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Review Article

Nonspeech Oral Movements and Oral Motor Disorders: A Narrative Review

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Purpose: Speech and other oral functions such as swallowing have been compared and contrasted with oral behaviors variously labeled *quasispeech, paraspeech, speechlike,* and *nonspeech,* all of which overlap to some degree in neural control, muscles deployed, and movements performed. Efforts to understand the relationships among these behaviors are hindered by the lack of explicit and widely accepted definitions. This review article offers definitions and taxonomies for nonspeech oral movements and for diverse speaking tasks, both overt and covert.

Method: Review of the literature included searches of Medline, Google Scholar, HighWire Press, and various online sources. Search terms pertained to speech, quasispeech, paraspeech, speechlike, and nonspeech oral movements. Searches also were carried out for associated terms in oral biology, craniofacial physiology, and motor control.

Results and Conclusions: Nonspeech movements have a broad spectrum of clinical applications, including developmental speech and language disorders, motor speech disorders, feeding and swallowing difficulties, obstructive sleep apnea syndrome, trismus, and tardive stereotypies. The role and benefit of nonspeech oral movements are controversial in many oral motor disorders. It is argued that the clinical value of these movements can be elucidated through careful definitions and task descriptions such as those proposed in this review article.

The craniofacial and masticatory musculature is deployed for a variety of behaviors, including speech, communicative and noncommunicative facial gestures, biting, chewing, swallowing, licking, and ventilation. These diverse behaviors use many of the same muscles but with differing patterns of activation. Research that compares speech and nonspeech orofacial movement (NSOM) derives partly from the longstanding question: In what ways does the motor control for speech differ from that for nonspeech movements using the same, or partly the same, musculature? NSOMs are of interest not only for speech and its disorders, as they have a broad spectrum of applications to behaviors involving the oral musculature. Considering these various applications is one way to elucidate the nature of NSOMs and their current or potential value in assessing or treating disorders of oral function.

The clinical application of NSOMs arises from the fact that orofacial and craniofacial movements are pertinent to a variety of disorders, including developmental speech and language disorders, motor speech disorders, drooling, feeding and swallowing difficulties, orofacial myofunctional disorders, obstructive sleep apnea, trismus, and tardive stereotypies. NSOMs have been studied in relation to each of these topics, and this review article appraises the value of NSOMs in contemporary clinical practice and research in these various applications. Within the last 2 decades, the use of NSOMs in developmental speech sound disorders has been heavily criticized (Forrest, 2002; Lof, 2008; Powell, 2008; Ruscello, 2008), and applications to motor speech disorders have come under increased scrutiny and skepticism (Weismer, 2006). But tasks based on NSOM have received more positive evaluations in other areas, such as treatment for obstructive sleep apnea and oropharyngeal dysphagia, as discussed in this review article. In addition, NSOMs continue to play a role as a control condition in studies of the motor patterns and neural control of speech. For example, many studies of functional brain activation for speech use nonspeech oral tasks as a comparison condition. Underlying the application of NSOMs to clinical practice and research are basic questions such as "What is an NSOM?" and "What is speech?"

Method of Review

This narrative review considers broadly the role of NSOMs in research and clinical activities, not only for speech but also for various functions that recruit some part of the musculature used in speech production and for which

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NSOMs have been proposed as diagnostic or treatment tools. Although speech is of central interest in this inquiry, NSOMs have a wide spectrum of applications to functions that share some part of the musculature used in speech. A review of the literature included searches of Medline, Google Scholar, HighWire Press, and various online sources. Search terms pertained to the general categories of speech, quasispeech, paraspeech, speechlike, and NSOMs in relation to clinical applications and research on neural and muscular components of the oral system. A large number of citations for nonspeech pertain to studies of auditory perception (e.g., perception of speech versus tones or other nonspeech stimuli), but these are not included in this review article because the focus is on motor activities of the orofacial system. Additional searches were conducted on terms in oral biology (especially craniofacial muscle characteristics) and motor control. Although speech and speech disorders are of central interest, this review article covers a wider range of oral functions in which NSOMs have played a role in practice and research.

Defining the Problem

Perplexity about the relationships among tasks classified as nonspeech, paraspeech or quasispeech, speechlike, and speech arises in part because there is no explicit, universally accepted set of criteria for their distinction. Table 1 shows the distinctions among several tasks commonly used in research and in clinical applications: NSOMs, paraspeech or quasispeech, nonword repetition (NWR), speechlike, and speech. This table identifies properties relevant to an eventual definition of terms. Definitional and methodological differences exist among studies that have compared motor performance in tasks designated with these terms for the design of experiments, clinical assessments, or clinical treatments. Investigators and clinicians generally have selected certain tasks that, in their opinion or within the parameters of a specific application, exemplify one or more of the categories just noted. An example of a three-way classification of an oral movement is Wohlert's (1993) study of labial movement in which lip pursing was considered a nonspeech task, lip rounding was considered a speechlike task, and production of a word containing a rounded phoneme was considered a speech task. A general definition is needed for NSOM tasks used for diverse purposes, including clinical assessment and treatment of speech and orofacial functions, identification of oral behaviors that appear in various pathologies (e.g., involuntary movements), and selection of control tasks for studies of sensory and motor functions in speech.

Nonspeech tasks often are explicitly or implicitly defined as tasks that do not involve speech. Nonspeech is therefore defined by exclusion, and speech rarely is defined at all. In its various documents, the American Speech-Language-Hearing Association (ASHA) apparently does not define speech, but it does define a speech disorder as an impairment of the articulation of speech sounds, fluency, and/or voice (ASHA, 1993). Accordingly, *speech* presumably can be defined to consist of the articulation of speech sounds, fluency, and/or voice. An implicit definition of speech generally is assumed, even though speech is not a monolithic behavior but rather subsumes a variety of sensory, motor, and cognitive skills that vary across behavioral tasks (Munhall, 2001; Segawa, 2013; Tasko & McClean, 2004; Van Lancker Sidtis, Rogers, Godier, Tagliati, & Sidtis, 2010). Munhall (2001) described various types of speech in relation to functional imaging studies and pointed out that speech behavior comprises a number of tasks, the properties of which should be considered in interpreting imaging results. Similarly, Dogil et al. (2002) concluded that the motor speech neural network varies with speaking task, with increasing articulatory complexity leading to a more focused activation. Effects of speaking task on neural activation also were reported by Simmonds et al.

Table 1. Major distinctions among nonspeech oral movements (NSOMs), speechlike, quasispeech or paraspeech, nonword repetition (NWR), and speech.

Behavior	Description of tasks	Phonetic structure	Carries meaning
NSOMs	Encompasses a wide range of orofacial movements, executed singly or in combination with other movements	None, as tasks are described in terms of movements or positions	No
Speechlike	Humming	No	No, except in unusual circumstances such as when humming may signal *yes* or *no* or has prosodic signaling value
Quasispeech or paraspeech	Sustained vowel production and/or syllable diadochokinesis	Yes; typically of limited variety and standardized for clinical use	No, except when real words (e.g., *buttercup*) are used in preference to nonsense syllables in diadochokinesis
NWR	Sequences of sounds	Yes; phonetic sequences are similar to real speech and typically follow phonotactic constraints in the native language	No; similarity to real words is avoided, and it is assumed that the words are meaningless
Speech	Word or sequences of words	Yes	Yes with some exceptions

(2014). The respiratory demands of different speaking tasks affect measures of cerebral blood flow in speech, thereby complicating the analysis of functional brain imaging (Scholkmann, Gerber, Wolf, & Wolf, 2013). The common conclusion of these reports is that neuroimaging studies of speech production (or other oral functions) should carefully specify the tasks and interpret the data accordingly.

Proposed Definitions and Taxonomic Considerations

This section gives definitions of both speech and (oral) nonspeech motor behaviors and discusses implications for taxonomies pertinent to these definitions. A *taxonomy,* or delineation of discrete classes in a phenomenon, is particularly useful in comparing and contrasting members of a large set or population. Because both speech and nonspeech behaviors constitute a range of behaviors, separate taxonomies are needed to place them in perspective and to allow suitable comparisons.

Definition of Speech

Speech is defined as movements or movement plans that produce as their end result acoustic patterns that accord with the phonetic structure of a language. This definition is generally consonant with others in the literature. For example, Ziegler and Ackermann (2013) regard the motor events in speaking as specific to the domain of linguistic expression. Both phonological and phonetic representations may be relevant, as neither is sufficient in itself (Pierrehumbert, 1990). This proposed definition is restricted in its application to the disciplines of speech science and speech-language pathology and is not intended for more general applications in rhetoric, psycholinguistics, and other specialties. Although speech can be—and usually is—used to convey meaning, this property is not essential to the various forms of speech, as discussed next.

Speech: Taxonomic Considerations

The proposed definition applies to a wide range of types or tasks of speech that have been recognized in laboratory and naturalistic investigations, as listed in Appendix A. This appendix is a step toward an eventual taxonomy of speaking behaviors that can be used to compare and contrast speaking tasks for purposes such as interpreting the results of functional brain activation studies. Despite the length of Appendix A, it is almost certainly incomplete in listing the possible range of speech behaviors. The common denominator across the different items appears to be performance of a *phonetic or phonological task*—that is, a task specified by the sounds of a given language (with some possible exceptions, as in *glossolalia* where the language purportedly may not be identified or even known to the speaker; McGraw, 2012; Motley, 1982). Examination of Appendix A reveals several dimensions or axes of contrasting speech motor function. The axes that have been most frequently studied include overt versus covert, propositional versus nonpropositional (automatic), meaningful versus meaningless, clear versus conversational, normal versus compensatory, typical speaking rate versus altered speaking rate, typical prosody versus altered prosody, entrained versus nonentrained, and spontaneous versus rehearsed.

