On-Demand Power Source for Medical Electronic Implants: Acousto-Mechanical Vibrations from Human Vocal Folds

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For use in vibration-driven power generation, we have quantitatively characterized the acousto-mechanical vibrations that propagate from the human vocal folds through the neck and head along the skeletal frames during speech production. The acousto-mechanical vibrations can excite vibration-driven energy harvesters at their resonance frequencies between 90-300 Hz and generate up to 0.15 mW/cm^3 on demand, which is sufficient to power a group of medical electronic implants and eliminate the use of bulky batteries that require periodic replacement [1, 2].

We have used five MEMS accelerometers (Analog Device's three-axis ADXL327BCPZ) simultaneously in each measurement run and accurately characterized the (1) amplitudes, (2) frequency/harmonic spectrum, and (3) available power densities of the acousto-mechanical vibrations at 25 locations on the head and neck (Fig. 1). The accelerometers were placed directly onto the skin and secured with non-conducting medical tape for measurements (Fig. 1). To maintain the consistent vibration amplitude from the vibration source between different measurement runs, one accelerometer was always kept on the right side of the larynx at the Measurement Point (MP) 1 (in Fig. 1) to serve as a reference point.

To characterize the acousto-mechanical vibrations present in various situations, five test participants were asked to (1) hum at a constant frequency; (2) read the first paragraph of the introduction in the paper by W. Tang and R. T. Howe [3]; and (3) generate a continuous hum from their lowest to highest frequencies. With only a few insignificant higher-order harmonics, the acousto-mechanical vibration from humming shows a single dominant peak (about 80% of the total energy) typically at 150 and 240 Hz for the men and women we tested, respectively, with acceleration ranging from 0.4 - 2.0 m/s^2 (Fig. 2) and propagates efficiently through the neck and head (Fig. 4a). We expect implanted energy harvesters will experience larger acceleration values due to improved contact with the skeletal frames. Using a simple PZT-strip cantilever, the vibrations can efficiently excite the energy harvesters to generate 0.15 mW/cm^3, which can be further improved [4]. While reading the paragraph, a few propagating dominant peaks are observed both in instantaneous (duration: 1/10s) and accumulated/averaged (1200 measurements) frequency spectra (Figs. 3 & 4a) with lower-tone voices showing smaller standard deviations (Fig. 5a), and harvesting from the most dominant peak can generate 28 μW/cm^3. In addition, the test participants have also successfully adjusted the location of the dominant vibration frequency at will: from 85 to 200 Hz for men and from 180 to 450 Hz for women (Fig. 5b). This allows more flexibility in the design, fabrication, and operation of the resonance-based energy harvesters. Our measurements also show that single-frequency-vibration impulses generated by humming are more efficiently transmitted to different locations through the skeletal frames and airways, especially to the nasal bones and spines (Fig. 5c).

We have also investigated the relationship between the vibration-propagation pattern and the structural symmetry of the head and neck. A high degree of asymmetry exists in the measured amplitudes of the mirroring parts of the head and neck. The symmetry in propagation pattern, however, becomes more prominent at locations with thinner epidermal layers.

Our acousto-mechanical-vibration-based energy-harvesting approach will provide a consistent, controllable, and efficient way to implement practical power generators for medical implants, as compared to those reported in previous research. Challenges encountered in earlier resonance-based harvesting approaches include broad frequency ranges, irregular availability, and fluctuating amplitudes of vibrations present in natural and biological environments [5, 6]. Also harvesting energy from sound waves has resulted in an insignificant power level because the air is a very thin medium highly ineffective for the propagation of mechanical energy [7].

