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More on the Role of the Mandible in Speech Production: Clinical Correlates of Green, Moore, and Reilly's (2002) Findings *AND* Methodological Issues in Studies of Early Articulatory Development: A Response to Dworkin, Meleca, and Stachler (2003)

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Letters to the Editor

More on the Role of the Mandible in Speech Production: Clinical Correlates of Green, Moore, and Reilly's (2002) Findings

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We would like to comment on Green, Moore, and Reilly's article, which appeared in the February 2002 issue of this journal [*Journal of Speech, Language, and Hearing Research*]. In that investigation, these clinical researchers examined upper lip, lower lip, and mandibular movements during repetitive bisyllable word productions by infants, toddlers, young children, and adults with normal developmental and neurologic histories. Kinematic traces from these articulators were analyzed using a computer-based movement tracking system. Results revealed that these oral structures may have sequential neuromotor developmental schedules, characterized by more mature movement patterns for speech emerging earlier in the mandible than in either the upper or lower lip. That is, that normal speech development involves the integration of lip and tongue activities into a more well-established, biomechanically dominant jaw operating sensorimotor system. To facilitate our response to this investigation, we have chosen first to extend the results by elaborating on the causally related role of the mandible in certain speech disordered populations, and second, to highlight how adjunctive methods of data collection may have strengthened the validity of the overall findings.

Clinical Implications

In an earlier study of the development of labiomandibular coordination during repetitive bilabial consonant productions Green, Moore, Higashikawa, and Steeve (2000) hypothesized that very young children who exhibit early speech motor delays may have a negative prognosis if they also struggle with limited mandibular control. From a clinical point of view, it is reasonable to extend this hypothesis by extrapolating the current findings by Green, Moore, and Reilly (2002) to select populations of children and adults with developmental or neurogenic articulation disorders who exhibit mandibular dyscontrol. On the basis of our present work with such patients and a reinforcing clinical literature database, we suggest that the mandible may play a leading role not only in normal articulatory development but also in the origin and persistence of certain abnormal speech behaviors.

More than three decades ago Mysak (1968) suggested that if articulatory efforts are disrupted by excessive orofacial activities, as observed in many children with cerebral palsy, therapeutic techniques designed to restrain these compounding events must be administered to facilitate speech improvement. Mysak described various methods to desensitize, weaken, and suppress such oromotor patterns. One recommended approach to modify a patient's hyperactive mandible required the clinician to grasp this structure, in order to restrain it physically, so as to diminish the intensity of neurologically primitive, involuntary behaviors while various sound productions were practiced in therapy. Ten years later Dworkin (1978) proposed a causal relationship between the articulatory imprecision exhibited by certain school-age children and their co-occuring interruptive, hyperactive mandibular movement patterns. Because these children did not present overt signs of central or peripheral nervous system abnormalities, these uncontrollable jaw behaviors were hypothesized to be manifestations of oroneuromotor immaturity. Traditional manner and place of production stimulative articulation exercises did not result in notable gains in speech intelligibility in these children. Clinical focus was then shifted to a treatment method that might effectively inhibit the disruptive jaw activity. Custom designed acrylic bite blocks of varying lengths were positioned between the upper and lower central incisor teeth. The children were required to bite down gently on a given block, so as to stabilize the mandible, while practicing both nonspeech and speech exercises of the lip and tongue musculature. Substantial improvements in speech proficiency and intelligibility were obtained in all of the children studied in a relatively short period of time.

Netsell and Daniel (1979), Kent and Lybolt (1982), Rosenbek and LaPointe (1985), Netsell (1985), and Dworkin (1991) discussed the potential diagnostic and therapeutic value of bite block use in the differential diagnosis and treatment of dysarthric patients. All of these authors described the application of bite blocks, made from dental impression putty, for two primary purposes: first, to evaluate whether the mandible helps or hinders lip and tongue movements during speech activities, and second, to induce greater lip and tongue movement independence by taking erroneous jaw activity out of the speech loop to improve overall articulation proficiency. Though their research was unrelated to the mandibular subsystem, Lazarus and Todor (1987) demonstrated limited independence of distinct limb components in individuals with overall characteristics of immature motor development. These authors observed that extraneous or associative movements of muscle groups not normally involved in the intended goal tended to decrease with neuromuscular maturation and specific motor exercises.

