Investigation of the Skull Bone Sound Waves Under Bone Conduction In-vivo

Aikaterini Dimitrakopoulou, Ivo Dobrev, Christof Röösli

Department of Otorhinolaryngology, Head and Neck Surgery, University Hospital Zürich, University of Zurich, Switzerland

Background

Previous studies have looked at sound propagation across the skull bone surface of cadaver heads. Various stimulation positions and coupling methods have been investigated, utilizing a range of bone conduction actuators. The surface motion has been quantified via Laser Doppler vibrometers (LDV), usually in 3 dimensions, at several hundred points on the whole skull, on the inner and outer surface. However, the in-vivo skull wave motion and its relation to observations in cadavers are still not well understood.

Aim

To quantify the surface waves speeds across the skin-covered skull in live humans and to compare it with previous data in cadaver heads.

Methods

Measurements were conducted on 10 volunteers (awake, no sedation). The skull was excited transcutaneously via a bone conduction hearing aid (BCHA), held by a 5N-steel-band at the temple. The resultant motion was monitored at ~100 points via a single-sensitivity-axis scanning laser Doppler vibrometer (SWIR Scan-Sense, Optomet, Germany) at the forehead, where the skin was covered with a flexible retroreflective tape. Stimulation was provided at 4 kHz, in order to evoke wave motion with at least half a wavelength within the measurement area (~10-12cm wide), while having sufficiently high output from the BCHA. Signal processing methods have been implemented in order to reduce the effect of motion artefacts from random body movements. In-vivo data is compared with equivalent surface wave measurements of cadaver heads, with and without skin.

Experimental setup

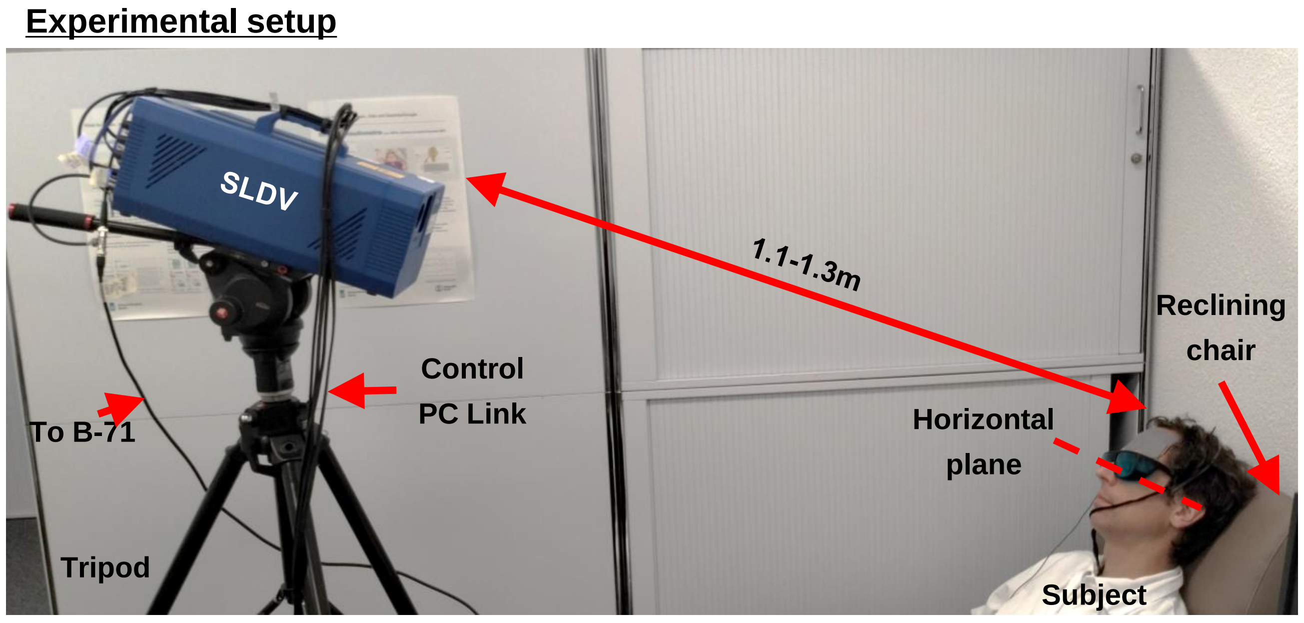

Fig. 1. *Subject is comfortably laying on a reclining chair set at 45 degree in a sound isolated room.*