Because speech is governed not only by motor processes but also by phonological and phonetic principles, it takes a variety of forms depending on the specific task. Munhall (2001) noted that it should not be assumed that different speaking tasks can be freely interchanged in interpreting data for patterns of neural activation. Similarly, it should not be assumed that different speaking tasks are equivalent with respect to motor patterns, sensory processing, or cognitive support. Speech can be imagined, dreamed, mouthed, whispered, shouted, articulated carefully or casually, used to express meaningful or meaningless messages, adjusted to changing auditory feedback or mechanical disruption, produced with or without co-speech gestures, uttered with varying types and degrees of emotion, imitated, or subjected to any of the other variations summarized in Appendix A. Even if a basic core neural network is involved in the various types of speech, the network would have to be elaborated, condensed, or otherwise modified as task conditions change. In short, speech is not a single task but a panoply of tasks that draw on various resources, and it is part of the remarkable power of the faculty of speech that it can be used in so many ways, often with apparent ease. Speech is perhaps more adaptable and modifiable than any other human motor behavior. Normal speech is described with words such as *typical, usual, conversational, everyday, nonnal,* and *neutral.* But speech is a universe of styles and registers that alternate at the speaker's will and even unconsciously, as in the case of unintended imitation of another speaker (Kappes, Baumgaertner, Peschke, & Ziegler, 2009) or phonetic convergence between college roommates (Pardo, Gibbons, Suppes, & Krauss, 2012). Not only does speech take multiple forms, but a given form can be nuanced in ways not consciously planned by the speaker. Even the divide between perceiving and producing speech can be questioned, given that listening to speech can modulate the excitability of speech muscles (Fadiga, Craighero, Buccino, & Rizzolatti, 2002) and can activate speech motor areas in the precentral gyrus (Pulvermüller et al., 2006).

Definition of Nonspeech Oral Movements

It is inevitable that a definition of *NSOMs* would refer to speech in some way. The following general definition is proposed: *NSOMs are motor acts performed by various parts of the speech musculature to accomplish specified movement or postural goals that are not sufficient in themselves to have phonetic identity.* This definition is broad enough to include applications in clinical testing, clinical treatment, and research design. The term *speech musculature* is intended to include the entire set of muscles commonly included in discussions of speech anatomy and physiology (Barlow, Andreatta, & Kahane, 1999; Hixon, Weismer, & Hoit, 2008) and is not necessarily restricted to the oral region. The definition also clarifies the relationship of NSOMs to speech movements, with the critical distinction being that speech inherently carries a phonetic purpose and structure (leaving aside for now the important questions of whether and how meaning should be considered in defining speech). Whether speech is whispered, mouthed, produced with voicing, or even imagined, its phonetic underpinning is intact. It is expected that speech and NSOMs will have some common biomechanical and motor properties, as muscles do not transform themselves as they perform one task or another. For example, the precision of both speech and nonspeech movements may depend on impedance control (Laboissière, Lametti, & Ostry, 2009). As discussed in a later section, most craniofacial muscles have the capability for diverse functional characteristics that can be used for distinct specializations.

NSOMs vary widely in their motor composition. For some NSOMs, the responsible articulator or motor system is identified, but in other cases there is no such specification. Examples of the former are lip pursing, jaw opening, and tongue protrusion. Examples of the latter are coughing, laughing, and blowing (motor acts that draw on more widely distributed muscle systems, sometimes including the oral articulators, larynx, and respiratory system). Accordingly, the definition proposed here applies to a potentially wide range of motor behaviors. A taxonomy of NSOM tasks is needed to delineate these behaviors and to identify parameters of description and analysis. Otherwise, NSOMs are amorphous, and there is no clear path to distinguishing among their nature and purpose or to understanding them in relation to speech, mastication, swallowing, or other functions of interest. It is doubtful that there is even an archetypal NSOM, although certain tasks appear to be more frequently used than others.

The definition offered here differs from other published definitions. For example, in defining *nonspeech oral motor exercises* (NSOMEs), Lof (2008) cites two definitions. First, Lof states that NSOMEs "can be defined as any therapy technique that does not require the child to produce a speech sound but is used to influence the development of speaking abilities" (p. 253). By this definition, speaking tasks involving covert or nonvocal production (see Appendix A) would be classified as NSOMEs, which would exclude a host of research and clinical procedures such as imagined, covert, or mouthed speech. The second definition cited by Lof is from McCauley, Strand, Lof, Schooling, and Frymark (2009):

> Oral-motor exercises are activities that involve sensory stimulation to or actions of the lips, jaw, tongue, soft palate, larynx, and respiratory muscles which are intended to influence the physiologic underpinnings of the oropharyngeal mechanism and thus improve its functions; oral-motor exercises may include active muscle exercise, muscle stretching, passive exercise, and sensory stimulation. (p. 344)

The problem with this definition is that it does not explicitly exclude speech behaviors of any kind; rather, it would encompass any and all sensory and motor activities of a large and diverse musculature. Ruscello (2008) reviewed definitions of nonspeech oral motor treatments (NSOMTs), but in the main these definitions consist of lists of activities rather than identification of the core attribute of such treatments. Use of the term *nonspeech* in describing movements, tasks, or exercises assumes that speech and nonspeech are mutually exclusive, which is why an explicit definition of *speech* is essential.

NSOMs: Taxonomic Considerations

A proposed taxonomy for NSOMs is given in Table 2, which pertains only to active movements under the control of the individual being examined and not to passive movements in which a structure is manipulated by a force that is external to the speech musculature. A separate taxonomy would have to be developed for passive movements and for delivery of sensory stimulation of selected structures or regions (e.g., electrical, tactile, or thermal stimulation). Various NSOM tasks can be differentiated from one another and from speech itself with respect to the participation of different motor systems. Other points of difference also need to be recognized, such as the acoustic consequence of the movements. Some NSOM tasks generate little or no sound, which eliminates a role of auditory feedback and an external focus on movement outcome. Therefore, Table 2 includes information not only on motor actions but also on the associated auditory product, if appropriate, of these actions. Ultimately, speech is a sensorimotor phenomenon, as recognized in contemporary neurocomputational models of speech production (Guenther & Vladusich, 2012; Hickok, 2012). Production of sound is a routine feature of speech, but silent or mouthed speech is still a form of speech.

The proposed definition of *nonspeech tasks* leaves room for another category of behaviors that are not necessarily regarded as speech, per se. These behaviors are sometimes called *quasispeech tasks* and have been linked especially (if not exclusively) with alternating motion rate tasks comprising speechlike syllables (*diadochokinesis*; Mackenzie, Muir, & Allen, 2011; Weismer, 2006). Another classification, *paraspeech,* has been used to designate diadochokinesis and vowel prolongation (Brendel et al., 2013). The term *speechlike* has various references in the scientific literature, mostly in studies of speech perception and in studies of babbling, but it has been used in studies of speech production in reference to the task of humming (Flöel, Ellger, Breitenstein, & Knecht, 2003) and sometimes as a general category that includes vowel prolongation and diadochokinesis. For present purposes, *speechlike* is distinguished from the other behaviors in question by defining it as humming (which is devoid of phonetic content). With this admittedly narrow definition, *speechlike* is different from *speech, paraspeech,* and *quasispeech*. Therefore, the behaviors considered in this review article would include *nonspeech, speechlike, quasispeech, paraspeech,* and *speech*. But because quasispeech and paraspeech are

Table 2. Classification of speechlike or nonspeech movements in terms of general function and participation of major muscle systems.

Muscle system	Vegetative (especially airway protection, alimentary functions)	Emotional expression	Gross motor equivalence to speech	Kinematic matching to speech
Oral only	1 Chewing, licking, sucking	7 Smiling	13 Lip, jaw, tongue, or cheek movement	19 Single articulator movement
Respiratory	2 Subglottal air pressure control	8 Sighing without phonation	14 Prolonged expiration	20 Subglottal pressure regulation
Respiratory and laryngeal (phonatory)	3 Grunting	9 Moaning, crying	15 Sustained phonation, humming, grunting	21 Phonation with f0 or intensity regulation
Oral and respiratory	4 Panting, blowing, snorting	10 Sighing	16 Whistling, blowing	22 Regulation of oral pressures or flows
Oral, laryngeal, and respiratory	5 Coughing	11 Laughing	17 Intoning simple sound	23 Articulatory movement during phonation
Audible result of movement	6 Coughing, panting, grunting	12 Moaning, crying, sighing, laughing	18 Intoning simple sound, whistling	24 Articulatory movement during phonation

Note. f0 = vocal fundamental frequency. Movements are classified as oral only; respiratory; respiratory and laryngeal; oral and respiratory; oral, laryngeal, and respiratory; and resulting in sound. Types of tasks, represented as column heads, are vegetative, emotional, having a gross motor equivalence to speech, and kinematically matched to speech. The numbers in the cells are used to identify the various tasks. For example, numeral 1 identifies vegetative behaviors that involve only the oral musculature.

conceptually overlapping, in this article they will be regarded as a single category: "paraspeech."

One of the attractive features of some NSOM tasks is the potential for quantitative measurement of selected variables for clinical assessment or for the use of prescribed levels of force or resistance in therapeutic applications. Examples of devices or systems of this kind are continuous positive airway pressure (CPAP), which has been used to treat hypernasality (Cahill et al., 2004; Kuehn et al., 2002); the Iowa Oral Performance Instrument (http://www.iopimedical.com), a pressure transduction system used to measure strength and endurance of the hand, lips, or tongue (Adams, Mathisen, Baines, Lazarus, & Callister, 2013); the lip force meter LF100 (Hägg, Olgarsson, & Anniko, 2008); and SwallowStrong (http://swallowsolutions.com), a device consisting of a mouthpiece that incorporates sensors that measure pressure at four distinct locations on the tongue. Many devices of this kind have been developed, but it is not the purpose of this review article to consider them in any detail but rather to make the basic point that certain NSOM tasks can be combined with physical measurements of quantities such as pressure or force.

In summary, both speech and nonspeech tasks take a variety of forms, and this diversity complicates the consolidation and interpretation of data from a variety of research techniques. The taxonomy in Table 2 is proposed as one step toward clarification and systematization of NSOMs. Examples are provided in the sections that follow. The definitions and taxonomies are now considered in relation to the following issues: task dimensions and complexity, muscular systems, neural representation, and, finally, clinical applications.

The Importance of Task Dimensions and Complexity to Comparisons of Speech and Nonspeech Movements

It has been proposed that speech motor and nonspeech oral motor control processes lie along a continuum and can be integrated in a general system of motor control (Ballard, Robin, & Folkins, 2003; Ballard, Solomon, Robin, Moon, & Folkins, 2009). If so, then it follows that the systematic study of nonspeech movements that are increasingly speechlike would eventually converge on speech, per se. An alternative possibility is that speech and nonspeech behaviors are dichotomous (Ziegler, 2003a, 2003b, 2006). If dichotomy rules, then it should be possible to identify a crucially discriminating dimension (or a set of dimensions) that consistently separates nonspeech movements from speech. As already noted, one purpose of this review article is to propose a taxonomy of NSOM tasks built on an analysis of task properties. The basic claim underlying this taxonomy is that various NSOM tasks are not equivalent in their neural or sensorimotor complexity but rather represent a repertoire of motor acts that differ in complexity and their similarity to speech movements. An analysis of this kind is needed to determine if speech versus nonspeech is better viewed as a dichotomy or as a continuum. Another motivation is to promote the principled comparison of nonspeech and speech movements that can be used for clinical and research purposes.

