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Baseline characteristics of cervical auscultation signals during various head maneuvers

I. Jestrović [a], J.M. Dudik [a], B. Luan [a], J.L. Coyle [b], E. Sejdić [a,*]

[a] Department of Electrical and Computer Engineering, Swanson School of Engineering, University of Pittsburgh, Pittsburgh, PA, USA
[b] Department of Communication Science and Disorders, School of Health and Rehabilitation Sciences, University of Pittsburgh, Pittsburgh, PA, USA

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ABSTRACT

Cervical auscultation (CA) is an emerging method of assessing swallowing disorders that is both non-invasive and inexpensive. This technique utilizes microphones to detect acoustic sounds produced by swallowing activity and characterize its behavior. Though some properties of swallowing sounds are known, there is still a need for a complete understanding of the baseline characteristics of cervical auscultation signals as well as how they change due to the patient's head motion, age, and sex. In order to examine these parameters, data was collected from 56 healthy adult participants that performed six different head movement tasks without swallowing. After preprocessing the signal, features were extracted. Dependent variables were time domain, frequency domain and time-frequency domain features. Statistical tests showed that only the skewness and peak frequency were not statistically different for all tasks. The peak frequency results indicate that head movement does not significantly affect the microphone signal, and that it is unnecessary to filter out the lowest frequency components. No sex differences were observed in the extracted features, but several features exhibited age dependence.

1. Introduction

Swallowing difficulties, or dysphagia can occur for many reasons [1]. Almost half of stroke patients suffer from dysphagia [2]. In stroke, dysphagia can impair one or more of the oral, pharyngeal, or esophageal contributions to the transfer of a swallowed bolus of food or liquid into the digestive system. Given that the upper aerodigestive tract is a single tube that is shared by the digestive system and the respiratory system, the numerous events that occur during this alternating access to the mechanism must be precisely executed to prevent swallowed material from entering the airway. Sensorimotor events that occur during a single swallow include oral and pharyngeal activities that systematically transfer intrabolus pressure from the mouth to the esophagus: oral propulsion of the bolus into the pharynx while preventing its leakage into the nasal cavity, and transfer of the bolus from the mouth, through the pharynx into the esophagus while ensuring that the airway is closed and the upper esophageal sphincter is adequately opened. Since the duration of a pharyngeal swallow is very brief (about 1 s) and several biomechanical events occur during this duration, the mistiming of the sequenced components of a swallow, or other sensorimotor impairments affecting swallowing can produce adverse events such as misdirection of a swallowed bolus into the airway leading to aspiration, in which food and fluids enter the trachea and into upper airways and lungs. Aspiration is a serious immediate consequence of dysphagia in many stroke patients and contributes significantly to the morbidity and mortality of these patients by producing pneumonia, airway obstruction, and other chronic pulmonary consequences [3]. Likewise, dysphagia after stroke is responsible for important adverse clinical outcomes such as malnutrition, dehydration, and impaired quality of life [4,5]. In fact patients with new onset of stroke who develop pneumonia after onset, have a three-fold increased relative risk of death compared to those that do not develop pneumonia after stroke onset [6]. Hence, early diagnosis of dysphagia is very important for patient safety and health [7]. One current gold standard for diagnosis is the videofluoroscopic swallowing study (VFSS), which is an imaging technique that uses X-rays for recording biomechanical events that occur during swallowing, and visualize the path of swallowed foods and fluids [8,9]. However, VFSS instrumentation is not always available for immediate access when needed by patients residing in settings in which it is not available, and in the absence of gold-standard instrumentation, reasonably sensitive screening methods are needed to identify patients with elevated likelihoods of aspiration.

Cervical auscultation (CA) is a screening method that has received much attention in the past two decades [10]. CA uses sensors attached to the patient's neck that record the acoustic sounds that

* Corresponding author. Tel.: +1 412 624 0508.
E-mail addresses: ivj2@pitt.edu (I. Jestrović), jmd151@pitt.edu (J.M. Dudik), bol12@pitt.edu (B. Luan), jcoyle@pitt.edu (J.L. Coyle), esejdic@ieee.org (E. Sejdić).

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occur during swallowing [11]. Clinically it is implemented with an ordinary stethoscope. Previous contributions have shown that sounds of normal and abnormal swallows are different [12], though identification of specific impairments, or characterization of the nature of the abnormal swallows has yet to be identified using CA. However if the value of CA can be raised by improving its ability to detect specific and clinically important biomechanical errors or bolus misdirection, it would become more useful in screening and possibly diagnosis. Because of its low cost, noninvasiveness and accessibility, an objective, valid and reliable method for clinically using CA would be attractive [13,14]. Current CA implementation methods utilize a subjective perceptual assessment by the test administrator to make a judgment regarding the clinical relevance of the sounds that occur during the swallowing event, and several prior studies have found such judgment methods to produce relatively low overall accuracy in identifying specific biomechanical and bolus-flow abnormalities [15]. However, developing algorithms for instrumented analysis may prove to produce a more objective characterization of swallowing events from acoustic data than perceptual judgment, and significantly increase the sensitivity and specificity of the examination.