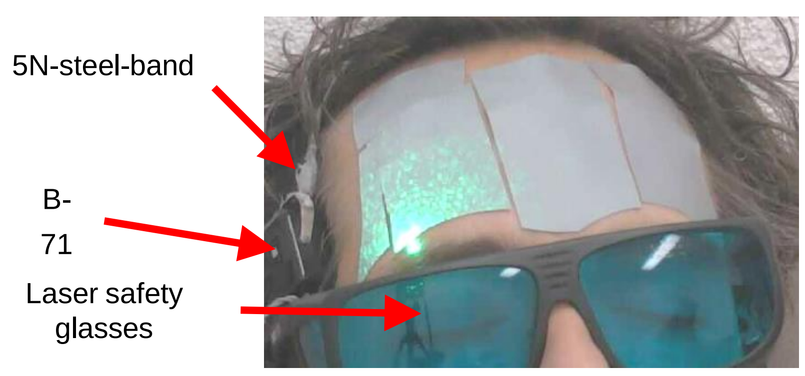

Fig. 2. *Flexible retroreflective tape were mounted on the forehead. Laser safety glasses, stimulation location at the left temple and the BCHA with the 5N stellband are indicated with red arrows.*

Artifact removal from raw data

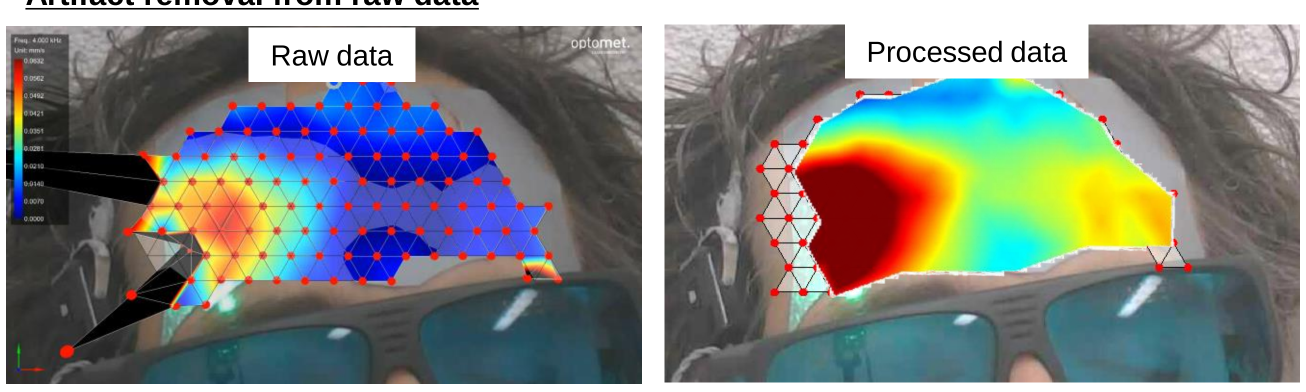

Fig. 3. *Comparison between raw data and processed data. Processing consists of low coherence detection, amplitude outlier analysis, spatial filtering and spline interpolation.*

Estimating wave speed by tracking trajectories of local extrema

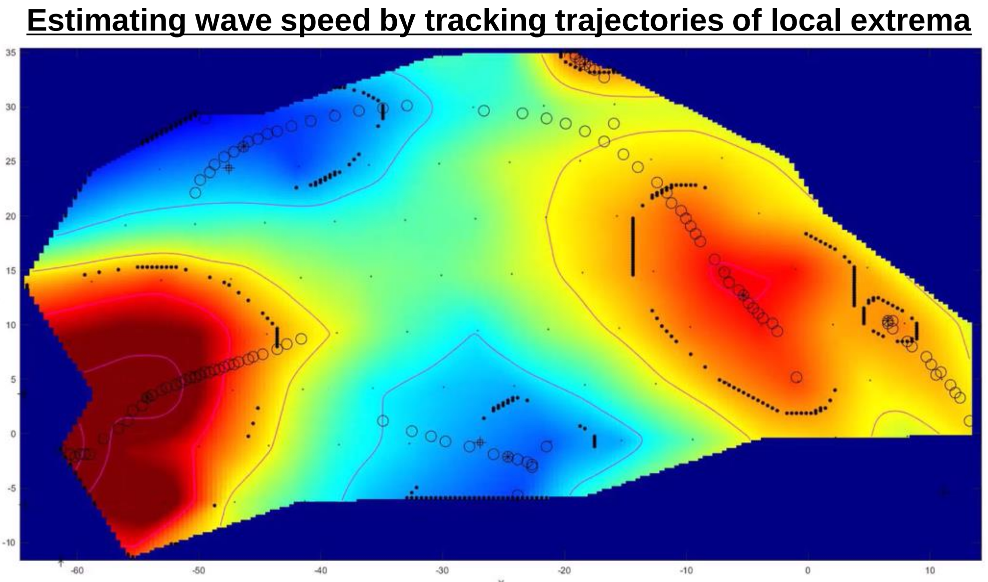

Fig. 4. *Representative result of the automatic estimation of local wave speed by tracking of the trajectories of local extrema (minima or maxima). By integrating the path travelled by detected local extrema, their wave speed can be estimated.*

