Facial Kinematics of a Speaker with a Palatal Lift Following Brainstem Impairment

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This study examined the impact of palatal lift intervention on articulatory kinematics for a speaker with acquired velopharyngeal incompetence (VPI) following brainstem tumor excision. Articulatory adaptations to VPI management may be expected in response to sudden changes in vocal tract aerodynamics and acoustics. This investigation was designed to address the following research questions: (1) Does articulatory performance change in response to palatal lift intervention? and (2) If so, are the observed performance changes in the direction of normal speakers? Changes were observed in response to the palatal lift in kinematic measures of cumulative distance, peak speed of movement, and consistency of movement patterns. Changes were most notable in upper lip performance, which appeared to be the result of compensatory adjustments. Although the experimental participant's performance with palatal lift intervention became more similar to that of the nondisabled controls, his performance was markedly different on many kinematic parameters.

Palatal lift intervention for velopharyngeal incompetence (VPI) improves speech performance and overall intelligibility (Esposito, Mitsumoto, & Shanks, 2000; Koidis & Topouzelis, 2003; Yorkston et al., 2001). The articulatory basis for speech improvement with the VPI intervention is poorly defined, because the primary focus of prior investigations has been on resonance and airflow management as well as overall speech intelligibility. Modifications in articulatory movements might be expected with VPI management, as patients need to accommodate sudden changes in vocal tract aerodynamics and acoustics. Immediate changes in articulatory movements may also be expected as effective VPI management can eliminate the need for compensatory gestures that were previously used to minimize nasal air emissions, optimize oral airflow and pressure, and increase acoustic contrast in hypernasal speech. The kinematic level of analysis is particularly well suited to identify subtle changes in articulatory performance with VPI that impact speech performance. Studies of orofacial kinematics (primarily of repaired lips) have been conducted on individuals with cleft lip and palate to measure articulatory movement changes after surgery (Gross, Trotman, & Moffatt, 1996; Trotman & Faraway, 1998; Trotman, Far
away, Silvester, Greenlee, & Johnston, 1998; Trotman, Phillips, Faraway, & Ritter, 2003; van Lieshout, Rutjens, & Spauwen, 2002). The purpose of this study was to examine the impact of a palatal lift prosthesis on articulatory kinematics for a teenager with VPI due to a brainstem tumor. This investigation was designed to address the following research questions: (1) Does articulatory performance change in response to palatal lift intervention? and (2) If so, are the observed performance changes in the direction of normal speakers? Presumably, palatal lift intervention will reduce the articulatory compensation and therefore normalize articulatory performance.

METHOD

Experimental Participant

The experimental participant was a 17-year-old male with a history of surgical excision of a brainstem glioma at 12 years of age. He sustained neurological damage, which initially resulted in severely reduced speech intelligibility (5%). He demonstrated flaccid dysarthria as characterized by severe hypernasality and imprecise articulation. He was fitted for a palatal lift prosthesis approximately 12 months postsurgical excision. He participated in extensive rehabilitation targeting increasing articulatory precision for several years. At the time of the study, his speech was 97% intelligible with the palatal lift and 85% without the lift as measured by the Sentence Intelligibility Test (Yorkston, Beukelman, & Tice, 1996).

Control Participants

Data were collected from seven (4 female and 3 male) neurologically intact 16-year-old speakers. These data were obtained from an existing data set from a study on speech motor development. All control participants were prescreened by interview and had a negative history of speech, language, and hearing deficits. All were native speakers of American English.

Speech Samples

The speech samples included the segments “uy Bo” and “a pu” from four repetitions of the sentence “Buy Bobby a Puppy” spoken at each participant’s habitual loudness and rate. The participants were provided with verbal instructions from the experimenter and read instructions projected on a large screen.

Data Collection and Recording

Movements of the lower and upper lips were captured three dimensionally at 120 frames per second using an 8-camera optical motion capture system (Eagle Digital System, Motion Analysis Corporation). This system tracked the movement of spherical reflective markers (approximately 2 mm in diameter) that were illuminated with an infrared light source. The lower and upper lip markers were located midline on the vermillion border of each lip. The lower lip marker represented the movement of both the lower lip and jaw. Reference markers on the participant's forehead were used to subtract head motion (both translation and rotation) from the lip markers. Speech was recorded digitally with a head-mounted microphone that was maintained at a constant mic-to-mouth distance.

