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Premature Infant Swallowing: Patterns of Tongue-Soft Palate Coordination Based Upon Videofluoroscopy

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Abstract

Coordination between movements of individual tongue points, and between soft palate elevation and tongue movements, were examined in 12 prematurely born infants referred from hospital NICUs for videofluoroscopic swallow study (VFSS) due to poor oral feeding and suspicion of aspiration. Detailed post-evaluation kinematic analysis was conducted by digitizing images of a lateral view of digitally superimposed points on the tongue and soft palate. The primary measure of coordination was continuous relative phase of the time series created by movements of points on the tongue and soft palate over successive frames. Three points on the tongue (anterior, medial, and posterior) were organized around a stable in-phase pattern, with a phase lag that implied an anterior to posterior direction of motion. Coordination between a tongue point and a point on the soft palate during lowering and elevation was close to anti-phase at initiation of the pharyngeal swallow. These findings suggest that anti-phase coordination between tongue and soft palate may reflect the process by which the tongue is timed to pump liquid by moving it into an enclosed space, compressing it, and allowing it to leave by a specific route through the pharynx.

Keywords

Infant; coordination; swallowing; videofluoroscopy; dysphagia; tongue; soft palate

1. Introduction

Premature infants beginning oral feedings in the NICU may be referred for videofluoroscopic swallow studies (VFSS) when diagnosed with poor feeding, outward signs of respiratory congestion combined with precipitous drop in percentage oxygen saturation, and suspicion of aspiration while swallowing (Rogers & Arvedson, 2005). Unless there are gross anatomical abnormalities or other exacerbating medical problems, swallowing difficulty, or dysphagia, is often attributed to immature coordination due to prematurity. The purpose of this study was to better understand the particular coordination patterns produced during swallowing by premature infants who are referred by their physician for a videofluoroscopic evaluation.

There are limited imaging studies of infant swallowing based upon videofluoroscopic (Mercado-Deane et al., 2001; Newman et al., 2001; Vazquez & Buonomo, 1999) or ultrasound methods (Bosma et al., 1990; Bu'lock et al., 1990; Miller & Kang, 2007), and compared to work with animals (German et al., 1998), little is known about coordination between tongue, soft palate, other structures during infant swallowing. Here, we used videofluoroscopic images to begin to explore coordination of premature infant swallowing. To do so, we conducted computer-assisted kinematic analyses of the recorded images of the tongue, soft palate, and liquid bolus head of 12 premature infants referred from hospital NICUs for VFSS.

The question of how to conceptualize coordination of premature infant swallowing is approached here from a dynamical systems theoretical perspective (Goldfield, 2007; Thelen & Smith, 1994). Coordination, a process by which order emerges from the interactions among the component parts, is a core concept in this approach (Turvey, 2007). Coordination observed in neuromotor behaviors, such as swallowing, occurs simultaneously at multiple levels of the motor system (e.g., motoneurons, muscles), and is organized in a temporary way by the requirements of species-specific, epigenetic, task-specific goals. Coordination patterns may be based upon measurements of muscle activations (e.g., EMG patterns), or on kinematic variables (e.g., position, velocity). A widely-used measure of coordination, based upon kinematic data, is called mean continuous relative phase, where an event is located in time with respect to corresponding events (Richardson et al., 2005). Here we use continuous relative phase to measure coordination between anatomical points along the tongue surface, and between the tongue points and the soft palate.

In complex physical and biological systems, there is a tendency for rhythmically moving components to mutually influence each other. This was demonstrated in early studies of bony fish (von Holst, 1973), and subsequently in other small vertebrates (Cohen, 1987). These same principles of coordination have been demonstrated in adult human speech (Saltzman et al., 1998) and more recently in adult swallowing (Steele & van Lieshout, 2008), as well as in our own work on infant breathing patterns (Goldfield et al., 1999a) and on the interactions between infant sucking and breathing patterns (Goldfield et al., 1999b). What is most notable about coordination is the tendency of components to enter stable patterns that persist temporarily under specific conditions, resist perturbation under certain kinds of change, and then rapidly reorganize when conditions exceed certain task-specific boundaries (Kelso, 1995). Here, we examined relative phase between tongue and soft palate to determine whether the distinctive characteristics of swallowing may be characterized by particular stale coordination patterns.

Swallowing events are typically characterized by stages in which a liquid bolus (for newborns) is drawn into the mouth (oral transfer) and the bolus is forcefully propelled through the pharynx to the sphincter entry to the esophagus (Dodds, 1989). However, it is well known from work in other areas of motor development, such as locomotion, that the activation of the muscles is timed to take advantage of the elastic (springy) characteristics of the soft tissues of the body for complementing muscular force production (Goldfield, Kay & Warren, 1993; Thelen & Ulrich, 1991). Like a spring that is compressed and released, soft tissue stores elastic potential energy (Vogel, 2003) in order to sustain a cycle of activity. By timing activations of the many muscle groups of the tongue to move in a direction opposite that of the soft palate (i.e., move antiphase with it), the tongue and soft palate may work together cooperatively for the purpose of pumping, i.e., moving liquid into a confined area, compressing it, and releasing it through a particular opening (Vogel, 2003). Therefore, a second goal of the study was to determine whether tongue and soft palate may exhibit antiphase coordination during infant swallowing.

