

Non-invasive imaging of the brain using near-infrared light

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General principles

Following a pioneering idea for non-invasive optical studies of the brain (Jöbsis, 1977), it is now well-established that near-infrared light gets transmitted through the intact scalp and skull to illuminate the brain (McCormick *et al.*, 1992; Gratton *et al.*, 1994; Fantini *et al.*, 1999). This is much like the sunlight penetrates through the clouds to illuminate the earth (the similarity between the two cases is that both the skull and the clouds act as stronger light diffusers than light absorbers). Figure 1 schematically illustrates the non-invasive approach to the optical study of the brain. An optical fiber delivers an optical signal onto a specific scalp location, while a separate optical fiber located at a different scalp location (which is typically 3 cm away from the illumination point) collects light that has probed the cerebral tissue. By using a number of such pairs of illumination-collection points on the scalp, one can perform optical brain mapping. The main absorber for near-infrared light in brain tissue is hemoglobin (the oxygen carrying protein in the blood) whose light absorption properties depend on its level of oxygenation. This accounts for the sensitivity of optical methods to changes in tissue perfusion and oxygenation, which are typically associated with brain activity (Hoshi and Tamura, 1993; Villringer *et al.*, 1993).

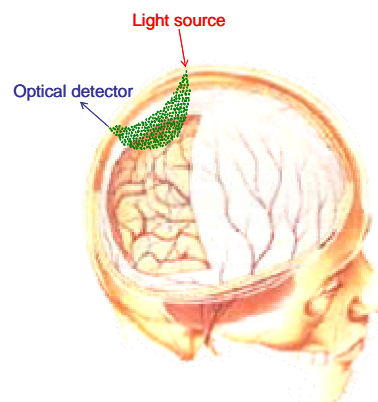


Fig. 1. Schematic representation of the non-invasive optical approach to brain imaging. The green area represents the tissue probed by light emitted at the red-arrow location and collected at the blue-arrow location.

The optical helmet

The illumination and collection optical fibers are secured on the subject's head by means of an *optical helmet*. It is important that the optical fibers are all in good contact with the scalp, so that a spring-loaded approach is preferred to gently push the fibers onto the scalp through the hair. Two optical-helmet designs aimed at probing the primary motor cortex are illustrated in Fig. 2.

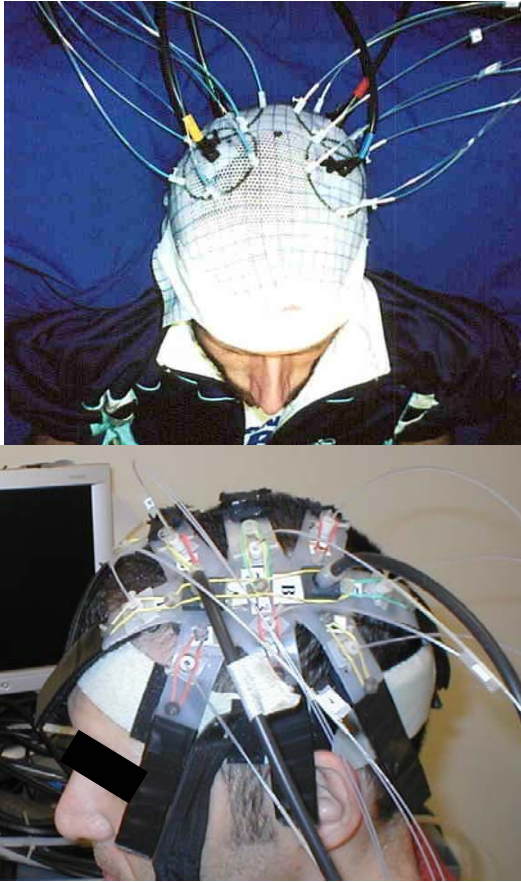


Fig. 2. Optical helmets for near-infrared imaging of the human brain. The small optical fibers (400 μm in diameter) are illumination fibers, while the larger black fibers (3 mm in active diameter) are collection fiber bundles.

