fNIRS Publications

By Application

Contents

Auditory System

As fNIRS measurements are characterized by silent operations, innumerous possibilities of studies intended to explore cortical activation in the presence of controlled sounds can be achieved. Besides a better understanding of auditory processes in the brain, this may facilitate critical improvements on current solutions for cochlear implants.

C. Olds *et al.*, “Cortical Activation Patterns Correlate with Speech Understanding After Cochlear Implantation,” *Ear Hear*, vol. 37, no. 3, pp. e160-172, Jun. 2016.

K.-S. Hong and H. Santosa, “Decoding four different sound-categories in the auditory cortex using functional near-infrared spectroscopy,” *Hearing Research*, vol. 333, pp. 157–166, Mar. 2016.

L.-C. Chen, M. Stropahl, M. Schönwiesner, and S. Debener, “Enhanced visual adaptation in cochlear implant users revealed by concurrent EEG-fNIRS,” *Neuroimage*, Sep. 2016.

L.-C. Chen, P. Sandmann, J. D. Thorne, M. G. Bleichner, and S. Debener, “Cross-Modal Functional Reorganization of Visual and Auditory Cortex in Adult Cochlear Implant Users Identified with fNIRS,” *Neural Plast*, vol. 2016, 2016.

N. Altvater-Mackensen and T. Grossmann, “The role of left inferior frontal cortex during audiovisual speech perception in infants,” *NeuroImage*, vol. 133, pp. 14–20, Jun. 2016.

N. Abboub, T. Nazzi, and J. Gervain, “Prosodic grouping at birth,” *Brain Lang*, vol. 162, pp. 46–59, Aug. 2016.

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C. Bouchon, T. Nazzi, and J. Gervain, “Hemispheric Asymmetries in Repetition Enhancement and Suppression Effects in the Newborn Brain,” *PLOS ONE*, vol. 10, no. 10, p. e0140160, Oct. 2015.

H. Santosa, M. J. Hong, and K.-S. Hong, “Lateralization of music processing with noises in the auditory cortex: an fNIRS study,” *Front Behav Neurosci*, vol. 8, p. 418, 2014.

L. Pollonini, C. Olds, H. Abaya, H. Bortfeld, M. S. Beauchamp, and J. S. Oghalai, “Auditory cortex activation to natural speech and simulated cochlear implant speech measured with functional near-infrared spectroscopy,” *Hear. Res.*, vol. 309, pp. 84–93, Mar. 2014.

T. T. Brink *et al.*, “The role of orbitofrontal cortex in processing empathy stories in 4- to 8-year-old children,” *Front Psychol*, vol. 2, p. 80, 2011.

For latest updates on health information pertaining to hearing, balance, taste, smell, and speech and language development, please visit:

http://www.nidcd.nih.gov/Pages/default.aspx

Brain-Computer Interface (BCI)

Given its great performance in the presence of muscle movements and the possibility of setting up measurements in realistic environments, fNIRS presents itself as an ideal candidate for the acquisition of cortical signals as reliable and representative inputs for Brain-Computer Interface investigations.

U. Chaudhary, B. Xia, S. Silvoni, L. G. Cohen, and N. Birbaumer, “Brain–Computer Interface–Based Communication in the Completely Locked-In State,” *PLOS Biology*, vol. 15, no. 1, p. e1002593, Jan. 2017.

F. M. Noori, N. Naseer, N. K. Qureshi, H. Nazeer, and R. A. Khan, “Optimal feature selection from fNIRS signals using genetic algorithms for BCI,” *Neuroscience Letters*, vol. 647, pp. 61–66, Apr. 2017.

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J. Shin, K.-R. Müller, and H.-J. Hwang, “Near-infrared spectroscopy (NIRS)-based eyes-closed brain-computer interface (BCI) using prefrontal cortex activation due to mental arithmetic,” *Scientific Reports*, vol. 6, p. 36203, Nov. 2016.

N. Naseer, F. M. Noori, N. K. Qureshi, and K.-S. Hong, “Determining Optimal Feature-Combination for LDA Classification of Functional Near-Infrared Spectroscopy Signals in Brain-Computer Interface Application,” *Front. Hum. Neurosci*, p. 237, 2016.

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C.-H. Chen, M.-S. Ho, K.-K. Shyu, K.-C. Hsu, K.-W. Wang, and P.-L. Lee, "A noninvasive brain computer interface using visually-induced near-infrared spectroscopy responses," *Neuroscience Letters*, vol. 580, pp. 22–26, Sep. 2014.