These two characteristics of coordinated swallowing – (1) organization around stable values of relative phase, and (2) cooperative tongue and soft palate motions that may use the elastic energy stored during a particular portion of a cycle to support muscular efforts to pump liquids during swallowing -- are used here to begin to address the underlying basis for swallowing among premature infants, as well as the nature of dyscoordination of prematurity. Our focus in this initial report of an ongoing longitudinal study is to characterize the coordination between tongue and soft palate of infants who were clinically diagnosed with poor coordination during oral feeding, and referred for videofluoroscopic swallow study. Specifically, we hypothesize that

1. suckling during oral transfer is characterized by an anterior-posterior lingual wave, as measured by a phase lag between anterior, medial, and posterior points digitally superimposed along the lingual surface, and
2. soft palate lowering and elevation during oral transfer, as liquid is filling the mouth, is characterized by a phase lag close to 180 degrees (anti-phase).

2. Method

2.1. Subjects

Subjects were twelve prematurely born infants receiving care in the Neonatal Intensive Care Unit (NICU) at Brigham and Women's Hospital, or Beth Israel Deaconess Medical Center, Boston, Massachusetts. Each infant was referred to Children's Hospital Boston for videofluoroscopic swallow study (VFSS) due to oral feeding difficulties (weak sucking, poor coordination of sucking, swallowing and breathing as determined by the nurse or by bedside evaluation by the speech-language pathologist) and suspicion of aspirating liquid below the level of the vocal cords during oral feedings. The referral procedure was as follows. The speech-language pathologists (KF, JP) determined from bedside evaluation and/or medical chart review whether any prematurely born infant met the inclusion criteria for the study. These included birth before the 33rd week of pregnancy, age at referral between 36 and 42 weeks postmenstrual age, referral by the NICU for poor oral feedings due to oropharyngeal dysphagia and/or suspected aspiration. Infants who exhibited any cranio-facial abnormalities, e.g., Pierre-Robin syndrome, or any serious medical conditions that required altered feeding routines, such as cardiac surgery, were excluded from the study. Infants were also excluded if they had a history of neurologic abnormality that would preclude feeding by oral means.

2.2. Procedures

The participating infants were all medically stable, as determined by the attending neonatologist. One or both parents and a nurse accompanied the infant to the radiologic procedure. Each infant was transported by his or her nurse in a mobile incubator, with oxygen support continuously available. The research procedure was identical to standard medical care, except for the addition of skin markers along the jaw line. The radiologic procedure was conducted by a pediatric radiologist (CB), with speech-language pathologists (KF, JP), and the research team (EG, SM) present. The parents, radiologists, clinicians, and researchers all wore lead aprons for protection against radiation. The radiology table adjacent to the camera head was placed in a vertical position. A Tumble Form seat was attached to a hospital-designed wedge, which, in turn, was attached to the footplate of the radiology table. Each infant was placed in a sitting position in the seat so that he or she was reclined at a 60 degree angle.

Each infant was further prepared for the evaluation by placement of two tiny metal markers (Beekly spot number 102, Beekley Corp., Bristol CT) along the jawline, halfway between the chin and earlobe. A pulse oximeter (Nellcor N-595, Tyco Healthcare, Pleasanton CA) was used to record percent oxygen saturation during the evaluation (not reported here). Once the baby was seated and strapped in, the radiologist positioned the camera head to obtain a lateral view, and narrowed the field of view so that there was minimal radiation exposure.

A speech-language pathologist prepared the fluids used for the VFSS evaluation, two consistencies of standardized portions of barium sulfate (Liquid E-Z Paque, EZ-Em, Westbury, New York). A consistency that simulated human milk or formula was prepared by diluting the barium sulfate with 5% glucose in water (Enfamil, Mead Johnson & Company, Evansville,

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Ind) to a 50% solution. In specially conducted laboratory rheology tests, we determined that barium sulfate diluted with sterile water to a 50% solution had a viscosity similar to that of human milk or formula. The diluted barium sulfate was modified from the premixed product, and fit the recommended American Dietetic Asssociation nomenclature of thin consistency, while the undiluted barium fit the nomenclature of nectar-like consistency (Steele et al., 2003). We adopt this nomenclature in the remainder of the article.

A silicone nipple, similar to the ones used in the NICU, was used to present all liquids to the infants throughout the evaluation. The entire radiation time was a maximum of three minutes, during which the video images were recorded to DVD for later clinical review and, for purposes of the research, detailed kinematic analyses. During the evaluation, each infant was presented with thin consistency barium sulfate by bottle and nipple for a period of 60 sec or less. We included the first 60 sec of swallowing, based entirely on a sequence of successive, uninterrupted swallows. Data from remaining additional swallows during the remainder of the evaluation are being prepared for a separate report. The speech-language pathologist clinically evaluated coordination of swallowing and airway protection throughout the videofluoroscopic examination.

