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Functional Near Infrared Spectroscopy, Part 3

Judit Gervain
Joseph P. Culver

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Judit Gervain

UMR 8242 CNRS-Paris Descartes
Laboratoire Psychologie de la Perception
45 rue des Saints-Pères, Paris, 75006, France

Joseph P. Culver

Washington University School of Medicine
Department of Radiology
Campus Box 8225
4525 Scott Avenue
St. Louis, Missouri 63110, United States

Following the fNIRS 2016 conference, we sent out a call for papers to report the science presented. Over three installments, these papers constitute a special section on fNIRS in *Neurophotonics* and capture the current advancement of the field. Part 1 of the special section appears in *Neurophotonics* Vol. 4, Issue 2. Part 2 appears in Vol. 4, Issue 4. Broadly, the papers cover new work in applications, algorithms, instrumentation, and paradigms.

As a sign of the continued maturation of fNIRS technology, the special section covers a wealth of applications to an increasingly broad range of topics, with a similarly increasing range of complexity and challenge. This is most evident in the studies of clinical populations. For example, an intriguing setting for fNIRS has been monitoring anesthesia. While optical techniques have been used frequently to image animals under anesthesia, the advancements in fNIRS techniques have paved the way for new studies (Hernandez-Meza et al.) of humans under anesthesia. Similarly, autoregulation, an important clinical variable, is now becoming a major research theme for fNIRS leveraged by improved measures of tissue oxygenation, blood dynamics and cerebral blood flow (CBF). Showing the complexity of the clinical environments in which fNIRS can be successfully deployed, one study examined the feasibility of measuring the impairment of autoregulation in pediatric patients with extracorporeal membrane oxygenation (Tian et al.). Examples of challenging awake and behaving clinical populations include measuring neural activation in children with hemiplegic cerebral palsy (Surkar et al.). Studies of aging include both the executive function in older adults (Halliday et al.), and memory deficits in Alzheimer's (Perpetuini et al.). Finally, the variety of clinical applications has greatly expanded, including CNS disorders novel to fNIRS studies such as fibromyalgia (Eken et al.).

Applications to children remain a central focus, where fNIRS provides measuring, monitoring, and imaging in an open setting outside of magnetic resonance imaging (MRI) scanners. A paradigm measuring the brain responses to naturalistic social scenes has become one of the success stories providing a robust, targeted approach to investigating brain function in kids (Hakuno et al.). Other studies have focused on discerning shape-from-motion in infants (Hirshkowitz et al.) and the relationship between hemodynamic activity and motor performance in six-month-old term and preterm

babies (Oliveira et al.). Fundamental to fNIRS studies, particularly with young children, are assumptions about the baseline optical properties. While previous NIRS papers have focused on optical properties in adults, there have been limited reports in infants. A new paper works to fill that gap by reporting the baseline optical properties measured in neonates using time-domain fNIRS (Spinelli et al.). Similarly, oxyhemoglobin-vs.-deoxyhemoglobin comparisons have been required in optimization of task protocols, though previous papers focused primarily on adults. New work reported in this special section addresses these optimizations in nontraditional paradigms, both in infants (Taga et al.) and adults (Dravida et al.).

Outside of children, a number of studies use fNIRS in naturalistic settings including studies on postural and walking tasks and other on physical exercise (Herold et al.). Similarly, the quiet nature of fNIRS allows studies at low background sound levels and this has been leveraged in studies of the influence of noise on mental activity, including cognitive load (Gabbard et al.).

