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Fantastic squeaks and where to find them: producing and analysing audible acoustics from leipäjuusto

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Abstract: Chewing not only converts food chunks to digestible proportions, it also conveys audible acoustics resulting in a perception on the type and condition of the food being eaten. As biomedical engineers, we may want to reproduce the same eating experience for those who cannot chew or for those who have allergic reactions to some foods. But to understand this psychoacoustic phenomenon better, it is crucial to understand what produces the sound of specific foods. The purpose of this paper is to present a straightforward methodology to produce audible acoustics from a notoriously loud Finnish delicacy and analyse the sound produced. One hundred samples of leipäjuusto and one hundred samples of Gouda cheese for controls were subjected to shear between a bamboo board and a wetted blade. All leipäjuusto samples and none of the Gouda cheese samples produced audible squeaks. A 0.1-s delay between blade displacement and sound production was observed. We attribute this delay to the buildup to release. The frequency spectra from pushing and pulling movements were observed to have only negligible differences. This indicated that the internal structure between events did not change. Therefore, the hypothesis that a disruptive event underlies the squeaking process is less plausible.

Keywords: psychoacoustics, chewing sensation, Fourier analysis, Savitzky-Golay filter, slip stick motion.

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1 Introduction

Food acoustics convey emotions. Whilst the loud sounds produced by biting apples, carrots, and potato chips [1] convey nuisance to their surroundings, it is hard to imagine eating these in the absence of the accompanying sounds. The specific clack of the division of a chocolate tablet in the mouth, the crunch of a cookie, and the sparkling sound of popping candy typically create an instant fulfillment, even if the flavour itself it rather one-dimensional. In fact, it has been posed that the sound of food influences the perception of its flavour [2].

It is therefore safe to assume that experiencing food acoustics is as old as eating itself. Crackling sounds of a crusty baguette tell us that it is fresh, whilst the sound of bubbles that come from a cask may tell us that the fluid inside is fermenting [3, 4]. Apart from these passive acoustics, active acoustics have been used to measure texture and quality of food [5–7]. In the multiphase food cheese, active acoustics and tapping have been used to monitor the presence of cracks and the formation of eyes [8–10]. Scientific research into the sounds that give squeaky cheeses their name is sparse. Admittedly, potential applications such as accelerating and decelerating ripening processes by understanding the nature of the squeaks may seem a little futuristic. However, that does not make squeak production any less entertaining.

Squeaky cheese is the common term for a family of cheeses that includes halloumi, mozzarella, bread cheese (juustoleipä, leipäjuusto), Oaxaca, and cheese curd [11–14]. When biting or chewing any of these, a squeaky sound is occasionally perceived. In attempts to reveal the internal structure of cheese, it has been studied with the aid of scanning electron microscopy, magnetic resonance imaging, and micro-computed tomography [15–19]. As some cheeses have been known to exude water after manufacture [20], it has been proposed that connecting cavities inside squeaky cheese form a resonating chamber. Alternatively, shear forces created by the teeth when biting cheese might force preexisting cavities to get physically connected to form such a chamber [21].

The purpose of this paper is to present a straightforward methodology to produce audible acoustics from these so-called squeaky cheeses, and analyse the resulting sounds.

2 Materials and methods

Acoustic experiments were performed on commercially available leipäjuusto, using a method previously published [19]. Gouda cheese was chosen for controls.

Elätuli Juustoleipä bread cheese (Vaasan Juustola Oy, Vaasa, Finland), prepackaged in 200-g pieces and Frico Gouda cheese (Koninklijke FrieslandCampina N.V., Amersfoort, The Netherlands), prepackaged in 440 ± 10-g pieces (Riitan Herkku Oy, Mustasaari, Finland), were manually cut into $x \times y \times z = 14 \times 20 \times 5\text{-mm}^3$ cuboids prior to experiments at room temperature. The standard deviations of the cuboid edges were determined to be less than 2 mm in each dimension using a standard ruler. Any squeaking during cutting was ignored.

