue contributes to a patient's dysphagia or dysarthria. This article reviews orofacial muscles, including the muscles of the tongue, lips, and cheeks, highlighting in particular their role in swallowing and speaking. It provides definitions of fatigue and describes assessment procedures. The author's research has focused on assessing fatigue, especially of the tongue, and elucidating the effects of exercising the tongue on speech and nonspeech tasks. Most of this work involves people who have Parkinson's disease and neurologically normal adults; results generally support heightened fatigue in Parkinson's disease. However, the effect of fatigue on functional activities remains unclear. Literature regarding the effects of orofacial fatigue on swallowing and speaking is notably sparse, but preliminary evidence indicates that these functions are rather robust.

Keywords

Fatigue; endurance; effort; tongue; facial muscles

Specialists in swallowing and speech disorders are well versed in the anatomy and physiology of the structures of the head and neck. This tutorial focuses on the orofacial muscles of the tongue, lips, and cheeks. Although speech-language pathologists (SLPs) know the locations and innervations of the muscles associated with these structures, they are often less aware of the specific physiologic properties of the muscles in terms of fatigability. The goal of this article is to present current data regarding orofacial muscle fiber types, exercise protocols used to induce fatigue, and the potential effects of fatigue on functional abilities.

This article begins with a brief overview of the muscles involved in orofacial motor function for swallowing and speech purposes. It then turns to basic definitions of fatigue and how it can be measured in speech-language pathology. Most of this work has been performed with the tongue as the primary muscle of interest. Findings from these studies, as presented here, reveal the endurance capabilities and functional robustness of the orofacial system.

OVERVIEW OF OROFACIAL ANATOMY

The anatomical structures of interest are selected from those of the lower face and the mouth. These structures include the lips, cheeks, and tongue. Clearly, the velopharynx and

oropharynx are relevant to swallowing and speech as well, but this review is restricted to the anterior oral cavity and lower face. The importance of these structures for the oral stages of swallowing and the articulation of speech will be highlighted.

Facial Muscles

The lips comprise circumferential muscles—the orbicularis oris superior and orbicularis oris inferior—which compose the upper lip and lower lip, respectively. These muscles are sometimes referred to as the perioral musculature. When contracted together, they act in a sphincteric fashion to round the mouth opening and protrude the lips. Lower lip elevation contributes to mouth closure by action of the mentalis muscle as well. Other muscles that insert around the mouth generally act to widen the oral aperture by pulling the lips upward, downward, and sideways. One of these muscles is the risorius, a thin, superficial muscle that traverses laterally across the cheek and inserts at the oral angle. A deeper, wider muscle that forms the bulk of the cheek is the buccinator. Both of these facial muscles insert anteriorly into the lips near the oral angle. The risorius is considered a muscle of facial expression because it retracts the oral angles. It also can act synergistically with the buccinator. The buccinator also can retract the lips, but its main function is to increase tension and bulk in the cheeks themselves. This muscle is often mentioned in books and courses on swallowing because it creates the necessary pressure to prevent residue from settling in the buccal cavities (also called the lateral oral sulci). In concert with the tongue, the buccinators aid in clearing the buccal cavities.

Mouth closure is important for swallowing so that the bolus stays contained in the mouth during mastication, bolus formation, and bolus propulsion during the oral phases of swallowing. For speech, labial approximation occurs for the bilabial consonants /p, b, and m/; lower lip elevation and retraction occurs during production of the labiodental phonemes /f and v/; and protrusion and rounding occur for certain phonemes, such as /u, o, r, ʃ, ʊɪ, and aɪ/. Facial expression also contributes to communication in important ways. The lips and lower face provide cues regarding the emotional or pragmatic intent of the message while simultaneously forming the sounds of the message itself. Finally, the lips are instrumental in expressing emotion and affection. All of these facilities can be affected in persons with impaired facial function.