In instrumentation, one of the most striking developments has been recent progress in diffuse correlation spectroscopy (DCS) (Tamborini et al.). While previously confined to feasibility studies, new DCS systems with multiple wavelengths, multiple distances, and faster sampling times now provide robust measurements of CBF and can be widely applied. Another dominant theme is wearable fNIRS systems. These papers include a review of fiberless approaches to fNIRS with a view toward whole scalp diffuse optical tomography (Zhao and Cooper). A challenge of wearable systems has been the lower channel counts and sparse sampling. An aspect of sparse sampling is addressed in a paper on a wearable modular fNIRS systems that include multiple distances with differential samplings of scalp skull and brain (Wyser et al.). Another wearable fNIRS paper reports re-arrangeable and exchangeable optical modules from Hitachi (Funane et al.).

Several multimodal studies were explored, including a review on simultaneous fNIRS and EEG studies (Chiarelli, Zappasodi et al.). Animal model fNIRS imaging systems provide an important foundation for fNIRS in humans. A novel approach to using structure illumination to generate fully contiguous spatial sampling with >1000 detector locations was presented for imaging mice (Reisman et al.). The use of structure illumination patterns provides reasonable frame rates >2 Hz from sCMOS detection imaging arrays. This imaging system provides an interesting framework for optimizing resolution, depth, and coverage.

In algorithms, head modelling has seen tremendous advancements over the last six years. New studies are looking at age-specific modeling for studies of children (Whiteman et al.). Other work shows that low-resolution mapping of the effective attenuation coefficient of the human head can be accomplished using a multi-distance approach to high-density optical recordings (Chiarelli, Maclin et al.). A number of studies have addressed motion artifacts, including exploration of overt speaking and ways to reduce speaking artifacts (Zhang et al.). The potential for artifacts and non-neuronal signals were also explored in a study of signals in the anterior-temporal region of the human head (Morais et al.).

Algorithm papers also focused on improving access to physiology and functional connections. For example, several papers focused on developing approaches to measuring or mapping either CBF or cerebral metabolic rate of oxygen metabolism (CMRO₂), or both. One such study measured the relationship among CBF, CMRO₂, and cerebral blood volume (CBV) using both traditional fNIRS and DCS (Nourhashemi et al.) in term infants. Others developed a more direct measure of metabolism through spectroscopy of oxidized cerebral cytochrome C oxidase changes (Brigadoi et al.). Finally, some groups continued to expand resting state methods for mapping functional connectivity, including the use of graph theory approaches to evaluating connectivity (Einalou et al.). With rapid growth in the field, there are new analysis packages coming on line, including one from Imperial College (Orihuela-Espina et al.).

Finally, groups continue to push new paradigms for mapping brain function and developing novel ways of interacting with neural signals. While historically fNIRS has been almost exclusively focused on mapping and encoding (how and

where functional tasks are carried out), new articles have begun exploring decoding (the inverse problem), that is deducing what the brain does based on fNIRS signals (Zinszer et al.). Other studies leveraged neurofeedback to upregulate the responses to imagined motor activity (Lapborisuth et al.). New paradigms continue to percolate in from the fMRI field, including methods that mix resting state functional connectivity with tasks paradigms to examine their interaction (Hassanpour et al.). These advance analysis schemes are facilitated by the ever increasing signal and image quality particularly found in the high-density imaging arrays. Other new paradigms capitalize on data that is unique to fNIRS. Some of the most forward-looking papers explored novel stimulation routes. Entirely new evoked pathways are being explored with transcranial laser stimulation. While optogenetics is a long way from being feasible in humans, these endogenous approaches provide some ability for direct cortical stimulation found with optogenetics (Wang et al.). Transcranial magnetic stimulation is logistically challenging in MRI, but it is much more compatible with fNIRS. This has been leveraged to look at evoked responses to TMS pulse-matched high frequency intermittent theta bursts (Curtin et al.).

In summary, this special section comprehensively takes stock of the most recent developments in fNIRS. As illustrated by the diversity of the topics covered, populations and experimental tasks tested, novel analysis methods and hardware advancements, the field has come a long way from early exploratory studies and has now reached the sophistication necessary to address some of the most complex challenges in neurosciences. We look forward to another installment coming out of the fNIRS 2018 conference.