Medical Engineering and Physics 37 (2015) 665–673

Contents lists available at ScienceDirect

Medical Engineering and Physics

journal homepage: www.elsevier.com/locate/medengphy

# Swallowing accelerometry signal feature variations with sensor displacement

Khondaker A. Mamun [a], Catriona M. Steele [d,e], Tom Chau [b,c,*]

[a] Department of Computer Science and Engineering, Ahsanullah University of Science and Technology, Bangladesh
[b] Bloorview Research Institute, Holland Bloorview Kids Rehabilitation Hospital, Toronto, ON, Canada
[c] Institute of Biomaterials and Biomedical Engineering, University of Toronto, Toronto, ON, Canada
[d] Toronto Rehabilitation Institute, University Health Network, Toronto, ON, Canada
[e] Department of Speech-Language Pathology, University of Toronto, Toronto, ON, Canada

ARTICLE INFO

*Article history:*
Received 20 October 2014
Revised 9 April 2015
Accepted 20 April 2015

*Keywords:*
Dysphagia
Accelerometry
Swallowing

ABSTRACT

Dual-axis accelerometry has recently shown promise as a non-invasive method for detecting swallowing impairment using signal processing and pattern classification algorithms. However, it is unknown whether variations in sensor placement alter signal characteristics, threatening the accuracy of signal processing classifiers for aspiration detection. To address this question, water swallows were recorded in 14 healthy adults using a dual-axis accelerometer in 13 different positions (baseline, and 2, 4, 6 and 8 mm above, below and to the right of baseline). The baseline position was midline, immediately below the thyroid cartilage during quiet breathing. After segmentation and pre-processing, signal features were extracted in multiple domains (time, frequency, time-frequency). The effect of sensor position on signal feature distributions was examined with non-parametric statistical analysis. The analysis showed that the sensor could be displaced by as much as 4 mm inferior and lateral to the baseline position and by up to 6 mm above the baseline location without significantly altering time-frequency features. In other words, when considering the baseline position as the origin, the admissible region for sensor placement spans 10 mm in the superior-inferior axis and 8 mm in the medial-lateral direction. Results of this study suggest that time-frequency representations of accelerometry signals are most robust to sensor placement variations around the baseline position. The implication of this finding is that a swallowing accelerometry classifier based on time-frequency features can likely tolerate small variations in sensor location without degradation in classification performance.



## 1. Introduction

Deglutition or swallowing is the well-defined, complex neuromuscular process for transporting food or liquid from the mouth to the stomach [1,2]. Patients with a range of different neurological disorders such as stroke, cerebral palsy and Parkinson's disease are at high risk of developing swallowing difficulties (dysphagia), where the swallow departs from the well-coordinated typical process [1]. Individuals with dysphagia are susceptible to aspiration, which is defined as the entry of foreign material into the airway below the true vocal folds [2]. If unmanaged, dysphagia can lead to devastating consequences including dehydration, malnutrition, aspiration pneumonia and even death [3,4]. Therefore, identification and careful management of dysphagia are important clinical goals in at-risk populations. Currently the video-fluoroscopic swallowing study (VFSS) is considered to be the gold standard method for dysphagia assessment [2,5]. This method entails the recording of a lateral X-ray video while the patient swallows food or liquid stimuli mixed with barium. The integrity of a swallow is then judged by clinical experts according to criteria such as the depth of airway invasion and the degree of bolus clearance after the swallow. Clinicians then choose appropriate intervention techniques based on their observations of the patients pathophysiology. However, VFSS requires expensive equipment as well as expertise from speech-language pathologists and radiologists [5]. VFSS is also not suitable for day-to-day monitoring due to the exposure to ionizing radiation [6]. Routine monitoring of swallowing function is necessary as the severity of swallowing difficulty can change over time.

Given the above challenges associated with VFSS, several alternative non-invasive techniques to ascertain swallowing function have been investigated, including pulse oximetry [7], cervical auscultation [8], acoustic [9] and electrophysiological methods [10]. An emerging approach is swallowing accelerometry, which entails the attachment of an accelerometer to the neck below the thyroid

* Corresponding author. Tel.: +1 416 425 6220x3515; fax: +1 416 425 1634.
*E-mail address:* tom.chau@utoronto.ca, tchau@hollandbloorview.ca (T. Chau).