Lingual Muscles

The tongue is arguably the most important oral structure for swallowing and the most important speech articulator. It is composed of a complicated arrangement of extrinsic and intrinsic muscles. Each extrinsic muscle has at least one external attachment that affixes to cartilage or bone. These include the genioglossus, hyoglossus, styloglossus, and palatoglossus muscles, which help to move, position, and shape the tongue. The fibers of the intrinsic tongue muscles terminate within the tongue itself. The muscles are named according to the direction and general location of their fibers as follows: superior longitudinal, inferior longitudinal, transverse, and vertical muscles. Although these muscles are formed of muscle fibers, they do not occur in definable muscle bellies as seen in other skeletal muscles. Slaughter et al¹ recently published exquisite data illustrating that fibers of the superior longitudinalis muscle are arranged in small bundles containing several fascicles that differ in length, creating an in-series design. Fibers of other muscles overlap and interdigitate with various intrinsic tongue muscles, making for complicated and intricate anatomy. Muscle fibers may have more than one motor endplate, indicating multiple innervations of single fibers.¹ The intrinsic muscles of the tongue help to shape and make fine adjustments of the tongue. Furthermore, they are important for changing the internal tension characteristics of the tongue body.

The sounds of speech traditionally are categorized by the general position of the tongue as it shapes the upper airway to filter sound. For vowels, the tongue is described as being high or low, front or back. For consonants, the point of contact or constriction is described, such as linguopalatal or linguodental. Tongue function for speech also is described by the shape of the tongue, such as grooved or convex. Recent accounts of tongue function for speech refer to functional segments of the tongue that deform it by compression or expansion.² For many phonemes, including diphthongs and glides, the transitioning between sounds is as integral to accurate production as is the posture of the tongue within a segment. The tongue generally is described by its mid-sagittal position or shape for speech. Conversely, for the oral preparation of a bolus for swallowing, the tongue moves in three dimensions within the oral cavity as needed to scrape off residue or shape a bolus. It may even protrude from the mouth to scrape food out of its container (envision reaching into the bottom of an ice cream cone). During the oral stage of swallowing, the bolus typically is positioned in the center of the tongue dorsum as it prepares to propel the bolus to the oropharynx. This involves moving the bolus posteriorly and “stripping” it off of the roof of the mouth. Of course, the most posterior aspect of the tongue, or the base of the tongue, plays a critical role during the pharyngeal stage of swallowing by retracting and contacting the posterior pharyngeal wall. Together with the pharyngeal muscles, the base of the tongue creates pressure to move the bolus toward the esophageal opening.

Research addressing lingual structure and function derives from the speech pathology literature, but it also is stimulated by interest in sleep disorders.³ In particular, concern about sudden infant death syndrome, obstructive sleep apnea syndrome, and snoring has motivated much of the research about the tongue. Facial function is studied in terms of swallowing and speech but also for purposes of cosmetic surgery. It is often instructive to draw on multiple fields and disciplines when studying a topic; lingual and facial functions lend themselves well to this principle. Combining the study of orofacial structures with the general topic of fatigue has been an important research focus. The study of fatigue has been enhanced by drawing on definitions and concepts primarily from the physiology and kinesiology literatures.

DEFINING AND ASSESSING FATIGUE

The classic definition of fatigue, attributed to Edwards,⁴ is a failure to maintain a required or expected force. This definition allowed fatigue to become operationalized and, therefore, measurable. Tasks were designed with a prescribed workload, and when the individual performing the task could not, or would not, continue, that moment in time was defined as the “point of force failure” or as “fatigue.” The locus of force failure was a topic of high interest during the 1980s and 1990s, which were prolific decades in the area of fatigue research. Fatigue is generally considered as originating from the peripheral nervous system (PNS) or the central nervous system (CNS). Peripheral, or muscle, fatigue arises because of changes at the level of the neuromuscular junction or muscle, and central, or mental, fatigue occurs when the CNS inadequately activates the PNS.⁵ Physiologists and kinesiologists turned their attention to the challenging task of developing techniques that would differentiate the contributions of peripheral fatigue and central fatigue.

Enoka and Stuart⁶ offered a comprehensive definition that explicitly noted the central component to the overall concept of fatigue. This was one of the first definitions in the literature to include an increased sense of effort as an integral part of fatigue. Their definition was revised slightly and published in a major review paper in 1992,⁷ and that definition is reproduced here. They stated that fatigue is “a general concept intended to denote an acute impairment of performance that includes both an increase in the perceived

effort necessary to exert a desired force and an eventual inability to produce this force” (p. 1631).