Analysis of the Kinematic Traces

The target speech segments in “uy Bo” and “a pu” were parsed from the beginning of the closing gesture to the end of the opening gesture of each VCV segment. The segment boundaries were determined from the lower lip signal because landmarks (i.e., zero-crossing in the associated velocity trace) associated with the onset and offset of the target gesture were easily identified on this signal. The parsed segments were imported into Matlab (2006) for analysis.

Reliability of measurement for all kinematic measures was determined using half of the experimental participant’s data, which was randomly selected and parsed by another researcher. Pearson product moment correlation between the first and second measurements was 0.97, indicating that the difference between the two measurements was negligible.

Cumulative Distance

The cumulative distance represented the distance the upper and lower lip markers traveled throughout the entire VCV segment.

Peak Speed of Movement

Peak speed of movement (mm/s) was obtained from the speed time histories, which were derived by
computing the first order derivative of each marker's Euclidean distance time history.

Movement Pattern Consistency Across Repetitions

The movement pattern of a single repetition of a speech segment was compared to the average movement pattern of all other repetitions. This measure indicated the degree of consistency in spatiotemporal characteristics of articulatory movements across repetitions. Movement patterns used for this analysis were time histories of the Euclidean distance from the origin of the head-defined coordinate system.

Statistical Treatment

An independent samples t-test was used to test within participant comparisons (with lift vs. without lift). Confidence intervals of 90% were calculated for the control group. For each kinematic measure, the experimental participant's data were compared to these confidence intervals to determine if performance fell within the bounds of normal performance. The use of interval estimation was chosen over significance tests due to the low number of participants in this study. Moreover, interval estimation has been advanced in the literature as providing more information than null hypothesis testing by allowing the comparison of a score against a particular distribution (Kirk, 1990).

RESULTS

Mean values for the control participants and the experimental participant (lift in vs. lift out condition) for all measures are provided in Figure 1. Significant differences between the lift in and lift out conditions are noted in the figure with asterisks ($p < 0.05$).

Palatal Lift in Versus Palatal Lift Out

**Lower Lip Cumulative Distance (mm) and Peak Speed (mm/s)**

With the lift in place, the experimental participant demonstrated a 10% decrease in cumulative distance for “uy Bo” and a 16% decrease for “a pu” in the lower lip compared to without the lift. Peak speed of movement significantly decreased 27% for “a pu” with the lift [$t (6) = -3.08, p = 0.021$] and 7% for “uy Bo,” which did not reach statistical significance.

**Upper Lip Cumulative Distance (mm) and Peak Speed (mm/s)**

The upper lip’s cumulative distance increased 33% for “uy Bo” and 44% for “a pu” with the lift compared to without [$t (6) = 2.78, p = 0.032; t (6) = 8.98, p = 0.001$, respectively]. Peak speed of movement increased 41% for “uy Bo” and 50% for “a pu” with the lift [$t (6) = 2.94, p = 0.026; t (6) = 6.37, p = 0.001$, respectively].

**Lower Lip Consistency of Movement Patterns (r)**

For the segment “uy Bo,” lower lip movement patterns, as indicated by the correlation coefficients, appeared to be more consistent across repetitions without the lift than with the lift (i.e., 0.98 vs. 0.45, respectively). However, this difference failed to reach statistical significance due to the small number of repetitions and high variability in the experimental participant’s performance. For “a pu,” the movement patterns were highly consistent ($r ≥ 0.89$), with no significant differences across the two conditions.

**Upper Lip Consistency of Movement Patterns (r)**

As indicated by the correlation coefficients in Figure 1, the upper lip displayed a similar pattern of performance to the lower lip (0.48 with lift and 0.74 without lift) for the segment “uy Bo.” However, these differences also were not significant due due the small number of repetitions and high variability in the experimental participant’s performance. Like the lower lip, the upper lip movement patterns were highly consistent for “a pu” ($r ≥ 0.90$), with no significant differences across the two conditions.