Studies that have compared speech with nonspeech or speechlike behaviors have pointed to several properties that may be useful dimensions to define *similarity* or *dissimilarity,* including (a) cortical preparation for movement

(Wohlert, 1993); (b) kinematic profile and linkages (Klusek, 2008; Matsuo & Palmer, 2010; Shaiman, McNeil, & Szuminsky, 2001; Sowman et al., 2009); (c) similarity of tongue shapes (Hiiemae & Palmer, 2003); (d) similarity of timing patterns (Franz, Zelaznik, & Smith, 1992); (e) extent of practice, with speech commonly regarded as an overlearned, highly practiced behavior (Moser et al., 2009); (f) respiratory drive for phonation (Nip, Green, & Marx, 2009); (g) neural network specialization (discussed in a later section); (h) degree of autonomic system arousal (Arnold, MacPherson, & Smith, 2014); and (i) task specificity (Clark, 2012; Poletto, Verdun, Strominger, & Ludlow, 2004; Tremblay, Houle, & Ostry, 2008; Wilson, Green, Yunusova, & Moore, 2008). If the last of these, task specificity, is appropriately defined, it could conceivably subsume the other factors, which is to say that speech is uniquely task specific and does not substantially overlay any other motor act with respect to its goals and dynamics. Keeping in mind that speech is not a single task, it may still be possible to define core aspects of speech that unify the various behaviors listed in Appendix A.

Coactivation of respiratory, laryngeal, and upper airway motor neurons is a potentially defining characteristic of speech—one that distinguishes speech from many, if not most, of the nonspeech or speechlike tasks that have been used in research and clinical practice. Speech, as usually accomplished, involves distributed motor control in which articulatory movements are combined with phonation and a modified respiratory pattern. As commonly noted in introductory texts in speech science, speech production involves more than 100 muscles located in the trunk, neck, and head. To illustrate the control problem of speech production, suppose that each muscle can have the binary states of either contracted or relaxed (of course, muscle activation is much more complex than that, as it involves gradations in degree and duration of contraction within individual muscles). Even with the severe simplification of two activation states for each muscle, the number of possible patterns of motor activation is 2^{100}, or more than 1 nonillion. As a further complication, these muscles are associated with a large and variegated population of muscle fibers (discussed in a following section). These properties derive from the distributed motor control that is basic to nearly all tasks of speech production, including phonation and articulation. In contrast, many of the NSOMs that have been used in clinical practice and research involve limited motor activation, sometimes only an isolated movement of an articulator, devoid of a larger movement context. The degrees of freedom problem is therefore very different between speech, with its multiarticulate complexity, and NSOMs that often involve one or two selected oral structures.

It is well established that speech uses only a fraction (20% or less) of the force capability afforded by its muscles (Amerman, 1993; Barlow & Rath, 1985; Hinton & Arokiasamy, 1997; Kent, Kent, & Rosenbek, 1987). Therefore, high levels of force developed in nonspeech activities, such as maximum compressive force, may have marginal relevance to motor control in speech. Maximum performance measures of the speech musculature have a long history but remain somewhat clouded as to standardization of procedures and interpretation of data (Kent et al., 1987). Rate of change of force production, independent of the magnitude of force, may be a more relevant variable in speech, but there have been few studies on this aspect of force control in relation to speech and nonspeech movements. In the main, speech movements do not deliver high levels of force, but the levels of force change quickly to meet the demands of seriated movement. It has been reported that lip and tongue movements in speech are faster (i.e., have a higher natural frequency) not only in comparison with limb movements but also in comparison with lip movements in a task of voluntary contraction (Ito, Murano, & Gomi, 2004). The different estimates of natural frequency obtained for speech movements of the lips versus voluntary contraction of the lips could mean that speech motor control recruits predominantly fast-twitch fibers, whereas motor control of voluntary contraction recruits predominantly slow-twitch fibers. Rate of performance has been an important factor in other studies comparing speech and nonspeech movements. Bose and van Lieshout (2012) reported that speechlike and nonspeech movements had similar kinematic and coordination characteristics for a common task goal of bilabial closure. But when rate of performance was increased, functional adaptations in the form of decreased amplitude and duration were observed only for the speechlike task, indicating that speechlike behaviors are subject to a different form of motor control strategy than similar nonspeech tasks.

Many commonly used tasks straddle the boundary between *speech* and *nonspeech,* or between *speech* and *quasispeech*, depending on how these terms are defined (and they usually are not, which adds to the confusion). *Syllable diadochokinesis,* also called *alternating movement rate,* is frequently incorporated in assessment and treatment protocols and is considered by some writers as speechlike or quasispeech (Weismer, 2006) or as paraspeech (Brendel et al., 2013) because it has phonetic content and can match the syllable rate of conversational speech but does not meet the usual definition of meaningful speech. Nonsense syllables and nonwords (pseudowords or nonce words) similarly fall into a gray zone between nonspeech and speech performance, depending on how speech is defined. The Children's Test of Nonword Repetition (Gathercole, Willis, Baddeley, & Emslie, 1994), the Nonword Repetition Test (Dollaghan & Campbell, 1998), the Syllable Repetition Test (designed for children with misarticulations; Shriberg et al., 2009), and the Preschool Repetition Test (Chiat & Roy, 2007; Roy & Chiat, 2004) have a borderline position, given that they include phonotactic sequences suitable for the language under test but these sequences do not form actual words in the language. In other words, the stimuli are phonetically acceptable but lexically nonexistent (but could be candidates for inclusion in the lexicon). NWR is used primarily to gauge phonological memory or phonological representation (Gathercole et al., 1994) but actually draws on many skills (Archibald & Gathercole, 2006; Archibald, Joanisse, & Munson, 2013; Coady & Evans, 2008). Rather little attention has been given to the interplay with motor control, although motor performance is intrinsic to the task, as demonstrated by Krishnan et al. (2013).

The role of meaning is an important issue. Whereas speech movements may be associated with meaning through lexical items, it is often assumed that NSOMs, nonsense syllables used in diadochokinesis, and nonwords used in NWR do not carry meaning. When meaning can be attached to a task, as in Wohlert's (1993) use of a word to compose a speech task, various linguistic and cognitive factors may come into play, not the least of these being a high degree of motor practice and perhaps motor programs associated with speech. The assumption in this review article is that "speech" is not necessarily defined in terms of the communication of meaning. Certainly, speech can be used to communicate meaning, but important attributes of speech can be ascertained in tasks that are generally considered to be free of meaning (e.g., diadochokinesis, vowel prolongation, NWR).

An important caveat must be noted. The primary focus of this discussion is on oral motor tasks, but laryngeal and respiratory participation cannot be neglected, given that speech is not only an oral behavior but also a laryngeal and respiratory one. The present discussion is limited to the kinds of oral movements traditionally included in the NSOM category. However, many of the activities subsumed in general discussions of NSOM draw on muscular systems beyond those that are strictly confined to the oral cavity. Therefore, the term *NSOM* can be misleading. It is important to delineate the total set of muscular requirements in any tasks that are labeled "speechlike" or "nonspeech."

Still needed is an analysis of speech and nonspeech tasks with respect to the physiological envelope of oral sensorimotor performance. As noted earlier, speech clearly departs from some commonly used nonspeech tasks (e.g., maximum force efforts) in that healthy speech relies on only a small portion of the physiologically possible force developed in oral structures. But speech does seem to share a maximum effort accomplishment in comparison with diadochokinetic tasks (for both syllables and isolated movements). The physiological requirements of speech differ from those for certain nonspeech tasks but not necessarily all such tasks.

Craniofacial Muscular Systems

Because the muscles and actions of interest in this review article serve a wide variety of functions, it is not surprising that they have been subsumed under different names that reflect particular functions, both speech and nonspeech. Commonly used functional divisions are listed in Appendix B.

Different functions may draw on the same muscles, but this does not mean that the muscles are recruited and controlled in the same way. The craniofacial muscles are a common subset of the functional divisions listed in Appendix B. These muscles are of particular interest in elucidating NSOMs because they are involved in the majority of NSOM tasks used in clinical assessment, clinical treatment, and control conditions for the study of speech motor control and neural activation. The craniofacial, masticatory, and laryngeal muscles are used in very different ways to accomplish very different purposes. Their pluripotential functionality arises in part from the characteristics of their muscle fibers. The craniofacial muscles as a group are different from limb and trunk muscles in having polymorphic muscle fibers (Kent, 2004; McLoon & Andrade, 2013; Sambasivan, Kuratani, & Tajbakhsh, 2011; Sciote, Horton, Rowlerson, & Link, 2003; Shuler & Dalrymple, 2001) and distinct myogenesis (Tzahor, 2009). The heterogeneous fiber composition of these muscles endows them with the capability for widely varying force production and variable rates of contraction. The craniofacial muscles differ not only from limb and trunk muscles in this respect, but they also differ from one another, in agonist–antagonist combinations, and sometimes even from belly to belly within the same muscle.

Different muscle-fiber types can be arranged in a continuum of contraction speeds ranging from low to high as follows:

I – IC – IIC – IIAC – IIA – IIAB – IIB – IIX

The continuum is enhanced by the presence of developmental isoforms (e.g., fetal), specialized isoforms (e.g., mandibular, cardiac), and hybrid fibers (e.g., IM/IIC), where the last of these usually have contraction speeds intermediate to their constituent pure isoforms.

Table 3 is a compilation of muscle-fiber types for the primary muscles of the craniofacial system related to speech and other oral functions. Probably no other human muscular system, with the possible exception of the ocular muscles, rivals the heterogeneity found in these muscles. One functional consequence is that these muscles can serve very different purposes. For example, the masticatory muscles can (a) generate large forces needed to break down food, (b) provide the stable platform needed for swallowing, (c) perform rhythmic actions used in mastication, or (d) assist the rapid phasic movements of the tongue and lower lip in speech production. Slower-type profiles (dominance of slow-twitch Type I fibers) are found in the zygomatic, jaw elevators, posterior tongue, palatal elevators, caudal pharyngeal constrictor, and the laryngeal abductor (posterior cricoarytenoid). These profiles are suited to tonic contractions and postural support. Faster-type profiles (dominance of fast-twitch Type II fibers) are found in the lips (orbicularis oris), jaw depressors, anterior tongue, palatal depressors, rostral pharyngeal constrictor, and laryngeal adductors. These profiles are suited to rapid phasic movements. Speech production draws on both slower (slow-twitch) and faster (fast-twitch) motor fibers, which cooperate to achieve the frequently concomitant goals of postural support and rapid movement. Even within the same articulator, different tasks can recruit different populations of

Table 3. Relative proportions of muscle-fiber types in human craniofacial muscles.