Increased sense of effort is attributed to an awareness within the CNS that neural drive has increased to accomplish the same amount of work. This awareness comes from a sort of carbon copy of the descending signal to the brain stem or spinal cord, which is referred to as an “efference copy.” This copy may come about as a neural signal, called a “corollary discharge,” that is channeled within the CNS. The notion of perceived effort as a reflection of central fatigue led researchers to use sense-of-effort scales and ratings in an attempt to quantify fatigue. There are several types of rating scales used, including a standard equal-appearing-interval scale, which is an ordinal scale, usually with a definition accompanying each of an odd number of points. Direct magnitude estimation (DME) is a ratio scale that avoids the problem of being limited by endpoints. With DME, a modulus is usually provided, which is some value that represents a standard or a reference. Raters are then allowed to provide numbers that vary in either direction from the modulus. Visual analog scales (VAS) are gaining in popularity as a psychometric rating scale. These scales provide a continuous scale of rating (usually an undifferentiated line) that is defined at its endpoints by extreme descriptors. The VAS is thought to avoid the difficulty with discrete ratings and to take less time to administer than other types of scales, although more training may be needed to achieve reliable ratings.^{8,9} In the author's work on the self perception of fatigue and effort, DME and VAS scales have been used, as discussed later.

Fatigue Properties of Orofacial Muscles

The muscles of the speech-production system, from the respiratory to laryngeal to articulatory muscles of the upper airway, are predominantly resistant to fatigue. Given the shared responsibility of many of these muscles with the life-sustaining functions of breathing and maintaining nutrition, it is not surprising that this system was designed to last. Surprisingly, however, recent research indicates that the muscles of the velum may be fatigable in persons with velopharyngeal incompetence. The majority of muscle fibers in normal velar muscles are highly fatigue resistant,¹⁰ yet the primary velar elevator, the levator veli palatini, appears to be more fatigable in persons with surgically repaired cleft palates than in speakers with normal velopharyngeal mechanisms.^{11,12} This could present functional problems for both swallowing and speech.

Most of the human tongue consists of primarily fatigue-resistant muscle fibers (types I and IIa, but there is a smaller representation of fatigable type IIb fibers); however, the anterior portion of the oral tongue (the tongue tip) has an even representation of fatigue-resistant (type IIa) and fatigable (type IIb) fibers.^{13,14} This most likely relates to the function of the tongue tip as a fast-moving articulator. The facial muscles are generally fatigue resistant (type IIa) or highly fatigue resistant (type I).¹⁵ This is particularly true for the orbicularis oris and buccinators muscles, the most relevant facial muscles for swallowing and speech functions.

Fatigue in Parkinson's Disease

The literature clearly indicates that fatigue is a primary concern for people with Parkinson's disease (PD). In large-group studies of PD, fatigue is found to be quite common and affects quality of life.^{16–24} Despite this evidence, fatigue still tends to be underdiagnosed.²⁵ Research that has attempted to identify the locus of fatigue in PD supports the notion that it is centrally, not peripherally, mediated.^{26–29} This is consistent with the pathophysiology of PD as a disorder of the basal-ganglia control circuit.

Self-Report with Scaling Procedures

In clinical situations, SLPs rarely assess fatigue and have no generally accepted specific methods for doing so. Primarily, fatigue is assessed by patient report. The clinician may not even think to ask about fatigue, but if it is problematic enough for the patient, he or she may mention it. There are standardized questionnaires available for assessing overall fatigue that could easily be implemented. They generally take only a few minutes for the patient to complete. Two that the author's research group has used are the Fatigue Severity Scale³⁰ and the Iowa Fatigue Scale.³¹ Other common choices are the Fatigue Assessment Inventory³² and the Multidimensional Fatigue Inventory.³³ Each of these scales involves rating various statements using equal-appearing-interval scales. The most widely used of these scales, the Fatigue Severity Scale, has been tested in a variety of subject groups including PD.²³ The recently published Parkinson Fatigue Scale³⁴ was designed specifically for patients with PD and would therefore seem to have better construct validity for this population.

