Retinotopic mapping of the human visual cortex using a high-density compact DOT system

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Introduction:

Prior work has shown that High-Density Diffuse Optical Tomography (HD-DOT) systems are capable of detailed spatial imaging of retinotopic visual stimuli [3]. Using a new, non-fiber-optic based HD-DOT system, we demonstrate similar results in a retinotopic mapping experiment. The compact, lightweight design of the array makes it highly suitable for use in clinical environments. This study demonstrates the system's spatial imaging capability.

Methods:

The DOT system consists of 10 source optodes and 18 detector optodes (Fig 1a) mounted on rigid-flex circuit boards for flexibility. Each source optode contains 5 time-encoded, amplitude modulated lasers operating at 5 different wavelengths ranging from 690-850nm. Separations between sources and detectors range from 13-87mm and contain 9 nearest neighbors. Data are digitized, processed, and transmitted to a laptop (frame rate = 5Hz) for post-processing.

Two subjects (S1 & S2) were enrolled and provided informed consent. Subjects were seated approximately 30in. from a computer monitor that was height adjusted for each subject. A sensor array (SA) was placed on the back of the subject's head above the inion (Fig 1b), and the SA was massaged into the hair to ensure optodes made contact with the scalp. The SA was held in place with an elastic band. All recordings were performed in a dark room and subjects wore noise blocking headphones to minimize external distractions.

Retinotopic mapping of polar angle was performed using a rotating wedge stimulus similar to previous studies [1,3]. Ten revolutions of a checkerboard wedge (Fig 2a) rotating in steps of 10^{o}/sec were presented either clockwise (S1 & S2) or counter-clockwise (S2). Subjects were instructed to focus on a crosshair in the center of the screen at all times.

Data were post-processed to generate images of oxy-hemoglobin (HbO) using previously described methods [4]. Briefly, data from all optode-pairs were bandpass filtered and downsampled to 1Hz to give one sample per wedge position. Signals with low SNR were removed; the remaining signals were imaged at each time point using standard HD-DOT procedures on a two-layer finite element slab model [2] to produce relative changes in HbO.

To map polar angle, we computed the cross-correlation of the HbO trend for each pixel with a cosine with a period of 1 revolution (T=36s). Here, the lag between the two corresponds to the delay between stimulus and maximum pixel activation; the image of the lags represents a map of the visual stimuli in the imaging field. Because not all tissue in the imaging field may respond well to the stimulus, pixels below 10% of the maximum observed cross-correlation magnitude were masked out of the maps.

