Sound analysis of swallowing a shear-thinning fluid

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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, however, they are tedious and costly. An alternative way is to non-invasively measure the swallowing time with a small device that can be used at home. GOKURI is an AI-powered smartphone-based point of care neckband-type device for the assessment of the swallowing function.

Previously developed model fluids exhibiting Newtonian, shear-thinning and a Boger flow behaviour were ingested and the sound spectra recorded using GOKURI and were compared to plain water. Within the 8 test subjects, the results indicated that there was a significant difference in swallowing duration between water and the shear-thinning fluid, see Figure 1. The swallows had large individual variations and a mean of 0.91 (±0.22) seconds. Water was 0.13 s faster to swallow than the shear-thinning fluid with a significant difference with 95% confidence interval.

INTRODUCTION

Dysphagia or problem in swallowing is common among elderly, which is especially an issue in countries having a high number of elderlies in their population, such as Sweden and Japan. The reasons are numerous, such as degenerative diseases and stroke. The common way to detect dysphagia is the observation of swallows with videofluoroscopy. However, these facilities are costly and cause exposure to radiation. Dysphagia patients commonly eat texture-modified food promoting safe swallowing. Besides increased viscosity, also an improved cohesivity prevents food to enter the trachea. Cohesivity of food can be referred as to the "degree of coherency provided by the internal structure of a material against its fractional breakup"[1]. A fractional breakup should be prevented to promote safe swallowing. GOKURI is an AI-powered smartphone-based neckband-type device for the assessment of the swallowing function[2]. The device, which has been developed for liquid boluses, uses the sound of the bolus moving alone the pharynx as well as the sound from swallowing related 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[2]. It has been shown that patients with dysphagia exhibit longer swallow durations as compared to healthy individuals[3]. Edible model fluids exhibiting Newtonian, shear-thinning and a Boger flow behaviour containing water, maltodextrin and xanthan gum in different concentrations were developed previously[4]. The model fluids were designed to overlap in shear viscosity at a shear rate of 50 s^{-1}, which is commonly used in the dysphagia field.

In this study the model fluids exhibiting Newtonian, shear-thinning and Boger characteristics were ingested while measuring the sounds of swallowing for healthy individuals. The results were compared to swallowing of plain 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.

EXPERIMENTAL SETUP

The sound of swallowing was recorded with a Swallowing Sensor GOKURI (Plimes Inc., Tsukuba, Japan) with a panel of 8 healthy individuals having an age of 22–57 years with a mean of 34 years. Model fluids that had been developed previously were swallowed[4] using a volume of 5 ml. For each individual about 5 swallows per fluid were recorded, which resulted in approximately 40 swallows per liquid. The model fluids were the following:

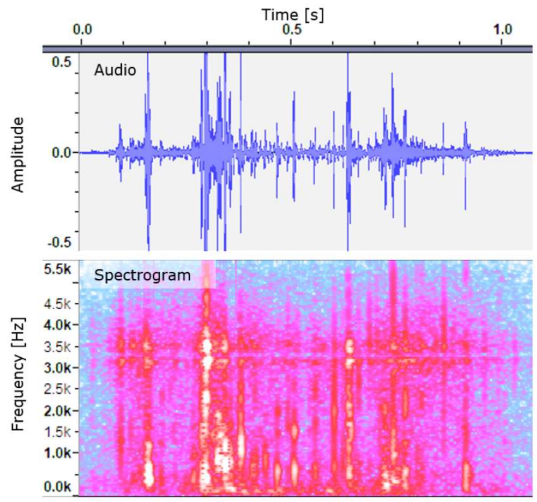
- Newtonian fluid (60.5% maltodextrin and water)
- Shear-thinning fluid (55% maltodextrin, 0.5% xanthan gum and water)
- Boger fluid (59% maltodextrin, 0.02% xanthan gum and water).

The three model fluids were compared to the swallowing sound of pure water. The audio recordings and the swallowing time stamps were extracted and manually corrected when needed using Audacity 2.3.2 (Audacity Team).

