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Speech versus Nonspeech: Different Tasks, Different Neural Organization

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Abstract

This article reviews the extant studies of the relation of oromotor nonspeech activities to speech production. The relevancy of nonspeech oral motor behaviors to speech motor performance in assessment and treatment is challenged on several grounds. First, contemporary motor theory suggests that movement control is task-specific; in other words, tied to the unique goals, sources of information and characteristics of varying motor acts. Documented differences in movement characteristics for speech production versus nonspeech oral motor tasks support this claim. Second, advantages of training nonspeech oral motor tasks versus training speech production are not supported by current principles of motor learning and neural plasticity. Empirical data supports experience-specific training. Finally, functional imaging studies document differences in activation patterns for speech compared to nonspeech oral motor tasks in neurologically healthy individuals.

Keywords

Nonspeech; speech production; motor learning; task specificity

Introduction

The use of nonspeech oral motor exercises (NSOMEs) is a common practice in treatment programs for a wide variety of speech disorders. The exercises are believed to facilitate speech sound production in children with articulation/phonological disorders, late talkers, children with neuromotor disorders (e.g., cerebral palsy, Down syndrome), as well as in adults with acquired speech disorders, such as dysarthria[1,2, 3]. Additionally, nonspeech oral motor behaviors are routinely used during evaluation of persons with motor speech disorders to facilitate diagnosis[4]. Use of these tasks in both treatment and evaluation protocols is based on several assumptions about the relation of nonspeech oral motor behaviors to speech production.

The first assumption is that the movement characteristics and task demands for speech and nonspeech oral motor behaviors are similar. While it may seem obvious that, because the same structures are used in both types of tasks, they are likely to be governed by a set of common principles, contemporary motor theory and empirical data suggest that this is not the case. A second assumption is that learning can be facilitated by breaking down the task of speech production behaviors into subcomponents. In other words, appropriate nonspeech tasks can be used to isolate single movement components that can then be combined in an additive way to generate the coordinative action of speech production. Evidence suggests that since speech is characterized by highly integrative subsystem interactions, with synergies existing between mechanically-linked and spatially-distant muscular structures, this assumption is also probably

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invalid. A third assumption is that the neural anatomical representation of the tasks in the human nervous system is similar. Data related to this assumption are sparse; however, there is at least some evidence that there is little overlap in the representation of these different tasks. This paper addresses these three assumptions by reviewing relevant empirical data and by summarizing arguments presented previously by Weismer[4,5] and Ziegler[6].

Relevance of nonspeech oral motor behaviors to speech production

Nonspeech oral motor behaviors have value for clinical diagnosis and in speech treatment programs if they share similar movement characteristics and task demands with speech production. The view, often called the "common effector perspective", suggests that when the same effectors (structures) are used for different activities they are necessarily controlled by a common set of control principles. General control principles, such as force and timing, are thought to subserve motor activities for any purpose involving the same effectors[7,8]. On the surface this appears logical, but contemporary motor theory and empirical data are strongly in opposition to such a view. The control of effectors appears to be task-specific with distinct neuromotor control systems responsible for specific motor activities. This task-specific view of motor control suggests that functions specialized for the act of speaking are different from those that control nonspeech oral motor tasks. Support for a task-specific model comes from studies examining movement characteristics in speech and nonspeech oral motor tasks in healthy persons, the lack of any apparent relation of nonspeech oral motor tasks to speech performance measures in clinical populations, and treatment studies where one task is trained and any effect on the other untrained task is observed.

Movements during speech production are directed toward generation of an acoustic signal that can be interpreted linguistically[9]. Perkell and colleagues[10,11] have suggested that speech motor control utilizes an *internal* model of the relation of vocal tract shapes to their acoustic consequences. Evidence from studies of motor equivalence, coarticulation, and kinematic variability support this point of view[10–15]. Nonspeech oral motor tasks, it can be argued, have goals that are related to an *external* visual-spatial or proprioceptive target and therefore, are very different from speech production. As an example, contrast the goal of tongue elevation during speech production versus a lingual 'push-up'[1]. During speech production, the goal of a tongue elevation movement is not to reach a certain point at the roof of the speaker's mouth, but rather to produce a sound that can be interpreted by a listener. In contrast, the goal of a lingual 'push-up' is simply to produce the required amount of force to complete the 'push-up.'