A Leikkuulautu bamboo board (Tokmanni Oy, Mäntsälä, Finland) was marked with an area for consistent sample placement. The board was positioned on top of SOEHNLE Page Compact 300 scales (Leifheit AG, Nassau, Germany). Immediately after cheese sample placement on the board, a wetted 6.8003.22 steel blade (Victorinox AG, Ibach-Schwyz, Switzerland) was held sideways and manually slid over the sample, twice in positive and twice in negative direction of displacement, whilst pushing down to ensure a weight indication of 4±2 N. Audio footage was collected with a cell phone at a 40.1-kHz sampling frequency and stored in `.m4a` format for offline processing. Video footage was captured with another cell phone at a 30-Hz frame rate and stored in `.mp4` format for ensuring reproducibility of the experiments and for offline processing. The display of the scales and the timer of the audio-recording cell phone were in the field of view of the video-recording cell phone, allowing for offline synchronizing.

Audio and video recordings were synchronised using Audacity® 2.3.2 software (Audacity Team, retrieved 08/05/2019 from https://audacityteam.org/) on a laptop computer. The audio data were divided and cropped into 800-ms segments, each starting at blade movement. Each segment was subjected to a 501-points fifth degree Savitzky-Golay filter in the frequency domain, using MATLAB® (The MathWorks, Inc., Natick, MA).

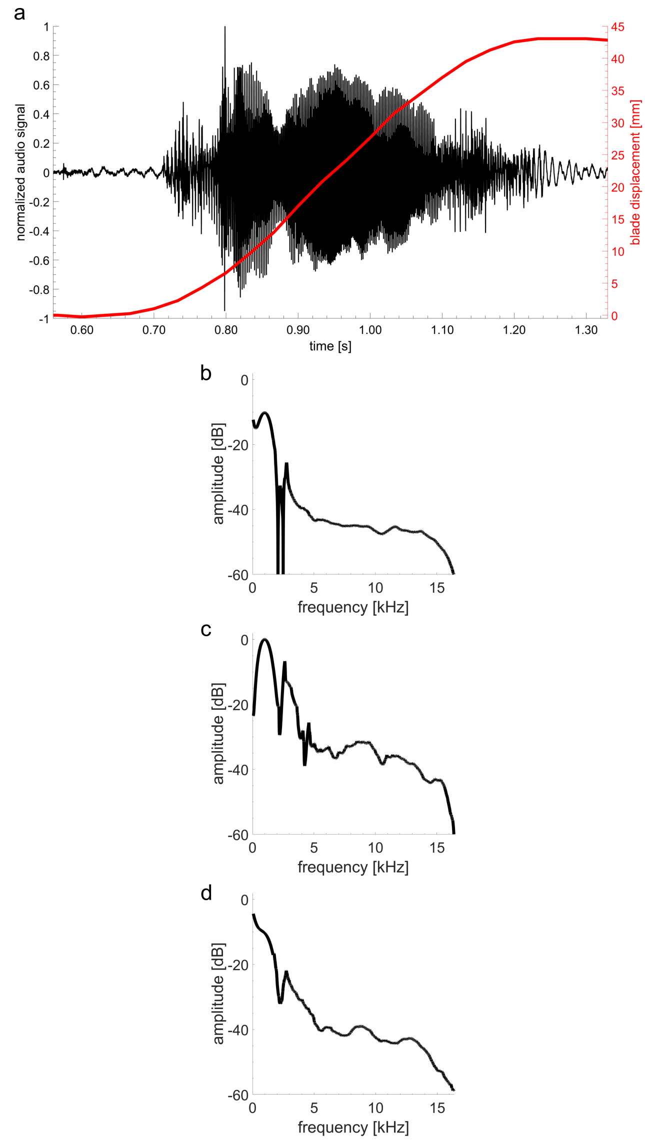

Fig. 1: Normalised audio signal (black) of a bread cheese squeak (a) and Fourier spectra of three windows of 0.15-s duration, starting at timestamps 0.60 s (b), 0.90 s (c), and 1.15 s (d), respectively. Blade displacement (red) has been superimposed in (a).

