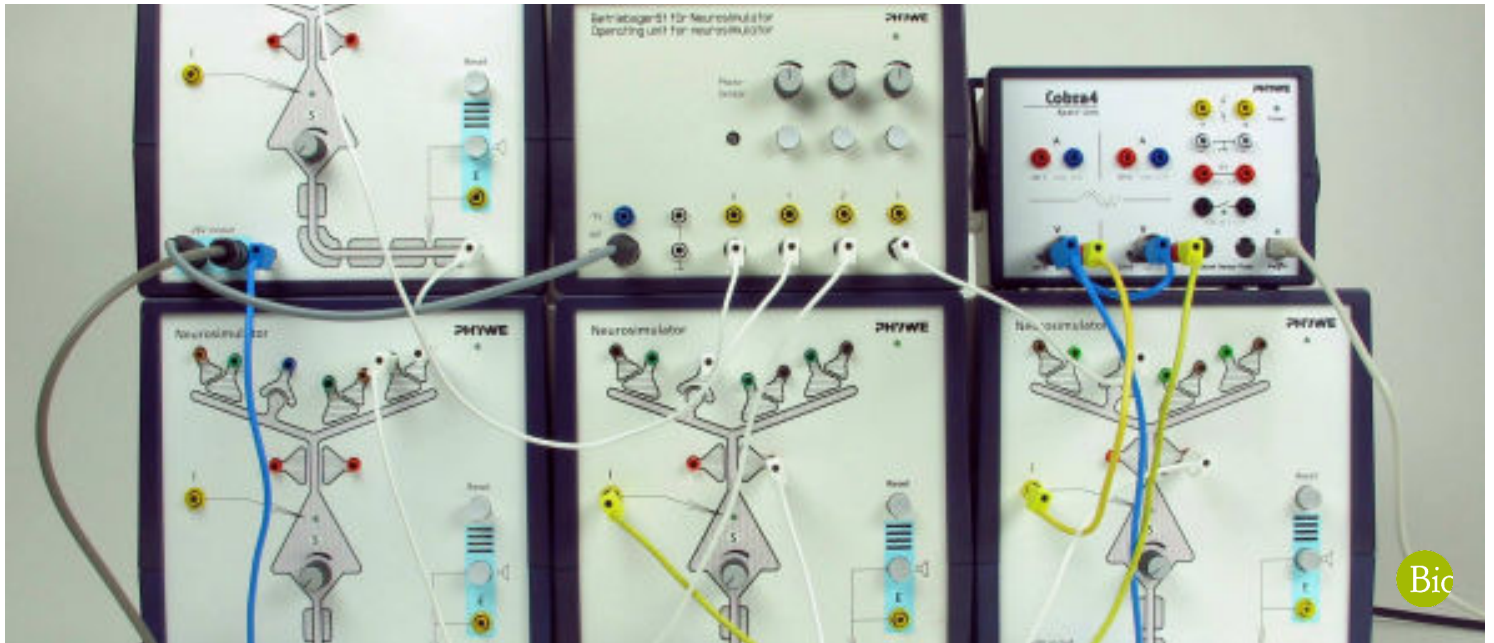# Neural networks with Cobra4 Xpert-Link

The neuron unit Neurosimulator simulates a generalised nerve cell with an apical dendrite and its synaptic contacts, a cell body (soma) and a nerve fibre(axon) with myelin sheathes and a Ranvier's ring.

Biology	Nervous system, neurobiology		
Difficulty level	**Group size**	**Preparation time**	**Execution time**
hard	2	10 minutes	45+ minutes

PHYWE
excellence in science

General information

Application

PHYWE
excellence in science
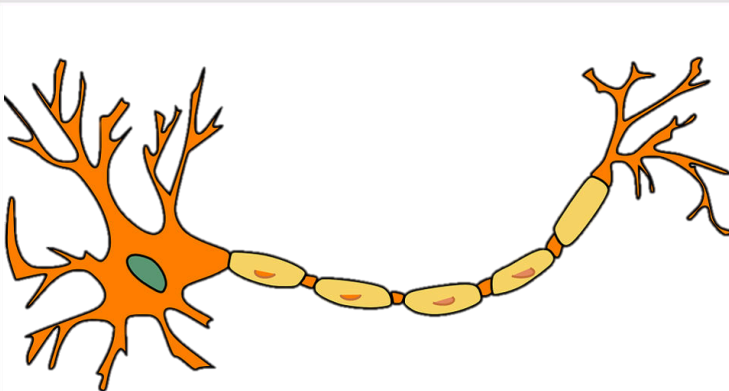
schematic representation of a neuron

The main structural and functional unit of the nervous system is the nerve cell, also known as a neuron. They are primarily involved in the process of transmitting and receiving information from and to the brain. Neurons transfer various messages from the different parts of the body to the brain and the neck. Although they have a lot in common with other cell types, they differ in particular in their function and structure.