2.3. Data reduction

The resolution of the lateral view of the infant's lingual-pharyngeal anatomy was 30 frames per sec, limited by the x-ray image intensifier used for clinical videofluoroscopy at Children's Hospital Boston. Following each VFSS evaluation, the recorded DVD data were converted to a format compatible with the software used for manual frame-by-frame kinematic analysis (MaxTraq and Max Mate, Innovision Systems, Columbiaville MI). During post-VFSS kinematic analysis, a software-generated overlay grid was aligned with the position of one of the skin markers on the infant's jawline, and all points were calibrated with respect to the grid. On each video frame, this grid was used to digitize points along the lingual surface and at a point on the soft palate. Each point digitized with the Max Traq software corresponded to x and y coordinates saved for analysis and display in the companion Max Mate program. These data were then saved as text files for relative phase analysis with custom programs written for MATLAB.

2.4. Determining relative phase of two time series

MATLAB programs were written by MJR to analyze the continuous relative phase of the time series formed by each lingual or soft palate point over successive frames. Continuous relative phase is a relationship between two time series in which a point on one is related over time to a second point on the other. The resulting phase is presented in angular degrees to reflect the cyclical nature of the relationship between the points over time. With the MATLAB programs, each time series resulting from a particular digitized point was normalized around zero, and low pass filtered (using a Butterworth filter) with a cut-off frequency of 10 Hz. A peak-picking algorithm determined peaks and valleys of the waveforms and used these to calculate mean and standard deviation of relative phase of any pair of digitized points.

2.5. Circular statistics

A statistical approach, termed circular or directional statistics (Batschelet, 1981), was used to calculate descriptive statistics for continuous relative phase. These tests assume sampling from a circular analog of the linear-normal distribution. Descriptive circular statistics, the mean angle and circular standard deviation, respectively, are based upon transforming rectangular coordinates based upon X and Y into polar coordinates by means of sine and cosine transformations. Circular statistics may be preferable to other nonparametric methods because the result can be interpreted directionally (i.e., spatially), e.g., for testing whether a phase angle for coordination differs significantly from 0 degrees.

3. Results

3.1. Subject characteristics

Table 1 presents a summary description of the sex, gestational age at birth, postmenstrual age at videofluoroscopic evaluation, and the clinical diagnosis resulting from the videofluoroscopic evaluation. Eight of the 12 infants were born at 26 weeks gestational age or less, indicating that there may be greater risk of swallowing difficulties associated with decreasing gestational age. However, this question was not specifically addressed in this study, and awaits analysis of our complete larger sample. Table 2 presents a summary of the recommendations for NICU oral feedings made by the feeding team following the videofluoroscopic evaluation.

3.2. Individual kinematic data

The following three sections present data from individual infants in order to illustrate how the points digitized at each frame were used to create a time series, and how relative phase was calculated from the time series.

3.2.1. Tongue motion—To examine whether the tongue motions during suckling were characterized by an anterior-posterior direction, we calculated time series for the digitized points at the anterior, medial, and posterior positions (see Figure 1). Anterior-posterior motion would be evident if there were a progressively larger phase lag between anterior-medial, medial-posterior, and anterior-posterior pairs of points. Figure 2a presents the time series of each point to illustrate the temporal lag between the posterior point and the other two points. Figure 2b plots the continuous relative phase, and shows that the anterior-posterior value is the largest of the three, as predicted for an anterior-posterior wave.

3.2.2. Coordination between tongue and soft palate elevation—We examined continuous relative phase between the medial tongue point and a point on the soft palate (see Figure 3) as it lowered and elevated to determine whether the two points were near anti-phase prior to initiation of the pharyngeal swallow. Initiation of the pharyngeal swallow was operationally defined according to the usage of Kahrilas (1993) as the beginning of bolus propulsion by the tongue and by elevation of the soft palate to close off the nasopharynx. The anti-phase pattern would be expected if the pharyngeal swallow were timed to capitalize on the potential energy stored and released as the soft palate lowered and elevated, respectively. The top panel of Figure 4 shows that there is a brief moment when tongue and soft palate simultaneously move in opposite directions. The corresponding continuous relative phase plot in the bottom panel shows that tongue and soft palate briefly enter an anti-phase pattern at initiation of the pharyngeal swallow, and then return to their previous phase relationship.

3.3. Group data

3.3.1. Tongue motion—The group data used to evaluate tongue motion consisted of the mean relative phase angles for each of the three tongue points calculated for each of the12 infants. The hypothesis that the tongue generates a peristaltic wave in the anterior-posterior direction implies a greater phase lag at the most posterior point relative to the tongue tip. Table 3 presents the mean vector and circular standard deviations for each of the three tongue points. Each point exhibited a phase angle close to 360 degrees (i.e., a small phase lag relative to 0 degrees), with low circular standard deviation. T-tests indicated that the mean phase angle at the medial point was significantly greater than that of the point at the tongue tip, $t(11)=3.479$, $p=.005$. However, there were no significant differences in mean phase angle between the tongue tip and medial point, or between the medial and posterior points. Thus, there is some support for the hypothesis that suckling movements generate a lingual anterior-posterior peristaltic wave.

