fNIRS Publications by Application

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1. Alternative Medicine

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

[1] Litscher, Gerhard, 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 23(4), 263-270 (2011).

Please visit: https://nccih.nih.gov/, for latest updates on complementary and integrative health strategies.

2. Alternative Medicine

A progressive disease, ALS can leave affected individuals unable to speak or otherwise communicate. Referred to as locked-in syndrome, NIRS studies at the University of Tuebingen have produced break-through capabilities that allow affected subjects to overcome this disability and to communicate with others.

[1] G. Gallegos-Ayala, A. Furdea, K. Takano, C.A. Ruf, H. Flor, and N. Birbaumer, "Brain communication in a completely locked-in patient using bedside near-infrared spectroscopy" Neurology, May 27, 2014 82:21 1852-1853doi:10.1212/WNL.0000000000000460.

Please visit: http://www.ninds.nih.gov/disorders/amyotrophiclateralsclerosis/ALS.htm for latest updates on NINDS research and clinical trials.

3. Auditory

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

[1] Chen, Ling-Chia, P. Sandmann, J.D. Thorne, C.S. Herrmann and S. Debener, "*Association of Concurrent fNIRS and EEG Signatures in Response to Auditory and Visual Stimuli*," Brain topography: 1-16 (2015).

[2] Pollonini, Luca, C. Olds, H. Abaya, H. Bortfeld, Michael S. Beauchamp, and John S. Oghalai, "*Auditory cortex activation to natural speech and simulated cochlear implant speech measured with functional near-infrared spectroscopy*," Hearing research 309: 84-93 (2014).

[3] Santosa, Hendrik, Melissa Jiyoun Hong, and Keum-Shik Hong, "*Lateralization of music processing with noises in the auditory cortex: an fNIRS study*," Frontiers in behavioral neuroscience 8 (2014).

Please visit: http://www.nidcd.nih.gov/Pages/default.aspx, for latest updates on health information pertaining to hearing, balance, taste, smell, and speech and language development.

4. Autism Spectrum Disorder

The many facets of this disorder make collection of functional neuroimaging data particular challenging. The low sensitivity of NIRS measures to abrupt motions and the hyperscanning resources developed by NIRx provide a range of capabilities not easily accomplished with alterative technologies.

[1] S. E. Fox, J. B. Wagner, C. L. Shrock, H. Tager-Flusberg, and C. A. Nelson, "Neural Processing of Facial Identity and Emotion in Infants at High-Risk for Autism Spectrum Disorders", Front. Hum. Neurosci. 2013; 7: 89.

[2] Irani F, Platek SM, Bunce S, Ruocco AC, Chute D." Functional near infrared spectroscopy (fNIRS): an emerging neuroimaging technology with important applications for the study of brain disorders", Clin Neuropsychol. 2007 Jan;21(1):9-37.

Please visit: http://www.nichd.nih.gov/health/topics/autism/researchinfo/Pages/goals.aspx, for latest updates on research opportunities from NICHD.

5. Brain-Computer Interface (BCI)

Given its great performance in the presence of muscle movements and the possibility of setting up measurements on realistic environments, fNIRS presents itself as an optimal candidate to acquire cortical signals as reliable and representative inputs for a Brain-Computer Interface investigation.

[1] Lee, Min-Ho, Siamac Fazli, Jan Mehnert, and Seong-Whan Lee. "Subject-dependent classification for robust idle state detection using multi-modal neuroimaging and data-fusion techniques in BCI." Pattern Recognition 48, no. 8: 2725-2737 (2015).

[2] Tumanov, Kirill, R. Goebel, R Mockel, B Sorger, G. Weiss. "fNIRS-based BCI for Robot Control." Proceedings of the 2015 International Conference on Autonomous Agents and Multiagent Systems. International Foundation for Autonomous Agents and Multiagent Systems, (2015).

[3] Khan, M. Jawad, Melissa Jiyoun Hong, and Keum-Shik Hong. "Decoding of four movement directions using hybrid NIRS-EEG brain-computer interface." Frontiers in human neuroscience 8 (2014).

[4] DiStasio, Marcello M. ,and J. T. Francis, "Use of frontal lobe hemodynamics as reinforcement signals to an adaptive controller", PLoS ONE 8(7), e69541 (2013).