A human body consists of billions of nerve cells. Their shape, size and structure depend on the localization and function in the body. But in general all human body neurons have three parts: a cell body, an axon, and dendrites.

Other information (1/4)

PHYWE
excellence in science

Prior knowledge

It is very usefull to perform the experiments "The nerve cell with Cobra4 Xpert-Link" (P4010764) and "Nerve cell interactions with Cobra4 Xpert-Link" (P4010864) first.

Scientific principle

Teaching system for conducting experiments on the topics of nerve cells, nerve cell interactions and neural networks.

Other information (2/4)

PHYWE
excellence in science

Learning objective

Students are familiarized with the functioning of a nerve cell by using the neuron unit Neurosimulator which simulates a generalised nerve cell with an apical dendrite and its synaptic contacts, a cell body (soma) and a nerve fibre (axon) with myelin sheaths and a Ranvier's ring.

Tasks

The experiment consists of 6 different subexperiments, which can be carried out independently of each other:

Transient (phasic) responses: focus on visual sense, Neuronal oscillator (body clock), Rotating excitation (short-term memory), Cerebral cortex and sensoric learning, Direction selectivity by unilateral inhibition and Self-calibration of paired sensory channels.

Other information (3/4)

PHYWE
excellence in science

The operating unit comprises the power supply of up to four neuron units, three touch simulators with a variable stimulating intensity and an optic sensor. The Cobra4 Xpert-Link is the perfect measurement device for all experiments. Up to 4 values can be measured: 2 values using the two internal voltage channels and 2 values via the Cobra4 Sensor Ports. (To use the sensor ports, a Cobra4 Sensor-Unit Electricity (12644-00) and a Cobra4 Xpert-Connect (12625-01) for each sensor port are needed additionally.)

Other information (4/4)

PHYWE
excellence in science

- The dendrite comprises exciting, inhibiting, presynaptic and Hebbian synapses which are marked by the corresponding colours of the sockets.

- Here the axons end in presynaptic buttons.These are represented together with a part of the (afferent) fibre providing the signal.

- The connection between the (efferent) axon of a neuron unit which leads away or the stimulus output socket of the operating unit and a synapse is established by means of a white cable which is inserted into the desired synapse socket.

- The yellow sockets serve for the derivation of the state of excitement of the simulated neuron. They must be connected to suitable measuring instruments (e.g.oscilloscope) or a computer interface.

- The action potentials can be made audible with the aid of the integrated acoustic monitor.

- The turning knob "S" serves for setting the "firingthreshold" of the neuron.

Safety instructions

PHYWE
excellence in science

The general instructions for safe experimentation in science lessons apply to this experiment.

Equipment

Position	Material	Item No.	Quantity
1	Neuro-simulator, power supply	65963-93	1
2	Neuro-simulator	65963-00	4
3	Cobra4 Xpert-Link	12625-99	1
4	Adapter, BNC male/4 mm female pair	07542-26	2
5	Connecting cord, 32 A, 250 mm, black	07360-05	1

Theory 1

PHYWE
excellence in science

Transient (phasic) responses: focus on visual sense

One type of neurons reacts only to stimulation changes, not ongoing stimulations. These are called ON and OFF neurons. They only respond to the start and/or disappearance of a stimulus with an activation that is mostly brief, and the more intense the stronger the stimulus change. These two types of neurons act on other neurons, e.g. on ganglion neurons of the visual sense system. In addition, such neurons can be found in the touch and olfactory sense systems. The circuit in this experiment – an example in the visual system – can be used to show the circuitry of the retinal ganglion cells with amacrine cells. In the retina, visual cells come into contact with bipolar cells, of which mostly several are connected to one ganglion cell at a time. In addition, the visual cells are interconnected with each other via horizontal cells and the ganglion cells via the amacrine cells. Each nerve cell so receives signals from several sense cells, and each sense cell leads signals to several nerve cells. Receptor potential builds up on the bipolar, horizontal and amacrine cells, but action potentials are first formed on the ganglion cells.

