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Premature infant swallowing: Patterns of tongue-soft palate coordination based upon videofluoroscopy☆

Eugene C. Goldfield*, Carlo Buonomo, Kara Fletcher, Jennifer Perez, Stacey Margetts, Anne Hansen, Vincent Smith, Steven Ringer, Michael J. Richardson, Peter H. Wolff

Children's Hospital Boston, Harvard Medical School, United States

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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.

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, Keckley, Petersen, & Hamner, 2001; Vazquez & Buonomo, 1999) or ultrasound methods (Bosma, Hepburn, Josell, & Baker, 1990; Bu'Lock, Woolridge, & Baum, 1990; Miller & Kang, 2007), and compared to work with animals (German, Crompton, & Thexton, 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

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* Corresponding author at: Children's Hospital Boston, Center for Behavioral Science, 300 Longwood Avenue, Pavilion 159 Boston, MA 02115, United States. Tel.: +1 617 355 8353.
E-mail address: eugene.goldfield@childrens.harvard.edu (E.C. Goldfield).

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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 (Goldfield, Richardson, Lee & Margetts, 2006; Richardson, Marsh, & Schmidt, 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, Lofqvist, Kay, Kinsella-Shaw, & Rubin, 1998) and more recently in adult swallowing (Steele & van Lieshout, 2008), as well as in our own work on infant breathing patterns (Goldfield, Schmidt, & Fitzpatrick, 1999) and on the interactions between infant sucking and breathing patterns (Goldfield, Wolff, & Schmidt, 1999). 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 re-organize 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 anti-phase 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 anti-phase 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° (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,