Muscle	I	IM	IIC	IIA	IIAB	IIB	IIX	Fetal	Cardiac	Tonic	Hybrid
Facial											
Orbicularis oris	X		X	XXXX							
Buccinator	XXX		X	XXX							
Zygomatic	XX			XX	XX						
Tongue											
Superior longitudinal	XXX			XX	X	X					X
Transverse longitudinal	XX			XXX	X	X					X
Genioglossus	X			XXX							X
Jaw											
Elevators	XXX	XX		X			X	X	X		XXX
Suprahyoid depressors	XXX			XXX			X				X
Infrahyoid depressors	XXX			XXX			X				X
Palatal											
Palatopharyngeus	X			XX	XX						X
Uvula	X			XXX	XX						
Levator veli palatini	XXX			X	X						
Tensor veli palatini	XXX			X	X						
Pharyngeal											
Pharyngeal constrictor, rostral	XX			XXX							X
Pharyngeal constrictor, caudal	XXX			XX							
Cricopharyngeal	XX			XXX							X
Cricothyropharyngeus	XXX			XX			X			XX	
Laryngeal											
Posterior cricoarytenoid	XXX			X							X
Cricothyroid	XX			XXX						XX	
Lateral cricoarytenoid	XX			XX			XX				
Thyroarytenoid	XX			XXX			XX				X
Vocalis	XX			XX			XX				

Note. X = present in limited number; XX = significant proportion; XXX = predominant fiber type. *Facial:* Freilinger et al. (1990); Hwang, Kim, & Hwang (2007); Schwarting, Schröder, Stennert, & Goebel (1982); Stål, Eriksson, Eriksson, & Thornell (1990). *Tongue:* Daughtery, Luo, & Sokoloff (2012); Granberg, Lindell, Eridsson, Pedrosa-Domellof, & Stål (2010); Saigusa, Niimi, Yamashita, Gotoh, & Kumada (2001); Stål, Marklund, Thornell, DePaul, & Eriksson (2003). *Masticatory:* Hoh (2002); Korphage, Brugman, & Van Euden (2000); Korphage & Van Eigden (2003); Osterland (2011); Sciote, Rowlerson, Hopper, & Hunt (1994); Stål (1994); Yu, Stål, Thornell, & Larson (2002). *Soft palate:* Stål & Lindman (2000). *Pharynx:* Leese & Hopwood (1986); Mu & Sanders (2001, 2007, 2008); Mu, Wang, Su, & Sanders (2007); Smirne et al. (1991); Sundman, Ansved, Margolin, Kuylenstierna, & Eriksson (2004). *Larynx:* Hoh (2005); Li, Lehar, Nakagawa, Hoh, & Flint (2004); Sciote, Morris, Brandon, Horton, & Rosen (2002).

muscle fibers, so that articulatory movements are distinct from voluntary nonspeech contractions in the recruited muscle-fiber types (Ito et al., 2004).

Muscle-fiber polymorphism is one aspect of the flexibility and adaptability of the craniofacial system in meeting the needs of highly specialized functions such as speech, mastication, and swallowing. Heterogeneity of muscle fibers is one possible reason why the same muscles can serve very different functions that rely on specific combinations of speed, force, and metabolism. Equivalence of function in a particular task may rest not only on the recruitment of specific muscles but also on recruitment of particular populations of motor units and muscle-fiber types. Task-specific motor units may be identified as the different combinations of muscle fibers that are recruited depending on the direction and dynamics of the intended force (Ito et al., 2004; Sciote & Morris, 2000). Table 3 is only a partial depiction of what might be called the "motor keyboard of speech production" (the choices available in a speaking task), showing in a general way how muscle-fiber types are distributed across muscles. The tabled information is incomplete because muscle-fiber types can differ between portions of a given muscle. Moreover, the muscles of the respiratory system are not represented in Table 3. But, the central point is that the craniofacial muscles have properties that are well suited to their varied functions. In comparing movements performed by a given structure in different tasks, it is important to assess the task requirements and the implications for recruitment of muscle fibers.

Neural Representation of NSOM Tasks vis-a-vis Speech Tasks

Recent articles dealing with the distinction between "speech" and "nonspeech" have asserted that speech motor control is associated with a left-lateralized (at least in right-handed individuals) neural network that is specialized for the unique properties of speech (Bunton, 2008; Ziegler, 2006; Ziegler & Ackermann, 2013). Specialization is not surprising given that speech necessarily is linked to the cognitive structures of language, whereas nonspeech actions are not. But the question that remains is whether some aspects of neural representation are shared by speech and nonspeech behaviors; if so, what advantage do these shared neural resources give to the study of speech and its disorders?

The importance of NSOM tasks derives from several factors, but especially the relative ease and completeness of peripheral description (movement specification) and a growing body of data concerning their neural representation. A link between cortical control and movement is an important part of the overall understanding of both NSOM tasks and speech production. A fairly extensive corpus of data has been established on neural activation patterns for speech and NSOM tasks using methods such as positron emission topography (PET), functional magnetic resonance imaging, and near-infrared spectral imaging (NIRSI) to measure localized changes in cerebral blood flow that are interpreted as changes in neural activation. Table 4 summarizes several studies to show similarities and differences in neural activation for speech and nonspeech. Table 4 is organized to indicate general areas of neural activation for different behaviors but should not be taken to imply that activations within an area or structure are isomorphic across speech and nonspeech tasks.

In a meta-analysis of 54 neuroimaging studies of nonspeech tasks involving respiration, lip movement, tongue movement, and swallowing, Takai, Brown, and Liotti (2010) concluded that the patterns of activation for these tasks is best described as "somatotopy with overlap" (a correspondence of specific body structures to specific points on the central nervous system). This result was interpreted to reflect the "intrinsic functional interconnectedness of the oral effectors for speech production" (p. 39). Activation patterns resembling somatotopy with overlap have been demonstrated in other studies, including comparisons of speech versus nonspeech movements (Grabski et al., 2012; Lotze, Seggewies, Erb, Grodd, & Birbaumer, 2000), swallowing versus nonspeech movements (Martin et al., 2004; Ogura, Matsuyama, Goto, Nakamural, & Koyano, 2012), and vocal versus nonvocal laryngeal tasks (Brown et al., 2009; Brown, Ngan, & Liotti, 2008). This is not to say that cortical neurons behave in exactly the same way for NSOM tasks as they do for speech and swallowing, but simply to say that there are strong similarities in the topography of cortical representation. *Proximal* does not mean isomorphic, and only a close and rigorous investigation is capable of settling this issue. The cortical map of speech is being determined with increasing clarity, even to the point of representation of phonemes and phonetic features (Conant, Bouchard, & Chang, 2014).

Aflalo and Graziano (2006) proposed that the topographic organization of the motor cortex for manual operations reflects a competition among several conflicting requisites, such as "somatic map of the body, a map of hand location in space, and a partitioning of cortex into regions that emphasize different complex, ethologically relevant movements" (p. 6288). Similarly, cortical representation of the speech articulation system could include a map of the vocal tract (articulatory–acoustic relationships), a map of the articulators in their respective anatomic working spaces, and a parcellation of the cortex into ethologically important functions (e.g., licking, chewing, and swallowing), which can occasionally be carried out in combination or sequencing with speech (e.g., chewing gum while talking, licking the lips during a long speech, or depressing the jaw for an inspiratory pause). Somatotopy with overlap ensures that speech and nonspeech motor functions can be accommodated and coordinated in an overall behavioral regime, such as conversing over dinner or integrating laughter with speech (Nwokah, Hsu, & Davies, 1999).

Although there is some variation among published descriptions of the network for overt speech, studies using brain imaging techniques generally have concluded that the network includes at least the following components: supplementary motor area, motor cortex, Brodmann area 44,

Table 4. Activation of selected brain structures for speech and nonspeech oral activities. X = activation reported; details are noted in some cells.

Study	Sensori-motor cortex	Premotor cortex	SMA	Inferior frontal gyrus	Temporal cortex	Insula	Thalamus	Basal ganglia	Cerebellum
Speech									
Chang, Kenney, Loucks, Poletto, & Ludlow (2009)	X		X	X	X	X	X	Lentiform nucleus, putamen	X
Eickhoff et al. (2009)	X	X	X	X		X		Caudate	X
Park et al. (2011)	X	X	X	X	X	X	X	X	X
Price et al. (2011)	X		X		X	X	X	Putamen	Inferior
Riecker et al. (2008)	X	X	X	X	X	X	X	Caudate putamen pallidum	Superior inferior
Sörös et al. (2006)	X	X	X	X	X	X	X	X	X
Nonspeech									
Byrd et al. (2009)	X		X	X		X		Caudate putamen	
Chang, Kenney, Loucks, Poletto, & Ludlow (2009)	X	X	X	X	X	X	X	Lentiform nucleus, putamen	X
Corfield et al. (1999)	X	X	X	X		X	X	Putamen	Superior inferior
Dresel et al. (2005)	X	X	X				X	X	X
Price et al. (2011)	X		X		X	X	X	Putamen	Inferior

sensory cortex, putamen, and cerebellum, as discussed in the following. Bohland and Guenther (2006) proposed a "minimal network for overt speech production." Studies indicate that this network includes mesiofrontal structures (supplementary motor area and anterior cingulate gyrus), bilateral pre- and postcentral convolutions, extending rostrally into posterior parts of the inferior frontal gyrus, the left anterior insula as well as bilateral components of the basal ganglia (notably the putamen and the globus pallidus), the cerebellum (notably the lobule VI, including the declive), the thalamus, and the superior temporal gyrus (Bohland & Guenther, 2006; Brown et al., 2009; Golfinopoulos, Tourville, & Guenther, 2010; Guenther, 2006; Price, 2010, 2012; Riecker, Brendel, Ziegler, Erb, & Ackermann, 2008; Simmonds et al., 2014; Sörös et al., 2006). Price (2012) offers an extensive review of PET and functional magnetic resonance imaging studies of speech perception and spoken language.

Clinical Applications of NSOMs

Assessment and Treatment of Speech Disorders

In speech-language pathology, a sizeable literature has accumulated on the use of NSOMs. Accordingly, this section is relatively lengthy in comparison with the other sections of this review article.

