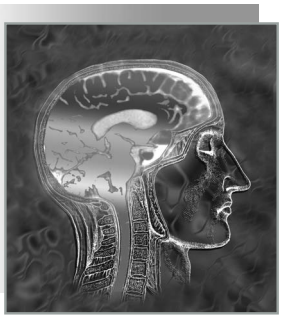

Optical Imaging of the Intact Human Brain

A View from the Guest Editors

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This special issue includes a collection of articles on the use of optical devices to measure brain activity in humans in a noninvasive manner and is intended to provide a sample of different aspects of this area of research. Although the existence of optical changes accompanying neuronal activity has been known since the 1940s (see Sable et al., this issue, for a review), noninvasive applications to human physiology and cognition have emerged only recently, and they are still being expanded and/or developed.

In this introductory editorial we will provide some context for integrating the various contributions to this special issue. We will briefly highlight the various types of optical signals that are commonly used for human studies, the classes of devices used for their measurement, and the possible current and future applications of these methods.

Optical Signals

The first article in this issue (Sable) reviews studies involving the measurement of optical signals in tissue preparations and animal models. These studies are invasive and, as such, have the advantage of being able to provide information about the biophysics and physiology underlying optical measures from neuronal tissue in some details. The remaining articles in this issue are focused on recordings from the intact adult human head, using near-infrared (NIR) light. Light within the NIR range (approximately 600–1,000 nm) can penetrate several centimeters into the tissue because common absorbers such as water and hemoglobin absorb less at these wavelengths.

Two types of optical signals can be recorded noninvasively: hemodynamic and neuronal. *Hemodynamic signals* are often referred to as functional near infrared responses (fNIRs) and are measured using a spectroscopic approach. In fact, the absorption spectra of oxy- and deoxy-hemoglobin cross over within the NIR window (isosbestic point), and therefore these two substances can be quantified separately by using two or more light wavelengths. When used to measure neuronal function, hemodynamic optical signals are intrinsically slow, peaking several seconds after the corresponding neuronal activity. This is because they reflect changes of blood flow in active areas of the brain, which trail neuronal activation by a few seconds, in a manner corresponding to functional magnetic resonance (fMRI) and ^{15}O positron emission tomography (PET) recordings. The articles by Nishimura, Chance, Izzetoglu and their colleagues report these types of measurements. The main advantages of these signals are their good signal-to-noise ratio (SNR) and the fact that they provide an inexpensive and portable (potentially field-ready; see the article by Chance) alternative to fMRI and PET measurements. In addition, they allow for separate quantification of oxy- and deoxy-hemoglobin, which are instead combined in the brain oxygen level dependent (BOLD) fMRI signal. Their main disadvantage is that, because of their underlying physiology, they cannot track well the timing of neuronal events.

The second class of optical signals that can be recorded noninvasively is *neuronal*. The mechanisms underlying these signals are less known but are likely to be due to volumetric changes in the neurons accompanying the influx of ions and water with activity (see the Sable article in this issue), which in turn influence the light scattering. These signals are small and have a relatively poor SNR, although developments in the recording and analysis tools have led to considerable improvements (see Maclin et al., in this issue and [1], [2]). The main advantage of these signals is that they can track neuronal (largely postsynaptic) activity as it occurs (i.e., on a millisecond scale) and with a reasonable spatial resolution (subcentimeter scale for intact human studies). Two of the articles reported in this issue (Maclin and Tse et al.) report these types of neuronal measurements [event-related optical signal (EROS)]; e.g., [3], [4].

Compared to other types of noninvasive brain imaging tools (e.g., PET, fMRI) both types of optical signals share the advantage of being less expensive and more portable and the disadvantage of being unable to image deep brain structures. Compared to electrophysiological measures of brain activity [magnetoencephalography (MEG) and event-related potentials (ERPs)], the EROS and other fast/neuronal optical recordings (e.g., [5]–[9]) share similar temporal resolution but provide a better spatial resolution. It is important to note that optical recordings can be easily obtained concurrently with other types of recordings, including ERPs (e.g., [10]–[12]) and fMRI [13], thus allowing investigators to provide a more integrated and complete picture of brain activity. Several of the articles reported in

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this issue use structural MR recordings and other alignment methods to line up the functional optical data over the underlying anatomy (for an extensive review of this issue see [14]). A number of sophisticated three-dimensional (3-D) reconstruction methods are also being developed (e.g., [13], [15]–[21]).

Measurement Devices

As briefly reviewed in the Nishimura article in this issue, the devices used to obtain noninvasive optical measures vary according to some basic principles. Continuous-wave (CW) devices allow for the measurement of light intensity changes with activity. Typically, they are better tuned for measuring slow hemodynamic signals, but under certain conditions they can also measure fast neuronal signals (e.g., [1], [2], [22]). The devices described by the Nishimura, Izzetoglu, and Chance articles are all CW devices. The one described by Nishimura (OTIS) has the advantage of being designed to record over hair (which otherwise is a major obstacle to light penetration), whereas the other two devices are designed to be positioned over the forehead, where hair is not an issue. The other category of devices represented in this volume is one where the light is intensity modulated (see the Maclin and Tse articles). These machines (frequency-domain devices) allow for the measurement of both intensity changes (ac, dc, and modulation) and phase shifts of the photon density wave. They are best suited for the measurement of fast signals but are also more expensive and complex to use.

Applications

Because of their relative portability, noninvasive optical methods such as fNIR and EROS can in principle be used in a number of applied domains, from clinical to field deployment, although currently the feasibility of various applications is still in the research development stage. The articles collected in this issue are in part the result of research funded by the Defense Advanced Research Project Agency (DARPA) Improving Warfighter Information Intake Under Stress Program, which is based on the field of augmented cognition [23]. This program focused on establishing the feasibility of monitoring an operator's brain activity to enhance cognitive performance in real time by avoiding catastrophic errors and by delivering information at the most appropriate times. The Chance and Izzetoglu articles in this issue summarize work done in this domain. Of course, research applications of optical methods, especially in cognitive neuroscience, are also extremely useful, as shown by the Tse article in this issue and by the flurry of publications in this area in the last few years (e.g., [11], [12], [24]–[26]). Given the flexibility of optical methods, their potential portability, and their ease of integration with other techniques, it is likely that a big expansion of these methods will occur over the next decade, of which the collection of articles in this issue is meant to give but a small preview.

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Gabriele Gratton received an M.D. from the University of Rome (1980) and a Ph.D. in biological psychology from the University of Illinois in 1991, doing research on event-related brain potentials and attention in the laboratory of Michael Coles and Emanuel Donchin. After post-doctoral periods at FIDIA pharmaceutical labs in Abano Terme, Italy (1991), and in the Dept. of Physics at the University of Illinois, he became an assistant professor in the Dept. of Psychology at Columbia University in New York. (1992–1996). He then moved to the University of Missouri–Columbia (1996–2001) and is currently a professor of psychology at the University of Illinois at Urbana–Champaign, where he co-directs the Cognitive Neuroimaging Lab with Prof. Monica Fabiani, situated in the Beckman Institute. He has been the recipient of the Early Career Award from the Society for Psychophysiological Research (SPR) in 1997 and is a fellow of the Association for Psychological Science (APS). His research involves the development of fast optical imaging and the integration of multiple brain imaging methods (including event-related potentials, optical imaging, and structural and functional MRI) in the study of cognition and executive function.

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