

# Design and Technical Validation of a Wearable Device for Monitoring Motion of the Hyoid Bone and Cartilaginous Throat Structures during Swallowing, Speech, and Breathing

Spencer Peterson<sup>1</sup>, N. Wesley Edwards<sup>1</sup>, Kali J. Power<sup>1</sup>, Jordan Ryan<sup>1</sup>, Matthew Hancock<sup>1</sup>, Richard Kelsey<sup>1</sup>, David T. Fullwood<sup>1</sup>, Ulrike H. Mitchell<sup>1</sup>, Miriam Cortez-Cooper<sup>2</sup>, Phillip Sechtem<sup>2</sup>, Pamela Barney<sup>3</sup>, John Kriak<sup>3</sup>, Anton E. Bowden<sup>1</sup>

<sup>1</sup>Brigham Young University, Provo, UT, USA, <sup>2</sup>Rocky Mountain University of Health Professions, Provo, UT, USA, <sup>3</sup>Noorda College of Osteopathic Medicine, Provo, UT, USA  
stp47@student.byu.edu

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**INTRODUCTION:** One of the earliest symptoms of many neurological disorders is dysphagia, where muscles in the throat are weakened or behave asynchronously with one another, making it more difficult to swallow or speak [1]. Recent advances in wearable sensor technology have enabled inexpensive, objective measurement of dynamic, time-dependent skin strains which may have application to the identification, quantification, and tracking of dysphagia and breathing capacity over time. The present work describes the development and initial testing of a wearable device that can measure real-time skin strains proximal to the hyoid, as well as track breathing during daily activities such as swallowing or speaking.

**METHODS:** The wearable device was made from a rectangular piece of cloth with four nanocomposite high-deflection strain sensors [2] arranged sequentially along the superior-inferior axis of the throat at intervals of 28 mm, attached to the participant's neck via square pieces of KT tape with a side length of approximately 30 mm. The dynamic skin strain data collected from the sensors was transmitted to a smartphone via a Bluetooth connection (see Figure 1, left). Device validation was performed on 17 healthy test subjects (15 subjects [9 female, 6 male] were aged 18-30 and 2 subjects [1 male, 1 female] were aged 60+). The device was positioned such that the 3<sup>rd</sup> sensor of the array was placed slightly underneath the palpated thyroid notch, and the 2<sup>nd</sup> sensor was placed on the hyoid bone. The 2 remaining throat sensors provided biomechanical measurements superior to and inferior to the hyoid region (see Figure 1, right). An additional sensor was placed on the abdomen crossing the subject's left costal cartilage, which was used to synchronously measure breathing frequency and magnitude. Participants were then asked to perform nine activities: 2 "wet swallows", where the subject would swallow 20 ml of water; 2 "dry swallows", where the subject would swallow normally with nothing in their mouth; 4 different speaking prompts; and a breathing exercise, where the subject would breathe normally through their nose for 10 seconds. Finally, following the completion of these exercises, participants were asked to share their thoughts on the usability of the device through a 10-question survey. This study was performed in compliance with our Institutional Review Board, and participants were required to sign an informed consent form prior to participating in the study.

**RESULTS:** The device successfully gathered skin strain data from the 17 participants during the swallowing, speaking, and breathing exercises. Figure 2 displays the data collected for the dry swallow test for 4 participants. The first 4 graphs for each subject depict the data for the neck sensors in order from top to bottom, and the 5<sup>th</sup> graph depicts the data for the abdominal sensor. Additionally, 82% of participants reported that the device was comfortable to wear, and 94% of participants reported that it did not restrict breathing or swallowing.

**DISCUSSION:** The data obtained in this study show that the device records detailed biomechanics data of the hyoid and adjacent throat structures during swallowing, speaking, and breathing and does so consistently. As different actions were performed by each participant, the device recorded changes in resistance values for each sensor. Each sensor monitors different areas of the subject's neck, allowing the investigator to see the movement progression of throat deformation during swallowing and speaking. These data verify the functionality of the device and provide a data set that can be used for comparison in future work on individuals with neurological disorders. Limitations of this study include the limited number of participants and largely homogeneous nature of the test subject group.

**SIGNIFICANCE:** The engineering validation of this device is the first step towards creating an inexpensive, wearable system that is capable of identifying and tracking dysphagia, dysarthria, and pulmonary ventilation, with applications to individuals with neurological disorders. The data collected in this study provides baseline information about the throat movement of a group of control subjects, which can eventually be used as a comparison group for those with and without neurological disorders.

**REFERENCES** [1] Suttrup and Warnecke (2016), *Dysphagia* 31:24-32, [2] Wonnacott, et al. (2024), *Sensors* 24(24):8192

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**IMAGES AND TABLES:**

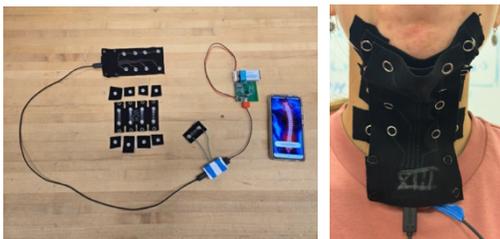


Figure 1: Device setup including the sensor array, wiring system, and smartphone app (left), Front-facing view of the device being worn by a participant (right).

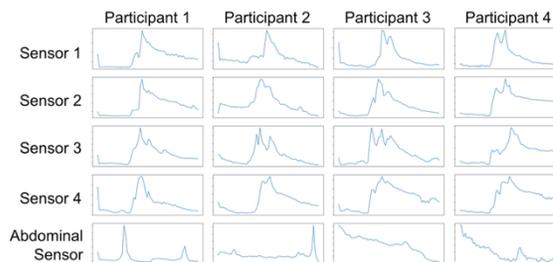


Figure 2: Dry swallow data for 4 participants (columns). Sensors 1-4 correspond to synchronized recordings of throat strain over the time of the swallow; Sensor 2 is aligned over the hyoid bone. The abdominal sensor provides synchronized abdominal strain as a surrogate for breathing amplitude during the swallow.