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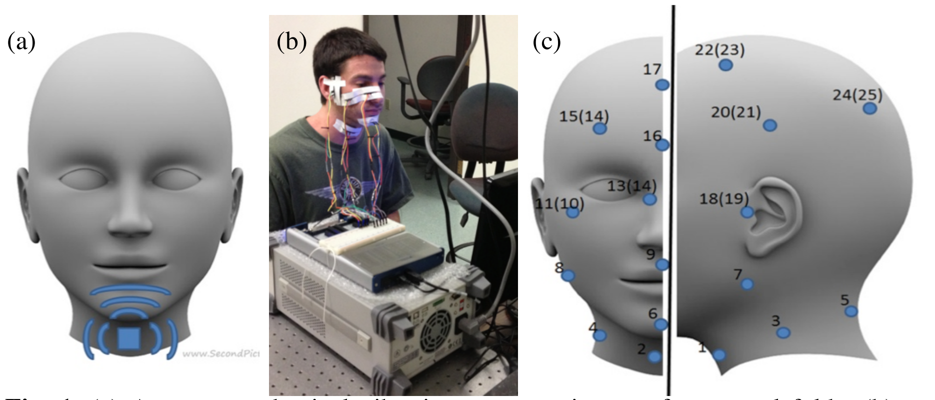

Fig. 1. (a) Acousto-mechanical vibrations propagating out from vocal folds; (b) our vibration-characterization setup with MEMS accelerometers, DAQ, and PC; and (c) locations of the measurement points (MP's) and numbers on the neck and head.

1	Larynix L (Ref.)	14	ForeHead L
2	Larynix R	15	Fore Head R
3	Neck L	16	ForeHead M
4	Neck R	17	ForeHead T
5	Neck - Back	18	Ear L
6	Mandible (Chin)	19	Ear R
7	Mandible (Corner) L	20	Temporal L
8	Mandible (Corner) R	21	Temporal R
9	Nasal Spine (Lip)	22	Parietal L
10	Zygomatic Bone L	23	Parietal R
11	Zygomatic Bone R	24	Occipital L
12	Nasal Bone L	25	Occipital R
13	Nasal Bone R		

Table 1. Measurement points (MP's) and their labels.

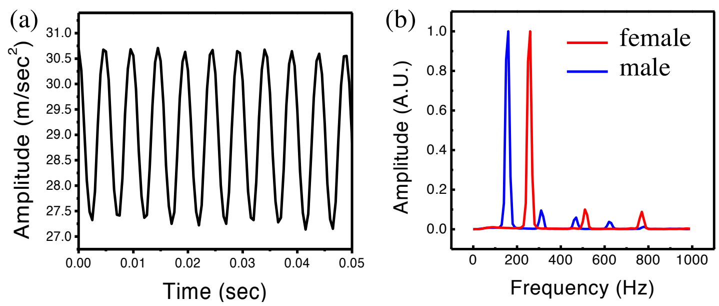

Fig. 2. (a) Temporal and (b) frequency measurements (average) of the acousto-mechanical vibrations from humming

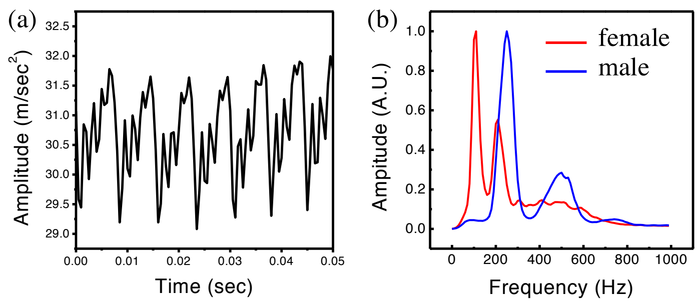

Fig. 3. (a) Temporal and (b) frequency measurements (average) on the acousto-mechanical vibrations from paragraph reading