PHYWE
excellence in science

Setup and procedure

Setup 1.1

PHYWE
excellence in science

Connect the Xpert-Link to the PC.

1. Transient responses

- The experiment is set up as per Fig.1.

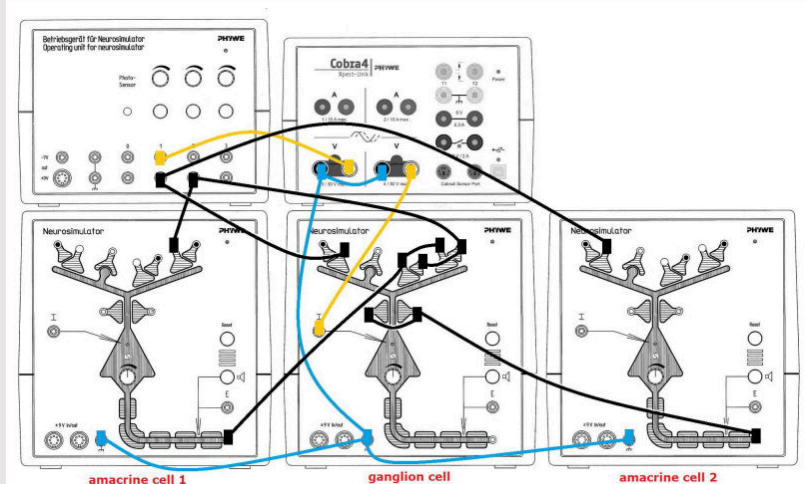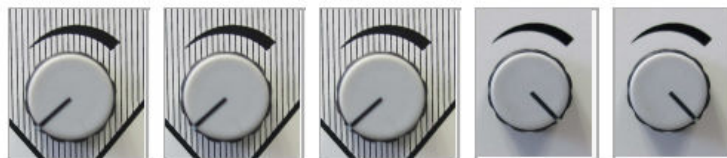- Two BNC-adapters (plug/socket 4 mm) are needed for voltage measurement.

Figure 1

Setup 1.2

PHYWE
excellence in science

- Neurosimulator 1, knob threshold: 0%

- Neurosimulator 2, knob threshold: 0%

- Neurosimulator 3, knob threshold: 0%

- Operating unit, knob stimulation intensity 1 (stimulus for ON): 100%

- Operating unit, knob stimulation intensity 2 (stimulus for OFF): 100%

Procedure 1

PHYWE
excellence in science
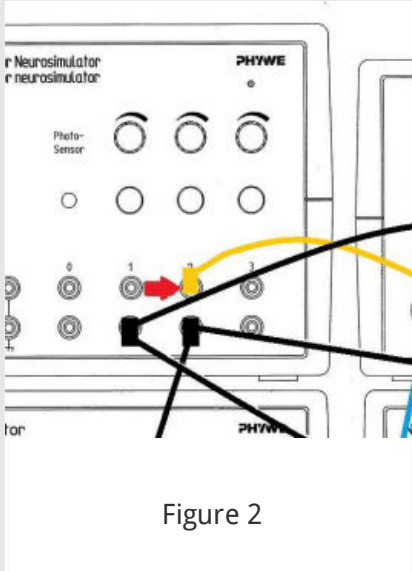
Figure 2

- ○ Start measurement in the measurement window.

- ○ Press the stimulation button 1 for approximately 5 seconds. Wait until the voltage has reached the initial value.

- ○ Plug the yellow cable into the black socket of channel 2 (red arrow, Fig. 2).

- ○ Press the stimulation button 2 for approximately 5 seconds. Wait until the voltage has reached the initial value.

- ○ Press the stimulation buttons 1 and 2 for approximately 5 seconds. Wait until the voltage has reached the initial value.

- ○ Finish the measurement as soon as the voltage has reached the initial value. Save and evaluate the results.