Assessment

NSOM tasks have a long history of application in clinical testing and assessment. Tasks of this kind are noted in classic texts and have been incorporated in a number of assessment protocols and test batteries for speech and nonspeech functions, including *Motor Speech Disorders: Substrates, Differential Diagnosis, and Management* (Duffy, 2005), Dysarthria Examination Battery (Drummond, 1993), Dysarthria Profile (Robertson, 1982), Frenchay Dysarthria Assessment (Enderby & Palmer, 2008), Kaufman Speech Praxis Test for Children (Kaufman, 1995), Nordic Orofacial Test–Screening (Bakke, Bergendal, McAllister, Sjogreen, & Asten, 2007), Oral Speech Mechanism Screening Examination–Third Edition (St. Louis & Ruscello, 2000), Orofacial Myofunctional Evaluation With Scores (de Felicio & Ferreira, 2008), Robbins-Klee Oral Speech Motor Protocol (Robbins & Klee, 1987), Verbal Dyspraxia Profile (Jelm, 2001), and Verbal Motor Production Assessment for Children (Hayden & Square, 1999). According to the Speech-Language Pathology Medical Review Guidelines (ASHA, 2011), "neurological motor speech assessment looks at the structure and function of the oral motor mechanism for nonspeech and speech activities including assessment of muscle tone, muscle strength, motor steadiness and speed, range, and accuracy of motor movements" (p. 43). Nonspeech motor acts are by no means exclusive to the oral domain, as such tasks have been used in the assessment of respiratory function related to speech (Hixon & Hoit, 1998, 1999, 2000; Spencer, Yorkston, & Duffy, 2003).

As just described, there is a substantial history in the development of tools to assess oral functions related to speech and other behaviors. The taxonomy in Table 2 can be used to compare different approaches to oral motor assessment. For example, (a) the oral motor function components in the Nordic Orofacial Test–Screening pertain almost entirely to Cells 1 and 13; (b) the oral mobility components in the Orofacial Myofunctional Evaluation With Scores are drawn almost exclusively from Cell 13; and (c) the Robbins-Klee Oral Speech Motor Protocol has oral function components that match Cells 1, 11 (or 12 if sound is considered), and 13. In general, the commonly used assessments draw on only a modest selection of the available alternatives, with a concentration on Cell 13 in Table 2. Whether a larger and more systematic use of the functions in Table 2 is warranted is a matter left to research, but a wider use of the tabled functions may help address issues such as coordination of muscle systems in various nonspeech tasks, as well as provide a basis of comparison among different clinical assessments.

The potential value of NSOMs and quasispeech tasks rests not only in their relationship to more complex speech behaviors but also in their potential to reveal neurological abnormalities that are of interest in their own right. For example, diadochokinesis has been suggested to be (a) an index of motor control in various dysarthrias (Ackermann, Hertrich, & Hehr, 1995; Konstantopoulos, Charalambous, & Veroeven, 2011; Masaki & Seiji, 2002; Nishio & Niimi, 2000; Wang, Kent, Duffy, Thomas, & Weismer, 2004; Ziegler, 2002), (b) a means of assessing axial neural functions in conditions such as Parkinson's disease (Skodda, Flasskamp, & Schlegel, 2010), (c) a sensitive measure of speech disturbance in ataxia (Sidtis, Ahn, Gomez, & Sidtis, 2011), (d) a prognostic parameter for the outcome of diffuse axonal injury in head trauma (Ergun & Oder, 2008), (e) a task that is sensitive to motor abnormality even in premanifest Huntington's disease (Saft, Schlegel, Hoffman, & Skodda, 2014), (f) a measure of treatment outcome in apraxia of speech (Hurkmans, Jonkers, Boonstra, Stewart, & Reinders-Messelink, 2012), (g) a component in a diagnostic protocol for childhood apraxia of speech (Murray, McCabe, Heard, & Ballard, 2015), and (h) an index of motor sequencing deficit in an endophenotype of speech sound disorder (Peter, Matsushita, & Raskind, 2012).

Diadochokinesis has a value in linking neural control capabilities with effector capabilities. For example, it is noteworthy that the orbicularis oris superior and inferior muscles of the lip (which, as shown in Table 3, have an abundance of fast Type IIA fibers) have a natural frequency of 6.1 Hz (Ito et al., 2004), which corresponds to the typical maximum diadochokinetic rate (Kent et al., 1987) and the rate of syllable production closely associated with activation of the cerebellum (Wildgruber, Ackermann, & Grodd, 2001). That is, the accomplishment of rapid speech production, as assessed in diadochokinesis, draws on the fast-twitch capability of the articulatory muscles and the rate-control neural circuit in which the cerebellum appears to play a critical role.

NSOMs used in assessment may not be equivalent to speaking tasks, but task equivalence is not the only criterion for judging the usefulness of motor tasks. Even when nonspeech tasks plumb motor abilities well outside the physiologic envelope of speech, there can be justification for their use. In neurodegenerative diseases such as Parkinson's disease or amyotrophic lateral sclerosis, as well as other neurological disorders, determination of maximum strength or capacity in a nonspeech task can serve as an indicator of motor impairment, possibly before specific functions such as speech are affected. Such clinical value has been reported for measures of tongue strength or endurance in amyotrophic lateral sclerosis (Langmore & Lehman, 1994; Weikamp, Schelhaas, Hendriks, de Swart, & Geurts, 2012), traumatic brain injury (Goozée, Murdoch, & Theodoros, 2001; Theodoros, Murdoch, & Stokes, 1995), myasthenia gravis (Weijnen et al., 2000), and Parkinson's disease (Solomon, Robin, & Luschei, 2000).

Treatment

It appears from survey data that NSOMs are frequently used in the treatment of children's speech sound disorders (Joffe & Pring, 2008; Lof & Watson, 2008), although frequency of use may be declining for younger clinical populations (Brumbaugh & Smit, 2013). Much of the criticism and caution regarding the therapeutic application of NSOMs pertains to this class of disorders (Forrest, 2002; Lass & Pannbacker, 2008; McCauley, Strand, Lof, Schooling, & Frymark, 2009; Powell, 2008; Ruscello, 2008). The preponderance of the evidence does not support the use of NSOM tasks in treating developmental speech sound disorders. The rationales for the use of NSOM tasks in clinical treatment include (a) influencing the resting posture and/or movement of the lips, jaw, and tongue (Hanson, 1994; Hodge, 2002); (b) increasing strength, improving muscle tone, and extending range of movement (Boshart, 1998; Marshalla, 2004); and (c) improving motor control and function through sensory stimulation (Clark, 2003). Ruscello (2008) observed that nonspeech oral motor treatments differ from phonetic and/or phonemic treatments because they specifically target nonspeech movements and oral postures as a step toward the development of motor patterns for speech sound production.

The therapeutic value of NSOM tasks may depend on the specific type of speech disorder. The category of developmental speech sound disorders embraces various hypothesized subtypes. For example, Bahr and Rosenfeld-Johnson (2010) proposed the clinical category of oral placement disorder for children who are not stimulable—that is, they cannot imitate targeted auditory and/or visual models that may be accompanied by instructions, cues, imagery, feedback, and encouragement. More research is needed to determine if oral placement disorder is a distinct clinical category with well-defined diagnostic features.

NSOMs frequently have been used in the treatment of dysarthria (Mackenzie et al., 2011), but this application is not without controversy (Hodge, 2002; Weismer, 2006). One of the most rigorously examined interventions, Lee Silverman Voice Treatment (LSVT; Fox, Ebersbach, Ramig, & Sapir, 2012; Fox et al., 2006), includes nonspeech motor exercises as one component. NSOMs also have been used in the behavioral management of speech production in childhood and adult dysarthria (Ray, 2001, 2002) and in treating respiratory/phonatory dysfunction (Spencer et al., 2003). Another clinical application of NSOM is *differentiated vocal tract control* (DVTC), or the concept that individuals can learn the voluntary manipulation of specific muscular and biomechanical structures within the larynx and vocal tract (e.g., false vocal fold activity, true vocal fold mass, and larynx height; Honda, Hirai, Estill, & Tohkura, 1995; Kmucha, Yanagisawa, & Estill, 1990; Madill, Sheard, & Heard, 2008; Yanagisawa, Estill, Mambrino, & Talkin, 1991). This concept is included in two models of vocal training: Estill Voice Training Systems (Santa Rosa, CA) and Voicecraft (Adelaide, South Australia). In general, persons receiving the training are cued initially to move the desired muscular structures in a familiar task, such as coughing, yawning, or laughing. The learned movement is then refined and shaped through repetition with kinesthetic and auditory feedback. Apparently, randomized clinical trials have not been reported on the outcomes of DVTC interventions.

NSOMs also can be a part of the practice of *orofacial myology,* defined as "the science and clinical knowledge dealing with muscles of the mouth and face (orofacial muscles) and the typical and atypical variations of the functions thereof" (ASHA, n.d.). The original focus of orofacial myology was on the horizontal dimension of oral function, especially tongue thrusting, but Mason (2008) stated that the "common denominator for myofunctional conditions is a change in the inter-dental arch vertical rest posture dimension, the dental freeway space" (p. 5). Among the therapeutic components that a speech-language pathologist might address are efforts to increase awareness of the muscles and postures of the orofacial system and to improve muscle strength and coordination (ASHA, n.d.). Presumably, NSOMs are one means to achieve these objectives. Although research on clinical outcomes from orofacial myology is not extensive, promising reports have been published on speech production in cerebral palsy (Ray, 2001) and adult dysarthria (Ray, 2002).

Motor Learning

Task specificity is a key concept in motor learning, but the term often is used without explicit definition. The specificity of learning hypothesis states that learning is accomplished most effectively when practice sessions incorporate context and movement conditions similar to those required during performance of the intended task. The degree of similarity is open to question. Defining the task of speech is complicated if one considers the various forms of speech described in Appendix A. If each form is taken to define a task with its own context and movement conditions, then speech is not a single task but rather a multiplicity of tasks. If the task of speech is narrowly defined, then it becomes difficult to determine the conditions under which generalization across tasks may occur. Research in the rehabilitation sciences generally raises doubt as to the formulation of any possible generalization or classification of movement particulars. A countervailing perspective is found in concepts such as structure learning. As applied to the motor system, *structure learning* implies "the learning of abstract motor strategies that are applicable in a wide range of environments that share common structures" (Braun, Mehring, & Wolpert, 2010, p. 163). The primary benefit of this approach is that it reduces the dimensionality of the space that the motor learning system needs to explore to deal with novel conditions.

Conclusion

This review article is not a disquisition on whether NSOM tasks should be part of clinical intervention for speech sound disorders. The recent literature is replete with thrust and parry on this issue, but a conservative conclusion is that the evidence is equivocal (McCauley et al., 2009; Ruscello, 2010). The vigorous discussion of these tasks in the treatment of developmental speech sound disorders has not shed much light on the more general question of whether NSOM tasks have any value in the clinical armamentarium. Wholesale rejection of these methods seems imprudent, given their inclusion in apparently useful assessments and efficacious interventions (e.g., LSVT and DVTC). The present review article has a modest objective: to propose a taxonomy of NSOM tasks that lends itself to systematic application and testing. The rationale for this taxonomy is that NSOM tasks represent an array of sensory and motor components, and these components are critical in judging the similarity or dissimilarity between a given NSOM task and a speech task.

