Investigating Swallowing Sounds of Viscous Fluids for Optimized Food for Dysphagia Management

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ABSTRACT

Problems with swallowing or dysphagia is an increasing problem due to the ageing population. Investigation methods commonly require clinical techniques which are tedious and costly. An alternative analysis is to measure the swallowing time non-invasively through monitoring of swallowing sounds. GOKURI is an AI-powered, smartphone-based, neckband-type device for the assessment of the swallowing function.

The present study investigated swallow sounds of food in comparison to those of water swallows. In total 19 healthy subjects were eating a full meal while their swallowing was recorded via the swallowing sensor. The results show that the time it takes for a person to swallow varies greatly. Nevertheless, the length of swallowing solid food differed significantly from water, which were slightly shorter to swallow (0.702s vs. 0.668 s respectively). This correlates well with our previous study where swallowing of water took shorter time compared to thicker Newtonian and a shear-thinning fluids.

INTRODUCTION

Swallowing disorders, also known as dysphagia, refer to difficulties or abnormalities in swallowing food, liquid, or saliva. Swallowing disorders can occur at any age but are more common among older adults and people with certain medical conditions, such as neurological disorders, head and neck cancer, or gastroesophageal reflux disease (GERD). Specifically, it is common in countries having a high share of elderly in their population, such as Sweden and Japan. Swallowing disorders can have serious consequences, such as malnutrition, dehydration, pneumonia, and decreased quality of life. Therefore, early diagnosis and treatment of swallowing disorders are crucial.

The most common way to detect dysphagia is the observation of swallows by videofluoroscopy. The technique involves X-ray imaging, where the patient swallows liquids containing contrast media. However, the necessary facilities are limited to hospitals and cause exposure to radiation.

GOKURI is an AI-powered smartphone-based, neckband device for the assessment of the swallowing function.[1] The device, which has been developed for liquid boluses, uses the sound of the bolus moving along the pharynx, see Fig. 1. By analyzing swallowing sounds, clinicians and researchers can detect abnormalities in the timing, and strength, of swallowing muscles, as well as the presence of aspiration (the entry of food or liquid into the airway) or penetration (the entry of food or liquid into the larynx without reaching the lungs). The sound from swallowing can be correlated with anatomical events such as the nasal passage closing or the closing of the upper esophageal sphincter to evaluate the frequency profile and detect the length of a swallow[1]. It has been shown that patients with dysphagia exhibit longer swallow durations as compared to healthy individuals[2].

To prevent malnutrition patients suffering from dysphagia commonly eat texture-modified food promoting safe swallowing. Besides the food being soft, moist, and easy to chew, also an improved cohesivity of the bolus prevents aspiration. Cohesivity of food can be referred as to the "degree of coherency provided by the internal structure of a material against its fractional breakup".[3] A fractional breakup should be prevented to promote safe swallowing.

There are several types of food that are recommended for dysphagia patients, depending on the severity of their condition. In Sweden there are three categories for solid food: paté, timbal and gel. Paté and timbal are pureed food. Paté has a somewhat coarser structure while timbal is very smooth. Gel food is eaten for more severe dysphagia.

This study is a continuation of a previous study[4] where model fluids – Newtonian, shear-thinning and Boger fluids were ingested and the swallowing sounds measured. In this continuative study we investigated healthy subjects eating texture-modified food. The swallow sounds were compared to the ones of water.