DME, with or without a modulus, has been an effective scaling method for differentiating fatigue between patient and control groups. Subjects are asked to rate their overall perception of fatigue or effort in relation to "no particular fatigue/effort." Instructions follow: "If 100 = no particular fatigue, how much fatigue do you feel when you talk?" Answers can be less than the modulus, implying that talking is energizing, or greater than the modulus, implying that talking is fatiguing. Solomon and Robin³⁵ posed a DME scale to groups of people with PD and to groups of those without neurologic disease and found that sense of effort as it related to fatigue was greater for the PD group, both in terms of activities of daily living and for speaking.

Peterson et al³⁶ used a visual analog scale to assess fatigue in a drug trial for chronic fatigue syndrome. They labeled the end points of the undifferentiated line "no problem" and "couldn't be worse." This is the scale Solomon et al³⁷ used in a recent study, wherein persons with PD and neurologically normal control subjects rated their overall perception of fatigue. Again, differences between groups emerged, with the PD group reporting greater fatigue overall across a variety of speech and nonspeech tasks that emphasized tongue function.

Behavioral Tasks to Assess Fatigue

Tasks used to assess fatigue are occasionally described in clinical texts. Stress tests have been suggested by Logemann³⁸ for swallowing and by Duffy³⁹ for speech. These involve prolonged activities intended to "stress" the system while using the specific tasks of interest. For the swallowing evaluation, Logemann recommended observing the patient before and after eating a meal, preferably by conducting a video-fluoroscopic evaluation of swallowing before and after several minutes of eating. Duffy's stress test for speech involved having patients count for several minutes. Alternately, they can read aloud for several minutes. The clinician listens for deterioration in any aspect of speech. Usually, stress tests are recommended for suspected cases of myasthenia gravis or a similar disease of the neuromuscular junction. In neuromuscular junction disorders, acetylcholine uptake is insufficient because of a reduced supply, presynaptic binding, or damage of the postsynaptic receptor sites. Reduction in function occurs rapidly, and a brief rest period usually leads to improved function. This is a peripheral mechanism for fatigue that is rapidly occurring. Stress tests such as these are unlikely to reveal central fatigue processes.

Endurance tests are also used to reflect fatigue, based on the straightforward definition that fatigue is a failure to maintain an activity. Usually, the patient is asked to sustain a sub-maximal output level for as long as possible. The author's research has used the Iowa Oral Performance Instrument (IOPI; Blaise Medical) to assess endurance. Subjects are asked to

sustain 50% of their maximum output (determined during a strength assessment); the trial is timed until the participant can no longer maintain output at or near that level. In a previous report, Solomon et al⁴⁰ developed and reported criteria for measuring this duration. For clinical purposes, the internal timer on the IOPI or a stopwatch suffices.

There are, however, several problems with this endurance assessment. First, it may be difficult for the patient to hold the pressure steady enough to perform the task. Surprisingly, when trials were examined for instability, there was no statistically significant group difference between subjects with PD and neurologically normal control subjects.⁴⁰ Still, motor instability remains a potential problem. Second, the task depends on muscle strength, because it is performed at a level determined by the person's strength. If a person is substantially weak, then the endurance task would be performed at a very low output level. Although this is normalized to that person, it may be difficult for him or her to sense and control such a low level of pressure. Third, the task, by definition, induces fatigue, so additional trials cannot be performed until after a substantial, as-yet-undetermined rest period. Finally, probably because it is difficult to repeat trials over a reasonable amount of time, there is insufficient evidence of trial-to-trial repeatability on this task. Studies that use multiple trials select the best performance as the endurance result, because this is a maximum-performance task. Variability between subjects within a group can also be high, perhaps owing to differences in muscle structure and function and differences in motivation and pain tolerance. These issues and others have been considered in previous review papers, which the reader may find instructive.^{41–43}

Tongue endurance tasks have been used as a measure of fatigue in PD. Results with the standard endurance task described previously have been equivocal, such that some researchers^{44,45} have found no significant difference between normal and PD groups, whereas Solomon et al,⁴⁰ who studied somewhat more severely disordered PD subjects, did report a significant group difference for tongue endurance. When data from two studies were combined,^{40,44} resulting in an analysis of 35 adults with PD and 35 neurologically normal subjects, tongue endurance and tongue strength were significantly lower in the PD group.⁴⁰ Alternate endurance tasks have been used as well, such as sustaining a maximum-effort tongue protrusion as long as possible⁴⁶ or sustaining and repeating a maximum-effort tongue elevation for a fixed period of time.⁴⁷ In these studies, the decrement in force over time seemed to indicate differences across groups or with various treatments.

