Syllabus of the course

"Introduction to Neuroimaging Techniques"

(4 ECTS**)**

Authors: Anna Shestakova, PhD (a.shestakova@hse.ru); Director of Centre for Cognition and Decision Making, National Research University Higher School of Economics.

Meeting Minute: MP Academic Council, Protocol №2.6-06/7 29/08/2019.

1. Course Description

a. Title of a Course

Introduction to Neuroimaging Techniques

b. Pre-requisites

- Calculus
- Linear Algebra
- Neuroscience

c. Course Type (compulsory, elective, optional)

Compulsory

d. Abstract

The "Introduction to Neuroimaging Techniques" course is one of the core introductory courses of the Programme that give and overview of the methodologies currently at place to study Cognition and Brain Function. Methods such as functional magnetic resonance imaging (fMRI), transcranial magnetic stimulation (TMS), Transcranial Direct Current Stimulation (tDCS) and Transcranial Alternating Current Stimulation (tACS), near-infrared spectroscopy (NIRS), and others provide us with new insights into the structure and function of the human brain along with more widely used electroencephalography (EEG). Recently, with the advent of superconductivity, a multichannel magnetoencephalography (MEG), the method that allow to record the activity of the same neural population as EEG does, came about and have been successfully applied for localizing sources in the brain. Nature and origin of electric, magnetic, NIRS, and blood-oxygen-level-dependent (BOLD) responses will be discussed throughout the course. The course is recommended for students of the Master's program who are using or going to use the advanced neuroimaging methodologies in their experimental work.

2. Learning Objectives

This course aims at familiarizing students of our program with contemporary neuroimaging methods to study brain activity non-invasively with a particular emphasis on fMRI, MEG,

multichannel EEG, TMS, tDCS, tACS, and NIRS (OI). Prior to the seminars and/or hands-on sessions on each methodology, an overview of basic principles and physics of the above-mentioned techniques and methods will be provided. The course is structured such that it will start with the lectures on essentials and basic principles of core methodologies and continues with the advanced topics of the neuroimaging techniques. World leading experts in the a.m. and other methodologies such as e.g. newly developed ontogenetic or brain-machine interfaces will be invited as well. Biomedical applications of neuroimaging will be discussed throughout the lectures with the particular focus on the brain-machine interfaces which are developed et the HSE at the CDM Centre equipped with the brain-navigated TMS and multichannel EEG.

3. Learning Outcomes

After completing the study of the "Introduction to Neuroimaging Techniques" the student should: be aware of the main spectrum of the neuroimaging techniques to non-invasively study the human brain function, understand their basic physical principles, biology, and mathematical computations underlying implementation of each of the core methodologies including electro- and magnetoencephalography (EEG/MEG), transcranial magnetic stimulation (TMS), transcranial alternating current stimulation (tACS), direct current stimulation (tDCS), near-infrared-spectroscopy (NIRS), functional magnetic resonance imaging (fMRI).

The course gives an opportunity to practice basic computational aspects of EEG and fMRI during the course seminars as well as includes laboratory visits at the HSE. The course is intertwined with the Advanced Neuroimaging Techniques where more advanced hands-on and computational practices are provided.

After completing the study of the discipline «Introduction to Neuroimaging Techniques» the student should have the following competences:

Competence	Descriptors (indicators of achievement of the result)	Educative forms and methods aimed at generation and development of the competence
The ability to reflect developed methods of activity.	The student is able to reflect developed methods of activity based on main concepts and approaches of the Neuroimaging Techniques.	Lectures and tutorials, group discussions, presentations, tests
The ability to propose a model to invent and test methods and tools of professional activity.	The student is able to propose a model to invent and test methods of the non-invasive whole-brain neuroimaging.	Lectures and tutorials, group discussions, seminars, tests
The ability to	The student is able to	Tutorials, group

