Neurosciences
Research Master Human Movement Sciences,
Exam 2012-2013

Notes:
- Provide your answers for the parts I, II, III on separate answer sheets.
- Please fill in your name and student number on each answer sheet.

Success!

Dick Stegeman
Coordinator

RM NEUROSCIENCES

Part I (20 points)

Question I.1
If subjects perform a steady precision grip (e.g., a constant, finite, isometric pinch force between index finger and thumb), one can find a specific characteristic in the spectral power of the encephalographic signals.

a) Within which frequency band and in which cortical area is this power most significant?
(2 points)

b) Once the subject starts moving, the power spectrum at the location alters. How does it look like now?
(2 points)

c) When the movement stops again, one finds another change. Again, describe what changes in the spectral power. And, what is the common idea about the functional relevance of this change?
(2 points)

Question I.2
When tackling neural activity mathematically, one may start with an (over)simplified model, namely the leaky integrate-and-fire (LIF) neuron.

a) Draw or explain in brief what the LIF model predicts as neural response to a single pulse-like input current if the membrane potential does just not reach threshold.
(2 points)

b) Suppose there is not a single input pulse but a sequence of them, i.e. a pulse train. Consider the case that the pulses all have the same amplitude as in a) and come at a fixed rate. Describe how the LIF response changes as a function of this rate?
(4 points)

Question I.3
The Kuramoto-model for phase oscillators reads

$$\dot{\phi}_j = \omega_j + \frac{\kappa}{N}\sum_{k=1}^{N}\sin\left(\phi_k - \phi_j\right)$$

which may yield synchronization, or better phase locking, between oscillatory units provided the coupling parameter κ exceeds a critical value κ_c. This phase locking can be viewed as generalization of coinciding neural activity, i.e. simultaneous spikes.

a) What is here the measure for synchronization, i.e. how can phase locking be assessed mathematically?
(4 points)

b) Given an example for a neural unit that may serve as generators for these phase oscillators?
(2 points)

c) Give an explicit example of a neuropathology for which the Kuramoto model provides a proper, yet qualitative description. Motivate your choice.
(2 points)

Part II (20 points)

Question II.1

Transcranial magnetic stimulation (TMS) can be used in essentially two different ways, (i) to measure and (ii) to modulate brain functions. Both single pulse TMS and repetitive TMS can be used for the second option, so to change or disrupt the function of a certain cortical area.

a) Which type of TMS can be used and how when a researcher wants to know precisely in time *when* a subject uses his/her supplementary motor area as part of a sequence of brain activities to perform a certain fast movement? Explain your answer. *(2 points)*

b) Also sketch an experiment in which TMS is used for the question *whether* the cerebellum is participating in a walking task of patients with Parkinson's disease? Explain your answer. *(2 points)*

For each of the two above goals also functional brain imaging techniques can be considered.

c) Which one for "when" and which one for "whether"? Explain your answer. *(2 points)*

Question II.2

MRI is used for different purposes. One is to make structural images.

a) Explain how the position and the density of a certain group of spinning H+ atoms can be identified with an MRI scanner. *(2 points)*

To differentiate between tissues, it is not only the H^+ density that makes one tissue type different from another one on an MRI scan. Also the so-called T1 and T2 time constants play a role.

b) Explain the background and the use of these time constants. *(4 points)*

It is also possible to measure increased local neural activity with functional MRI (fMRI).

d) Explain on which principle fMRI is based and why this technique is relatively slow and indirect. *(2 points)*

c) The intrinsic slowness of fMRI gives overlapping responses when successive neural events follow each other (too) frequently. A signal processing technique, called deconvolution, can circumvent this problem only when two basic assumptions are valid. Which two assumptions? *(2points)*

Question II.3

It is possible to determine nerve conduction both of peripheral sensory nerves and of peripheral motor nerves. The median nerve towards the hand is a mixed nerve, containing both sensory nerve fibres and motor nerve fibres. By stimulating that nerve at a certain position along the wrist, one stimulates both types of fibres simultaneously.

a) Describe how the clinician still can make a distinction between the two fibre types? *(2 points)*

EEG signals have a relevant frequency content starting below 1 Hz. EMG signals are not relevant below approximately 5Hz.

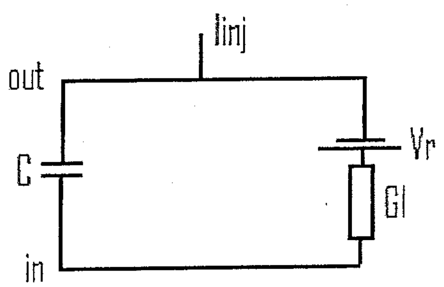
b) Why are EEG signals mostly measured by Ag/AgCl electrodes that need much maintenance, while EMG signals can be measured by simpler metal electrodes. *(2 points)*

Part III (20 points)

Important remark:

Below you will find three questions.
You should answer only two of them, namely either
Questions III.1 and III.2 or
Questions III.1 and III.3.
You are free to choose between these alternatives.
So, do not answer both questions III.2 and III.3, because only one of those two will be graded.