[5] Fazli, Siamac, J. Mehnert, J. Steinbrink, B. Blankertz. "Using NIRS as a predictor for EEG-based BCI performance." Engineering in Medicine and Biology Society (EMBC), 2012 Annual International Conference of the IEEE. IEEE, (2012).

[6] Hu, Xiao-Su, K.-S. Hong, and S.S. Ge, "fNIRS-based online deception decoding," J. Neural Engineering 9, 026012 (2012).

[7] Fazli, Siamac, J. Mehnert, J. Steinbrink, G. Curio, A. Villringer, K.R. Müller, and B. Blankertz, "Enhanced performance by a hybrid NIRS-EEG brain computer interface," NeuroImage59(1), 519-529, doi: 10.1016/j.neuroimage.2011.07.084 (2012).

[8] Waldert, Stephan, L. Tüshaus, C.P. Kaller, and C. Mehring, "fNIRS exhibits weak tuning to hand movement direction," PLoS ONE 7(11): e49266. doi:10.1371/journal.pone.0049266 (2012).

[9] Herff, Christian, F. Putze, D. Heger, C. Guan, T. Schultz, "Speaking mode recognition from functional Near Infrared Spectroscopy," Conf Proc IEEE Eng Med Biol Soc. 2012:1715-8 (2012).

[10] Gottemukkula, Vikas, R. Derakhshani, "Classification-guided Feature Selection for NIRS-based BCI," Neural Engineering (NER), 2011 5th International IEEE/EMBS Conference on. IEEE, (2011).

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; http://www.sciencedirect.com/science/article/pii/S0165027014002702, for latest updates on NIH and DARPA funded efforts for BCI funded research.

6. Brain Perfusion

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

[1] Tessari, Mirko, Anna Maria Malagoni, Maria Elena Vannini, and Paolo Zamboni, "*A novel device for non-invasive cerebral perfusion assessment*," Veins and Lymphatics 4, no. 1 (2015).

[2] Stojanovic-Radic, Jelena, Glenn Wylie, Gerald Voelbel, Nancy Chiaravalloti, and John DeLuca, "*Neuroimaging and cognition using functional near infrared spectroscopy (fNIRS) in multiple sclerosis*," Brain imaging and behavior 9, no. 2: 302-311 (2014).

[3] Habermehl, Christina, C.H. Schmitz, and J. Steinbrink, "*Contrast enhanced high-resolution diffuse optical tomography of the human brain using ICG*," Optics Express 19, 18636-18644 (2011).
Please visit: http://braininitiative.nih.gov/, for updates on the latest announcements on the NIH brain initiative: Brain Research through Advancing Innovative Neurotechnologies® (BRAIN).

7. Breast Cancer

[1] Schreiter, N.F., N. Volkwein, P. Schneider, M.H. Maurer, S.K. Piper, C.H. Schmitz, and A. Poellinger, "Optical imaging of breast cancer using hemodynamic changes induced by Valsalva maneuver," Fortschritte auf dem Gebiet der Röntgenstrahlen und der bildgebenden Verfahren 184, 358-366 (2013).

[2] Flexman, Molly L., H.K. Kim, J.E. Gunther, E. Lim, M.C. Alvarez, M.C. Alvarez, E. Desperito, K. Kalinsky, D. Hershman, and A, H. Hielscher, "Optical biomarkers for breast cancer derived from dynamic diffuse optical tomography," J. Biomedical Optics 18(9), 096012 (2013).

[3] Flexman, Molly L., M.A. Khalil, R. Al abdi, H.K. Kim, C.J. Fong, E. Desperito, D.L. Hershman, R.L. Barbour, and A.H. Hielscher, "Digital optical tomography system for dynamic breast imaging," J. Biomedical Optics 16, 076014 (2011).

[4] Al Abdi, R., H.L. Graber, Y. Xu, and R.L. Barbour, "Optomechanical imaging system for breast cancer detection," J. Optical Society of America A 28, 2473-2493 (2011).

[5] Schneider, P., S.K. Piper, C.H. Schmitz, N.F. Schreiter, N. Volkwein, L. Lüdemann, U. Malzahn, A. Poellinger, "Fast 3D near-infrared breast imaging using indocyanine green for detection and characterization of breast lesions," Fortschritte auf dem Gebiet der Röntgenstrahlen und der bildgebenden Verfahren 183, 956-963 (2011).