More recently, Dworkin (1996) reported that insertion of a bite block in two different patients with writhing oromandibular behaviors secondary to Meige's syndrome (cranial-cervical dystonia) resulted in immediate conversion from moderate speech unintelligibility to near normal speech intelligibility in each individual. This author argued that the co-occurring abnormal lip and tongue signs and symptoms exhibited by these patients may have been sequelae of the hyperactive jaw rather than primary manifestations of the underlying movement disorder. It was suggested that the block neutralized this trigger mechanism by facilitating postural balance and motor stability of the mandible. This hypothesis supported the earlier works of Fowler and Turvey (1980); Gay, Lindblom, and Lubker (1981); and Abbs and Kennedy (1982), all of whom demonstrated that in normal speakers the presence of a bite block to fix the jaw in a specified open position did not adversely affect overall articulatory ability, owing to the availability of afferent-based open-loop central nervous system pathways that are normally available to help regulate such adaptive speech motor responses. Kelso and Tuller (1983) proposed that these types of on-line compensatory behaviors reveal the inherent, self-equilibrating, synergistic articulatory capabilities of the tongue, lip, and jaw musculature.

Possible Limitations of Current Findings

The theory of motor equivalence suggests that achieving a constant target can be accomplished by means of variable contributions from motor components in the control hierarchy of that goal (Hebb, 1949; Hughes & Abbs, 1976). It has been well established that with multiple articulatory repetition tasks, as in the current investigation, there can be complementary activities of two or more distinct muscle groups for the same movement patterns (Abbs, Gracco, & Blair, 1984; Perkell, Matthies, Svirsky, & Jordan, 1996; Sharkey & Folkins, 1985). This covarying phenomenon can make it difficult to gauge the degree to which any given articulator actually contributes to specific movement behaviors. Notwithstanding this methodological limitation, and constrained by the inability of very young children to generate elaborate conversational speech, in the current study Green et al. (2002) elected to employ repetitive bilabial CVCV productions in order to compare labiomandibular activities in children of differing ages to those of adults. Whereas close analysis of such utterances can produce useful information about certain articulator trajectories, it neglects any underlying global oroneuromotor adaptations that might naturally occur during more complex, running speech activities. If a chief objective of this investigation was to determine whether the jaw attains mature movement patterns earlier than the lips, perhaps more accurate results would have accrued if such comparative measurements also included connected discourse events, at least from the older study participants. We suggest that without these types of data, conclusions about age-specific articulatory movement biases remain debatable, inasmuch as mature speakers do not typically engage in such experimentally contrived speech acts. Thus, Green et al. may have been able to strengthen their primary finding that very young children rely on the mandible to approximate adult-like speech patterns if such tendencies by the older participants were measured under more normal speaking conditions.

Furthermore, the older study participants were instructed to read aloud the target words at normal conversational rates; productions from the youngest participants were elicited through imitation or spontaneous play activities. Such differences in speech sampling methods raise additional important concerns about the validity of the comparative findings between these study populations. Previous EMG and X-ray microbeam kinematic investigations of lip, tongue, and jaw movements during repetitive articulatory tasks have demonstrated that such patterns are almost never stereotypic (Abbs & Kennedy, 1982; Abbs, Gracco, & Cole, 1984; Adams, Weismer, & Kent, 1993; Gay, Ushijima, Hirose, & Cooper, 1974; McClean, 2000; Ostry, Vatikiotis-Bateson, & Gribble, 1997; Shaiman, Adams, & Kimelman, 1997). Broad variations in the relative displacements of these articulators from trial to trial were commonly observed by these researchers, and fast rates of speech tended to induce greater amplitudes, velocities, and irregularities of movements than slower speaking rates, at least in some individuals. McClean (2000) specifically suggested that because articulator trajectories may be significantly influenced by speech rate processes, the speaking rate of all participants should be regulated in future investigations of tongue, lip, and jaw biomechanics in order to control this motor effect. In the current investigation, Green et al. primarily sought to determine whether jaw motion patterns exhibit early stability relative to associated lip activities. Because the kinematic data reported by these researchers were not uniformly obtained, owing to the different methods used to elicit speech samples from all of the study participants, greater caution should have been exercised relative to the principle conclusion that the youngest participants exhibited adult-like jaw movement patterns. Of lesser concern, but nonetheless of interest to us, is whether or not the torso and limb adjustments characteristic of the uncontrolled play activities used to elicit speech from the youngest children could have artificially contaminated upstream orofacial movement behaviors.