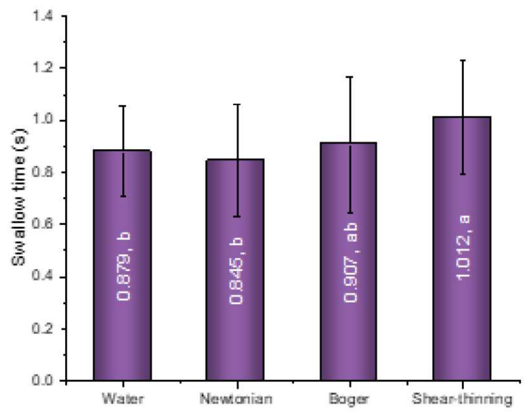
RESULTS AND DISCUSSION

The swallowing sensor is presented in Fig. 1. It is placed around the neck of the patient with the opening to the front. The microphone is situated in the end opposite of the LED diode. The sensor is connected to a mobile device with an app that displays the number of swallows, the average swallow length, and the amount 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.

The three different model fluids were swallowed by the panel and in addition water swallows. An example of the audio signal of three subsequent water swallows is illustrated in Fig. 2a. Jayatilake and co-workers have previously related the anatomical events to their respective sounds, such as the movement of the soft palate and the larynx while bolus moving into the pharynx, movement of the bolus into the oesophagus through the upper esophageal sphincter (UES), and returning of the larynx back to the resting position[2]. Fig. 2a also shows the respective spectrogram, which is obtained by Fast Fourier Transform (FFT). The frequency indicates the tone pitch, where lower tones are lower in the graph and higher



(a)



(b)

Figure 2: (a) Recording of a swallow with shear-thinning model fluid with the amplitude on the top and the spectrogram on the bottom. (b) shows the average swallow durations of the tested liquids with their significance marked with different letters.

tones show higher on the y-axis. The magnitude of the response (the strength of frequency components or the volume) is represented by the colour (blue for low and red/white for high amplitude). In this case a Hamming window type was used and a window size of 256. The frequency ranges up to 4.5 kHz, with the power spectrum of frequencies above 4.5kHz tapering off gradually. Swallow sounds are noted to be mainly in the lower frequency range.

The automatic time stamps, which the app sets as the onset and end of the swallow events sometimes had to be manually corrected. To help identifying the swallow events manual time stamps where set each time when a person swallowed. Visual inspection of the shape of the audio and spectrogram of the various fluids did not yield identifiable patterns. Furthermore, spectral analysis with frequency metrics, like centroid frequency and max frequency, were unable to identify the type of liquid. A more through analysis is currently conducted to try to discover identifiable frequency content of different liquids.

Differences between subjects were large. The subject variability is also reflected by the error bars in Fig. 2b. The figure illustrates the mean swallow durations for the four tested fluids water, Newtonian, Boger, and Shear-thinning fluid. The error bars showing the standard deviation and the significance is indicated by different letters in the bars. The mean swallowing time of all liquids and swallows together was 0.91 (±0.22) seconds. The shear-thinning fluid had the longest swallow duration of 1.01 (±0.26) seconds and differed significantly to both water and Newtonian swallows, which had a mean of 0.88 (±0.17) seconds and 0.84 (±0.22) seconds, respectively. As previous measurements of the extensional properties showed, the shear-thinning fluid exhibits the highest extensional viscosity followed by the Boger fluid[4]. The Newtonian fluid and water naturally have no extensional properties. We hypothesise therefore, that the Shear-thinning fluid is elongated in the throat causing the longer swallow duration and at the same time making swallowing easier and safer by its cohesivity.

CONCLUSIONS

The study indicates, that the modification of the viscosity alone does not increase the swallowing duration, but the extensional properties are expected to do so. That suggests, that it is not sufficient only to tailor the viscosity of food for dysphagia patients, but extensional properties have to be taken into account to promote safe swallowing.

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