PHYWE
excellence in science

Evaluation

Results 1

PHYWE
excellence in science
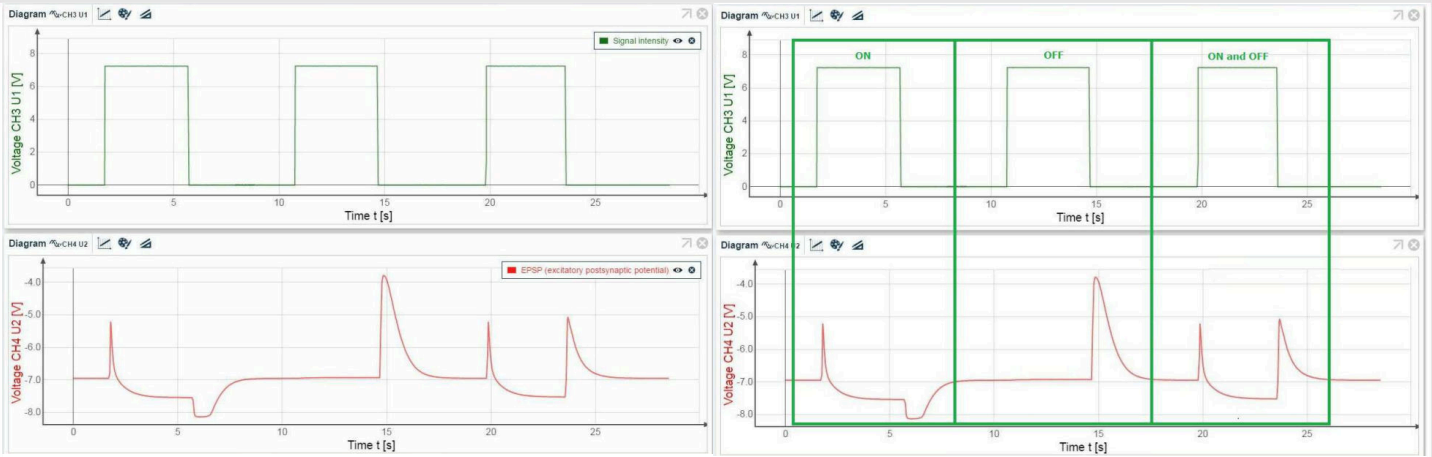
Figure 3

Theory 2

PHYWE
excellence in science

Neuronal oscillator (body clock)

Many animal and human modes of behavior exhibit rhythmic characteristics. The periodicity of such rhythmicity that is created in the central nervous system can extend over months (e.g. seasonal rhythm), days (e.g. hormonal rhythm), hours (e.g. sleep wake cycle) or seconds (e.g. the rhythmic movement of many animals). In each case, neural oscillators are necessary as timing generator for such behavior. The circuit example shows how individual neurons can be brought to oscillating behavior when grouped. The rhythmic behavior of this neural network is based on the time-delayed negative feedback across a veto synapse. Through this, the input signal is switched off at regular time intervals. Because of the membrane time constant of the neuronal module (due to its capacitative properties), there is not an abrupt signal drop-off. With a time delay that is essentially determined by the signal strength, the small excitement at the veto synapse also again leads to such a small inhibition that the stimulation signal can again be effective. I.e. the inhibition at the veto synapse becomes so weak after some time of increasing inhibitory strength that it cannot inhibit the excitatory synapse any more.

Setup and procedure

Setup 2.1

Connect the Xpert-Link to the PC.

1. Transient responses

- The experiment is set up as per Fig.4.

- Two BNC-adapters (plug/socket 4 mm) are needed for voltage measurement.
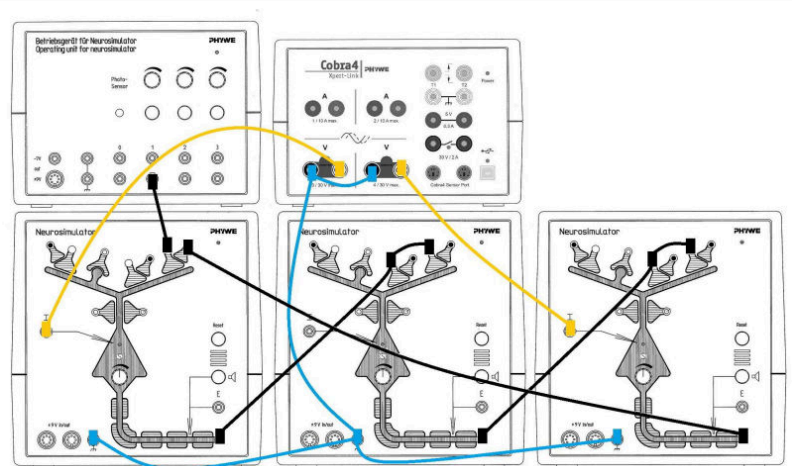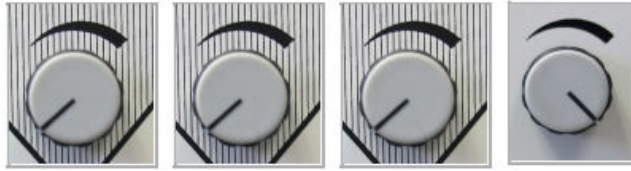