N. Naseer, M. J. Hong, and K.-S. Hong, "Online binary decision decoding using functional near-infrared spectroscopy for the development of brain–computer interface," *Exp Brain Res*, vol. 232, no. 2, pp. 555–564, Nov. 2013.

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X.-S. Hu, K.-S. Hong, and S. S. Ge, “fNIRS-based online deception decoding,” *J Neural Eng*, vol. 9, no. 2, p. 26012, Apr. 2012.

C. Herff, F. Putze, D. Heger, C. Guan, and T. Schultz, “Speaking mode recognition from functional Near Infrared Spectroscopy,” *Conf Proc IEEE Eng Med Biol Soc*, vol. 2012, pp. 1715–1718, 2012.

S. Fazli, J. Mehnert, J. Steinbrink, G. Curio, A. Villringer, K.-R. Müller, and B. Blankertz, “Enhanced performance by a hybrid NIRS-EEG brain computer interface,” *Neuroimage*, vol. 59, no. 1, pp. 519–529, Jan. 2012.

S. Fazli, J. Mehnert, J. Steinbrink, and B. Blankertz, “Using NIRS as a predictor for EEG-based BCI performance,” *Conf Proc IEEE Eng Med Biol Soc*, vol. 2012, pp. 4911–4914, 2012.

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For latest updates on NIH and DARPA funded efforts for BCI funded research, please visit:

http://www.nibib.nih.gov/news-events/newsroom/brain-computer-interfaces-come-home;

http://www.nidcd.nih.gov/funding/programs/npp/Pages/workshop_bci_summary.aspx;

Brain Perfusion

Brain perfusion assessment in clinical environments has mostly been performed by techniques that cannot accomplish constant monitoring of the *brain. Due to its intrinsic capability of constant monitoring as well as the unique portability, fNIRS has clear potential for intensive care unit applications.*

M. Tessari, A. M. Malagoni, M. E. Vannini, and P. Zamboni, “A novel device for non-invasive cerebral perfusion assessment,” *Veins and Lymphatics*, vol. 4, no. 1, Mar. 2015.

J. Stojanovic-Radic, G. Wylie, G. Voelbel, N. Chiaravalloti, and J. DeLuca, “Neuroimaging and cognition using functional near infrared spectroscopy (fNIRS) in multiple sclerosis,” *Brain Imaging Behav*, vol. 9, no. 2, pp. 302–311, Jun. 2015.

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For updates on the latest announcements on the NIH brain initiative: Brain Research through Advancing Innovative Neurotechnologies® (BRAIN), please visit:

http://braininitiative.nih.gov

Clinical Neurology

With the capabilities of constant monitoring of oxygenation, perfusion and autoregulation, fNIRS has a high potential for diagnoses of cerebrovascular disease and severe brain injury. Other clinical neurology methodologies, including epileptic disorders and central nervous system tumors, may benefit from the technique on the preoperative function localization.

A. M. Kempny *et al.*, “Functional near infrared spectroscopy as a probe of brain function in people with prolonged disorders of consciousness,” *NeuroImage: Clinical*, vol. 12, pp. 312–319, Feb. 2016.

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H. Obrig, “NIRS in clinical neurology - a ‘promising’ tool?,” *Neuroimage*, vol. 85 Pt 1, pp. 535–546, Jan. 2014.

For the latest listing of clinical trials involving brain disorders, please visit:

http://www.ninds.nih.gov/disorders/clinical_trials/index.htm

Cognitive States

fNIRS adds another dimension to studies investigating cognitive functions and mental states, since it is a portable technique not too sensitive to motion artifacts. Attention processes, inhibition mechanisms, and working memory, as well as other cognitive states, may be studied in natural environments with a fast setup preparation.

M. Mücke, C. Andrä, M. Gerber, U. Pühse, and S. Ludyga, “Moderate-to-vigorous physical activity, executive functions and prefrontal brain oxygenation in children: A functional near-infrared spectroscopy study,” *Journal of Sports Sciences*, pp. 1–7, May 2017.

A. Unni, K. Ihme, M. Jipp, and J. W. Rieger, “Assessing the Driver’s Current Level of Working Memory Load with High Density Functional Near-infrared Spectroscopy: A Realistic Driving Simulator Study,” *Frontiers in Human Neuroscience*, vol. 11, Apr. 2017.