Question III.1



An experimenter injects electric current into a space clamped neuron. A sinusoidal current of angular frequency ω is used. The experimenter very slowly increases the strength of the injected current until the neuron spikes.

a. Write down the cable equation for this experimental situation (including the injected current). *(2 points)*

The neuron's membrane will respond linearly to the injected current, as long as the neuron does not start spiking.

b. Find an expression for the dependence of the amplitude of the injected current at the spiking threshold on the frequency and the time constant associated with the neuron's membrane. *(3 points)*

c. From the answer in b., or using the equivalent electric circuit, determine what type of filter (i.e. low-pass, high-pass, or band-pass) the neuronal membrane constitutes. *(2 points)*

d. Given that the time constant equals the product of membrane resistance and membrane capacitance, determine how the cut-off frequency (or frequencies) depends on the size of the neuron? *(3 points)*

Question III.2
If you chose to answer this question, you should not answer Question III.3!

We have described three different learning mechanisms in this course: sensitization, habituation and conditioning.

a. For each of these mechanisms describe the underlying mechanisms. Describe the time scales and strength of the learning effects. *(5 points)*
b. If you would have to build an artificial neural network that shows all these three types of learning, how would you incorporate these different learning mechanisms in the network? Is this possible without feedback? *(5 points)*

Question III.3
If you chose to answer this question, you should not answer Question III.2!

Many commercial EEG devices have a setting where the surface Laplacian of the potential field at the scalp is used (the so-called "source derivation").

In this setting, the signal at each electrode is not compared to a single reference system, but instead is compared to the signal at neighboring electrodes, in such a way that the resultant source derivation signal at electrode k closely resembles the 2nd spatial derivative over the scalp surface at the position of electrode k:

$$\hat{V}(x,y,t)\Big|_k = \frac{d^2}{dx^2}V(x,y,t)\Big|_k + \frac{d^2}{dy^2}V(x,y,t)\Big|_k$$

Where V(x,y,t) is the potential at the scalp surface, x and y are orthogonal directions along the scalp surface, t is time and "$a|_k$" is a shorthand notation for the value of "a" at the position of the EEG electrode labeled k.

So the above expression would read:
"the source derivation at the location of EEG electrode k is ideally defined as the sum of the second (partial) derivative to x of the potential at the location of EEG electrode k and the second (partial) derivative to y of the potential at the location of EEG electrode k".

a. Assuming that the head may be modeled as a homogeneous volume conductor, and that the underlying activity can be modeled by a single dipole that is <u>radial</u> to the scalp surface and pointing towards the surface, sketch the iso-potential lines (lines connecting points of equal electric potential) at the scalp surface overlying the source. Also sketch how the potential, and the first and second spatial derivatives vary over a straight line through the position where the potential profile is maximal. Indicate where the source derivation would be maximal. (You are not required to find a mathematical expression). *(1 points)*
b. Assuming that the head may be modeled by a homogeneous volume conductor and that the underlying activity can be modeled by a single dipole that is <u>tangential</u> to the scalp surface, sketch the iso-potential lines at the scalp surface overlying the source. On the straight line connecting the locations where the minimum and maximum potential are observed, sketch how the potential and the first and second spatial derivatives

vary. Indicate where the source derivation would be maximal. (Again you are not required to give a mathematical expression). *(2 points)*

c. The use of the surface Laplacian derivation is often motivated by the basic equation that describes the forward problem in EEG research:

$\nabla \cdot \sigma \nabla V = -\nabla \cdot \vec{j}^{\,i}$

which may also be written more explicitly, using matrix notation, as:

$$\begin{pmatrix} \frac{d}{dx} & \frac{d}{dy} & \frac{d}{dz} \end{pmatrix} \cdot \sigma \begin{pmatrix} \frac{d}{dx} \\ \frac{d}{dy} \\ \frac{d}{dz} \end{pmatrix} V(x,y,z) = -\begin{pmatrix} \frac{d}{dx} \\ \frac{d}{dy} \\ \frac{d}{dz} \end{pmatrix} \begin{pmatrix} j_x^i & j_y^i & j_z^i \end{pmatrix}$$

What is the physical interpretation of this equation? *(2 points)*

d. Explain why the surface Laplacian indeed would resemble the underlying source density, if the conductivity would be a constant scalar property σ as in the equation. (Hint: what current flows in the z-direction?)
Is this also true in your sketches from the questions III3a. and III3b.? *(3 points)*

e. Why does the source derivation signal have more noise than the original EEG recording? *(2 points)*