Movement characteristics of nonspeech oral motor behaviors and speech production

Movement characteristics of nonspeech oral motor tasks and speech production obtained from neurologically healthy individuals have been compared in several studies. Task related differences were reported in all cases. Results show that motions of the jaw [16–18] and jaw muscle activity organization [19–21] are different for speech and nonspeech tasks. Task dependency has also been reported for lip muscle activity in both children and adults[22,23]. Qualitative differences in facial muscles electromyography (EMG) for speech and nonspeech tasks have also been reported[24]. Different EMG ranges for the levator veli palatine muscle in blowing tasks compared to speech tasks was reported by Kuehn and Moon[25]. Distinct "wave-like" tongue motions were reported in swallowing tasks but not speech tasks[26]. Based on these data, nonspeech oral motor movements and speech movements do not appear to be similar in the same individuals and do not share the same underlying patterns of muscle control.

A small literature on the relation of measures of nonspeech oral motor task performance to measures of speech production in persons with neurological impairments also suggests little or no relation between the two tasks. Citations and a summary of the tasks studied and findings are shown in Table 1. This list is believed to be an exhaustive search of the literature. Measures of oromotor-nonverbal performance used in these studies included evaluation of maximal strength, submaximal force or pressure control, speed of force or pressure increase, and/or endurance of the oral articulators (primarily jaw, lip, and tongue). Speech production measures were typically in the form of speech intelligibility or severity scores obtained as scaled estimates or percent correct. Nine of the 13 studies failed to find any link between nonspeech oral motor task measures and measures of speech intelligibility. Three studies reported equivocal or weak findings. Two studies revealed high correlations between speech and nonspeech measures; however, these should be interpreted cautiously as there may be a third-variable explanation for these positive findings [see Weismer[4] for discussion of third variable].

In an effort to refute the overwhelming evidence of differences in characteristics of speech and nonspeech oral motor tasks, it has been argued that the nonspeech oral motor behaviors used in published studies are not speech-like, and therefore, the true relation of the two tasks has not been fully explored[8]. Ballard and colleagues have suggested that speech motor and nonspeech oral motor control processes lie along a continuum. Study of nonspeech movements with increasingly speech-like characteristics will reveal control characteristics of speech production. Although, Ballard and colleagues do not specify when a nonspeech task is sufficiently speech-like to be representative of speech production much of their experimental work utilizes visual motor tracking tasks (VMT). They write, “VMT, which involves tracking a moving target with the articulators is a nonspeech task that is useful in studying coordination of the speech production system….” The claim of greater similarity between VMT and speech production compared to static force-hold tasks and speech production appears to be related to the inclusion of movement in the task. With this in mind, Bunton and Weismer[27] attempted to create an oral motor task with movement as a key feature and paired it with phonation and lung volume changes to make it even more speech-like. In the task, neurologically normal adults were required to produce sequences of lingual force impulses that were modeled on sequences of syllables produced as reiterant speech. It was thought that this task would successfully mimic tongue force requirements of speech production sequences. Results suggested, however, that the force patterns in the nonspeech task were not like those expected during speech production. It is not clear how speech-like nonspeech task should be, and begs the question: Why not study speech production instead? Further discussion of concerns about the abstract nature of nonspeech oral motor tasks can be found in Bunton and Weismer[27], Weismer[4,5] and Ziegler[6].

Treatment Studies

A direct approach to testing the relation of nonspeech oral motor behaviors to speech production skills would be to employ a training program that targeted one behavior (e.g., strength), train that behavior to some criterion and then observe the effect, if any, on a second variable that had not been trained (e.g., speech intelligibility). If proper experimental controls have been used, including control conditions and patients, and blinded judgments of speech performance, a post-training improvement in speech intelligibility would be strong evidence for a meaningful link between the two behaviors[4]. Only one such training study been published. Dworkin, Abkarian, and Johns[28], reported no effect of a lingual strength-training program on speech performance in a woman with apraxia of speech. This is only a single study, and clearly, other studies of this type are warranted; but the results do not support a link between nonspeech oral motor behaviors and speech production deficits.

Motor Learning

Principles of motor learning suggest that learning a complex behavior can be facilitated when it is decomposed into smaller units[29]. Since speech production is a complex behavior, it follows that breaking the task of speech production into parts during training will improve learning efficiency. Although such principles apparently motivate the use of nonspeech oral motor exercises, they are based on the assumption that the single movement components are combined in an additive way to generate the coordinative action of speaking. Empirical studies of motor learning, however, have demonstrated that two key factors, task complexity and task organization, determine if training parts of a task will be more or less effective than training the task as a whole[30].