http://dx.doi.org/10.1016/j.medengphy.2015.04.007
1350-4533/

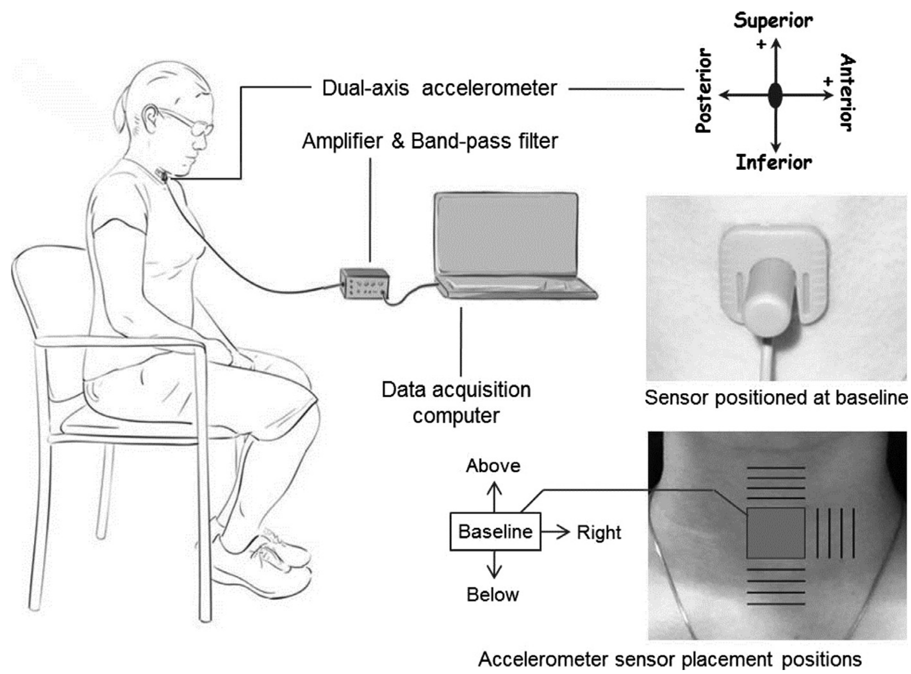


**Fig. 1.** Experimental setup. The accelerometry sensor, axial orientation, sensor placement positions and signal acquisition instruments are shown.

cartilage to capture the cervical vibrations associated with swallowing. Swallowing accelerometry has been proposed as a method for aspiration detection in several studies [11–16]. Most recently, the potential for automatic aspiration detection based on dual-axis swallowing accelerometry has been demonstrated in a pediatric population with neurological deficits [17] and adult populations with stroke [18–20].

Despite promising findings in the above studies, only signals from the baseline position (midline, immediately below the thyroid cartilage during quiet breathing) have been considered to date. For clinical usability it is important to quantify the impact of slight variations in sensor position on swallowing accelerometry signal features. Therefore, in this study, we compared dual-axis swallowing accelerometry signals recorded in the baseline position with those obtained from twelve different positions emanating from the baseline position. Specifically, we studied swallowing accelerometry signals collected in adults from positions superior to, inferior to and to the right of the baseline position in 2 mm increments. Knowledge of signal feature variations with respect to sensor position will inform protocol designs for clinical swallowing accelerometry measurements as well as the further development of accelerometry-based classifiers of swallowing activity.

## 2. Experimental paradigm and signal acquisition

### *2.1. Participants*

Fourteen healthy adults (12 females and 2 males) ranging in age from 18–65 years (average 26 ± 8.02 years) with no history of swallowing difficulties, stroke or other neurological conditions, head or neck cancer, spinal cord injury or tracheostomy participated in this study. Participants had a broad distribution of heights (165.51 ± 7.39 cm), weights (63.55 ± 13.24 kg) and neck circumferences (33.32 ± 3.33 cm). The study was approved by the research ethics board of Holland Bloorview Kids Rehabilitation Hospital. Participants provided informed written consent prior to study participation.

### *2.2. Experimental protocol*

Each participant attended two 30-min data collection sessions. In each session, an accelerometer (ADXL322, Analog Devices) was placed on the participant's neck. The axes of the accelerometer were aligned with the superior–inferior and anterior–posterior anatomical axes. In total, thirteen sensor positions were considered. These consisted of the baseline position (midline cervical location with the superior boundary of the sensor aligned with the lower palpable boundary of the thyroid cartilage during quiet breathing) and twelve other positions, i.e., 2, 4, 6 and 8 mm above, below and to the right of the baseline position, as shown in Fig. 1. To keep the protocol within a tolerable time limit, the sensor was only placed at 9 of the 13 different sensor positions (including baseline) for each individual participant. However, across participants, data from all 13 locations were obtained. The skin was marked with non-permanent ink and a flexible measuring tape was used to ensure accurate positioning of the sensor each time. Before sensor attachment at each position, the neck was swabbed with isopropyl alcohol (70%). At each location, the sensor was adhered to the skin using double-sided medical tape.

After attachment of the sensor, the participant was provided with a disposable cup containing 10 ml of water, as measured by a digital scale (Ohaus Adventurer Pro AV812C). Participants were then instructed to empty the contents of the cup into their mouth and swallow, ensuring that their head remained in an upright neutral position while swallowing. Each participant repeated this task 10 times in each sensor position. Participants were asked to initiate the swallowing task upon hearing an audible cue (a verbal instruction to initiate swallow), which was generated 5 s after the beginning of signal recording. Participants were allowed to complete each swallowing task at a comfortable pace.

### *2.3. Instrumentation*

Fig. 1 illustrates the experimental setup, sensor placement positions and axial orientation. In each sensor position, data from the two channels corresponding to the two axes were passed through a pre-amplifier with a bandpass filter (Model P55, Grass Technologies,