8. Clinical Neurology

fNIRS capabilities of constant monitoring of oxygenation, perfusion and autoregulation results on a high potential for future application of the technique on diagnosis for 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.

[1] Obrig, H, "*NIRS in clinical neurology – a 'promising' tool?*," NeuroImage 85: 535-546 (2014).
Please visit: http://www.ninds.nih.gov/disorders/clinical_trials/index.htm, for latest listing of clinical trials involving brain disorders.

9. Cognitive States

Cognitive functions and mental states can be widely explored with fNIRS since this is a portable technique that is not too sensitive to motion artifacts. Attention, working memory, decision making, among other applications may be studied in natural environments with a fast setup preparation.

[1] Stojanovic-Radic, Jelena, Glenn Wylie, Gerald Voelbel, Nancy Chiaravalloti, and John DeLuca. "*Neuroimaging and cognition using functional near infrared spectroscopy (fNIRS) in multiple sclerosis*," Brain imaging and behavior 9, no. 2: 302-311 (2014).

[2] Bogler, Carsten, J. Mehnert, J. Steinbrink, J. Haynes, "*Decoding vigilance with NIRS*," PLOS e101729 (2014).

[3] Khan, M., Melissa Jiyoun Hong, and Keum-Shik Hong, "*Decoding of four movement directions using hybrid NIRS-EEG brain-computer interface*," Frontiers in Human Neuroscience 8 (2014).

[4] Bahmueller, J., Dresler, T., Ehlis, A., Cress, U. and Nuerk, H., "*NIRS in motion – unraveling the neurocognitive underpinnings of embodied numerical cognition,"* Frontiers in Psychology, Vol. 5, 743, 1, doi: 10.3389/fpsyg.2014.00743 (2014).

[5] DiStasio, Marcello M. ,and J. T. Francis, "*Use of frontal lobe hemodynamics as reinforcement signals to an adaptive controller*", PLoS ONE 8(7), e69541 (2013).

[6] Hu, Xiao-Su, K.-S. Hong, and S.S. Ge, "*fNIRS-based online deception decoding*," J. Neural Engineering 9, 026012 (2012).

Please visit:
http://www.nimh.nih.gov/labs-at-nimh/research-areas/clinics-and-labs/lbc/index.shtml, for latest description on NIH's intramural efforts to explore cognition and its influences on mental health.

10. Connectivity

fNIRS can bring connectivity studies to a new level of applications with the hyperscanning modality, which 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, representing a higher subject engagement to the task.

[1] Holper, L., Scholkmann, F., and Seifritz, E., "*Time-frequency dynamics of the sum of intra- and extracerebral hemodynamic functional connectivity during resting-state and respiratory challenges assessed by multimodal functional near-infrared spectroscopy,"* NeuroImage 120 481-492 (2015).

[2] Tak, S., A. M. Kempny, K. J. Friston, A. P. Leff, and W. D. Penny, "*Dynamic causal modelling for functional near-infrared spectroscopy,*" NeuroImage 111: 338-349 (2015).

[3] Mehnert, Jan, A. Akhrif, S. Telkemeyer, S. Rossi, C.H. Schmitz, J. Steinbrink, I. Wartenburger, H. Obrig, and S. Neufang, "*Developmental changes in brain activation and functional connectivity during response inhibition in the early childhood brain*," Brain and Development 35(10), 894-904, doi: 10.1016/j.braindev.2012.11.006 (2013).

[4] Barbour, Randall L., 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 Transactions on Neural Systems and Rehabilitation Engineering 20, 170-183 (2012).

[5] Niu, Haijing, S. Khadk, F. Tian, Z.-J. Lin, C. Lu, C. Zhu, and H. Liu, "*Resting-state functional connectivity assessed with two diffuse optical tomographic systems*," J. Biomedical Optics 16(4); 046006 (2011).

[6] Mehnert, Jan, C. H. Schmitz, H. E. Möller, H. Obrig, and K. Müller, "*Simultaneous Optical Tomography (OT) and fMRI with and without Task Activation*," Proc. Intl. Soc. Mag. Reson. Med. 18: 1098 (2010).

Please visit: http://www.neuroscienceblueprint.nih.gov/connectome/, for description of the Human Connectome Project.