From these studies, it seems reasonable to expect performance on tongue endurance tasks to be poorer in patients with PD, although the effect may be relatively difficult to detect in some small groups or individuals. Importantly, one must consider the potential functional significance of reduced tongue endurance. Examination of correlations between the precision of speech produced by subjects with moderately severe PD and their results on the tongue endurance task revealed no significant relationship.⁴⁰ This calls into question the presumed relationship between fatigue and speech, at least in this disorder and with this method. It is quite possible that more prominent fatigue associated with other disorders may play a role in the execution of speech production, but such a population has not yet been investigated in this way.

Solomon et al⁴⁸ developed an alternate assessment task that capitalizes on the notion that effort increases as a person sustains an activity (Fig. 1A). If effort increases as the tongue sustains a contraction at a fixed output level (i.e., the endurance task), then output level should decrease as a person keeps the sense of effort the same. Schematic plots of this reciprocal relationship are provided in Figure 1. For the constant-effort task, schematized in Figure 1B, subjects were asked to start a trial at 50% of maximum strength (shown as 50% maximum pressure); to close their eyes, thereby removing visual feedback (“close your

eyes”); and to “concentrate on keeping the effort the same; don't let it get any harder or any easier to do.” This task was performed with handgrip and tongue elevation maneuvers. Others have used this task with elbow flexion^{49,50} and handgrip contractions.⁵¹ For the arm, hand, and tongue, the literature demonstrates that the output signal decreases in an exponential fashion as effort is held constant the majority of the time—about 80% of trials were described with a negative exponential function with a positive asymptote, as illustrated in Figure 1B.

Solomon et al^{48,52} reported this result in two groups of healthy young adults and two groups of healthy older adults. They contended that the slope of the decreasing function reflects central processes related to fatigue, primarily because of the rapid time course of pressure decay. Normally, the pressure curve for the tongue decreased to about two-thirds of its original level in about 5–7 seconds, determined by calculating a time constant $1/a$ from the equation $f(t) = e^{b-at} + c$, where t is time, b is the natural log of the y-intercept minus c , and c is the asymptote. According to the presumed neurophysiologic mechanism for this task, the negative term in the equation represents the decreasing rate of lingual lower motor neurons that would occur with constant upper motor neuron activation. If the function decreased more rapidly, then this would reflect an increase in the perception of effort that leads to an increase in central activation.

This hypothesized mechanism was tested by having people perform the constant-effort task before and after exercise. In two studies, young healthy adults engaged in a short but intense period of tongue exercises, consisting of maximal-pressure tongue elevations against the IOPI bulb placed on the roof of the mouth, repeated at a rate of approximately one per second.^{48,52} The tongue was considered “fatigued” when it could not compress the tongue bulb with a pressure equal to 70% of maximum for three consecutive trials. It took about 1 minute of exercise to meet this criterion. As predicted, the time constants were shorter, reflecting the steeper decrease in pressure during the constant-effort task. As illustrated in Figure 2A,^{48,52} the time constants generally were half as long. This supports the notion that performance on the constant-effort task reflects fatigue.

Interestingly, when subjects with PD performed the constant effort task when rested, their results resembled those of the young healthy subjects after they had exercised the tongue (Fig. 2B).³⁵ If the time constants derived from the constant-effort task reflect fatigue, then this supports the concept that the fatigue frequently reported by persons with PD can be demonstrated with this task. This intriguing finding led to further exploration of the potential clinical value of using the constant-effort task as a behavioral assessment of fatigue.