Competence	Descriptors (indicators of achievement of the result)	Educative forms and methods aimed at generation and development of the competence
independently become acquainted with new research methods, to change scientific profile of activity.	independently become acquainted with new methods of the whole brain Neuroimaging Techniques.	discussions, hands-on-training, seminars.
The ability to improve and develop intelligent and cultural level, to build track of professional development and career.	The student is able to improve and develop intelligent and cultural level, to build track of professional development and career based on the knowledge of cutting-edge non-invasive Neuroimaging Techniques	Lectures, group discussions, tests, discussions of recommended literature, hands-on-training.
The ability to analyze, verify and assess the completeness of information during professional activity and work under ambiguity.	The student is able to analyze, verify and assess the completeness of information about neuroimaging methods and work under ambiguity.	Lectures, group discussions, tests, discussions of recommended literature, hands-on-training.
The ability to conduct professional (including research) activity in international environment.	The student is able to conduct professional (including research) activity in international environment regarding main concepts of noninvasive Neuroimaging Techniques.	Lectures, group discussions, colloquium, projects in mini-groups, discussions of essays.
Capability to organize independent scientific, research, consulting and applied activity on the basis of juridical and professional standards and duties.	The student is able to organize independent scientific, research, consulting and applied activity on the basis of juridical and professional standards and duties.	Lectures, group discussions, colloquium, projects in mini-groups, discussions of essays.
The ability to communicate orally and in written form in English in the frame of professional and scientific intercourse.	The student is able to discuss problems of cognitive science both orally and in written form.	group discussions, tests, quizzes
The ability to use modern IT technologies for search and processing of information, work with professional databases and net communication.	The student is able to use modern IT technologies for search and processing of information, work with professional databases and net communication to solve the Neuroimaging Techniques problems.	Tutorials, hands-on training
The ability to describe	The student is able to describe	Lectures, group

Competence	Descriptors (indicators of achievement of the result)	Educative forms and methods aimed at generation and development of the competence
problems and situations of professional activity in terms of humanitarian, economic and social sciences to solve problems which occur across sciences, in allied professional fields.	problems and situations of professional activity in terms of Neuroimaging Techniques.	discussions, tests, examinations
The ability to detect, transmit common goals in the professional and social activities.	The student is able to detect, transmit common goals in the field of the Neuroimaging Techniques .	Discussion and analysis of the results of the home task and individual work

4. Course Plan

Topics:

- Introduction to Contemporary Neuroimaging Techniques
- Essentials of electroencephalography , EEG/ Principles of EEG signal analysis/ Analyzing EEG signal
- Essentials of magnetoencephalography, MEG/principles of MEG signal analysis/ Analyzing MEG signal
- Essentials of transcranial magnetic stimulation, transcranial/principles of TMS signal analysis
- Essentials of transcranial direct-current stimulation/principles of tDCS and tACS signal analysis
- Essentials of functional magnetic resonance tomography (fMRI) / Principles of fRMI signal analysis
- Essentials of Brain-Computer Interfaces
- Essentials and Applications of Near Infrared Spectroscopy

Overview of main topics offered in the course

- Essentials of electroencephalography, EEG

What is Electroencephalogram (EEG)?

When was EEG discovered?

What is the origin of brain activity?
What are the basic EEG rhythms?
How can we measure EEG?
How can we process EEG signals?
What are the application areas of EEG?

- Essentials of magnetoencephalography, MEG

Why are pyramidal cells considered the main source of MEG signal.
Why it is not recommended to enter the MEG room with a metal spoon in a cup of tea?
Earth geomagnetic field? 10-4 (av. Milli and micro) – What is the magnetic field amplitude that is measured with the SQUID? What is the MEG signal units?
Where is Josephson junction used? In which methodology?
What is the differences between gradiometers and magnetometers?
What is the course of Primary currents Jp. What is the source of Volume currents Jv ?
What is electromagnetic induction?
Which laws are included in the system of Maxwell equations?

- Essentials of transcranial magnetic stimulation, TMS & principles of TMS signal analysis

What does r in rTMS stand for? What is n in nTMS stand for?
What does EMG stand for? How is it different from MEG? What is the difference between ERP and MEP?
Why is the TMS theory is converse to MEG?
How to calculate the Flux of magnetometer coil?
Why a 3D focusing is not possible for TMS?
What does Lenz's low define?
What happens at the axon membrane when the brain is noninvasively stimulated by the TMS?

- Essentials of functional magnetic resonance tomography (fMRI)

Basic concepts of BOLD-fMRI
Neurophysiology of BOLD response: neurovascular coupling
Limitations of BOLD-fMRI for cognitive studies

- Essentials of Near-infrared spectroscopy, NIRS or optical imaging, OI

This part of the course will be devoted to outlining a very promising yet not fully developed methodology of the so-called near-infrared spectroscopy, a subclass of optical imaging

techniques for studying the whole brain function in humans. Using near-infrared light that can penetrate biological tissue reasonably well, it has become possible to assess brain activity in human subjects through the intact skull non-invasively. After early studies employing single-site near-infrared spectroscopy, first near-infrared imaging devices are being applied successfully for low-resolution functional brain imaging. Advantages of the optical methods include biochemical specificity, a temporal resolution in the millisecond range, the potential of measuring intracellular and intravascular events simultaneously and the portability of the devices enabling bedside examinations.