3.3.2. Coordination between tongue motion and soft palate elevation—To test the hypothesis of tongue and soft palate coordination near anti-phase at the time of the pharyngeal swallow, the phase angle between the medial tongue point and the point on the soft palate was calculated. The mean vector was 150.485, and the circular standard deviation was 34.668. Thus, the mean phase angle was close to 180 degrees, with the standard deviation indicating that coordination between tongue and soft palate may have regularly shifted to an anti-phase pattern and then returned to a phase lag pattern. To further evaluate this possibility, the mean phase angles of tongue and soft palate coordination for the first 12 swallows of each of the 12 infants (144 total) were calculated and plotted as a single distribution in the circular histogram presented in Figure 6. The figure reveals an approximately bi-modal distribution of phase angles, with swallows occurring either near the mean or at 180 degrees (anti-phase). Thus, there is some support for the hypothesis that the coordination pattern between tongue and soft palate exhibited two stable states, a brief phase lag between tongue and soft palate, and a longer phase lag between tongue and palate resulting in tongue-soft palate coordination close to anti-phase.

3.3.3. Patterns of coordination over successive swallows—Another potential contributor to the observed distribution of tongue-soft palate phase angles in Figure 6 is the sensory and motor experience that occurs over successive swallows. While we were not able to distinguish sensory from motor experience using analysis of kinematic data, we were able to examine whether the anti-phase coordination pattern might be more likely after the experience of a sequence of swallows. If so, then the anti-phase pattern of tongue-soft palate coordination may appear later in the swallow sequence compared to earlier swallows. To examine this possibility, the mean and standard deviation of the continuous relative phase for the 12 infants was calculated at each swallow position (from 1 to 12), and is plotted in Figure 7. The figure clearly shows that coordination between tongue and soft palate moves closer to anti-phase over successive swallows. Moreover, the standard deviation of continuous relative phase decreases most rapidly at the same time that coordination comes close to anti-phase. This suggests that the anti-phase pattern may become more stable later in the sequence (since SD of continuous relative phase is an index of coordination stability (Scholz & Kelso, 1990). A Wilcoxon matched pairs test indicated that the mean continuous relative phase of tongue-soft palate coordination for the first six swallows of the 12 infants (143.02) was significantly different than the last six swallows (156.42), $Z= 1.99$, $p=0.046$. Thus, there is a greater likelihood that tongue-soft palate coordination is close to anti-phase during the later swallows in a sequence than during earlier swallows.

4. Discussion

The findings generally confirm the study hypotheses. First, coordination of preterm infant swallowing is organized around patterns of relative phase that may transform intrinsic rhythmic motions of the oral anatomy into its distinctive organizational stages. Suckling during oral transfer is characterized by an anterior-posterior lingual wave that may serve the function of moving liquid to the back of the mouth, the basis for the oral transfer stage. The progressively larger phase lag in an anterior-posterior direction observed in this videofluoroscopy study is consistent with ultrasound findings of tongue peristalsis by others (e.g., Bosma et al., 1990). Indeed, as has been shown for chest and abdomen motions during breathing (Greenspan et al., 2005), increasing or decreasing the phase lag between different anatomical structures may be a means for changing the efficiency with which muscular effort is converted into mechanical actions.

Second, as successive cycles of tongue movement fill the mouth with liquid, the relative phase between the tongue dorsum and an elevating-lowering point on the soft palate moves towards an anti-phase pattern. The shift towards anti-phase supports the hypothesis that changes in tongue shape result in lingual movement that is simultaneous with, but in an opposite direction to, the lowering and elevation of the soft palate. Functionally, this creates a lingual-palatal space for containing liquid as it accumulates during pumping actions, provides a seal against leakage to the airway or nasopharynx, and forcefully moves the liquid through the pharynx to the upper esophageal sphincter. What do these three functional changes achieve? One possibility is that stabilization of a synergic spatial arrangement among these specific parts of the oral anatomy transforms the mouth for a specialized function, namely, sensory-regulated pumping (Crompton et al., 2008). A positive displacement, or fluid-static, pump accumulates liquid within a confined space, reduces the volume of that space, and then forces the liquid to leave by a specific outlet (Vogel, 2003).

One way for muscular timing to harness the mechanical properties of the tongue, an incompressible but highly flexible muscular hydrostat (Gilbert et al., 2007) is to take advantage of the wave-like nature of its rhythmic movements. Thus, we first examined whether infant tongue movements, in anticipation of swallowing, exhibit wave-like anterior-posterior coordination patterns. Muscular timing may also capture potential energy for the work of swallowing as the tongue changes its shape, so that the dorsum is in an anti-phase location with respect to soft palate elevation. The palato-pharyngeal arch is, upon dissection, surprisingly large, and has structural properties amenable for storing elastic potential energy, as it holds together the laryngeal cartilages (Crompton et al., 2008). With each lowering, the palato-pharyngeus muscle shortens and, during elevation, may release this energy to support the pharyngeal swallow. By initiating muscular timing of the pharyngeal swallow so that tongue and soft palate are anti-phase, these organs may be used together to produce a forceful impulse that moves accumulated liquid from the mouth to the opening of the upper esophageal sphincter. Here, we examined whether the movements of tongue and soft palate during the stages of oral transfer and initiation of the pharyngeal swallow are characterized by a tendency towards anti-phase coordination.