Assessment and Treatment of Related Communication and Oral Disorders

Whatever the relationships may be between NSOMs and speech disorders, there is a continuing enquiry into the possible role of NSOMs in other communicative and oral behaviors. The following sections examine some of these, but the list is by no means exhaustive.

Relationship Between Motor Behavior and Language

Although it was initially assumed that specific language impairment is not related to problems in other areas such as motor development, recent research points to the contrary conclusion. Children with language disorders or dyslexia often present with atypical motor skills. The relationship has been shown in studies of gross and fine general motor skills (Bishop, 2002; Dewey & Wall, 1997; DiDonato Brumbach & Goffman, 2014; Fawcett & Nicolson, 1995; Finlay & McPhillips, 2013; Hill, 2001; Noterdaeme, Mildenberger, Minow, & Amarosa, 2002; Rechetnikov & Maitra, 2009; Vischer, Houwen, Scherder, Moolenar, & Hartman, 2007; Webster, Majnemer, Platt, & Shevell, 2005) and oral motor skills (Amorosa & Noterdaeme, 1992; Amorosa & Scheimann, 1989; Dewey & Wall, 1997; Noterdaeme et al., 2002; Stark & Blackwell, 1997). Oral motor performance also appears to be a predictor of verbal fluency in individuals with autism (Amato & Slavin, 1988; Belmonte et al., 2013; Gernsbacher, Sauer, Geye, Schweigert, & Goldsmith, 2008). Co-occurrence of language and motor impairments does not establish a causal link but rather may show a tendency for both language and motor functions to be disturbed by a common underlying disorder. A relationship between oral motor function and language also is indicated in studies of typical development (Wang, Lekhal, Aarø, & Schjølberg, 2014). Examination of motor skills, including oral motor skills, may be useful in providing an overall assessment of children with delayed language development. "Specific language impairment" may not be specific to language after all. Although the language impairment may be an especially salient feature, it is not necessarily the sole aspect of the disorder, and important insights may be gained by placing the language impairment in a larger context of functional impairments.

Assessment and Treatment of Feeding Difficulties and Drooling

NSOM tasks have been used to assess and treat problems related to mastication and swallowing, including drooling. Tongue movement has been reported to be an independent predictor of aspiration in individuals with dysphagia (Leder, Suiter, Murray, & Rademaker, 2013). Reviews of the evidence for NSOM in treatment have been published for both children and adults. For children, the evidence is insufficient to draw a firm conclusion about the value of NSOM exercises for either swallowing disorders (Arvedson, Clark, Lazarus, Schooling, & Frymark, 2010) or drooling (Fairhurst & Cockerill, 2011; Silvestre-Rangil, Silvestre, Puente-Sandoval, Requeni-Bernal, & Simó-Ruiz, 2011). Evidence that drooling in cerebral palsy is related to dysfunctional oral motor control (Erasmus et al., 2009) is rationale for the use of oral motor exercises as a treatment. Limited evidence of improved function following use of NSOM tasks has been reported for adults. Increased isometric and swallowing pressures have been observed following lingual strengthening exercises in a group of older adults (Robbins, Gangnon, Theis, Kays, & Hind, 2005). Benefits also have been observed for labial or lingual strengthening exercises in individuals who had strokes (Hägg & Anniko, 2008; Robbins et al., 2007; Yeates, Molfenter, & Steele, 2008). The reports published to date may have value in determining the dosage in future studies. The frequency and overall duration of treatments in several studies were as follows: daily for 3 months (Carroll et al., 2008), three times daily for at least 5 weeks (Hägg & Anniko, 2008), daily for 2 months (Kang et al., 2012), 5 days per week for 1 month (Lazarus, Logemann, & Huang, 2003), 3 days per week for 8 weeks (Robbins et al., 2007), and two to three times per week for a total of 24 to 90 sessions depending on the patient (Yeates et al., 2008). The positive results in these studies encourage further research to determine the magnitude and duration of benefits.

Treatment of Obstructive Sleep Apnea Syndrome

During sleep in individuals with an anatomically small upper airway, failure of the pharyngeal muscles to maintain patency results in collapse of the airway. This condition, obstructive sleep apnea syndrome (OSAS), not only disturbs sleep but predisposes individuals to a number of serious medical problems. OSAS is typically managed with CPAP or oral appliances such as those used to promote mandibular advancement. Although CPAP is considered to be an efficacious intervention, patient compliance is a major concern (Yetkin, Kunter, & Gunen, 2008). Oral appliances can be effective but can have an undesirable side effect of changing dental occlusion (Hoekema, Stegenga, & de Bont, 2004).

Positive clinical outcomes from behavioral therapy have been reported in two randomized clinical trials involving oral exercise. In a study by Guimaraes, Drager, Genta, Marcondes, and Lorenzi-Filho (2009), patients were instructed by speech pathologists to perform lingual and facial exercises for 20 min daily. The exercises included brushing the tongue with a toothbrush, contacting the tip of the tongue to the palate and sliding the tongue backward, pronouncing vowels quickly or continuously, and keeping the tongue in a specified position when eating. The authors concluded that "oropharyngeal exercises significantly reduced OSAS severity and symptoms and represent a promising treatment for moderate OSAS" (p. 962). See Steele (2009) for a comment on the report by Guimaraes et al. (2009) and Steele, Bailey, Molfenter, and Yeates (2009) for a review of strength training of the tongue. Puhan et al. (2005) studied the effects of playing the didgeridoo, a wind instrument that involves phonation and breath control. After 4 months of playing this instrument approximately 6 days per week for about 25 min a day, the average Apnea–Hypopnea Index decreased by about 50%. In a study of myofunctional therapy, Pitta et al. (2007) reported improvements in OSAS following 16 daily sessions of isometric, isotonic, and isokinetic exercises. Finally, Diaferia et al. (2013) concluded that speech therapy alone or in association with CPAP may be an alternative treatment for the improvement of quality of life in patients with OSAS. Although these reports are not sufficient to establish standards for clinical intervention, they invite replication and further study. One common aspect of these three studies is that the treatments were frequent (daily or nearly so) and extended for up to 3 or 4 months. This information may help set dosage in future studies, preferably randomized clinical trials. In their systematic review of studies in this area, Valbuza et al. (2010) concluded that "there is no accepted scientific evidence that methods aiming to increase muscle tonus of the stomatognathic system are effective in reducing AHI [Apnea–Hypopnea Index] to below five events per hour" (p. 299).

Trismus

Trismus, or hypomobility of the jaw (typically appearing as reduced mouth opening), can occur as the result of several conditions, including dental disease or procedures, temporomandibular joint dysfunction, oral surgery, radiation therapy for head and neck cancer, infection, arthritis, and trauma. Oral exercises have been shown to be effective in increasing mouth opening in patients with trismus, although the benefit varies with etiology (Dijkstra, Kalk, & Roodenburg, 2004). One of the devices specifically developed for such treatment is TheraBite, which is used by physical therapists and speech-language pathologists.

Involuntary Hyperkinetic Oral Movements

A striking feature of involuntary oral movements is that they occur with considerable frequency in neurological and psychiatric disorders. The abnormal movements take several forms, including bruxism, orofacial dyskinesias, oromandibular dystonia, hemifacial spasm, and oral and facial tics (Bhidayasiri & Boonyawairoj, 2011; Clark, 2006). The hyperkinetic disorder can manifest in a single organ (e.g., jaw opening, tongue protrusion), or it may involve a number of contiguous or noncontiguous structures. Orofacial tardive stereotypies (formerly known as *orofacial tardive dyskinesias*) are associated especially with first-generation antipsychotic (neuroleptic) medications and are a well-known example of involuntary orofacial movement (Bhidayasiri & Boonyawairoj, 2011). A *stereotypy* is defined as a "seemingly purposeful, coordinated but involuntary, repetitive, ritualistic gesture, mannerism or utterance" (Bhidayasiri & Boonyawairoj, 2011, p. 134).

The movements include jaw movements (up and down or lateral), chewing, grimacing, wormlike movement of the tongue, tongue protrusion, lip smacking, and lip pursing (many of the same movements assessed in clinical evaluations of oral motor function). Involuntary vocalizations also can occur, especially humming and belching. These stereotypies also have been reported in nonmedicated patients with schizophrenia, in individuals with autism, and in otherwise healthy elderly individuals, especially those who are edentulous. Clark (2006) pointed out that some patients with hyperkinetic oral movements can modify or suppress these movements by appropriate tactile stimulation, such as touching the chin or holding an object in the mouth (effects known as *geste antagonistique*). Although the pathophysiology of orofacial stereotypies is not well understood, one possibility is that distorted information from higher levels of the mesolimbic region causes dysfunction of lower level output structures of this region (Koshikawa, Fujita, & Adachi, 2011). Mouthing movements in some elderly individuals have been linked to cerebellar pathology (Appenzellar & Biehl, 1968). Involuntary oral movements were implicated in one case of foreign accent syndrome (Tetsuo, Minoru, Noriko, Yuko, & Rieko, 2002).

NSOMs as Comparison or Control Conditions in Research on Speech and Oral Motor Control

When properly selected, NSOM tasks are useful as control conditions in the study of motor control for behaviors such as speech, chewing, and swallowing. The tasks that have been selected for this purpose are numerous, ranging from simple movements of a single structure (Cell 13 of Table 2) to concatenations of movement elements to form sequences. The taxonomy in Table 2 can help in the interpretation of data from the various studies of kinematics, motor learning, and neural activation. When NSOM tasks are used as control conditions, it is frequently the difference between the NSOM task and the target (speech) task that is most critical to the design and interpretation of experiments. Relevant differences include the task objective, effectors involved, and kinematic properties. In addition, task performance can be affected by instruction and practice.

Among the NSOM tasks that have been used in comparisons with speech are various vegetative acts, such as sniffing or coughing (Poletto et al., 2004), visual tracking (Vaughan, Neilson, & O'Dwyer, 1988), trained movements or aerodynamic patterns (Bunton & Weismer, 1994; Clark, Robin, McCullagh, & Schmidt, 2001; Klusek, 2008), pairs of sounds formed by orofacial and vocal tract gestures (Chang, Kenney, Loucks, Poletto, & Ludlow, 2009), humming (Flöel et al., 2003), and whistling (Dresel et al., 2005). These tasks vary in their complexity and their similarity to speech. Chang, Kenney, Loucks, Poletto, and Ludlow (2009) used pairs of sounds of orofacial and vocal tract gestures, such as cough–sigh, laugh–tongue click, and whistle–cry. It was noted that the nonspeech targets were easily performed by the participants even though they represented complex oral motor sequences that lacked phonemic structure.