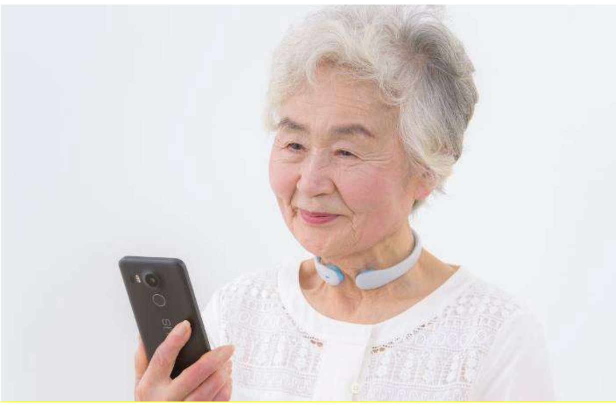

FIGURE 1: The swallowing sensor is placed on the patient's neck and records the sound during swallowing. It is connected to a mobile device where an app displays the swallow duration in real time and dysfunctionality can be detected directly.

MATERIALS AND METHODS

The sound of swallowing was recorded with a Swallowing Sensor GOKURI (Plimes Inc., Tsukuba, Japan). The panel consisted of 19 healthy individuals having an age of 19 – 65 years, (11 females, 8 males) with a mean of 42 years. The subjects ate a meal that contained 4 – 5 ready-to-eat potatoes and two types of sauces (BBQ and dill and lemon sauce) bought at a local grocery store, as well as two of each a chicken and a bean paté (á 40 g) kindly provided by Findus. Components as well as the puréed ingredients and recipes are available (Findus Special Foods, 1999). The timestamps of the swallows were marked by a button in the software to exclude plain saliva swallows. Tap water was given either before or after the meal and the swallow sounds were recorded in the same manner. The audio recordings and the swallowing time stamps were extracted and analyzed.

RESULTS AND DISCUSSION

The swallowing sensor presented in Fig. 1 is placed around the neck of the patient with the opening to the front. The microphone is located in the end opposite of the LED diode. The sensor is connected to a mobile device with an app that monitors swallowing sounds and displays the number of swallows, the average swallow length, and the number of swallows per recording. Swallows are detected automatically by the app and the audio recording, and the duration of the swallows can be extracted subsequently by connecting the mobile device to a computer or through a web interface to which the files are uploaded automatically. The inclination of the head is also monitored and can be extracted.

An example of the audio signal of a food swallow is illustrated in Fig. 2. The audio signal is shown on top and the spectrogram below. The frequency is the tone height of the sound. High tones appear further up and low tones further down. The colour scale is the intensity or the volume of the sound. It was observed that the swallows vary greatly in sound frequency, depending on the individual and type of swallow (e.g. water or food), making it difficult to find common frequency patterns in food and water swallows.

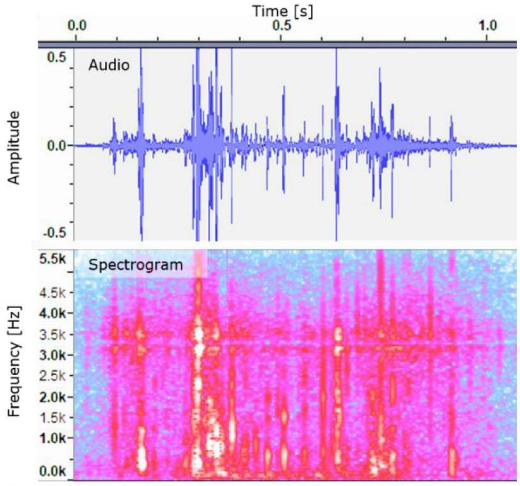

FIGURE 2: Example of a recording of a swallow showing the amplitude on the top and the respective spectrogram below with the frequency on the y-axis. The frequency can be understood as the tone height. The colour is the intensity or volume of the sound.

The panellists were asked to eat the meal and their swallowing sounds were recorded as described. Four of the subjects did not finish the entire meal and only part of their data was used, see table 1. It took an average of 38 individual swallows for the subjects to eat their meal with a standard deviation of 16. The standard deviation indicates that it differed largely between the individuals (between 19 and 69). The total eating time was 10.7 minutes (±3.9 min) from the first until the last swallow. Of the entire panel the swallows per minute was 3.7 in average. With 3.9 the standard deviation was rather large there as well. When the swallow duration was extracted the start until the end of the swallows were marked.