The familiar stages of swallowing may reflect the operation of the dual functions of such a pump: (1) the oral stage occurs when peristaltic actions of the tongue transfer liquid through the lips to the back of the mouth, while at the same time maintaining a tight seal around the lips and insuring that apposition between tongue and soft palate seals the nasal passage, (2) the initiation of the pharyngeal swallow occurs when oral tissues containing the liquid are stretched, the tongue dorsum is lowered, and the soft palate elevates. By timing the muscle contractions that initiate swallowing relative to the peak of elastic potential energy stored in the tissues, at anti-phase, the nervous system may take advantage of the phenomenon of resonance in oscillatory systems. At resonance, there is maximal transfer of potential energy to kinetic energy in order to do work (Goodman et al., 2000).

The differences in feeding recommendations for the 12 infants, as reported in Table 2 are, perhaps, not surprising. Half of the infants were considered “safe” oral feeders, and were able to return to the NICU with a recommendation that they be allowed to continue oral feedings with human milk or formula. The remaining infants exhibited clear indications of dysphagia and aspiration. These infants received a diagnosis of “poor coordination”, and a recommendation was made for either specially thickened milk or formula, or restriction to nasogastric tube feedings. However, there is currently little contact between a fundamental understanding of the nature of coordination, or of the relation between different kinds of feeding experiences, clinical diagnoses, and recommendations for clinical care. By defining coordination with respect to specific phase relationships of the tongue and soft palate, as we did in this study, it may be possible to better link theory and clinical practice. However, many questions remain. Why does dysphagia seem to improve when infants swallow nectar thick compared to thin consistency liquids? How is the coordination of the tongue and soft palate related to specific velocity characteristics of bolus transit? Our ongoing work on the effect of nectar thick liquids on the coordination of tongue and soft palate, on the role of specific experiences for the development of swallowing, and application of other mathematical tools to swallowing are steps towards that goal.

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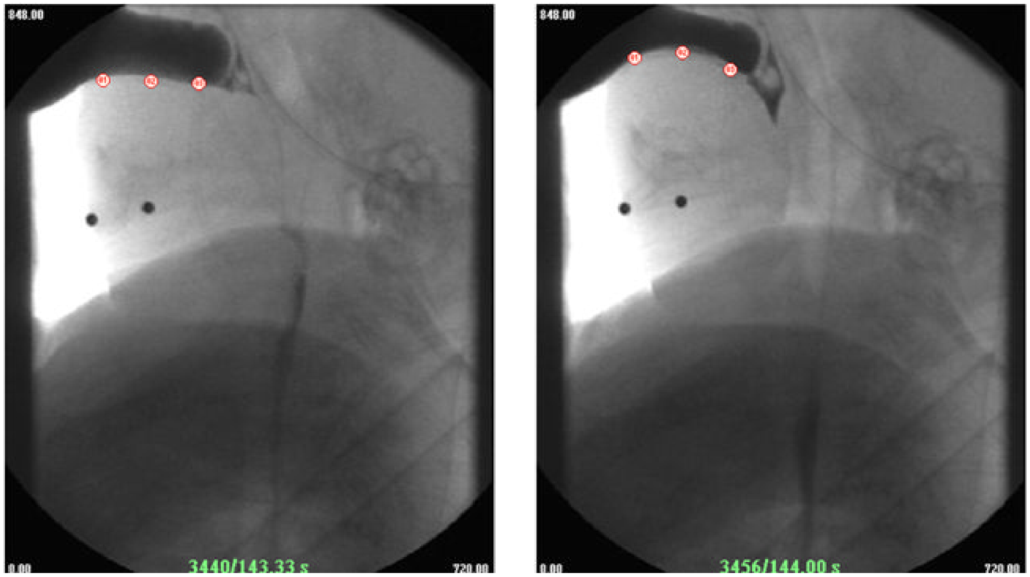

Figure 1.
Sequence of video frames during videofluoroscopy of a preterm infant clinically referred due to feeding problems seen in the NICU. The numbered circles indicate points digitally superimposed on successive frames. Point 1 is the tongue tip, point 2 is the medial tongue point, and point 3 is the posterior tongue point. Each circle was placed at the boundary between light regions (the tongue) and dark regions (the bottle nipple filled with barium sulfate) forming the tongue apposition with the nipple. The left panel indicates the tongue rest position during suckling, and the right panel shows the maximum compression of the nipple.