Results

Skull surface wave motion in cadaver heads

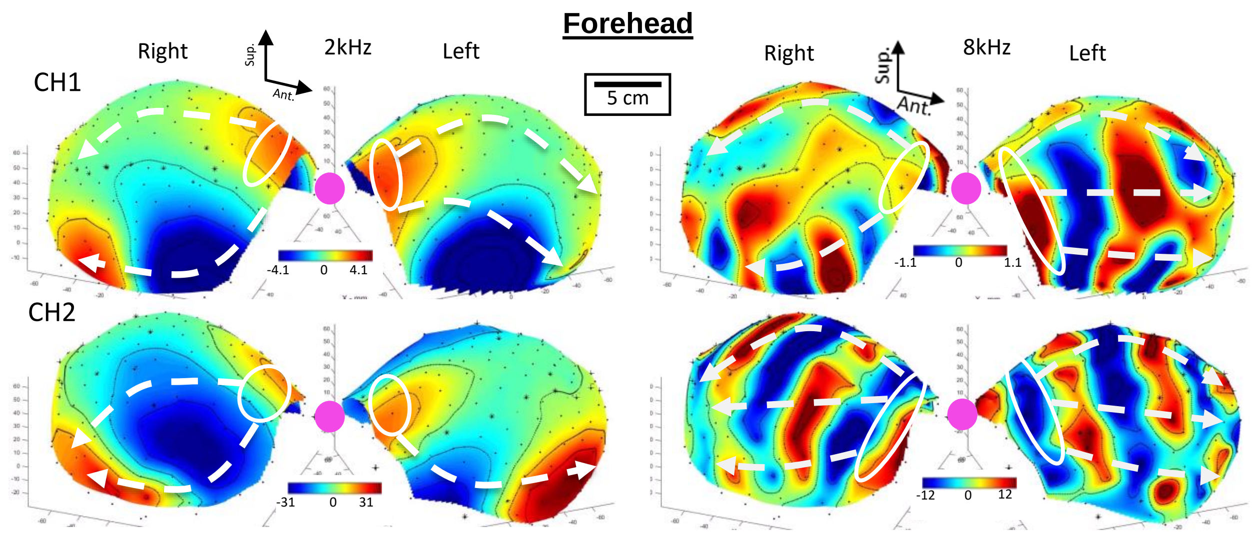

Fig. 5. *Instantaneous velocity of the skull bone surface of cadaver heads (from a set of 5), for forehead stimulation at 2 and 8 kHz. Indicated are the actuator location (pink dot), the estimated wave origin (white circle). Wave speed is 400-600m/s*

Effect of skin on surface wave velocity estimated in cadaver heads

Three-dimensional velocity response at ~20 points (~4 x 5, 25mm pitch) on the superior section of a cadaver head was recorded at the intact skin surface as well as the bone surface, with only minor modification of the skin. Specifically, the bone surface was recorded through small holes (<5mm dia.) thought the skin. Wave pattern was nearly identical in both cases, with only attenuation at higher frequencies. Wave speed was 450-500m/s, corresponding to transcranial time interval of 0.4 ms, previously estimated in subjects.

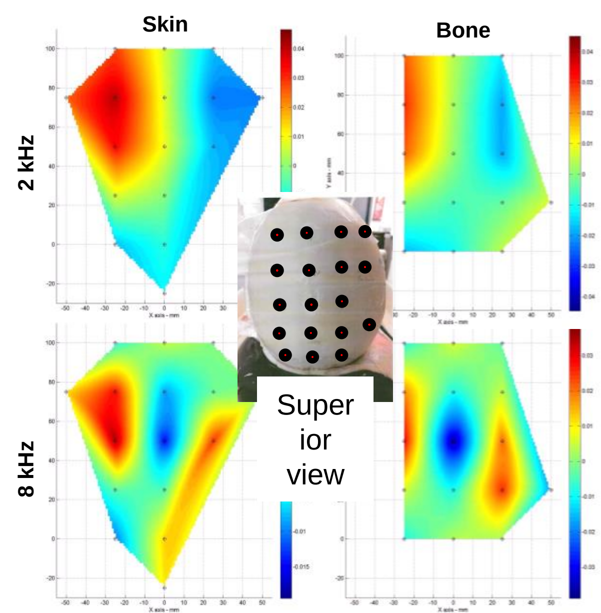

Fig. 7. *Scan pattern and instantaneous velocity of the intact skin and the skin covered bone surface at 2 and 8 kHz.*