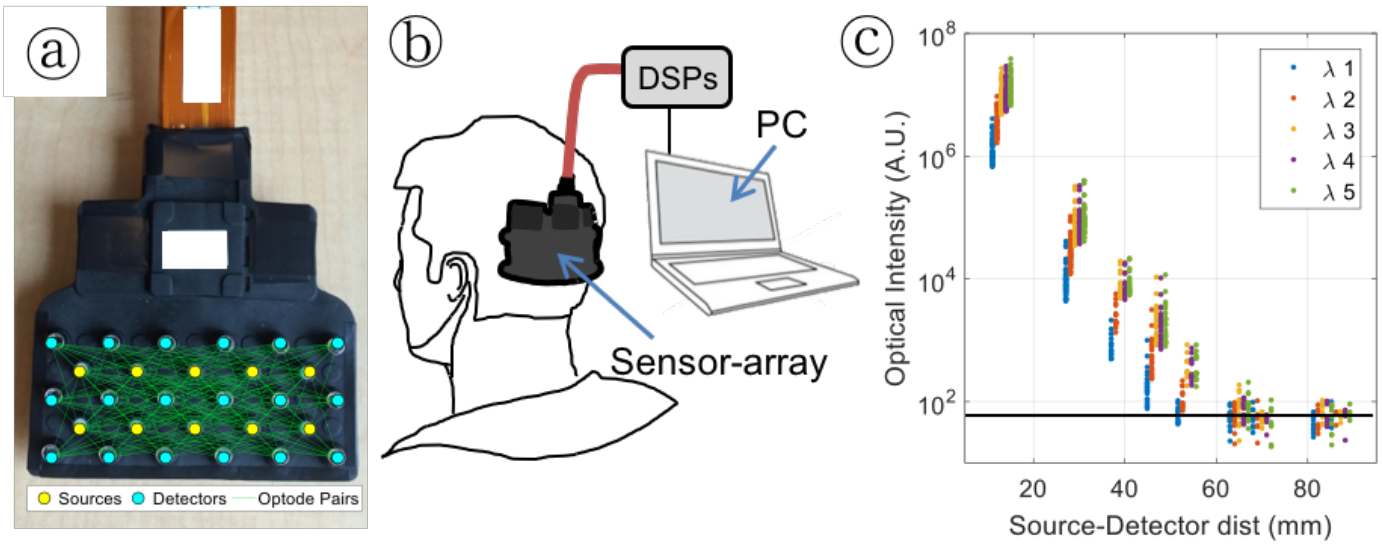

Figure 1 – Experimental setup using a new, wearable, lightweight HD-DOT system. ⓐ The fiber-optic-free DOT sensor-array has a high-density imaging arrangement of 10 sources (yellow circles) and 18 detectors (blue circles). Green lines indicate all measurement pairs, ranging from 1–9 nearest neighbors. ⓑ Sensor-array (SA) placement over the visual cortex. A DSP interface unit (DSPs) connects the SA to the host PC. ⓒ Detected optical intensity levels for five wavelengths vs. source-detector distances on Subject 1 averaged over 1 sec (~5 image frames). The optical signals span a range of 7 orders of magnitude (solid black line indicates the dark noise standard deviation level).

Results:

Fig 1c shows the optical intensity data for S1. The compact, lightweight HD-DOT SA measures signals over 7 orders of magnitude (Fig 1c). Fig 2b shows the region of maximal HbO change moving around the cortical tissue for different positions of the rotating wedge. The HbO temporal responses (Fig 2c) for 3 pixels from distinct regions of tissue show strong periodic responses with different phases. Fig 3b maps the phases for different pixels from S1; the phase of any pixel indicates the wedge position (Fig 3a) it is most sensitive to. The response shows the typical pinwheel pattern associated with retinotopic mapping of primary visual cortex. Fig 4b shows the same map for S2, though the right hemisphere does not show the typical pinwheel pattern. However, repeating the experiment using a counter-clockwise rotating wedge shows a similar response map (Fig 4c). This demonstrates the reproducibility of the atypical response which may be specific to the subject's neuroanatomy.