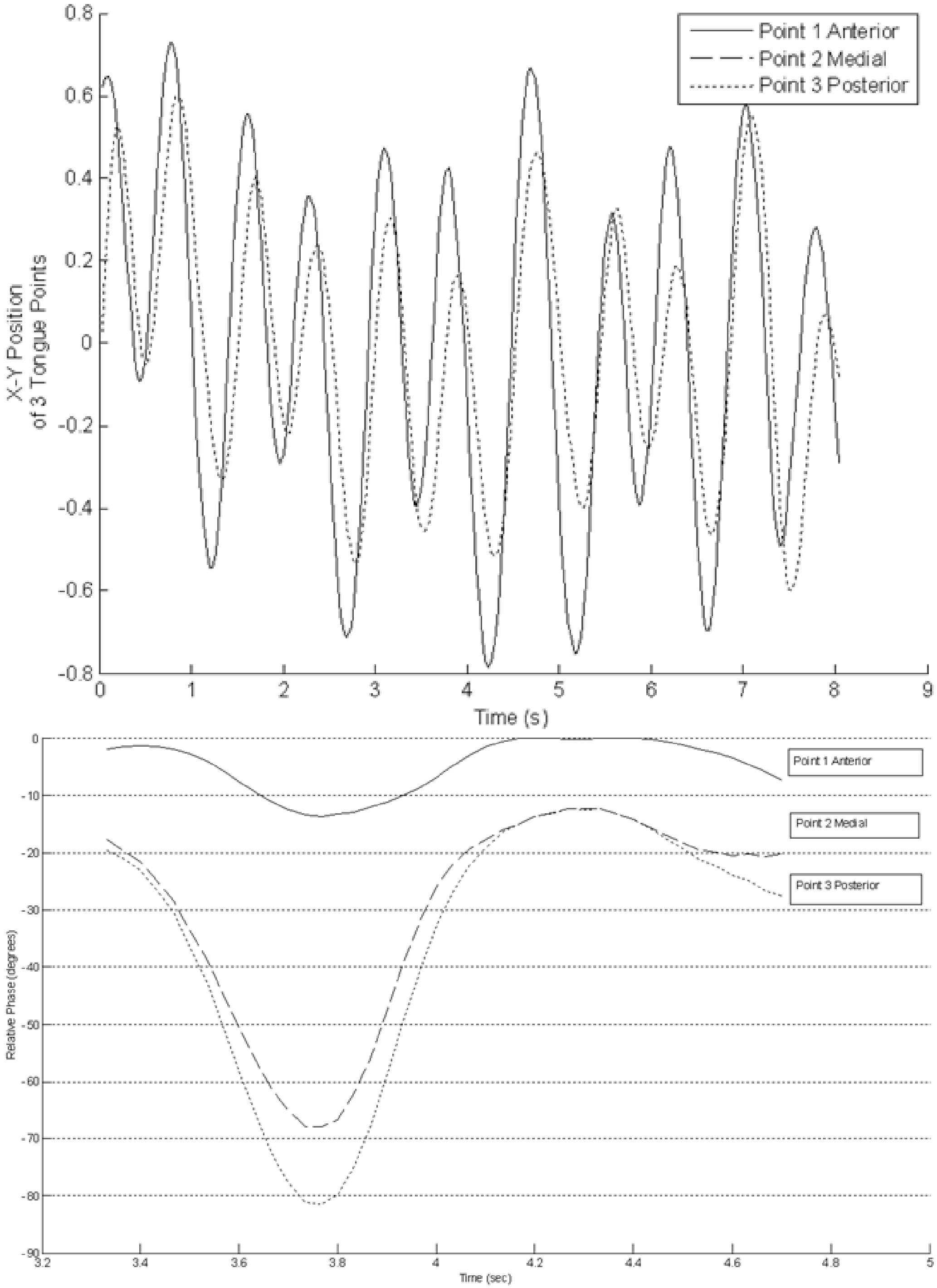

Figure 2.
(a) Time series created from the sequence of digitized points over successive frames in Figure 1. Note the increasing phase lag of the points proceeding in an anterior-posterior direction. (b) Plot of the continuous relative phase calculated from the relation between the three points, taken a pair at a time. Note that the posterior point exhibits the largest phase lag, as expected for an anterior-posterior peristaltic wave.

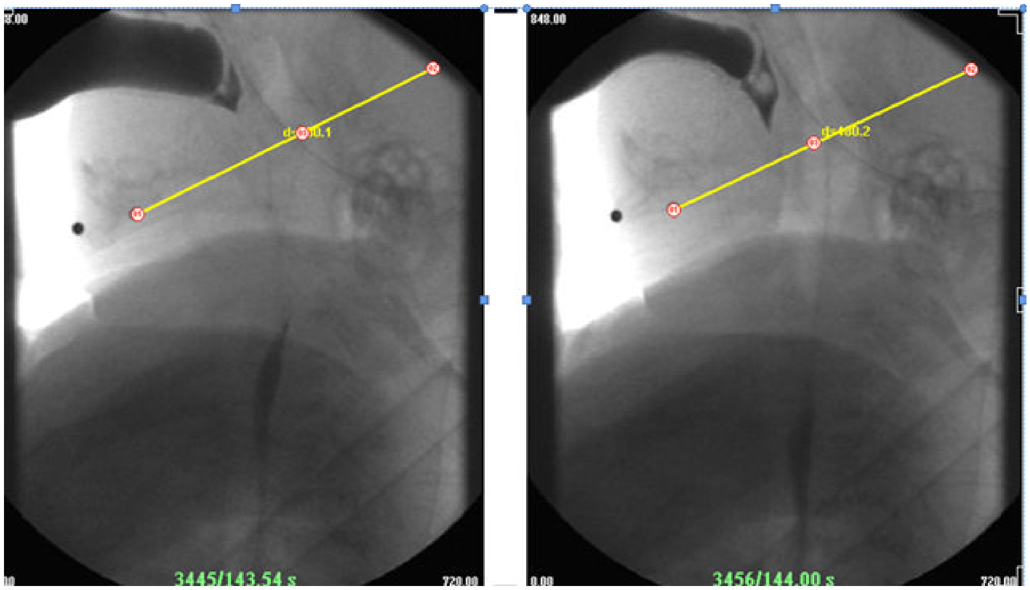

Figure 3.
Sequence of video frames as in Figure 1, but now with a fixed line superimposed between a landmark metal sphere taped on the skin and a reference point on a digitally superimposed rectilinear grid. The numbered circle is a point digitized at the light-dark boundary of the soft palate crossing the fixed line. The two panels illustrate the motion of the soft palate as it elevates (left) and lowers (right).