11. Developmental Changes

The portability of the technique, performance in presence of general movements and feasibility to explore cortical response to social interactions represent the greatest advantages of fNIRS towards studies on brain functional changes during development of infants and children.

[1] Mehnert, Jan, A. Akhrif, S. Telkemeyer, S. Rossi, C.H. Schmitz, J. Steinbrink, I. Wartenburger, H. Obrig, and S. Neufang, "*Developmental changes in brain activation and functional connectivity during response inhibition in the early childhood brain*," Brain and Development 35(10), 894-904 (2013).

Please visit: https://www.nichd.nih.gov/about/overview/directors_corner/Pages/default.aspx,
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 among others.

12. Emotion

Our interaction with our environment and others often determines our emotional wellbeing. Its capacity to operate in the natural environment including measures involving interactive social settings makes fNIRS a powerful new tool in our efforts to understand the many features affecting emotional states.

[1] Vanutelli, Maria Elide, and Michela Balconi. "Perceiving emotions in human–human and human–animal interactions: Hemodynamic prefrontal activity (fNIRS) and empathic concern." *Neuroscience letters* 605 (2015): 1-6. http://www.sciencedirect.com/science/article/pii/S0304394015300409,

Please visit: http://www.nimh.nih.gov/labs-at-nimh/research-areas/clinics-and-labs/edb/index.shtml, for description of the latest research updates from NIMH.

13. Epilepsy

Having notably greater image resolution and stability compared to EEG, and low sensitivity to motion artifacts, fNIRS measures can be an ideal sensing strategy for investigations aimed at identifying salient biomarkers and seizure foci.

[1] P. Pouliot, T. P. Y. Tran, V. Birca, P. Vannasing, J. Tremblay, M. Lassonde, D. K. Nguyen, "Hemodynamic changes during posterior epilepsies: An EEG-fNIRS study", Epilepsy Research Vol. 108, pgs. 883–890 (2014.

[2] D.K. Nguyen, J. Tremblay, P. Pouliot, P. Vannasing, O. Florea, L. Carmant, F. Lepore, M. Sawan, F. Lesage, M. Lassonde, "Non-invasive continuous EEG-fNIRS recording of temporal lobe seizures", Epilepsy Research, Vol. 99, pgs. 112–126 (2012).

[3] Irani F, Platek SM, Bunce S, Ruocco AC, Chute D." Functional near infrared spectroscopy (fNIRS): an emerging neuroimaging technology with important applications for the study of brain disorders", Clin Neuropsychol. 2007 Jan;21(1):9-37.
Please visit: http://www.ninds.nih.gov/disorders/epilepsy/epilepsy.htm, for information on the latest investigative and treatment strategies for assessment of epilepsy.

14. 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.

[1] Hu, Xiao-Su, K.-S. Hong, and S.S. Ge, "*Recognition of stimulus-evoked neuronal optical response by identifying chaos levels of near-infrared spectroscopy time series*," Neuroscience Letters 504, 115-120 (2011).

[2] Medvedev, A., 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 Research 1236, 145-158 (2008).

Please visit:
http://www.nibib.nih.gov/science-education/science-topics/optical-imaging;
http://www.report.nih.gov/nihfactsheets/ViewFactSheet.aspx?csid=105, for an informative discussion on the various strategies of optical imaging techniques.

15. Infant Monitoring

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

[1] Gervain, J., "*Plasticity in early language acquisition: the effects of prenatal and early childhood experience*," Current opinion in neurobiology 35: 13-20 (2015).

[2] Wilcox Teresa, Biondi Marisa. "fNIRS in the developmental sciences", WIREs Cogn Sci 2015, 6: 263-283. doi: 10.1002/wcs.1343

Please visit: https://www.nlm.nih.gov/medlineplus/infantandnewborndevelopment.html, for an informative summary of time lines for sensory, motor and psychosocial development in infants and young children.

16. Learning Disabilities

Early intervention is key to avoiding long-term adverse outcomes resulting from learning disabilities. The capacity to acquire near whole head measures with wearable systems, use in natural settings and with interacting subjects, makes fNIRS and excellent choice for investigations of the manifold factors influencing learning.

Please visit: http://www.nichd.nih.gov/health/topics/learning/Pages/default.aspx and https://www.clinicaltrials.gov/ct2/show/NCT02205268 for latest updates on research strategies and clinical trials involving learning disabilities.