It is equally important to point out that there can be a considerable interdependence or motor equivalence between the magnitude of jaw displacements across utterance repetitions and the associated degrees of vocal effort expressed by speakers. Schulman (1989) and Dromey and Ramig (1998) studied the speech aerodynamic, acoustic, and supraglottal kinematic effects of loud speech. Results of these investigations generally revealed that increases in vocal intensity induced correspondingly greater subglottal pressure and glottal resistance levels, shorter intervocalic bilabial stops and longer vowel durations, larger lip and jaw displacements, and tighter lip compressions than softer voice productions. These findings help to illustrate that speech articulation normally depends on respiratory, laryngeal, and upper airway synergistic temporal and spatial interactions. Such multimovement coordination provides insights on the neural drive adjustments underlying variable speech motor control outputs, and supports the theory of hierarchical motor equivalence covariability among the movement patterns of various muscle groups. The older participants in the current study by Green et al. were requested to limit all utterances to conversational loudness levels; volume levels used by the younger participants were not only unregulated by these examiners, they were probably quite variable as well. Thus, the potentially confounding effect of marked reciprocity between the articulatory and phonatory subsystems was not controlled by these investigators. The conclusions they have drawn pertaining to the leading role of mandibular movement patterns in the emergence of more specialized speech motor skills may be considered premature in the absence of analyses of the possible neurophysiologic linkages of these speech mechanism constituents.

Conclusion

The current findings of Green et al. suggest that the mandibular operating system assumes dominant responsibilities in early normal speech development. We would add that such sensorimotor potency may translate into a system that is vulnerable to movement control disturbances. Previously published research and our own clinical observations have clearly highlighted several different clinical populations whose articulation disorders were largely attributable to immature or interruptive mandibular activities. Despite, or perhaps because of, its biologic propensity to excel physiologically as a prime mover of speech activities, the lower jaw may be at greater risk than other articulators for speech motor breakdowns, both developmentally and later in life owing to mechanical or neurologic injury or disease—akin to the vulnerability of crowded highways and busy airports to more frequent and severe setbacks or accidents than less congested travel routes. Notwithstanding the inherent methodological limitations of the current research by Green et al., their findings have helped pave the way for a better understanding of the biomechanical, coordinative interactions of the lips and mandible during speech production. The focus of future investigations should shift to examining similar behaviors in children and adults with different types of articulation disorders. Information derived from such studies may prove invaluable in the design of clinical treatment programs for individuals whose speech difficulties are judged causally related to limited sensorimotor independence of the lip, tongue, and jaw musculature.

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Methodological Issues in Studies of Early Articulatory Development: A Response to Dworkin, Meleca, and Stachler (2003)

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We appreciate the opportunity to clarify our previous findings in response to questions raised by Dworkin, Meleca, and Stachler (2003), who have cited our work with respect to its implications for the study and treatment of speech motor impairment. These researchers raise the possibility that differences in articulatory performance across the age groups may have been related to group differences in speech sampling methods rather than to development. They imply that because our younger (i.e., 1- or 2-years-old) participants' utterances were obtained with reduced experimental control relative to the older participants' (play vs. reading), their articulatory performance should have been less consistent than the older participants' because of naturally occurring variations in loudness and rate, and potential "upstream" effects related to "torso and limb adjustments." Several aspects of our experimental design mitigate these concerns and, most importantly, our findings are the opposite of predicted effects arising from speech sampling differences across age groups: (a)Adult-like stability was observed in the infants' jaw movement patterns despite the fact that infant vocalizations were elicited under less controlled conditions. (b) Each participant served as his or her own control, which permitted the evaluation of differences across articulators during development. (c) Postprocessing techniques minimized linear-scaling differences in articulatory movement across repetitions. (d) Finally, trunk mobility was restricted during data collection.