Optical signatures of motor cortex activation

Figure 3 shows the optical response measured on the left primary motor cortex of a human subject during a right-hand-tapping task. The subject wore an optical helmet like the ones shown in Fig. 2, and was asked to perform hand-tapping for three periods of 10 seconds, which are indicated by the blue areas in Fig. 3. During these tapping periods, the tissue concentration of deoxy-hemoglobin decreases ($\Delta[\text{Hb}] < 0$) while the concentration of oxy-hemoglobin increases ($\Delta[\text{HbO}_2] > 0$). This hemodynamic pattern (decrease in $[\text{Hb}]$, increase in $[\text{HbO}_2]$) is indicative of a localized increase in blood flow in response to brain activation (Maki *et al.*, 1995; Obrig *et al.*, 1996; Villringer and Chance, 1997; Colier *et al.*, 1999; Benaron *et al.*, 2000).

Figure 4 shows optical maps of brain activation during right-hand tapping (top panel) and left-hand tapping (bottom panel). In both cases, it is the contralateral brain side (i.e. the side that is opposite to the tapping hand) that shows the stronger optical response. The optical mapping can be performed in real time, with an image acquisition rate as fast as 6.25 Hz (i.e. one optical brain map every

160 ms) (Franceschini *et al.*, 2000). This real-time capability, together with the non-invasiveness and the relative insensitivity to subject's movement, provides unique opportunities for applications of near-infrared brain imaging in basic research as well as medical diagnostics and monitoring.

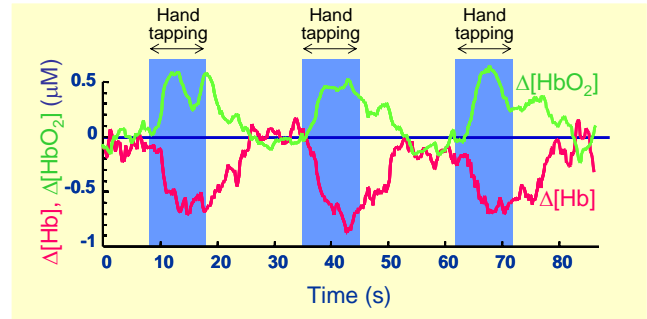


Fig. 3. The increase in the cerebral concentration of oxy-hemoglobin (positive $\Delta[\text{HbO}_2]$) and the decrease in the cerebral concentration of deoxy-hemoglobin (negative $\Delta[\text{Hb}]$) are the signatures of brain activation. These traces were recorded on the left motor cortex of a human subject during a right-hand-tapping protocol (hand tapping occurred during the periods indicated by the blue bars).

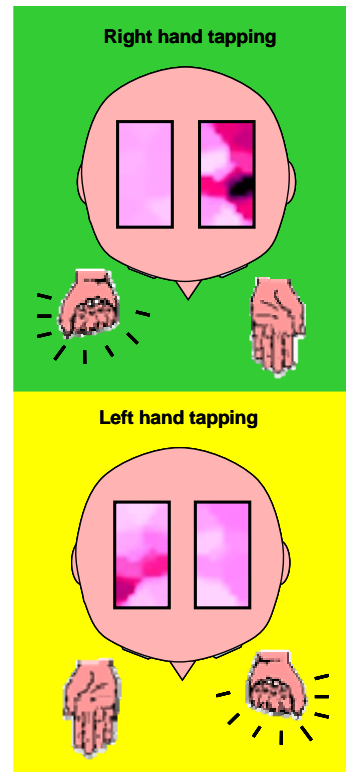


Fig. 4. Optical maps of right and left brain sides during right-hand tapping (top) and left-hand tapping (bottom). The brain side opposite to the tapping hand shows activation (the darker areas indicate a local increase in blood flow in response to brain activation).

Acknowledgments

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