Task complexity is defined as those information-processing demands that are placed on the subject by each of the task dimensions independently, while task organization refers to the demands imposed on the subject due to the nature of the interrelationship existing among task dimensions[31]. For speech production, both complexity and organization are relatively high, although it is probably not possible to separate the dimensions entirely. Consider several examples presented by Forrest[32]. Production of the syllable [b4] requires the jaw to move in an inferior direction while the tongue rides on it. This task could be considered to have relatively few interrelated dimensions and thus has low complexity and organization. In contrast, production of the syllable “boo” requires lip-rounding plus an inferior-anterior jaw trajectory. The inter-articulator complexity and organization are comparatively greater for this CV production. Next, consider the word “strand.” At a minimum the lips, tongue, jaw, velum, larynx, and respiratory system must be coordinated in a short temporal window to produce the word successfully, therefore the organization and complexity of production have increased significantly relative to the CV productions.

In a study examining the benefits of training a part task versus training the whole task, Wightman and Lintern[33] described three ways a motor task can be decomposed to facilitate learning, they include segmentation, fractionation, and simplification. Segmentation partitions the task into a series of spatial and temporal subcomponents with identifiable start- and endpoints. This approach is analogous to treating a single phone, where a sound is practiced in isolation to some criterion level before it is integrated into a syllable context. Fractionation of a task decomposes simultaneously produced elements into isolated subcomponents. For speech production, this would allow practice on the independent movements of articulators that combine to produce a phone. Consider production of the lingua-alveolar consonants [t] or [d]. Fractionated practice might involve isolated superior movements of the tongue tip with fixed position of the tongue body, vocal folds, respiratory system, jaw and lip[32]. As this isolated gesture is mastered, a second component, for example jaw depression, would be practiced independently. Fractionation tasks take the form of nonspeech activities that may approximate components of speech production. A final means to decompose a task for training is simplification. Simplification is a procedure where aspects of the target skill are made easier by adjusting characteristics of the task. For example, treatment for an /s/ might begin with the homorganic stop [t][34]. Because stops require a ballistic movement they are considered easier to produce than fricatives[35], beginning treatment for /s/ with the placement of the [t] may simplify the movement pattern and give the child a reference for production.

In terms of learning efficiency, Wightman and Lintern[33] report that for complex tasks that are highly organized only segmentation appears to provide a significant advantage over whole-task training. Fractionation of behavior, they suggest, reduces the efficiency of learning, as the interrelated parts may not provide the relevant information for the appropriate development of neural substrates (see also[36]). Simplification of a task yielded learning that was comparable to that of whole-task training.

A series of recent consensus statements on the application of neuroplasticity principles to behavioral intervention programs published in the *Journal of Speech, Language, and Hearing Research*[36,37], support Wightman and Lintern's[33] findings. Neural plasticity refers to the mechanism, by which the brain encodes, learns or relearns behaviors[37]. Two key principles of neural plasticity include specificity and salience[36]. The principle of specificity states that changes in neural function following practice may be limited to the specific function being trained. Consistent with this principle are a small set of studies which have shown that training in swallowing did not automatically generalize to improvements in voice or speech intelligibility for individuals post-stroke[38,39]. The principle of salience states that the practice behaviors need to be relevant to the task being trained in order for it to be encoded in the brain. Put differently, simple repetitive movements or strength training may not enhance skilled movements and therefore, have less potential for inducing changes in neural function underlying speech production. Training on lip strength, for example, may only benefit the neural control for lip movement and force but may not spontaneously transfer to speech production because the relevance of the movement is not apparent.

In summary, part training does not appear to facilitate acquisition of the whole behavior in cases where the target activity is highly organized and has interdependent parts. Since speech is characterized by highly integrative subsystem interactions, with synergies existing between mechanically linked and spatially distant muscular structures, the assumption that part training improves learning efficiency is probably not valid.

Neural Anatomical Considerations

Investigations of the neural basis of speech motor control in normal individuals have compared cortical activation patterns during speech and oral-motor nonspeech tasks as a means to dissociate brain areas responsible for production of speech. Many of the studies were not designed to provide direct evidence of task-specificity; however, strong evidence of differences in neural organization has emerged. An observed difference between speech and nonspeech oral motor tasks is the lateralization of activation. For example, in an fMRI study of healthy right-handed subjects, Wildgruber and colleagues[40] compared covert speaking to vertical tongue excursion, a nonspeech task. He reported that at the level of the primary motor cortex, speech movements were associated with increased activation in the left motor strip, whereas the nonspeech task was associated with a bilateral symmetric activation. Similarly, Riecker and colleagues[41] reported that speaking was accompanied by unilateral right-sided activation of the cerebellum whereas nonspeech lateral tongue movements were associated with bilateral cerebellar activation. Bilateral motor cortical activation has also been reported in a PET study of nonspeech tongue-tracking movements[42]. Horowitz et al.[43] has also reported lateralization differences in PET activation data for speech production compared to a nonspeech motor control task that involved laryngeal and oral articulatory movements associated with sounds (i.e., a nonspeech task that employed all of the muscle groups activated in speech but was devoid of meaning). Widespread bilateral cortical activation was shown to be associated with nonspeech movements by Bonilha and colleagues[44] whereas activation was limited to the left hemisphere for speech movements.