L. Holper, L. D. Van Brussel, L. Schmidt, S. Schulthess, C. J. Burke, K. Louie, E. Seifritz and P. N. Tobler, “Adaptive Value Normalization in the Prefrontal

Cortex Is Reduced by Memory Load,” *eNeuro*, vol. 4, no. 2, p. ENEURO.0365-17.2017, Mar. 2017.

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C. Bogler, J. Mehnert, J. Steinbrink, and J.-D. Haynes, “Decoding vigilance with NIRS,” *PLoS ONE*, vol. 9, no. 7, p. e101729, 2014.

J. Bahnmueller, T. Dresler, A.-C. Ehlis, U. Cress, and H.-C. Nuerk, “NIRS in motion—unraveling the neurocognitive underpinnings of embodied numerical cognition,” *Front. Psychol*, vol. 5, p. 743, 2014.

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For the latest description on NIH’s intramural efforts to explore cognition and its influences on mental health, please visit:

http://www.nimh.nih.gov/labs-at-nimh/research-areas/clinics-and-labs/lbc/index.shtml

Complementary and Integrative Medicine

Acupuncture, interactions of herbal medicines with conventional drugs, pain management, meditation, Yoga, Tai Chi and Qi Gong are among other alternative therapies whose serious inquiry is well supported by fNIRS. NIRx experts can help you plan experimental strategies best suited to explore nontraditional yet promising methods.

G. Litscher, G. Bauernfeind, X. Gao, G. Mueller-Putz, L. Wang, W. Anderle, I. Gaischek, D. Litscher, C. Neuper, and R. C. Niemtzow, “Battlefield Acupuncture and Near-Infrared Spectroscopy–Miniaturized Computer-Triggered Electrical Stimulation of Battlefield Ear Acupuncture Points and 50-Channel Near-Infrared Spectroscopic Mapping,” *Medical Acupuncture*, vol. 23, no. 4, pp. 263–270, Dec. 2011.

For latest updates on complementary and integrative health strategies, please visit

https://nccih.nih.gov

Connectivity

fNIRS brings connectivity studies to a new level. The hyperscanning modality enables both online feedback as well as offline analysis regarding within- and between-subjects connectivity. In addition to that, fNIRS fast sampling rate for hemodynamic states allows for a quick update rate of connectivity feedback, resulting into enhanced subject engagement.

S. Tak, A. M. Kempny, K. J. Friston, A. P. Leff, and W. D. Penny, "Dynamic causal modelling for functional near-infrared spectroscopy," *Neuroimage*, vol. 111, pp. 338–349, May 2015.

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R. L. Barbour, H. L. Graber, Y. Xu, Y. Pei, C. H. Schmitz, D. S. Pfeil, A. Tyagi, R. Andronica, D. C. Lee, S.-L. S. Barbour, J. D. Nichols, and M. E. Pflieger, "A programmable laboratory testbed in support of evaluation of functional brain activation and connectivity," *IEEE Trans Neural Syst Rehabil Eng*, vol. 20, no. 2, pp. 170–183, Mar. 2012.

H. Niu, S. Khadka, F. Tian, Z.-J. Lin, C. Lu, C. Zhu, and H. Liu, "Resting-state functional connectivity assessed with two diffuse optical tomographic systems," *J Biomed Opt*, vol. 16, no. 4, p. 46006, Apr. 2011.

J. Mehnert, C. Schmitz, H. E. Möller, H. Obrig, and K. Mueller, *Simultaneous optical tomography (OT) and fMRI with and without task activation*. 2010.

For a description of the Human Connectome Project, please visit:

http://www.neuroscienceblueprint.nih.gov/connectome/

Developmental Changes

The portability of fNIRS, its performance in presence of general movements and the feasibility it offers in exploring cortical responses in social environments, represent the greatest advantages for studies on brain functional changes during development of infants and children.

C. Issard and J. Gervain, “Adult-like processing of time-compressed speech by newborns: A NIRS study,” *Developmental Cognitive Neuroscience*. Oct. 2017.

M. Mücke, C. Andrä, M. Gerber, U. Pühse, and S. Ludyga, “Moderate-to-vigorous physical activity, executive functions and prefrontal brain oxygenation in children: A functional near-infrared spectroscopy study,” *Journal of Sports Sciences*, pp. 1–7, May 2017.