A new cohort of 12 adults with PD and 13 neurologically normal adults was enrolled in a study to examine whether speech-like exercises performed for 60 minutes would induce fatigue, and whether that could be demonstrated with the constant-effort task.³⁷ First, before subjects engaged in the exercises, the constant-effort task was performed and compared across groups. As before, time constants were shorter for the PD group than for the normal control group (Fig. 2B).³⁷ However, self ratings of fatigue, using VAS, taken after separate tasks yielded conflicting results. Ratings made immediately after each of six 10-minute sets of syllable repetitions failed to indicate increased fatigue, yet ratings taken after each constant-effort trial did reveal greater fatigue after the six sets of exercise. Because these ratings reflect the self-perception of fatigue, the time constants derived from the constant-effort task were expected to decrease over the series of exercise sets. The data did not support this expectation. Figure 3 illustrates the mean time constants from each assessment. Clearly, the control subjects' time constants were longer than those for the PD subjects. However, the difference from baseline to the last one or two sets of exercise was not statistically significant. When each time point was compared with baseline, the time

constants analyzed after the first or second 10-minute set differed significantly from baseline, but they were longer, indicating a slower rate of pressure decay. The increase in time constants near the beginning of the exercise program may reflect a renewed sense of energy and vigor resulting from the speech-like exercises, which is consistent with comments made by several subjects.

FUNCTIONAL RELEVANCE OF OROFACIAL FATIGUE

The relevance of fatigue to overall functioning, be it motor, cognitive, social, or emotional, is well established. However, aside from a relatively rich literature about vocal fatigue,^{53,54} the literature relating fatigue to orofacial-motor function for swallowing and speech is sparse. Despite little empirical data to support such an association, anecdotes abound. References to fatigue at SLP professional presentations are frequent, including such comments as “fatigue affected the patient's ability to swallow safely through a meal,” or “we scheduled appointments to avoid fatigue,” or “the patient reported that speech is worse when she is fatigued.” The research literature, however, provides a very different picture.

Solomon⁵⁵ conducted a study that successfully demonstrated a decrement in speech precision after exercising the tongue to the point of fatigue. In this study, eight healthy people, ages 16–30 years, exercised their tongues by pushing against the IOPI bulb as hard as they could for 6 seconds. They then rested for 4 seconds. This 10-second cycle was repeated until the participants could not reach 50% of their initial maximum output (strength) for three consecutive cycles. This was defined as the point of fatigue. Using median results for the eight participants, it took 32 minutes to achieve tongue fatigue using this protocol. The study included three separate speech tasks, administered in this fixed order: slow syllable repetitions, fast syllable repetitions, and sentence reading. Between tasks, the tongue exercises were repeated to the point of fatigue. Therefore, before reading the experimental sentences, the subjects exercised the tongue for a median of 51 minutes. Speech precision deteriorated, according to auditory perceptual ratings by experienced SLPs and inexperienced lay listeners, for all eight speakers (Fig. 4). Even with this robust finding, there were few acoustic correlates to the decreased speech precision. The particular acoustic parameters that changed with fatiguing the tongue included certain features of lingual-alveolar consonants but also tended to involve vowels and diphthongs. Speaking rate and other temporal aspects of speech did not differ with tongue fatigue for any of the three speech tasks.

A conclusion from this study is that it is possible to fatigue the normal tongue but also that it takes quite a bit of strenuous exercise to do so. Once the tongue is truly fatigued, then robust changes in speech can be documented. Recovery from fatigue, defined as a return to near-normal strength, was relatively brief (15-minute median). After recovery, speech precision improved, but not back to baseline levels.

To investigate whether tongue fatigue could be induced from speaking alone, rather than by intensive exercises, Solomon and Makashay⁵⁶ designed a speech-like exercise task for a study comparing the effects of speech-like exercises in persons with PD and in those without neurologic disorders. Participants repeated strings of the syllables /ti/, /si/, /ʃi/, /ɔɪ/, and /aɪ/ as quickly as possible. They were instructed to produce each individual syllable string on a comfortable breath and to use their typical voice. Six 10-minute sets were performed, for a total of 60 minutes of exercise. Data were collected between sets. It was expected that speech would not be appreciably affected in normal speakers but that participants with dysarthria and fatigue associated with PD would demonstrate an exacerbation of dysarthria and fatigue after these speech-like exercises.