17. Locked-In Syndrome

Imagine you can see, hear and think clearly but cannot move or speak. Being a consequence of disease or trauma, the 10-year survival rate of subjects with this syndrome is nearly 80% [1]. fNIRS imaging is proving to be a valuable tool in decoding thoughts from locked-in subjects, allowing them to communicate.

[1] E. Smith, "Locked-in syndrome" BMJ. 2005 Feb 19; 330(7488): 406–409.

Also see http://gocognitive.net/interviews/prevalence-locked-syndrome, for an insightful discussion with Professor Niels Birbaumer on his approaches to enable communication with locked-in subjects.

Please visit: http://www.ninds.nih.gov/disorders/lockedinsyndrome/lockedinsyndrome.htm, for latest updates on research and treatment efforts to address this debilitating syndrome.

18. Multilingual Brain

There is growing evidence that children who learn more than one language have improved long-term outcomes. NIRx systems and technologies are currently supporting a European-wide study aimed at quantifying metrics of brain function in the bilingual child.

[1] Gervain, Judit. "Plasticity in early language acquisition: the effects of prenatal and early childhood experience." *Current opinion in neurobiology* 35 (2015): 13-20.

Please visit: http://cordis.europa.eu/project/rcn/193857_en.html, for outline of this exciting use of fNIRS technology from NIRx.

Also see, http://www.nichd.nih.gov/news/releases/Pages/022315-podcast-bilingualism.aspx

19. Motor Execution

Motor execution and fine movements depend on coordinated action of brain function with peripheral muscles. Portability, use in natural environments, and compatibility with bioelectric measures make fNIRS an optimal choice for any application related to motor execution.

[1] Helmich, I., Holle, H., Rein, R., Lausberg, H., "*Brain oxygenation patterns during the execution of tool use demonstration, tool use pantomime, and body-part-as-object tool use*," International Journal of Psychophysiology, 96, 1-7 (2015).

[2] Khan, M. Jawad, Melissa Jiyoun Hong, and Keum-Shik Hong, "*Decoding of four movement directions using hybrid NIRS-EEG brain-computer interface,*" Frontiers in Human Neuroscience 8 (2014).

[3] Helmich, R., N. Niermann, and H. Lausberg, "*Hemispheric differences of motor execution: A near-infrared spectroscopy study*, "Advances in Experimental Medicine and Biology 789, 59-64 (2013).

[4] Waldert, Stephan, L. Tüshaus, C.P. Kaller, and C. Mehring, "*fNIRS exhibits weak tuning to hand movement direction*," PLoS ONE 7(11): e49266. doi:10.1371/journal.pone.0049266 (2012).

Please visit: https://www.nlm.nih.gov/medlineplus/movementdisorders.html, for an informative discussion on health information related to movement disorders.

20. Mother-Child Interactions

Most neurosensing technologies applicable to the adult, do not translate well to child studies. More challenging still are interactive environments where the aim is to appreciate subtleties of social interactions without bias. Having good performance and comfort with children and capability for live interactions, fNIRS is proving a value resource in the study of mother-child interactions.

[1] S. B. Perlman, B. Luna, T. C. Hein, and T. J. Huppert, "fNIRS evidence of prefrontal regulation of frustration in early childhood", NeuroImage, Vol. 85, pgs. 326–334 (2014)

[2] M. H. Shalinsky, I. Kovelman, M.S. Berens, L.A. Petitto, "Exploring Cognitive Functions in Babies, Children & Adults with Near Infrared Spectroscopy", J Vis Exp. vol 29, pg 1268, (2009)

Please visit: http://www.nichd.nih.gov/ncmhep/Pages/index.aspx for updates on NICHD's focus involving mother-child studies; also see related efforts involving the human placental project, http://www.nichd.nih.gov/research/HPP/Pages/default.aspx

21. Multi-modal

In order to render measurements more robust and with a great amount of information provided by different methods, many groups appreciate multi-modal applications with fNIRS. Typical modalities are EEG, Eye-Tracking and fMRI, while tDCS and TMS may also be applied to modulate brain activity.