**Comparison to Control Participants**

**Lower Lip Cumulative Distance (mm) and Peak Speed (mm/s)**

Relative to the control group’s articulatory performance, the experimental participant’s lower lip performance improved in response to the palatal lift. Cumulative distances decreased from 43.52 mm without the lift to 39.70 mm with the lift for the segment “uy Bo,” which brought the values within the range of the control participants’ confidence interval. For “a pu,” values decreased from 29.77 mm without the lift to 25.73 mm with the lift, which brought performance closer to the control
For the segment “uy Bo,” the experimental participant’s cumulative distance increased from 4.41 mm without the lift to 6.02 mm with the lift and peak speed increased from 26.66 mm/s without the lift to 45.16 mm/s with the lift, which brought performance closer to the control group mean and within the control group’s confidence interval. For the segment “a pu,” the upper lip demonstrated a similar pattern of perfor-

**Figure 1.** Mean values for the lower and upper lips for two speech segments (“uy Bo” and “a pu”) across three kinematic parameters (cumulative distance, peak speed, and consistency of movement patterns). Ninety percent confidence intervals are plotted for the control participants. Asterisks indicate significant differences between the lift-in and lift-out conditions for the experimental participant at the 0.05 level. Note that the axes are scaled differently for each articulator.
mance. These changes brought the experimental participant’s performance closer to the control group mean, but not within the control group’s confidence interval.

Lower and Upper Lip Consistency of Movement Patterns (r)

For “uy Bo” and “a pu,” the results from the movement pattern consistency analysis for the upper and lower lip were nonsignificant. There was high variability in the experimental and control participants’ performance for the segment “uy Bo.”

DISCUSSION

The most significant changes in articulatory kinematics in response to the palatal lift were observed in the upper lip. Specifically, upper lip movements became larger and faster with the lift in place. These kinematic changes appeared to be due to the elimination of a compensatory response to nasal air escape or hypernasality during the lift out condition.

Airflow Management Versus Hyperarticulation

The function of the upper lip movement changes is uncertain, but may represent the experimental participant’s attempt to either minimize nasal air emission or modify oral articulation to enhance acoustic contrast. Presumably, the participant could have modified his oral excursions to encourage oral airflow and generate greater pressure. However, the kinematic findings were of reduced articulatory excursion, which did not support an effort to increase articulatory or acoustic distinctiveness. Observation of digital video confirmed this interpretation, showing that the experimental participant immobilized the upper lip, perhaps in an attempt to minimize nasal air emission by “clamping down” the nares. These findings might be interpreted to suggest that the participant prioritizes airflow management over articulatory/acoustic distinctiveness. The choice to obstruct nasal flow was particularly interesting because it had almost no perceptible effect on minimizing nasal air escape.

Articulatory Performance and Intelligibility

With the lift, the experimental participant’s articulatory performance tended to become more similar to that of control participants. However, although his speech was 97% intelligible with the lift in, his upper lip performance was still distinct from that of the control participants. Without additional testing, it is difficult to determine if these differences are a characteristic of prosthetic intervention or due to the acquired neurological impairment. Overall, these results demonstrate the sensitivity of kinematic analyses for identifying subtle changes in articulatory performance that are not detectible using auditory-perceptual based observations.

Consistency of Movement Patterns Increased Without Palatal Lift

The palatal lift produced an unexpected result on articulatory movement consistency analysis for the segment “uy Bo.” Specifically, movement pattern consistency was higher without than with the lift even though the experimental participant’s speech was perceptually judged as excessively hypernasal without the lift. This increase in movement consistency appeared to be a direct consequence of the participant’s immobilization of the upper lip during hypernasal speech. This result suggests that, relative to normal performance, disordered articulatory performance may not only be characterized by excessive movement variability, but also by reduced movement variability. In practice, the significance of token-to-token replicability on speech output is poorly understood.

CONCLUSION

These findings provide quantitative evidence for articulatory performance improvements in response to palatal lift intervention in a single speaker. Specifically, compensatory responses were highly evident at the kinematic level. With the lift in place, compensatory responses diminished and articulatory movements became more similar to those of the control participants for most kinematic measures. Although, the experimental participant’s articulatory performance still varied from that of the control participants on kinematic measures even with the lift in. Additional research is needed with larger numbers of individuals to determine if the current study’s results are consistent with the performance patterns of others with VPI due to acquired neurological impairment.

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