A number of studies have investigated swallowing sounds (e.g., [16,17,11]). However, none of the studies have investigated the baseline characteristics of cervical auscultation signals (i.e., when swallows are not present). Understanding such characteristics is important for several reasons. First, cervical auscultation signals can potentially contain signal components that are present even when no swallowing is performed, such was the case for swallowing accelerometry signals [18]. Second it is possible that, like for accelerometry signals, the baseline characteristics of swallowing sounds could be affected by the patient's movement or head position. For example, Sejdić et al. [19] showed that head motions can severely impact swallowing accelerometry components, and later developed an algorithm for removing those components [20]. Similarly, microphones can sometimes record sounds associated with skin displacement (e.g., [21,22]). Therefore, the same procedure should be investigated for swallowing sounds to reduce the effect of acoustic artifact on CA signals that may mask data that reflect physiologic events. Also relationships between the different head positions or compensatory postures used during swallowing, age, gender and other diagnostic differences among patients, may affect the resultant acoustic sounds of the swallowing event; if these could be accounted for and subtracted from the overall CA product signal, the resultant signal would have more value as diagnostic data.

To address these open questions, we examined baseline characteristics of cervical auscultation signals in time domain, frequency domain and time-frequency domains. In particular, these signals were examined while participants completed several tasks in head neutral position and the chin-tuck (head/neck flexion) positions which is a common compensatory posture used with some dysphagic patients to mitigate specific aspects of dysphagias. Sex and age dependence were also examined.

2. Methodology

2.1. Data acquisition from participants

Fifty-six people, aged from 18 to 65, with no previous self-reported history of neurological diseases, swallowing disorder, head, neck or spinal trauma, neck, brain or mouth cancer or abnormal brain activity, participated in the data acquisition process. Each subject provided written consent and provided basic demographic information such as their age. The study was approved by Institutional Review Board at the University of Pittsburgh.

We recorded sounds with a contact microphone (AKG C411L, AKG Acoustics GmbH, Vienna, Austria) that had a frequency response from 10 Hz to 18 kHz. We also recorded accelerometry signals using a dual-axis accelerometer (ADXL322, Analog Devices, Norwood, MA, USA). However, swallowing accelerometry signals were not considered in the current manuscript. All signals were recorded using LabView software Signal Express (National Instruments, Austin, TX, USA) which provided 40 kHz sampling rate, and recorded data was saved to a hard drive.

The sensors were attached to the subject's anterior neck with double sided tape. The accelerometer was positioned below the thyroid cartilage as shown in Fig. 1 and the microphone was positioned far enough from the accelerometer such that the two sensors would not come into contact. After the placement of sensors, the subject was asked to complete six different tasks. First the resting state was recorded, where the subject was asked to refrain from moving, talking, or swallowing for 1 min. Next, the subject was instructed to hold their head in the head neutral position and hold their breath for 10 s while again refraining from moving, talking, or swallowing. The next four tasks each consisted of subjects tilting their heads then returning to the neutral starting position ten times in one of four directions: in the sagital plane (flexion, extension), and in the coronal plane (right and left lateral flexion) (Fig. 2). During these tasks, the subjects were asked again to refrain from talking or swallowing.

2.2. Pre-processing

The raw signals were pre-processed by the algorithm reported in previous studies (e.g., [18]). In order to annul effects from the recording devices, a finite impulse response filter, was created using AR coefficients from 18 baseline recordings, a method described in [18]. After filtering, the signals were denoised with 10-level discrete wavelet decomposition using the discrete Meyer wavelet with soft-thresholding. The global denoising threshold as proposed in [23] was used for wavelet denoising.

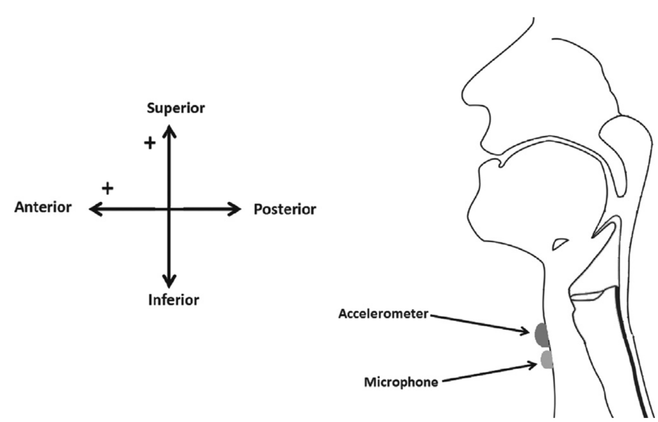

Fig. 1. Position of accelerometer and microphone.

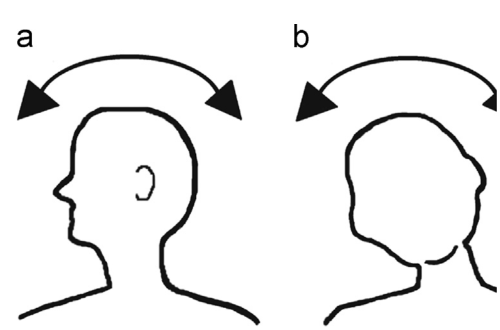

Fig. 2. Different head motion: (a) flexion and extension and (b) right and left lateral flexion.