5. Reading List

a. Required

EEG-MEG Riitta Hari, Aina Puce MEG-EEG Primer Oxford University Press/2017 ISBN-13: 978-0190497774 ISBN-10: 0190497777
e-copy (in the HSE library)
MEG Risto J. Ilmoniemi, Jukka Sarvas
Brain Signals Physics and Mathematics of MEG and EEG
MIT Press/2019 SBN-13: 978-026203982 ISBN-10: 0262039826

TMS Probing Cortical Excitability with Transcranial Magnetic Stimulation Dubravko Kičić October, 2009 Overview in PDF format (ISBN 978-952-248-057-6) [12797 KB] Dissertation is also available in print (ISBN 978-952-248-056-9)http://lib.tkk.fi/Diss/2009/isbn9789522480576/

tDCS Noninvasive Human Brain Stimulation Timothy Wagner, Antoni Valero-Cabre, and Alvaro Pascual-Leone Annu. Rev. Biomed. Eng. 2007. 9:527–65
First published online as a Review in Advance on April 19, 2007 The Annual Review of Biomedical Engineering is online at bioeng.annualreviews.org doi: 10.1146/annurev.bioeng.9.061206.133100

NIRS Arno Villringer and Britton Chance. Trends Neurosci 1997 20, 435–442
Non-invasive optical spectroscopy and imaging of human brain function

b. Optional

EEG/MEG Hämäläinen, Matti et al. ' Magnetoencephalography—theory, instrumentation, and applications to noninvasive studies of the working human

brain'. Reviews of Modern Physics 65.2 (1993): 413-497. DOI: 10.1103/revmodphys.65.413

FMRI · Huettel, Song, McCarthy (eds) Functional magnetic resonance imaging. Sinauer 2004

Logothetis NK (2008) What we can do and what we cannot do with fMRI. Nature 453:869–878.

TMS 3. Bestmann, Sven. 'The Physiological Basis Of Transcranial Magnetic Stimulation'. Trends in Cognitive Sciences 12.3 (2008): 81-83. DOI: 10.1016/j.tics.2007.12.002

6. Grading System

	Type of work	Characteristics	
		#	
Type of grading	Seminar performance (20) (P)	36	
	Midterm test 1 (MT1)	1	Written test
	Midterm test 2 (MT2)	1	Written test
	Final exam (FE)	1	Written exam
Final	Grade formula, M-mark	$M_{cumulative} = 0.3*M_p + 0.3*M_{mte1} + 0.3*M_{mte2}$ $M_{final} = 0.7M_{cumulative} + 0.3*M_{FE}$	

7. Guidelines for Knowledge Assessment

Overall assessment consists of classwork and homework. Students have to demonstrate their knowledge in each lecture topic concerning its fundamental aspects: from biological to mathematical, from psychological to physical. The topics are connected through the discipline and have increasing complexity.

Intermediate assessment is given in the form of two midterm exams in written. Students have to demonstrate knowledge of the main concepts and facts taught during the corresponding module. The facts for answers can be retrieved from the class materials as well as from the recommended literature. The examples of the questions are provided before the examination, e.g. during the seminars.
Final assessment is in the form of the final exam in written. Students have to demonstrate an ability to integrate the knowledge obtained in both modules.

The grade formula:

Midterm exam (M_{TE}) will be held in written and may be organized in the form of a multi-choice questions with a unique set of (from 10 to 20) questions for each participant, the average mark will be given for each exam.

Final exams (M_{FE}) will be also held in written and may contain both multi- choice questions and open question.

Participation (**Mp**) estimated based on the Number of attended lectures and seminars

Final course mark (M_{final}) *is obtained from the following formula*:

$$M_{cumulative} = 0.2*M_p + 0.4*M_{mte1} + 0.4*M_{mte2}$$

$$M_{final} = 0.6M_{cumulative} + 0.4*M_{FE}$$

The grades are rounded in favour of examiner/lecturer with respect to regularity of class. All grades, having a fractional part greater than 0.5, are rounded up.

Table of grade accordance:

Ten-point Grading Scale	**Five-point Grading Scale**	
1 - very bad 2 – bad 3 – no pass	Unsatisfactory - 2	**FAIL**
4 – pass 5 – highly pass	Satisfactory – 3	**PASS**
6 – good 7 – very good	Good – 4	
8 – almost excellent 9 – excellent 10 – perfect	Excellent – 5	

8. Methods of Instruction

The following educational technologies are used in the study process:

- Lectures involving continuous use of multimedia presentations, demonstrations and movies.
- Self-study of required readings
- Hands-on trainings and presentation of practical aspects of applying methodologies
- Discussion and analysis of topics in the group;

9. Special Equipment and Software Support (if required)

The course requires a laptop, projector, and acoustic systems to give lectures and the computer class with the MatLab and SPM to give hands-on classes.