TABLE 1: Mean number of swallows, swallow duration, time to eat and swallows per minute of eating one meal including standard deviation (SD) and number of subjects.

	AGE (YEARS)	NUMBER OF SWALLOWS	SWALLOW DURATION (S)	TIME TO EAT (MIN)	SWALLOWS PER MIN
Mean	42	38	0.70	10.7	3.7
SD	13	16	0.20	3.9	1.2
n =*	19	15	19	15	19

*The number of subjects varies due to that some of the panellists did not eat the entire meal.

As shown before, the sound components can be coupled to certain anatomical activities during a swallow.[1] In our previous study we showed that the rheology of the fluids swallowed influenced the swallowing length significantly.[4] While having the same viscosity at $50 s^{-1}$ the swallowing length differed significantly between a Newtonian and a shear-thinning fluid in that a swallow of the same volume of a shear-thinning fluid was longer than the Newtonian fluid. We hypothesized that the shear-thinning fluid elongated in the pharynx and could cause the longer swallow time. For the meal, where each swallow could not be identified with volume the swallow duration was 0.7 s (±0.2 s).

The subjects were asked to drink water either before or after the meal and their sounds were measured and compared to the food swallow durations. Fig. 3 illustrates the swallowing length of the water swallows as compared to the food swallows. The difference was small with 0.67 s for water and 0.70 s for food, yet significantly different between the groups ($p < 0.05$). This indicates that it is possible to detect food vs. water swallowed. Further analysis is being undertaken to analyze if the swallowing patterns can be differentiated depending on the type of food and rheological characteristics.

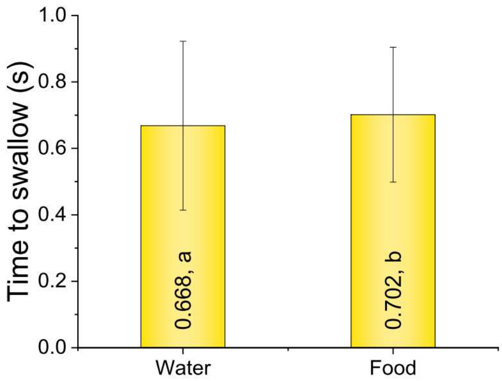

FIGURE 3: Mean swallow durations of water and food where the error bars mark the standard deviation. The samples differ significantly from each other ($p < 0.05$) indicated by the different letters.

REFERENCES

(1) Jayatilake, D.; Ueno, T.; Teramoto, Y.; Nakai, K.; Hidaka, K.; Ayuzawa, S.; Eguchi, K.; Matsumura, A.; Suzuki, K. Smartphone-Based Real-Time Assessment of Swallowing

Ability from the Swallowing Sound. *IEEE J. Transl. Eng. Health Med.* **2015**, *3*, 1–10. https://doi.org/10.1109/JTEHM.2015.2500562.

(2) Santamato, A.; Panza, F.; Solfrizzi, V.; Russo, A.; Frisardi, V.; Megna, M.; Ranieri, M.; Fiore, P. Acoustic Analysis of Swallowing Sounds: A New Technique for Assessing Dysphagia. *J. Rehabil. Med. Off. J. UEMS Eur. Board Phys. Rehabil. Med.* **2009**, *41*, 639–645. https://doi.org/10.2340/16501977-0384.

(3) Nishinari, K.; Turcanu, M.; Nakauma, M.; Fang, Y. Role of Fluid Cohesiveness in Safe Swallowing. *Npj Sci. Food* **2019**, *3* (1), 5. https://doi.org/10.1038/s41538-019-0038-8.

(4) Andersson, J.; Kwang Tan, C.; Jayatilake, D.; Suzuki, K.; Stading, M. Sound Analysis of Swallowing a Shear-Thinning Fluid; ATNRS, 2021; Vol. 29.