The participants rated their overall perception of fatigue, using VAS, and both groups reported increased fatigue when they read sentences after doing the syllable-repetition exercises. Surprisingly, however, the syllable-repetition task itself was not associated with an increase in self-rated fatigue. Nine normal listeners judged sentences that were spoken before the first and after the last set of exercises. They were asked to decide which sentence in the pair sounded more precise and, during a separate listening session, which one sounded more natural. There were no significant differences (Fig. 5). Certain individual talkers appeared to exhibit differences, but there was no systematic change in speech precision or naturalness overall. This protocol provides evidence that the tongue is resistant to decrements in function (indicative of fatigue) from speaking alone, even when the speech task is intensive and the speech-production system is disordered.

It is not possible to confirm from these data whether the exercise task succeeded in fatiguing the tongue in these speakers, because no fatigue criterion was set. Instead, a fixed amount of time was prescribed for these exercises. It is the investigators' strong impression that participants in this study would not have voluntarily continued the experiment because of the tediousness of the task. Furthermore, it is unknown how long this task would have needed to continue for tongue fatigue to be achieved, but one could surmise that it would have taken an inordinately long time. Other factors would have undoubtedly interfered, such as vocal fatigue, hunger, and sleepiness.

Although the subjects with PD and those who were neurologically normal reported increased fatigue when they performed the constant-effort task and when they read sentences after 60 minutes of speech-like tongue exercises, they did not report increased fatigue immediately following the exercises themselves. It is possible that the exercises actually acted to energize them, a hypothesis that is supported by the finding of longer time constants measured from the constant-effort task after 10–20 minutes of exercise. It is also supported by anecdotal comments made by several subjects during the experiment. However, after 50–60 minutes of exercises, the time constants returned to near-baseline levels, participants expressed boredom and frustration, and fatigue ratings for the constant-effort task and for the sentence-reading task increased. The effect of fatigue may have been delayed, or the exercise task may have been sufficiently distracting to remove the participants' attention from their own sense of fatigue. Whatever the reason, it seems clear that the exercise paradigm used was not sufficiently fatiguing to affect function for speech. This supports the notion that speech and its associated articulatory system are robust and resistant to fatigue, even for people with compromised speech-production systems.

SUMMARY AND FUTURE DIRECTIONS

There are several take-home messages that one can derive from this review of the literature on orofacial fatigue. First, the definition of fatigue includes an increase in the self-perception of effort during an activity. Therefore, to assess fatigue appropriately, one must ask the patient how much effort it takes to do the task of interest. Second, fatigue can be demonstrated as a deterioration in performance as a fatiguing activity ensues. In practical terms, this involves evaluating effort and performance over time. Attempts to quantify differences in the sense of effort between normal and disordered persons using a nonaversive task—the constant-effort task—have been successful in group analyses but appear to be too variable across trials and between people to consider using clinically at this time. Methods for improving reliability of performance are necessary before implementing this procedure clinically. Nonetheless, rating scales should be implemented clinically to standardize the assessment of a patient's report, and behavioral tests may provide some helpful information about fatigue and its potentially deleterious effects.

The dilemma remains to explain and document the persistent issue of fatigue in the dysphagia and dysarthria literature. There are particular populations for which fatigue is a primary issue. Disorders of the neuromuscular junction, such as myasthenia gravis, are obviously the most relevant of the peripheral-fatigue disorders. Once these are diagnosed, many cases can be effectively treated with medication. Diseases of the CNS that include fatigue as a primary symptom should be evaluated in terms of swallowing and speech as well. The author's laboratory has attempted to identify and test the effects of centrally mediated fatigue on speech in PD but has met with little success. There are other neurologic disorders that have strong support in the literature of fatigue as a primary symptom.⁵⁷ These include multiple sclerosis, amyotrophic lateral sclerosis, postpolio syndrome, and post-Guillain-Barre syndrome. Of course, other symptoms co-occur, making it difficult to assess the unique contributions of fatigue to dysfunction. For example, in multiple sclerosis, slowness of movement caused by reduced nerve conduction velocity is paramount. Weakness dominates the symptoms of amyotrophic lateral sclerosis. The one disorder characterized exclusively by persistent fatigue of central origin, chronic fatigue syndrome, is not a diagnosis that is often seen in speech-language pathology clinics. Should it be concluded that fatigue alone has no demonstrable effect on communication or eating? If patients report fatigue associated with these activities, is that adequate justification for instituting a management plan? Is it necessary to show a concomitant decrease in activity along with the increased sense of effort that occurs with fatigue?