Comparisons of speech and nonspeech have been used to determine if conditions widely believed to be specific to speech also have effects on nonspeech tasks. In particular, studies of this kind have been conducted on both stuttering and apraxia of speech. It has been concluded that individuals who stutter differ from fluent speakers in both speech and nonspeech behaviors (Chang, Kenney, Loucks, & Ludlow, 2009; Choo, Robb, Dalyrimple-Alford, Huckabee, & O'Beirne, 2010; Max, Caruso, & Gracco, 2003). Apraxia of speech (both developmental and adult forms) also has been reported to affect nonspeech as well as speech movements (Aram & Horwitz, 1983; Ballard, Granier, & Robin, 2000; McNeil, Weismer, Adams, & Mulligan, 1989; Murdoch, Attard, Ozanne, & Stokes, 1995; Robin, Jacks, Hageman, Clark, & Woodworth, 2008). The implication of these findings is that the disorders in question have general motor effects rather than being restricted to speech. Systematic examination of different NSOMs, like those identified in Table 2, may illuminate the nature of the motor impairment. Interpretation of the data from these studies may benefit from the classifications in Table 2 or from an extended taxonomy that distinguishes additional movement types.

General Discussion

NSOM tasks have been used for a variety of research and clinical purposes. Interpretation of their value is hindered by ambiguities in their definition and by the variations in their composition. Similarly, interpretation of data on speech behaviors is complicated by their variability according to speaking style, purpose, and task parameters. Taxonomic analysis may be helpful in interpreting studies of speech, paraspeech, quasispeech, and nonspeech tasks and, ultimately, in understanding the relationship between speech and related behaviors involving similar musculature and overlapping patterns of neural activation. Taxonomies may facilitate the development of improved theoretical understanding through the consistent and reliable classification of observations and tasks. For example, a possible framework of movement tasks of increasing complexity would be as follows:

1. Movements of a single articulator (e.g., movement of the tongue tip to contact the alveolar ridge with restrained jaw position)
2. Coordinated articulatory movements (e.g., movements of the tongue and jaw to make contact of the tongue tip with the alveolar ridge)
3. Diadochokinesis (a repeated series of articulatory movements, single or coordinated)
4. NWR (production of a nonword stimulus)
5. Speech production of real words in tasks of varying complexity

Advances in motor skill learning may help shape the understanding of speech and nonspeech motor control. One of these advances is *structure learning,* defined as the similarity of related motor tasks that can constrain the distribution of likely control parameters, thereby reducing the dimensionality of the control problem (Braun, Aertsen, Wolpert, & Mehring, 2009; Kobak & Mehring, 2012). Also relevant is recent work showing that the learning of a motor skill proceeds through stages (Luft & Buitrago, 2005). In the acquisition stage, learning is rapid and occurs within the training session. In the slow learning stage, learning at a slower rate occurs between training sessions, possibly benefitting from consolidation processes during sleep. In the interval just after training begins, the skill is vulnerable to interference by other skills and by protein synthesis inhibition, which is evidence that consolidation occurs during the test periods between training sessions. It has been shown that patterns of brain activation change dynamically in both training sessions and in the rest periods. Motor skill learning should be distinguished from strengthening or endurance exercises. The former pertain to acquisition of a new skill, whereas the latter deal with increased muscle force.

Recent criticisms of NSOM tasks in the treatment of developmental speech sound disorders invite a more general scrutiny of the clinical application of these tasks. Notwithstanding the frequent and historical use of these tasks in the assessment and treatment of various disorders of speech and other oral functions, data supporting their value, particularly to the exclusion of treatments incorporating speech or other targeted functional movements, remain limited. NSOM tasks also are incorporated in several interventions, including LSVT and DVTC, indicating that tasks may contribute to improved speech and voice if they are part of a systematic treatment that focuses on the ultimate behavior of interest.

A question still needing a definitive answer is whether NSOMs provide useful leverage into the treatment of communication disorders or oral motor disorders of any type. To be useful, NSOMs may need only to resemble the target behaviors in some fundamental respect that can be used to modify a motor response, whether by strengthening or altering the basic motor pattern. The relationship between NSOMs and basic oral functions such as swallowing may be closer than the relationship between NSOMs and speech. There are many ways in which speech motor function differs from other functions performed by the same musculature. But are the differences sufficient to render a complete cleavage, or is it more appropriate to conceptualize the two kinds of behavior as proceeding from partially shared resources? Although there is good reason to be skeptical about the clinical utility of NSOMs, it is premature to write their epitaph. Further developments may gain traction by a careful definition of terms, specification of task variables, and sensitive measures of outcome.

The following conclusions are drawn from this narrative review:

1. Speech is appropriately conceived as a variety of tasks and not as a single invariant behavior. In this respect, speech may be more flexible and diverse than any other skilled motor behavior. Data from different speech tasks should be compared with due caution, taking into account their specific demands on cognitive, sensory, and motor resources.
2. NSOMs are diverse in their motor composition, and this diversity should be recognized in research that compares NSOMs with one another, with speech tasks, or with other behaviors involving the oral musculature. A categorization of NSOMs with respect to their constituent properties would help in the design of research and clinical procedures. Definition of *NSOM* depends critically on a definition of *speech,* given that nonspeech and speech activities are mutually exclusive.
3. Controversy continues over the value of NSOMs in the assessment and treatment of communication disorders such as developmental speech sound disorders and motor speech disorders. Evidence for the clinical value of NSOMs appears to be stronger for swallowing disorders and obstructive sleep apnea syndrome, but the evidence base is best regarded as nascent.
4. Future research on the relationship between speech and nonspeech motor behaviors would benefit from careful definitions and classifications of the tasks selected for comparison. The uncritical use of broad categories of speech and nonspeech tasks can cloud the interpretation of data and hinder comparison of results across studies.
5. NSOMs have been examined in a range of behaviors and clinical conditions and are not restricted in their application to speech disorders. Some of these other areas of application fall within the scope of practice of speech-language pathology (ASHA, 2007).

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Appendix A (p. 1 of 3)

Varieties of Speech That Have Been Investigated in Experimental or Naturalistic Studies

Type of speech	Description	Comment
Speech with sound		
Automatic (nonliteral) speech	Two types are commonly recognized. The first, also known as embolalia, is the verbalization of words or phrases that seem to be produced without conscious effort, such as false starts, hesitations, and repetitions that serve as verbal filler during more propositional speech. The second is the production of highly routinized verbal sequences such as counting from one to 10, reciting the days of the week, or using common expressions such as *good-bye*.	Automatic speech clinically is contrasted with propositional speech because the former sometimes is retained when the latter is impaired, as in some aphasias. It has been shown that automatic speech is not associated with activation of the same cortical areas used in propositional speech (Bookheimer, Zeffiro, Blaxton, Gaillard, & Theodore, 2000).
Backward speech Cowan, Leavitt, Massaro, & Kent (1982)	A speaker reverses the alphabetic or phonetic content of a message; for example, *this* is produced as “sith.”	Fluent backward speech may be a means to study the mental representation of speech.
Bite-block speech	Speech is produced while the talker clenches a block between the upper and lower jaws, thereby preventing movement of the mandible.	In healthy talkers, the compensation for a bite block is immediate (Fowler & Turvey, 1980); see also *compensatory speech*.
Brain–computer interface system controlling a speech synthesizer in individuals who are paralyzed (cortical neural prosthetics) Brumberg, Nieto-Castanon, Kennedy, & Guenther (2010); Leuthardt et al. (2011)	In one application of this strategy, an intracortical microelectrode brain computer interface was used to predict intended speech information directly from neuronal activity associated with speech production.	Silent, inner, or imagined speech might be considered the substrate that can be expressed through a speech synthesizer as well as a human vocal tract.
Citation (canonical, laboratory, perfect) speech Xu (2010)	Carefully articulated speech produced under laboratory conditions; may involve sensors attached to the speech production system	Citation speech typically is similar to clear speech in having high intelligibility and quality. It has been the traditional standard in experimental phonetics.
Clear speech Picheny & Durlach (1985, 1986)	Speech produced in an effort to ensure maximum intelligibility, often in the face of a potentially interfering factor such as background noise; compare with conversational speech	Clear speech acoustically is associated with a slower speaking rate (owing in part to the insertion of longer and more frequent interword pauses), a wider dynamic range of vocal fundamental frequency, greater sound pressure levels, more salient releases of stop consonants, and greater obstruent root-mean-square intensity.
Compensatory speech Baum & McFarland (1997)	Speech produced in response to a short- or long-term disruption, such as experimentally induced mechanical perturbations, bite block, dental prosthesis or appliance, or oral surgery	Studies indicate that speech motor control can be adjusted to compensate for both short- and long-term disruptions.
Conversational (natural) speech Picheny & Durlach (1985, 1986)	Speech produced in a casual situation usually involving familiar topics and listeners; compare with clear speech	Conversational speech typically lacks or has in diminished degree the acoustic characteristics noted for clear speech.
Dreamed speech (covert)	Speech produced during dreaming; can be heard by others in the vicinity	In individuals with Parkinson’s disease and rapid eye movement sleep behavior disorder, speech often is more intelligible, louder, and better articulated during rapid eye movement sleep behavior disorder (De Cock et al., 2007).
Emotional speech	Speech that expresses an emotion such as anger, sadness, happiness, or fear; sometimes contrasted with neutral speech	The emotion can be spontaneous or simulated, as by an actor. Databases of emotional speech have been obtained for purposes such as automatic speech recognition (Douglas-Cowie, Campbell, Cowie, & Roach (2003).
Empty speech Nicholas, Obler, Albert, & Helm-Estabrooks (1985)	Speech that is semantically void (e.g., comprising automatisms, vague circumlocutions, or single words)	A primarily clinical concept that refers to speech patterns that may occur in dementia, aphasia, and psychiatric disturbances
Entrained (cycled or synchronous) speech Cummins (2009)	Speech produced with respect to an exogenous rhythm, such as a metronome (cycled speech) or another speaker (synchronous speech)	Entrainment has been viewed as the yoking of two dynamical systems.
Exaggerated (overarticulated) speech	Speech produced with unusually large ranges of articulatory movement and/or force; similar to hyperspeech but with more deliberate and extensive movements	This type of speech is used in some clinical treatments. It also has characteristics like those seen in infant-direct speech (motherese or parentese).