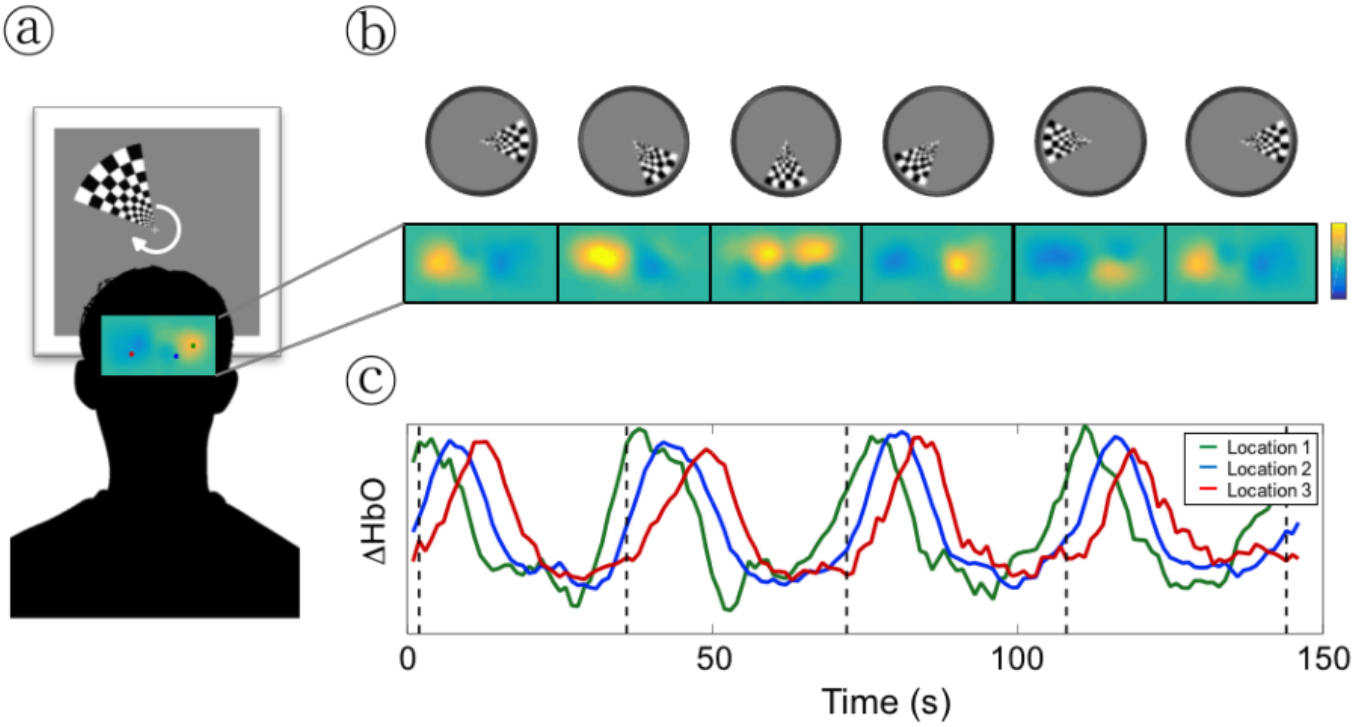

Figure 2 – Imaging results from the rotating wedge stimulus for Subject 1. ⓐ The visual stimulus is a reversing logarithmic checkerboard (10-Hz contrast reversal) rotating wedge with width of 60° (inner radius: 1°, outer radius: 14°). The wedge advances in discrete steps of 10° every second. ⓑ HbO response images for different wedge positions show the activation area moving with the wedge. ⓒ Temporal trends of HbO for three different pixels within the imaging field. The locations of the three pixels are indicated by colored points on the activation image in panel ⓐ. Dashed lines indicate the start of a new revolution of the rotating wedge. The HbO responses at all three pixel locations exhibit strong periodic behavior at the frequency of the stimulus rotation; however, the pixels differ in phase reflecting each pixel's sensitivity to different wedge positions.

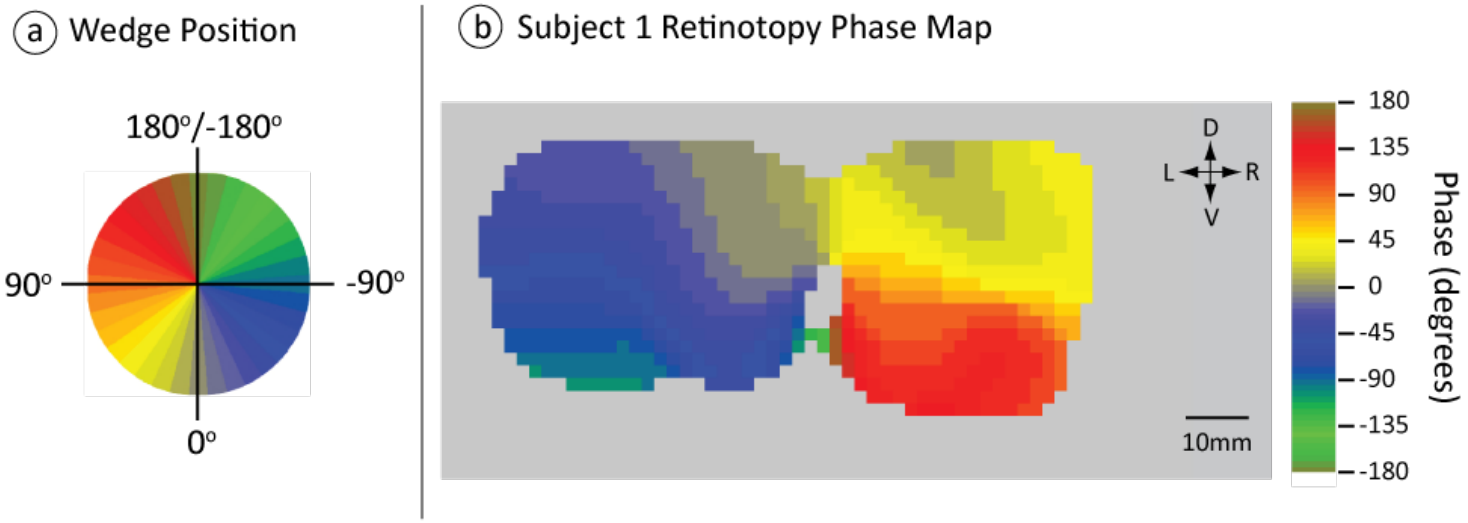

Figure 3 - Subject 1 retinotopy phase map. ⓐ Color map of the wedge position. The experiment begins with the wedge at 0° and rotates in a clockwise direction. ⓑ Map of the phase of the HbO response. The phase map is masked to remove areas with weak correlation with the reference sinusoid. The masking removes areas where our DOT system has poor sensitivity, but it also removes some areas with poor activation (e.g. the midline between hemispheres). After removing the constant neurovascular delay, the response map reflects a mirrored left/right and top/bottom version of the original wedge position map. The phase map shows no significant areas of response to wedge positions between -90° and -180°. This may be due to the fact that the sensor array is not large enough to capture all of the primary visual cortex; alternatively, the areas of visual cortex that respond to these wedge positions may be located at deeper depths than our optical sensors can image.