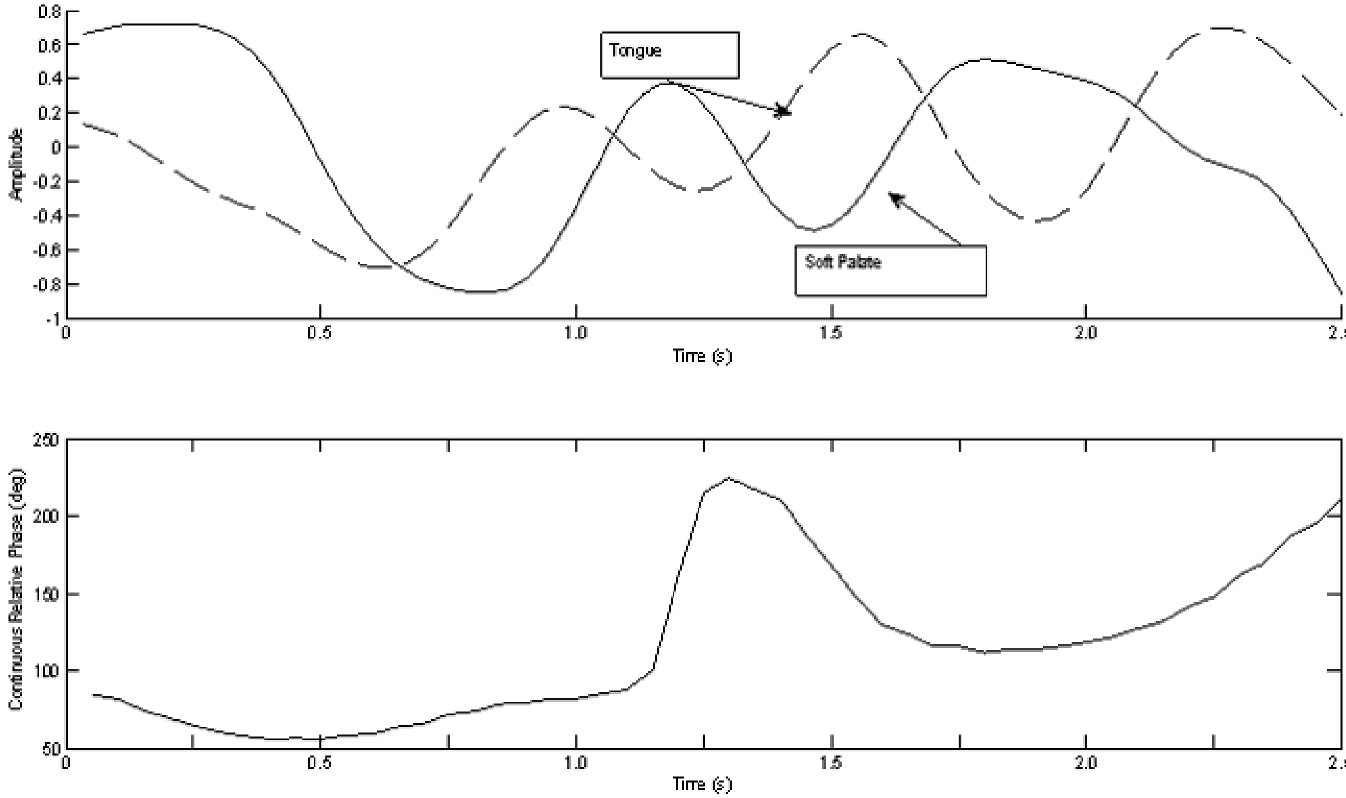

Figure 4.
The top panel overlays the time series of the soft palate elevation and the medial tongue point to show that there is a brief moment when the two structures move in opposite directions at the same time (i.e., anti-phase). The bottom panel is a plot of the continuous relative phase of the two time series, indicating that at that brief moment, tongue and soft palate are close to 180 degrees, or anti-phase, and then return to their previous phase relationship.