Appendix A (p. 2 of 3)

Varieties of Speech That Have Been Investigated in Experimental or Naturalistic Studies

Type of speech	Description	Comment
Feedback-altered speech Hashimoto & Sakai (2003)	Speech in which normal feedback is altered in some way; the most commonly used alterations are auditory and include delayed auditory feedback and frequency shifted feedback	Altered feedback can disrupt nonstuttered speech but can result in improved speech in individuals who stutter or who have speech disorders associated with Parkinson's disease.
Glossolalia (speaking "in tongues") and xenoglossia (the vocalization of a foreign language unknown to the speaker)	Speech that is produced fluently but lacks any readily comprehended meaning to the speaker; practiced in some Pentecostal or charismatic churches as well as other religious groups and may be taught through modeling (Spanos, Cross, Lepage, & Coristine,1986)	Available evidence indicates that there may be different patterns of phonetic and linguistic content (Motley, 1982; Osser, Ostwald MacWhinney, & Casey, 1973). Also, brain activity may differ from that in ordinary communicative speech (McGraw, 2012; Newberg, Wintering, Morgan, & Waldman, 2006).
Hyperspeech Lindblom (1990)	According to Lindblom's (1990) H&H theory, this form of speech is used when speakers believe that signal-complementary factors (e.g., context) may not be sufficient to ensure that a listener will understand the message.	Hyperspeech appears to be similar to clear speech in that the speaker makes special effort to enhance intelligibility.
Hypospeech Lindblom (1990)	According to Lindblom's H&H theory, this form of speech is used when speakers believe that signal-complementary factors (e.g., context) are sufficient to ensure that a listener will understand the message.	Hypospeech appears to be similar to conversational speech in that the speaker relies on factors such as context to convey the spoken message.
Imitated speech Garnier, Lamalle, & Sato (2013); Kappes et al. (2009)	Speakers can imitate, often without intention, characteristics of another's speech, including suprasegmental features and temporal and spectral cues at the phonetic level.	Speakers are sensitive to nonphonological details when listening to another speaker, and these details influence tasks such as imitation of words or nonwords.
Infant-directed speech (also known as caretaker speech, motherese, or parentese) Bryant & Barrett (2007); Fernald (1992)	An apparently universal speech register used by adults when addressing infants	Features of infant-directed speech include a higher average pitch, pronounced pitch contours, and hyperarticulated vowels.
Intoned (sung) speech	Speech that is produced with the melodic features of singing	Speaking and singing differ in their neural correlates (Özdemir, Norton, & Schlaug, 2006), which helps explain the therapeutic benefits of intonation-based therapy (Schlaug, Marchina, & Norton, 2009).
Loud speech Schulman (1989); Stathopoulos & Sapienza (1993)	Speech produced with high intensity (increased vocal effort)	Loud speech has been incorporated in LSVT LOUD (Fox et al., 2006, 2012).
Meaningful speech (propositional)	Speech as it is generally recognized—as a sequence of sounds that carries meaning in a language	This form of speech is the most complete with respect to its linguistic, phonetic, and motoric aspects.
Nonsensical speech (nonsense)	Speech that does not convey meaning, usually because it involves phonetic sequences that do not conform to the words in a given language	Nonword repetition is used in language assessment and is taken primarily as an index of phonological memory or phonological representation.
Paraspeech Brendel et al. (2013)	Simplified speech tasks such as diadochokinesis and vowel prolongation	Simple speaking tasks without meaning
Propositional speech (literal)	Speech used to express meaning	
Quasispeech Weismer (2006)	Simplified utterances comprising an alternating or repeated syllable or sustained sounds (especially vowels or fricatives)	Quasispeech uses phonetic elements but in a highly simplified way, usually as repeated syllables or isolated sounds.
Reiterant speech (nonsense syllable mimicry) Larkey (1983); Nakatini, O'Connor, & Aston (1981)	Production of a basic syllable, such as /ma/, that is used repeatedly to replace other syllables in a target utterance with an attempt to preserve the prosodic pattern	Reiterant speech is used especially to study speech production related to the prosodic pattern of speech.
Shadowed speech Marslen-Wilson (1973)	Speech produced in an attempt to replicate or echo the speech of another, as quickly as possible, without prior knowledge of the forthcoming utterance	Shadowing is imitation with a premium on reaction time so that the person who shadows tries to reproduce the other speaker's utterance with minimum delay (on the order of the duration of a syllable).
Sleep talking (somniloquy)	Speech produced by an individual who is asleep	Sleep talking is more frequent in children than in adults (Arkin, 1966; Reimão & Lefévre, 1980).

Appendix A (p. 3 of 3)

Varieties of Speech That Have Been Investigated in Experimental or Naturalistic Studies

Type of speech	Description	Comment
Speaking rate adjustments	Speakers can change the rate at which speech is produced.	Changes in speaking rate affected the topology of velocity-time functions of articulatory movements (Adams, Weismer, & Kent, 1993).
Speech with co-speech gestures (hands or other body parts) Willems & Hagoort (2007)	Speech produced concurrently with movements of other motor systems	The co-speech gestures, coordinated with speech, can aid communication.
Speech while walking	Speech produced spontaneously while walking	Walking while talking reduces gait speed in young and older adults (Plummer-D'Amato, Altmann, & Reilly (2011).
Spontaneous speech Xu (2010)	Extemporaneous speech; speech that is produced naturally as in typical discourse	The most natural and freely determined form of speech
Start–react effect for speech Stevenson et al. (2014)	Rapid release of prepared speech in response to a loud acoustic stimulus capable of eliciting a startle response	The effect has been observed for a consonant–vowel syllable (Stevenson et al., 2014).
Syllable-timed speech	Speech produced with minimal differentiation in linguistic stress across syllables; usually accomplished by saying each syllable in time to a rhythmic beat	Syllable-timed speech alters the normal stress pattern of English and has been used as a treatment for stuttering (Trajkovski et al., 2009).
Tongue twister Mr. Twister (2013)	A sequence of sounds, usually alliterative, for which speech errors are likely; also see *silent tongue twister*	Analyses of speech errors have been used to infer the nature of phonological and motoric processing in speech production.
Vocal disguises, imitation, and impersonation Eriksson (2010)	A speaker disguises his or her vocal identity or impersonates another speaker; also called *mimicry*	In entertainment, a vocal impersonator is also known as an impressionist.
Whisper Monoson & Zemlin (1984); Stathopoulos, Hoit, Hixon, Watson, & Solomon (1991)	Speech produced without vocal fold vibration	Whisper has been used as a control condition in which phonation is replaced by a noise source.
Xenoglossia	See *glossolalia*	
Speech without sound		
Covert speech	See *silent speech*	
Dreamed speech (silent) Shimizu & Inoue (1986)	Individuals recall speaking in their dreams even though others may not have heard them speak.	Speech in dreams is accompanied by phasic discharges in speech—but not nonspeech—muscles. Lucid dreamers regulate breathing in similar ways for dreamed speech and covert speech (LaBerge & Dement, 1982).
Imagined (imaginary); see also *silent speech* Tian & Poeppel (2012)	Speech that is mentally performed without audible output or visible articulatory actions	Imagined speech is like imagined actions in other body systems. It is associated with activation of some of the same neural sites activated in actual speech production.
Inner speech	See *silent speech*	
Mouthed speech, mussitation	Speech that lacks phonation but otherwise retains articulatory movements	Mouthed, silent, and subvocal speech are similar, if not identical.
Silent (inner) speech	Speech that is uttered without phonation or other audible sound sources, such as whisper	Silent speech presumably is the same as imagined speech. It has been proposed that silent speech is based on a phonological representation that is flexibly adapted to articulatory features (Oppenheim & Dell, 2011).
Silent speech interfaces Denby et al. (2010)	Speech processing in the absence of an intelligible acoustic signal	Also see *brain–computer interface system*
Silent tongue twister	See *tongue twister*	Silent reading of tongue twisters is slow relative to control passages, and errors are similar to those in spoken material (Postma & Noordanus, 1996).
Subvocal speech	See *silent speech*	

Appendix B

Common Functional Divisions of the Motor Systems of Speech and Other Oral Behaviors

Aerodigestive tract: The anatomic conduit that is so named because of its dual functions of ventilation and deglutition. It includes the oral cavity, sinonasal tract, larynx, pyriform sinus, pharynx, and esophagus. The tract has two major bifurcations, one dividing the oral and nasal cavities and another separating the esophagus and the trachea. Neural control over this apparatus is accomplished through the corticobulbar system. The superior portion of the aerodigestive tract is defined as the region that includes the oral cavity, oropharynx, pharynx, larynx, upper trachea, and upper esophagus. Portions of this tract are used in speech, swallowing, and ventilation.

Alimentary tract: The musculomembranous digestive tube extending from the mouth to the anus.

Craniofacial muscles: The various muscles involving the cranium and face that are innervated by the cranial nerves and control the positions and movements of structures of the head, face, mouth, pharynx, and larynx. These muscles compose more than 10% of the approximately 640 muscles in the human body. They appear to be distinct from limb muscles in a number of important respects (McLoon & Andrade, 2013), some of which may be pertinent to the specialization for speech production (Kent, 2004). Craniofacial muscles often are distinguished from the mandibular muscles.

Facial muscles (also called mimetic muscles or muscles of facial expression): A group of striated muscles innervated by the facial nerve that control facial expression, among other functions. A total of 43 muscles compose this muscle group, which is derived from the second pharyngeal arch and supplied by the facial nerve (cranial nerve VII).

Hyomandibular system: The mandible and hyoid bones along with their associated soft tissues, including musculature.

Mandibular (masticatory) muscles: The muscles that move the jaw by acting on the temporomandibular joint have a different innervation and embryological origin than the craniofacial muscles and are therefore often considered separately. The four muscles of mastication are the temporalis, masseter, and lateral and medial pterygoids, derived embryologically from the first pharyngeal arch and supplied by the mandibular division of the trigeminal nerve (cranial nerve V).

Splanchocranium: The portion of the skull that arises from the first three branchial arches and forms the supporting structure of the jaws.

Stomatognathic system: The mouth, jaw, and closely associated structures that are involved in mastication. It is sometimes called the *chewing system* or *masticatory system* and includes the mandibular or masticatory muscles as a subset.

Vocal tract: The column of air extending from the vocal folds to the mouth or nares. This tract is the resonating cavity (or cavities) used to produce the sounds of speech. It is best defined with respect to the acoustic aspects of speech production, but it can be described in terms of the various tissues that form its boundaries. The musculature of the vocal tract includes all muscles that participate in the formation of speech sounds.