Skin surface wave speed varies across the forehead in subjects

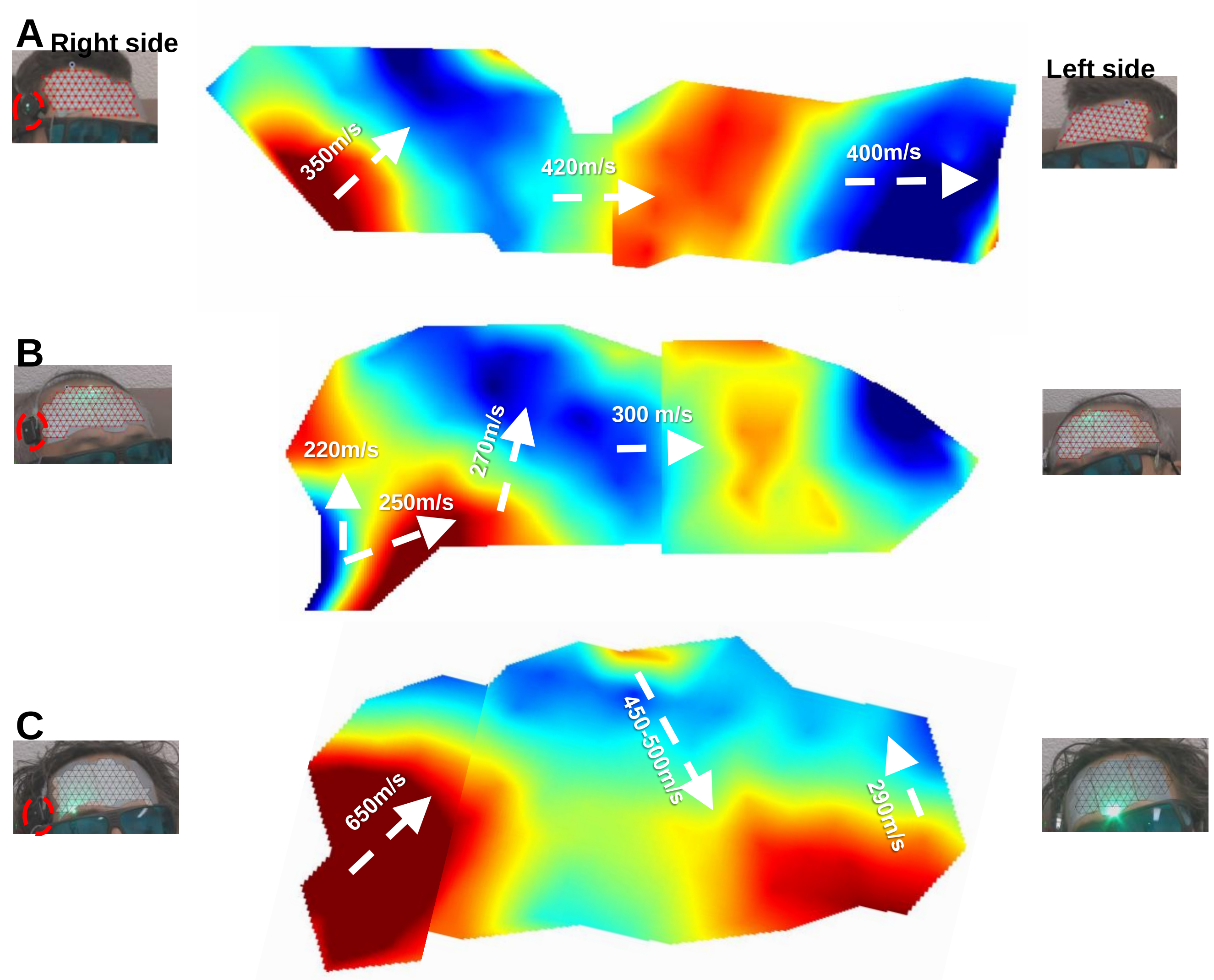

Fig. 8. *Wave speed and direction of sound propagation for a representative group of subjects differed across the measured area. Sound propagated away from the actuator in a horizontal and superior direction.*

Conclusions

- **Cadaver heads data indicated no major change due to the presence of skin in the spatial distribution (wavelengths) of the wave patterns across the superior skull.**
- **Motion of skin appears attenuated relative to the skull vibration at higher frequencies.**
- **Wave speed is similar between live humans and fresh frozen cadaver heads**
- **Propagation speed of the traveling waves is consistent with previous measures of time interval between ipsilateral and contralateral sides.**

References

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