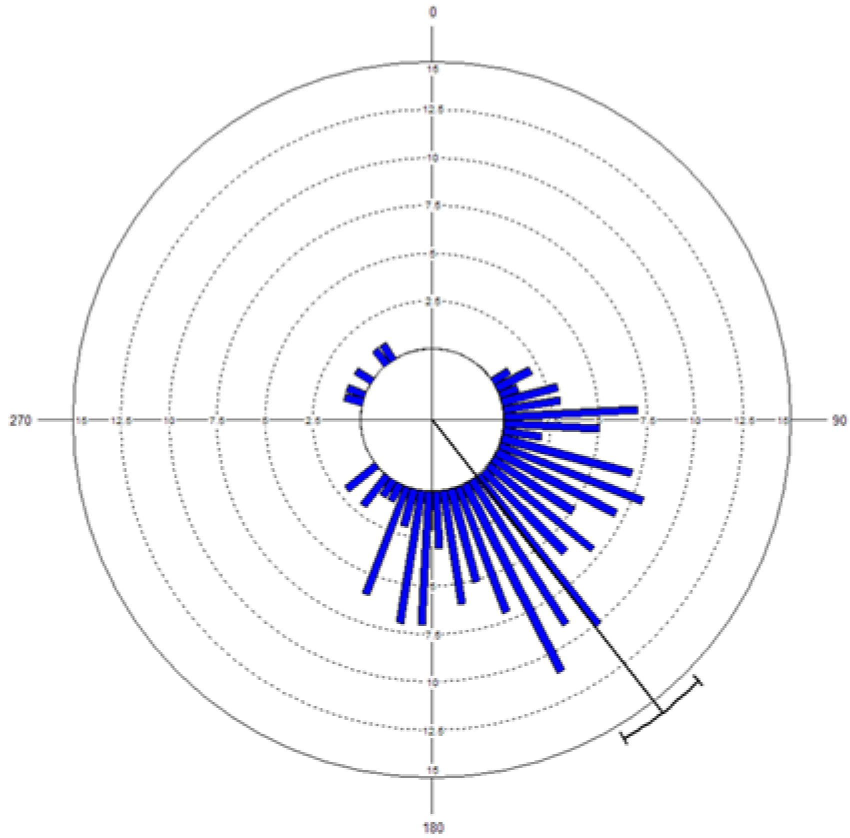

Figure 5.

A circular histogram of the phase angles characterizing tongue-soft palate coordination for the 12 swallows produced by each of the 12 subjects. The line from the radius indicates the mean and standard deviation for all 144 individual swallows.

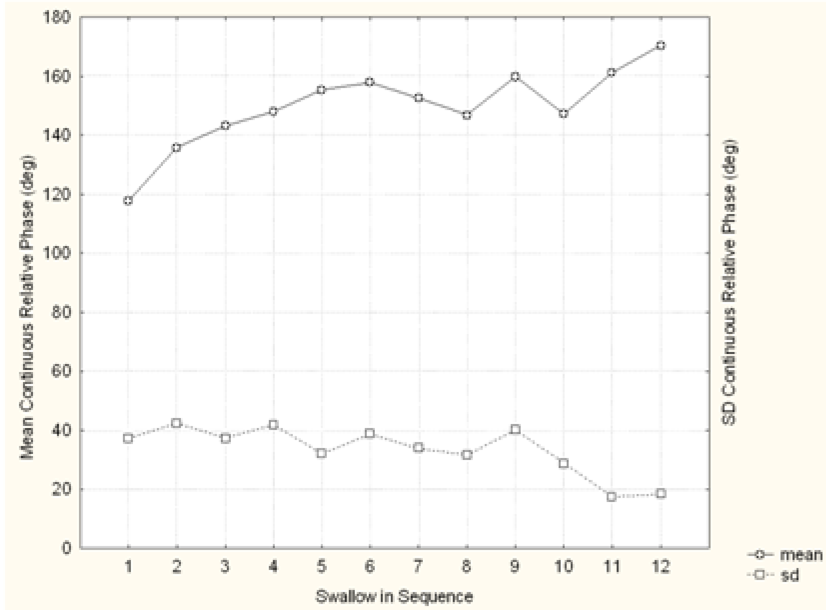

Figure 6.
Mean and standard deviation of continuous relative phase of tongue-soft palate coordination for the 12 infants at each successive swallow, from 1 through 12. Note that the increase of relative phase during the last few swallows is accompanied by a concomitant decrease in SD of relative phase, a measure of coordination stability.

Table 1

Demographic Characteristics of Subjects

Number	Sex	Birth Weight (g)	Gestational Age (weeks)	Postmenstrual Age at VFSS (weeks)
1	F	940	24.5	38
2	M	850	26	39
3	F	750	26.43	38
4	F	660	28.5	39
5	F	700	26	38
6	M	770	31.71	39
7	M	830	24.71	39
8	M	650	24	38
9	F	710	28	39
10	M	720	26	40
11	F	750	30	38
12	F	590	24	39
Mean		743.33	26.65	38.67
SD		95.85	2.45	0.65

Table 2

Clinical Recommendation Made Following Videofluoroscopic Evaluation

Number	Clinical Recommendation For NICU Feedings	Recommendation For Follow-up Videofluoroscopic Evaluation
1	NPO[1]	Yes
2	Nectar[2]	Yes
3	Nectar	Yes
4	Thin[3]	No
5	NPO	Yes
6	Thin	No
7	Thin	No
8	Thin	No
9	Thin	No
10	Nectar	Yes
11	Thin	No
12	NPO	Yes

Note.

[1]Recommendation is made for nasogastric (NG) tube feedings only while in NICU.

[2]Recommendation is made and specific recipe provided for amending human milk or formula during NICU oral feedings to nectar-thick consistency.

[3]Recommendation is made to allow infants to continue oral feedings with thin consistency liquids (human milk or formula).

Table 3

Descriptive Circular Statistics for Phase Angle of the Three Tongue Points (degrees)

	Tongue Point		
	1	**2**	**3**
Circular Mean	358.951	351.718	353.388
Circular SD	4.154	5.744	8.582