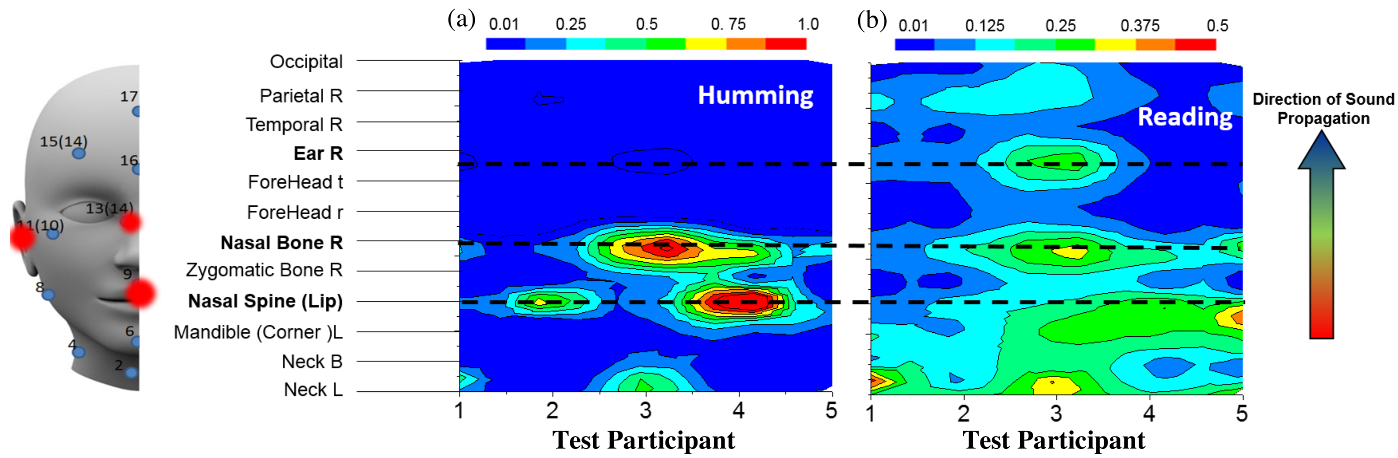

Fig. 4. 2D harvestable energy-density map over the neck and head based on the measurements: (a) when humming; and (b) when reading the paragraph. The energy density increases as the color shifts from blue to red. The formation of hot spots, which are the best locations for energy harvesting, are clearly visible on the contour maps, especially around the nasal bones, ears, and nasal spines.

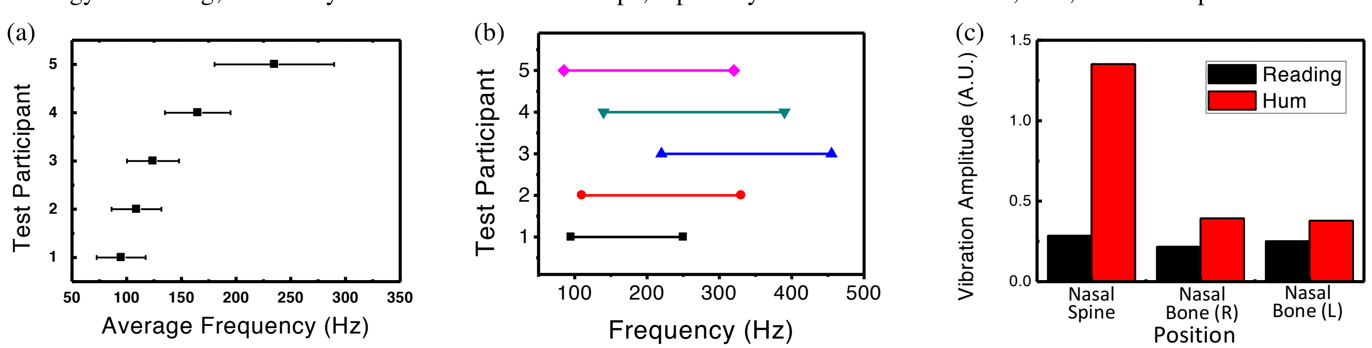

Fig. 5. (a) Standard deviations of frequency spectra measured while reading the paragraph, with lower-tone voices showing less variations; (b) tunable ranges (between 85 – 450 Hz) of the dominant vibration peaks demonstrated by the test participants; and (c) vibration amplitudes measured at three different hotspots show that the acousto-mechanical vibration generated during humming propagates most efficiently.