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For updates from Dr. Catherine Spong, acting director of NICHD, on new program initiatives including Learning Disabilities Innovation Hubs, Precision Medicine Initiative, Intellectual and Developmental Disabilities Research Centers, please visit:

https://www.nichd.nih.gov/about/overview/directors_corner/Pages/default.aspx

Emotions

Near-infrared spectroscopy is non-invasive and particularly well suited for evaluating activity in the prefrontal cortex, one of the regions involved in emotional processing. More specific areas related to emotional processing, such as the frontopolar cortex, are easily accessible for measurements by NIRS, making the technique particularly suited to explore the emotional domain.

M. Balconi, M. E. Vanutelli, and E. Grippa, "Resting state and personality component (BIS/BAS) predict the brain activity (EEG and fNIRS measure) in response to emotional cues," *Brain Behav*, p. n/a-n/a, Mar. 2017.

M. E. Vanutelli and M. Balconi, "Perceiving emotions in human-human and human-animal interactions: Hemodynamic prefrontal activity (fNIRS) and empathic concern," *Neurosci. Lett.*, vol. 605, pp. 1–6, Sep. 2015.

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M. Balconi, E. Grippa, and M. E. Vanutelli, “Resting lateralized activity predicts the cortical response and appraisal of emotions: an fNIRS study,” *Soc Cogn Affect Neurosci*, vol. 10, no. 12, pp. 1607–1614, Dec. 2015.

Event-Related Optical Signal

fNIRS is potentially the only imaging method that may be capable to measure both hemodynamics and neuronal activity. The Event-Related Optical Signal, caused by changes in light scattering from activated neurons, is observable when employing high frequency sampling with fNIRS.

X.-S. Hu, K.-S. Hong, and S. S. Ge, “Recognition of stimulus-evoked neuronal optical response by identifying chaos levels of near-infrared spectroscopy time series,” *Neurosci. Lett.*, vol. 504, no. 2, pp. 115–120, Oct. 2011.

A. V. Medvedev, J. Kainerstorfer, S. V. Borisov, R. L. Barbour, and J. VanMeter, “Event-related fast optical signal in a rapid object recognition task: improving detection by the independent component analysis,” *Brain Res.*, vol. 1236, pp. 145–158, Oct. 2008.

For an informative discussion on the various strategies of optical imaging techniques, please visit:

http://www.nibib.nih.gov/science-education/science-topics/optical-imaging;

http://www.report.nih.gov/nihfactsheets/ViewFactSheet.aspx?csid=105.

Infant Monitoring

Infant monitoring is based on continuous measurements of cortical activity within a population that may be characterized by its constant movement. The low sensitivity of fNIRS to motion artifacts make this technique an ideal choice for studies intended to explore the many unknown features of the infant brain.

C. Issard and J. Gervain, "Adult-like processing of time-compressed speech by newborns: A NIRS study," *Developmental Cognitive Neuroscience*. Oct. 2017.

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A. Galderisi, S. Brigadoi, S. Cutini, S.B. Moro, E. Lolli, F. Meconi, S. Benavides-Varela, E. Baraldi, P. Amodio, C. Cobelli, C., et al., "Long-term continuous monitoring of the preterm brain with diffuse optical tomography and electroencephalography: a technical note on cap manufacturing," Neurophoton, vol. 3, no. 4, pp. 045009–045009, 2016.
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For an informative summary of timelines for sensory, motor and psychosocial development in infants and young children, please visit:

https://www.nlm.nih.gov/medlineplus/infantandnewborndevelopment.html

Motor Execution

Motor execution and fine movements depend on coordinated action of brain function and peripheral muscles. Its portability, ease of use in natural environments, and compatibility with bioelectric measures make fNIRS an optimal choice for studies investigating motor execution.

A. C. de Lima-Pardini *et al.*, "Measuring cortical motor hemodynamics during assisted stepping ? An fNIRS feasibility study of using a walker," *Gait & Posture*, vol. 56, pp. 112–118, Jul. 2017.

M. Balconi, D. Crivelli, and L. Cortesi, "Transitive Versus Intransitive Complex Gesture Representation: A Comparison Between Execution, Observation and Imagination by fNIRS," *Applied Psychophysiology and Biofeedback*, Jun. 2017.

M. Abtahi, A. Amiri, D. Byrd, and K. Mankodiya, "Hand Motion Detection in fNIRS Neuroimaging Data," *Healthcare*, vol. 5, no. 2, p. 20, Apr. 2017.