Management programs for fatigue in relevant neurogenic disorders focus mainly on energy conservation and organizing daily activities around episodes of fatigue.⁵⁸ It may be beneficial for SLPs to become familiar with such approaches when dealing with patients whose fatigue interferes with function. Can exercise also enhance endurance and improve sustenance of daily activities? Some evidence is available that indicates that the answer is yes,^{59–62} but this conclusion is still controversial. Perhaps encouraging moderate levels of activity will help patients with dysphagia or dysarthria as well. Until future research provides a reliable and practical method of assessing fatigue behaviorally, however, the research indicates that the most valid and useful tool for documenting status and progress is the use of rating scales to reveal self-perceptions of effort and fatigue.

Aside from the issue of studying and treating relevant populations of patients, relevant groups of muscles should also be considered. Could it perhaps be more applicable to look at velar, pharyngeal, or laryngeal fatigue when considering fatigue related to dysphagia? How can SLPs identify patients and groups of muscles that would be good candidates for endurance exercises? Assessment tools are needed to reliably identify specific muscles that are prone to fatigue and to track progress with endurance training.

The use of oral-motor exercises to improve swallowing and speech remain popular in clinical settings, but there is a dearth of data to demonstrate efficacy. Future research should use valid and sensitive tools and procedures for assessing strength and fatigue. Using unbiased and objective measures will help to identify appropriate candidates, document specific impairments, and monitor progress with treatment programs. Clearly, this review has raised more questions than it has answered, but it should serve as a basis for identifying areas of need for more research. Rigorous empirical studies are crucial for developing the evidence-based clinical procedures that are so important for justifying SLP services.

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Figure 1.

Schematic representation of the presumed relationship between effort and pressure (as exerted on the Iowa Oral Performance Instrument bulb) during two tasks. Both signals are expressed as a percentage of maximum. In panel A, pressure is maintained at a constant level, and effort increases until its maximum level, leading the subject to abort the trial. In panel B, effort is maintained at a constant level, and pressure decreases exponentially to a positive asymptote; the trial is aborted when an independent observer determines that the asymptote has occurred.

Figure 2.

(A) Time constants derived from the constant-effort task with the tongue by young, healthy adults ($n = 6$ in 1996⁴⁸; $n = 10$ in 2002⁵²) before and after inducing tongue fatigue with repetitions of maximal-effort contractions. (B) Time constants for healthy older adults matched in age with adults who have Parkinson's disease ($n = 16$ Parkinson's disease and 16 controls in 2005³⁵; $n = 12$ Parkinson's disease and 13 controls in 2006³⁷).

Figure 3.

Time constants derived from the constant-effort task with the tongue before and after speech-like exercises (fast syllable repetitions) by adults with Parkinson's disease and age-matched neurologically normal control subjects.³⁷

Figure 4.

Change in perceived precision of articulation for sentences produced before and after fatiguing tongue exercises by eight normal participants (talkers).⁵⁵ Articulatory precision was rated by eight experienced speech-language pathologists on a 7-point scale, where the midpoint was defined as “typical” speech precision. Positive-going bars indicate that speech sounded less precise after tongue fatigue was induced. Data were ranked according to the amount of change, as averaged across the listeners’ ratings. (Modified from Solomon⁵⁵)

Figure 5.

Change in perceived articulatory precision and speech naturalness for sentences produced before and after 60 minutes of speech-like tongue exercises by 13 normally speaking adults and 12 adults with dysarthria and fatigue associated with Parkinson's disease.⁵⁶ Articulatory precision was rated by nine adults trained in communication disorders using a paired-comparison task. Results are plotted as the difference in the percentage of sentences that were perceived to be more (positive values) or less (negative values) precise or natural after the exercises. There were no statistically significant differences in either parameter or for either group with exercise.⁵⁶