[1] Zaidi, A., Munk, M., Schmidt, A., Risueno-Segovia, C., Bernard, R., Fetz, E., Logothetis, N., Birbaumer, N., and Sitaram, R., "*Simultaneous epidural functional Near-InfraRed Spectroscopy and cortical electrophysiology as a tool for studying local neuro-vascular coupling in primates,*" NeuroImage (2015).

[2] Chen, L., Sandmann, P., Thorne, J., Herrmann, C.. Debener, S., "*Association of Concurrent fNIRS and EEG Signatures in Response to Auditory and Visual Stimuli*," Brain Topography: 1-16 (2015).

[3] Lee, M., Fazli, S., Mehnert, J., and Lee, S., "*Subject-dependent classification for robust idle state detection using multi-modal neuroimaging and data-fusion techniques in BCI,*" Pattern Recognition 48, no. 8: 2725-2737 (2015).

[4] Kopton, I., and Kenning, P., "*Near-infrared spectroscopy (NIRS) as a new tool for neuroeconomic research,*" Frontiers in human neuroscience 8 (2014).

[5] Khan, M., Hong, M., and Hong, K., "*Decoding of four movement directions using hybrid NIRS-EEG brain-computer interface,*" Frontiers in Human Neuroscience 8, 244, 1 (2014).

[6] Nikulin, V., T. Fedele, J. Mehnert, A. Lipp, C. Noack, J. Steinbrink, G. Curio, "*Monochromatic Ultra-Slow (~ 0.1 Hz) Oscillations in the human electroencephalogram and their relation to hemodynamics,*" NeuroImage 97: 71-80 (2014).

[7] Daehne, S., F. Biessmann, F. Meinecke, J. Mehnert, S. Fazli, K. Muller, "*Integration of multivariate data streams with bandpower signals,*" Multimedia, IEEE Transactions on 15.5: 1001-1013 (2013).

[8] Fazli, S., J. Mehnert, J. Steinbrink, B. Blankertz, "*Using NIRS as a predictor for EEG-based BCI performance,*" Engineering in Medicine and Biology Society (EMBC), 2012 Annual International Conference of the IEEE. IEEE, (2012).

[9] Barbour, Randall L., 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 Transactions on Neural Systems and Rehabilitation Engineering 20, 170-183 (2012).

[10] Fazli, S., J. Mehnert, J. Steinbrink, G. Curio, A. Villringer, K.R. Müller, and B. Blankertz, "*Enhanced performance by a hybrid NIRS-EEG brain computer interface*," NeuroImage59(1), 519-529, doi: 10.1016/j.neuroimage.2011.07.084 (2012).

22. Multiple Sclerosis

Having variable long-term debilitating effects, and often affecting younger women, multiple sclerosis is a progressive autoimmune disorder involving a likely interplay between Vit-D, sunlight exposure and exposure to certain forms of childhood viral illnesses. fNIRS capacity to explore resting state and event related hemodynamic responses makes this a valuable tool in assessing the long-term effects of MS on the CNS.

[1] Stojanovic-Radic, Jelena, Glenn Wylie, Gerald Voelbel, Nancy Chiaravalloti, and John DeLuca. "Neuroimaging and cognition using functional near infrared spectroscopy (fNIRS) in multiple sclerosis." Brain imaging and behavior 9, no. 2 (2014): 302-311.

Please visit: http://www.ninds.nih.gov/disorders/multiple_sclerosis/detail_multiple_sclerosis.htm

for recent updates involving NIH funding priorities and investigative efforts for MS.

23. Naturalistic Environment

With the advent of portable and wearable solutions, in addition to the intrinsic performance in the presence of movements, functional Near-Infrared Spectroscopy is currently the ideal solution for any studies that intend to evaluate the cortical activation within environments most similar to the reality.

[1] Helmich, I., Holle, H., Rein, R., Lausberg, H., "*Brain oxygenation patterns during the execution of tool use demonstration, tool use pantomime, and body-part-as-object tool use*," International Journal of Psychophysiology, 96, 1-7 (2015).

[2] Piper, S.., A. Krueger, S. Koch, J. Mehnert, C. Habermehl, J. Steinbrink, H. Obrig, and C.H. Schmitz, "*A wearable multi-channel fNIRS system for brain imaging in freely moving subjects*," NeuroImage, 85 64-71 (2014).