J. B. Balardin, G. A. Z. Morais, R. A. Furucho, L. R. Trambaiolli, and J. R. Sato, "Impact of communicative head movements on the quality of functional near-infrared spectroscopy signals: negligible effects for affirmative and negative gestures and consistent artifacts related to raising eyebrows," *J. Biomed. Opt*, vol. 22, no. 4, pp. 046010–046010, 2017.

M. Balconi, L. Cortesi, and D. Crivelli, "Motor planning and performance in transitive and intransitive gesture execution and imagination: Does EEG

(RP) activity predict hemodynamic (fNIRS) response?," *Neuroscience Letters*, vol. 648, pp. 59–65, May 2017.

M. Abtahi, A. M. Amiri, D. Byrd, and K. Mankodiya, "Hand Motion Detection in fNIRS Neuroimaging Data," *Healthcare*, vol. 5, no. 2, p. 20, Apr. 2017.

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A. M. Kempny *et al.*, "Functional near infrared spectroscopy as a probe of brain function in people with prolonged disorders of consciousness," *NeuroImage: Clinical*, vol. 12, pp. 312–319, Feb. 2016.

M.-H. Lee, B.-J. Kim, and S.-W. Lee, "Quantifying movement intentions with multimodal neuroimaging for functional electrical stimulation-based rehabilitation," *Neuroreport*, vol. 27, no. 2, pp. 61–66, Jan. 2016.

D. Carius, C. Andrä, M. Clauß, P. Ragert, M. Bunk, and J. Mehnert, "Hemodynamic Response Alteration As a Function of Task Complexity and Expertise—An fNIRS Study in Jugglers," *Front. Hum. Neurosci*, p. 126, 2016.

A. P. Buccino, H. O. Keles, and A. Omurtag, "Hybrid EEG-fNIRS Asynchronous Brain-Computer Interface for Multiple Motor Tasks," *PLOS ONE*, vol. 11, no. 1, p. e0146610, Jan. 2016.

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For an informative discussion on health information related to movement disorders, please visit:

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Multi-modal

In order to render measurements more robust, information may be provided by different modalities. Many groups appreciate multi-modal applications with fNIRS. Typical combinations are fNIRS and EEG, Eye-Tracking or fMRI, but tDCS and TMS have also been applied to concurrently modulate brain activity.

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Neuroeconomics

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Pain Research

Obtaining pain indicators from brain activity can be particularly interesting when the efficiency of pain treatments is to be evaluated, or when determining pain levels from people that may not be able to verbally communicate. fNIRS in particular, is a promising tool for this area giving its portability and noninvasiveness.

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Social Interaction

The ability of fNIRS to measure two or more subjects simultaneously, enables researchers to study cortical activity in response to social interaction. This way, a new dimension is added to studies investigating topics such as empathy, competitive and cooperative tasks, mother-child interactions and truth telling.

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Somatosensory

fNIRS determines changes in hemoglobin oxygenation in the human head non-invasively, and has the advantage of being more robust to motion artifacts than fMRI. In addition, the application of fNIRS is more convenient for somatosensory research, especially when measuring patients with chronic pain, as measurements can take place on a more comfortable bench compared to the MR scanner bench.

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Speech and Language

Realistic experiments involve verbalized speech. As such, they should account for the muscle movements that are required for this process, and the eventual artifacts that these may cause. The robustness of fNIRS in the presence of muscle movements as well as its portability in comparison to other imaging techniques, render this technology a very promising tool for studying speech and language under a great variety of conditions.

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Technology Advances

Frequently, research is limited by the technologies available. Efforts towards overcoming current limits, by design of new hardware and software solutions, is therefore much appreciated. Research aiming for technological advance constantly pushes forward and creates a wide range of new possibilities to be explored by the whole scientific community.

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Traumatic Brain Injury (TBI)

fNIRS offers a practical, portable, and relatively inexpensive alternative to assess correlates of brain oxygenation. Moreover, it allows to coregister other neurophysiological and behavioral data in a “near natural” environment. Because of this, the technique is promising for the field of *clinical neurology, and indeed fNIRS has been used to detect changes in cerebral hemodynamics after severe Traumatic Brain Injury.*

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Visual Stimulation

fNIRS techniques have become increasingly popular because of their easy and safe operation, cost-efficiency, good temporal resolution, and the clear and robust results they deliver in real time. As such, fNIRS is ideal to explore visual stimulation, and indeed vision-related fNIRS research is very active.

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