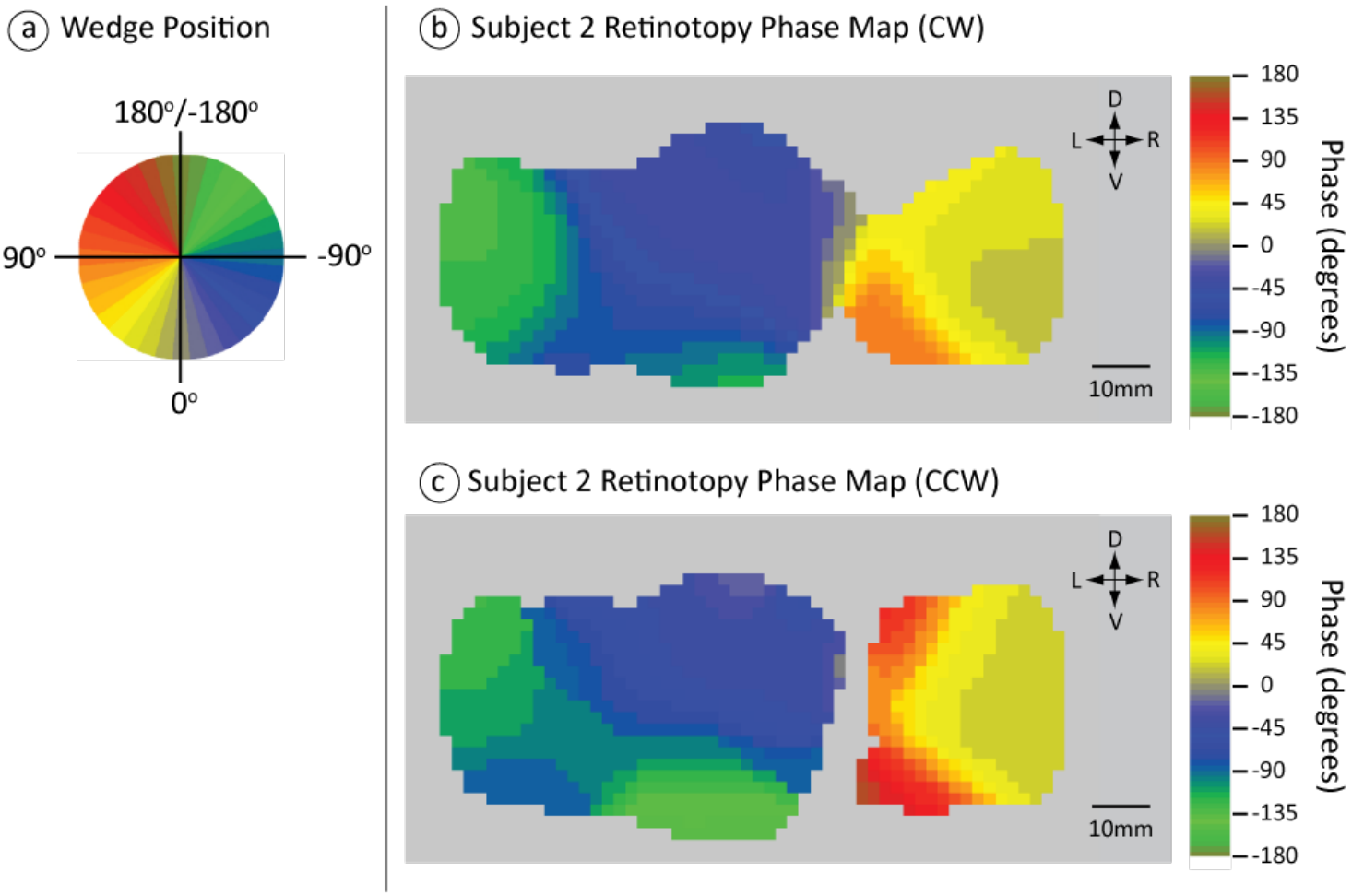

Figure 4 - Subject 2 retinotopy phase maps. ⓐ Color map of the wedge position ⓑ Map of the phase of the HbO response to a clockwise rotating wedge stimulus. The hemispheric divide revealed by masking the phase values shows that the array was placed off-center with more of the left hemisphere captured in the imaging field. ⓒ To test repeatability of the response, we repeated the experiment with a counter-clockwise rotating wedge. Both clockwise and counter-clockwise stimuli produced similar response maps. We also used the response to the two stimuli to estimate a common neurovascular delay of 9.25s. The phase maps in ⓑ and ⓒ include this delay which was also applied to the results for Subject 1 (Fig 3).

Conclusions:

We have demonstrated the spatial sensitivity of our compact HD-DOT system to small changes in cerebral perfusion using a classic retinotopic mapping experiment. Initial results from two subjects show spatial sensitivity to changes in wedge position from a rotating wedge experiment.

Imaging Methods:

NIRS [1]

Neuroanatomy:

Cortical Anatomy and Brain Mapping [2]

Keywords:

Near Infra-Red Spectroscopy (NIRS)
NORMAL HUMAN

OPTICAL
Optical Imaging Systems (OIS)
Vision

[1|2]Indicates the priority used for review

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Optical Imaging

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