[3] Bahmueller, J., Dresler, T., Ehlis, A., Cress, U. and Nuerk, H., "*NIRS in motion – unraveling the neurocognitive underpinnings of embodied numerical cognition,"* Frontiers in Psychology, Vol. 5, 743, 1, doi: 10.3389/fpsyg.2014.00743 (2014).

[4] F.C. Robertson, T.S. Douglas, and E.M. Meintjes, "Motion artifact removal for functional near infrared spectroscopy: A comparison of methods," IEEE Transactions on Biomedical Engineering 57(6), 1377-1387 (2010).

24. Neuroeconomics

One of the pillars of neuroeconomics research is based on decision making, which may be evaluated from prefrontal lobe activity given a task. Although this has been explored with fMRI in the past, the restricted environment does impose a limit to the number of applications that can be explored. fNIRS may represent a notorious improvement to the field while enabling outdoor measurements that can be combined with simultaneous Eye-Tracking measurements.

[1] Kopton, I., and Kenning, P., "*Near-infrared spectroscopy (NIRS) as a new tool for neuroeconomic research,*" Frontiers in Human Neuroscience 8, 549, 1 (2014).

25. Pain Research

Having precise pain indicators obtained from brain activity can be particularly interesting to evaluate the efficiency of pain treatments, as well as to retrieve pain levels from people that may not be able to verbally communicate it. fNIRS, in particular, is a promising tool for this area giving its portability.

[1] He, J., F. Tian, H. Liu, Y. Peng, "*Cerebrovascular responses of the rat brain to noxious stimuli as examined by functional near-infrared whole brain imaging*," J. Neurophysiology 107, 2853-2865 (2012).

26. Psychiatric Disorders

Appreciation of the biological mechanisms underpinning psychiatric disorders is a long-term aim of many investigative studies. fNIRS presents new opportunities to explore this complex and varied problem without the need for complex resources or restricted environments.

[1] A.C. Ehlis, S. Schneider, T. Dresler, and A.J.Fallgatter "Application of functional near-infrared spectroscopy in psychiatry", Neuroimage. vol 85, pgs. 478-88. (2014).

[2] S. Koike, Y. Nishimura, R. Takizawa, N. Yahata, K. Kasai, " Near-infrared spectroscopy in schizophrenia: A possible biomarker for predicting clinical outcome and treatment response", Frontiers in Psychiatry, Vol 4, Article 145 (2013).

Please visit: http://www.nimh.nih.gov/health/topics/index.shtml, for updates on investigations and treatment strategies for psychiatric disorders.

27. Social Interaction

fNIRS ability of measuring two or more subjects at the same time enables researchers to study the effects of social interaction in the cortical activity. Possible applications on this area can be empathy, competitive and cooperative tasks, mother-child interactions, truth telling, among others. Also, this field may be explored by measuring activity from an individual interacting with animals, for example.

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28. Speech and Language

Realistic experiments involving verbalized speech should naturally account for the muscles required for this process and the eventual artifacts that these may cause. fNIRS robustness 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 on a great variety of conditions.

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29. Stroke Rehabilitation

In addition to the advantages towards brain perfusion monitoring, stroke rehabilitation may benefit from fNIRS because of its portability and ease of application. These features allow for assessment during whole-body movements as well as neurofeedback methods indicators of the brain function, which may be of particular interest for training at home.

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30. Technology Advances

The most often limitation of any research study is related to the limits offered by the technologies available. The efforts towards the design of new hardware and software solutions to overcome current limits are therefore much appreciated as they constantly push the technology state of the art and create a wide range of new possibilities to be explored by the whole research community.

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32. Traumatic Brain Injury (TBI)

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33. Visual Stimulation

The intrinsic portability of the technology allied with the performance in the presence of movements makes fNIRS a promising tool to explore particular visual stimulation studies, for example concerning age-related hemodynamic changes, alcohol ingestion and, specially, brain monitoring during sleep.

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35. Yoga

The beneficial health effects of Yoga are well documented. It is shown to reduce heart rate and blood pressure, and may also help relieve anxiety and depression. Involving varied postural changes and levels of activity, the relative insensitivity of fNIRS to motion artifacts and availability of wearable systems, makes fNIRS an ideal choice for measures on subjects performing Yoga.

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Please visit: https://nccih.nih.gov/health/yoga/introduction.htm, for updates on NCCIH funding and information involving Yoga and its health benefits.