Motor aspects of speech production are highly automatic and under normal circumstances require no conscious attention. Functional imaging studies of motor learning have shown that skill acquisition is associated with changes in both the activation patterns of the motor cortex[45,46] and movement representations as revealed using transcranial magnetic stimulation [47–49]. With regard to speech production, these findings suggest that the extensive learning associated with speech development gives rise to task-specific organization and distinct neural representations. Nonspeech oral motor tasks, on the other hand, are novel. Even though they may involve the same musculature as speech, the tasks are so different that their control must be assumed to be based on different neural networks. This does not imply that, through learning, structural neural substrates become strictly demarcated for different tasks, rather task specific systems are separate to the extent that each of them has unique properties, are subserved by specialized neural circuitry, and can be selectively impaired following damage[6].

Even though there exists strong preliminary evidence suggesting differences in the underlying neural anatomical substrates for speech production compared to nonspeech oral motor behaviors, additional studies using both anatomical and functional neuroimaging techniques are needed to examine how brain structure is altered as the result of learning, during either normal development, or following behavioral intervention.

Summary

It has been argued that there is little theoretical or empirical reason to regard nonspeech oral motor tasks as useful tools in the practice of speech-language pathology. Motor control theory asserts that motor control processes are tied to the unique goals, sources of information (i.e., feedback) and characteristics of varying motor acts, even when those share the same effectors and neural tissue. Differences in underlying patterns of control is supported empirically by evidence of dissimilarities between nonspeech oral motor movements and speech movements in neurologically healthy adults, failed attempts to demonstrate a link between speech production measures and nonspeech oral motor measures, and evidence that learning complex behaviors needed for speech production is not facilitated by part-task learning.

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Table 1

Studies in which measures of nonspeech oral motor (NS) and speech performance (S) have been compared in individuals with a various neurological disorders. A positive finding is indicated by a plus, a negative by a minus, and both signed indicates mixed findings. Studies are listed in chronological order.

Study	Patient Type	Finding	Summary
Hixon & Hardy[50]	Cerebral Palsy	−	**NS:** Nonspeech AMR, Speech DDK **S:** scaled speech defectiveness
LaPointe & Wertz[51]	Brain Injury	−	**NS:** Isolated oral movements, oro-motor sequencing tasks **S:** severity of articulatory defectiveness
Dworkin, Aronson, & Mulder[52]	Amyotrophic Lateral Sclerosis	+	**NS:** Tongue force **S:** articulatory defectiveness
Barlow & Abbs [53,54]	Cerebral Palsy	+	**NS:** Jaw + tongue + lip force stability **S:** speech intelligibility
Dworkin & Aronson[55]	Various	−	**NS:** Tongue strength, speech DDK **S:** scaled intelligibility
DePaul & Brooks[56]	Amyotrophic Lateral Sclerosis	−/+	**NS:** Speed of tongue or lower lip force production **S:** scaled speech severity
Langmore & Lehman[57]	Amyotrophic Lateral Sclerosis	−/+	**NS:** Maximum (nonspeech) repetition rates of lips, tongue, jaw **S:** scaled speech severity
McHenry, Minton, Wilson, & Post[58]	Traumatic Brain Injury	−	**NS:** Oro-facial force **S:** speech intelligibility
Solomon et al.[59]	Parkinson Disease	−	**NS:** Lingual fatigue **S:** speaking rate
Solomon et al.[60]	Parkinson Disease	−/+	**NS:** Tongue strength **S:** severity of speech defectiveness
Thompson, Murdoch, & Stokes[61]	Upper Motor Neuron Disease	−	**NS:** Tongue strength **S:** perceptual ratings of articulatory performance
Thompson, Murdoch, & Stokes[62]	Upper Motor Neuron Disease	−	**NS:** Lip force, vowel or consonant precision **S:** speech intelligibility
Theodoros, Murdoch, & Stokes[63]	Traumatic Brain Injury	−	**NS:** Lip and tongue strength **S:** perceptual rating of severity
Solomon, Robin, & Luschei[64]	Parkinson Disease	−	**NS:** Tongue strength and endurance **S:** articulatory precision and speech defectiveness