Characterizing Brain Micromotion Using Diagnostic Ultrasound

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Introduction: Currently used functional neuroimaging modalities all have limitations either because of reduced portability for ambulatory tasks (e.g. functional MRI and PET), or because of low depth-resolved spatial information (e.g. functional near infrared spectroscopy and EEG). Ultrasound imaging is portable, can provide sufficient depth penetration to image tissue well within the brain at frame rates high enough to capture cardiac induced motion and with spatial resolution high enough to distinguish closely spaced objects (approximately 750µm). Thus, it has the potential for functional brain imaging during ambulatory tasks, or complex transient events such as epileptic seizures. Functional activation of a localized region of the brain is expected to alter local pulsatility: small volumetric changes in tissue induced by cardiac cycle. We are developing a functional ultrasound imaging method based on measuring local pulsatiliy of brain tissue. The goal of this work is to characterize typical velocities in different regions of the brain in a control baseline condition.

Materials and Methods: A preliminary experiment was conducted on five volunteers (three men and two women) following approved procedures. A custom head frame built to hold an ultrasound transducer to the transtemporal window was assembled and then placed onto the participant's head. The head frame was adjusted until the brain stem was visible in the brightness mode image displayed on the ultrasound machine. Raw radiofrequency ultrasound data were collected using an Ultrasonix Sonix RP US system (Richmond, BC, Canada) with a 2-4MHz transducer. This process was repeated five times for each subject, with the head frame disassembled between trials. The position and orientation of the transducer with respect to the head was recorded using Ascension Technology's 3D Guidance TrakSTAR (Burlington VT, USA) electromagnetic position sensing system. Position sensors were placed on the subject's forehead, occipital protuberance, and the ultrasound transducer. Tissue velocities in the brain were estimated using a conventional autocorrelation-based estimator performed on ten scan lines at depths just before the anterior horn of the brain stem (as shown in Fig. 2). The peak velocity for every cardiac cycle in an 8 second period was recorded and averaged for each depth and scan line. This yielded an average velocity for this region for each of the five trials per subject. Position sensor data was used to calculate the angle between the long axis of the ultrasound transducer and the plane containing the sensors on the subject's head.

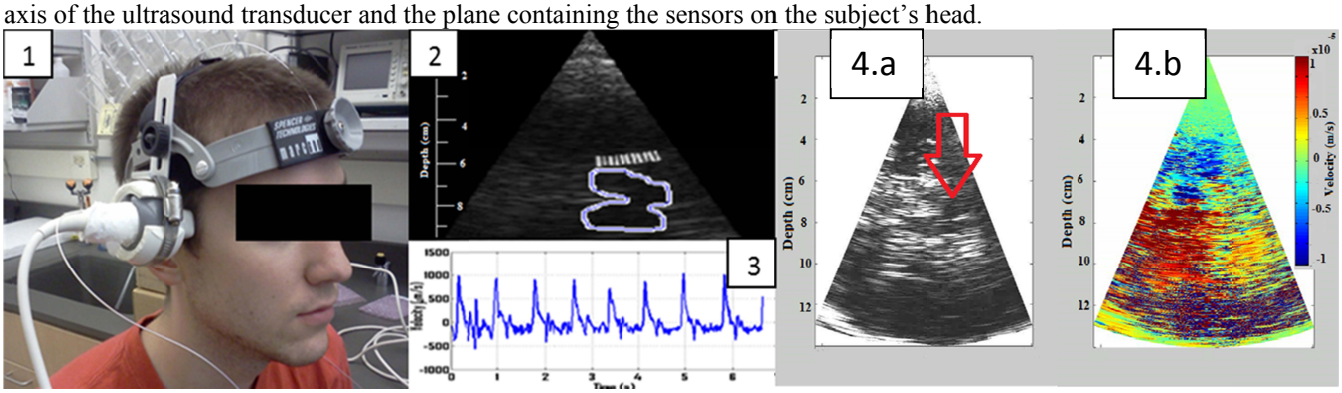

Fig. 1 The head frame holding the transducer to the trans temporal window. Fig. 2 An example of region selection, the brain stem is outlined and the white dashes above are the scan lines where velocities were collected, Fig 3 An example of tissue velocities of brain pulsations (8 peaks over 6 seconds = 80 bpm). Fig 4 B-mode image (a), the red arrow points to the brain stem, and a functional image of the brain (b) side by side. The functional image shows velocities towards the transducer in the proximal hemisphere and away from the transducer in the distal hemisphere as expected.

Results: Functional images showed pulsations throughout the brain, with the largest pulsations occurring close to the Circle of Willis next to the brainstem as expected. The velocities measured for each trial were in the range [208.4, 937.9] µm/s with a mean of 504.6 µm/s and standard deviation equal to 158.4 µm/s. By limiting the data set to only the trials which had a transducer angle between -5° and 5°, standard deviation reduced significantly with velocities equal to 493.9 ± 84.3 µm/s.

Conclusions: In this preliminary study we were able to produce functional motion maps from brain tissue pulsations (Fig. 4.b). Results of this study suggest that velocity measurements are sensitive to the spatial position of the cross section of the brain interrogated. Spatial distribution of pulsations are not uniform within the brain volume and might indicate differences in local perfusion. A better understanding of the exact brain structures and vasculature being viewed may help explain the changes in velocity. Recruitment of more participants in this study is ongoing, and in the future more accurate transducer positioning will be performed between trials, and the position of the ultrasound slices will be compared to structural MRI to provide some insight into brain structures and corresponding pulsatility signatures.