3 Results and discussion

Figure 1a shows an example of the sound produced by bread cheese. Blade displacement has been displayed on the same time scale.

It was noted that audible sound was produced with a delay of 0.1 s with respect to initial displacement of the blade. Sound production continued until 0.1 s after blade displacement had stopped. The displacement of the blade was measured to be 2.5 mm before sound production. This displacement was consistent throughout the experiments.

To find an explanation for this delay, let us briefly consider the working of quite a different string instrument. With a viola, friction force builds up during an attack with steady bow force and acceleration. The first slip happens when friction can no longer hold the string, as the static-friction limit is reached [22]. Later slips create periodic force spikes that in turn trigger string releases [22]. To use the viola analogy on squeaky cheese: if the connecting cavities are the chamber, the cheese fibers are the strings, and the blade is the bow. Thus, we attribute the delay before sound production to the buildup to release. For purely academic purposes, it would be interesting to attack squeaky cheese with a viola bow, rather than a wetted blade, or the other way around.

Frequency spectra of the three stages of a squeak have been shown in Figure 1b–d. The first stage was a rubbing sound, the second stage a clearer tone, and the third stage a thudding sound. In all three spectra, peaks were observed at a fundamental frequency of 1 kHz. The second stage showed pronounced higher harmonics at 3 kHz and 5 kHz.

With the bread cheese, all four hundred rubs produced audible squeaks. None of the four hundred rubs over Gouda cheese produced a squeak. Therefore, for the cheeses chosen, there was no need to automate or roboticise the experimental process.

Figure 2 shows the frequency spectra of the synchronised bread cheese squeaks in positive (push) and negative displacement (pull) directions.

At frequencies greater than 8 kHz, the control spectra were overlapping the bread cheese spectra. The spectra from first versus second movements were observed to have only negligible differences. This indicated that the internal structure between events did not change.

It would be interesting to investigate whether these experiments can be downscaled to allow for ultrasonic palpography on biological samples. As a futuristic medical application, we are thinking of ultrasonic imaging of the shear from incisions by surgical blades.

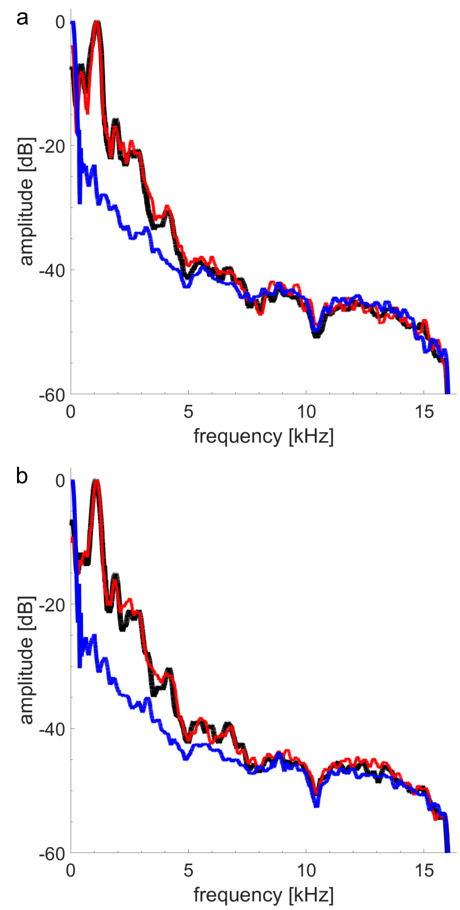

Fig. 2: Normalised Fourier amplitude spectra of synchronised bread cheese squeaks from pushing (a) and pulling (b) movements. Black lines represent the first movement, red lines represent the second movement in the same direction, and blue lines represent non-squeaking controls.

4 Conclusions

A method to produce audible squeaks from bread cheese was presented, only requiring a wetted blade and a bamboo board. Due to the negligible differences between push and pull generated sounds, the hypothesis that a disruptive event underlies the squeaking process is less plausible.

Author Statement

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