(a) Even though infant vocalizations are obtained without benefit of usual methods of experimental control (e.g., controlled rate, loudness, utterance type), our youngest participants exhibited jaw movement patterns that were not significantly different from those of the adults (see Figure 4 of Green, Moore, & Reilly, 2002). The strength of this effect supports the ecological validity of our findings, providing additional evidence for the presence of neuromotor biases in prelinguistic articulatory behavior. The influence of across-age elicitation effects would only have been supported if we had observed greater variability across the infants' repetitions than across the older participants'.

(b) Because there is no *a priori* reason to expect that the manner in which an utterance was elicited would differentially affect the articulators (upper lip, lower lip, and jaw), the infants served as their own controls. The results, however, revealed a significant articulator effect. Although infants' jaw movement patterns were not significantly different from those of the older children and adults, their lip movement patterns were significantly more variable than those of older children and adults. This articulator-specific finding can not be easily explained by group differences in speech elicitation methods.

(c) Amplitude and time normalization were used to minimize the statistical effects of typical kinematic variability across repetitions induced by rate and loudness variation, including trading relations among articulators (complementary covariation). Speech rate and loudness are often controlled in studies of articulatory coordination and control. However, because these parameters are not feasibly manipulated in infants, normalization was used to minimize linear-scaling differences across space and time for each set of kinematic signals (see Smith, Goffman, Zelaznick, Ying, & McGillem, 1995; Smith, Johnson, McGillem, & Goffman, 2000). The effects of this procedure are shown in Figure 3 of Green et al. (2002), which displays the raw and normalized articulatory waveforms from 10 repetitions of ”baba” produced by an adult speaker. In this figure, the untreated waveforms show normal temporal and amplitude variation across repetitions for each articulator; in contrast, the normalized kinematic signals align closely in space and time. The uniformly high correlations exhibited by all participants in the intrasubject comparisons (see Figure 6 of Green et al., 2002) further suggest that these transformations effectively reduced kinematic variability across repetitions.

We concur, of course, with Dworkin and colleagues' (2003) restatement of the commonly held supposition that speech rate and loudness should be controlled in most experimental investigations of articulatory coordination and control. Dworkin and his co-authors state that "… fast rates of speech tended to induce greater amplitudes, velocities, and irregularities of movements than slower speaking rates" (p. 1018). The vast majority of findings in this area, however, have demonstrated that slowed speech is more strongly associated with "irregularities in movement" compared with typical or rapid speech (Adams, Weismer, & Kent, 1993) and a decrease or no change in articulatory displacement at fast rates (e.g., Dromey & Ramig, 1998; Gay, Ushijima, Hirose, & Cooper, 1974; Kuehn & Moll, 1976; Ostry & Munhall, 1985).

(d) The potential influences of inertial forces from motions of the torso and limbs on articulatory motion were unlikely to be systematic in this experiment. Trunk motion was minimized by positioning the children in a high chair with restraining straps and a lap tray. Moreover, the consequence of trunk and limb motion on articulatory motion would not be expected to be systematic across repetitions because of the inconsistency in which they appeared within and across trials, and the expected inconsistency in their magnitude and direction. Thus the finding of early stability in jaw movement patterns is inconsistent with the pattern of variability that would be predicted from the influence of trunk or limb motion on articulatory kinematics.

Finally, we concur with the impression that our findings should be viewed as preliminary. Like any new experimental finding, these results must be replicated in independent laboratories. It is our intention that the questions addressed, the experimental methods developed, and the findings described provide additional impetus and direction for future investigations on the development of speech motor control.

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