Figure 4

Setup 2.2

PHYWE
excellence in science

- Neurosimulator 1, knob threshold: 0%

- Neurosimulator 2, knob threshold: 0%

- Neurosimulator 3, knob threshold: 0%

- Operating unit, knob stimulation intensity 1: 100%
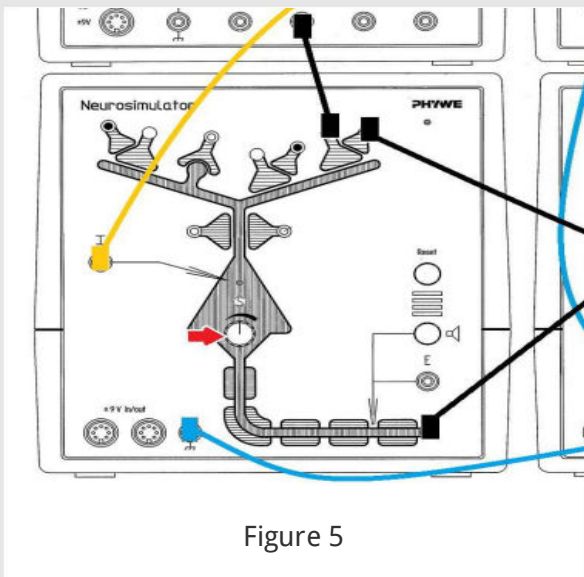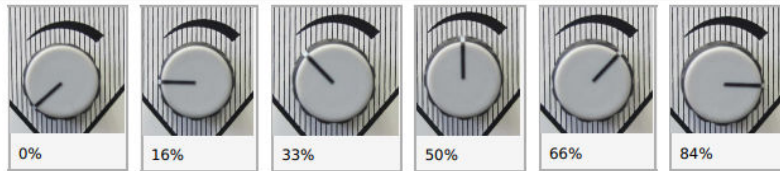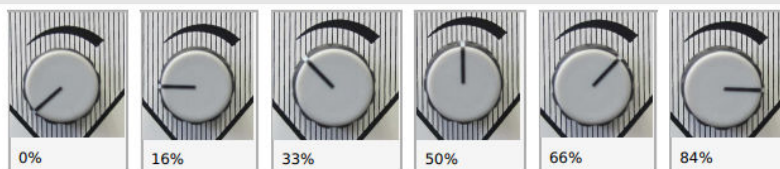
Procedure 2.1

PHYWE
excellence in science

Figure 5

- Start measurement in the measurement window.

- Press the stimulation button 1 for approximately 15 seconds.

- Finish the measurement as soon as the voltage has reached the initial value.

- Save and evaluate the results.

2. Transient responses with different threshold on Neurosimulator 1

- Change the oscillation by different settings of the threshold knob on Neurosimulator 1 (Fig. 5).

Procedure 2.2

PHYWE
excellence in science

○ Start measurement in the measurement window.

○ Start with threshold knob on 0%. Press the stimulation button 1 for approximately 5 seconds. Wait until the voltage has reached the initial value.

○ Turn the threshold knob on 16%. Press the stimulation button 1 for approximately 5 seconds. Wait until the voltage has reached the initial value.

○ Turn the threshold knob on 33%. Press the stimulation button 1 for approximately 5 seconds. Wait until the voltage has reached the initial value.

Procedure 2.3

PHYWE
excellence in science

○ Turn the threshold knob on 50%. Press the stimulation button 1 for approximately 5 seconds. Wait until the voltage has reached the initial value.

○ Turn the threshold knob on 66%. Press the stimulation button 1 for approximately 5 seconds. Wait until the voltage has reached the initial value.

○ Turn the threshold knob on 84%. Press the stimulation button 1 for approximately 5 seconds. Wait until the voltage has reached the initial value.

○ Finish the measurement, save and evaluate the results.
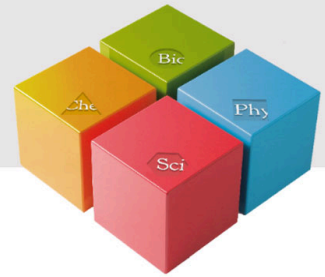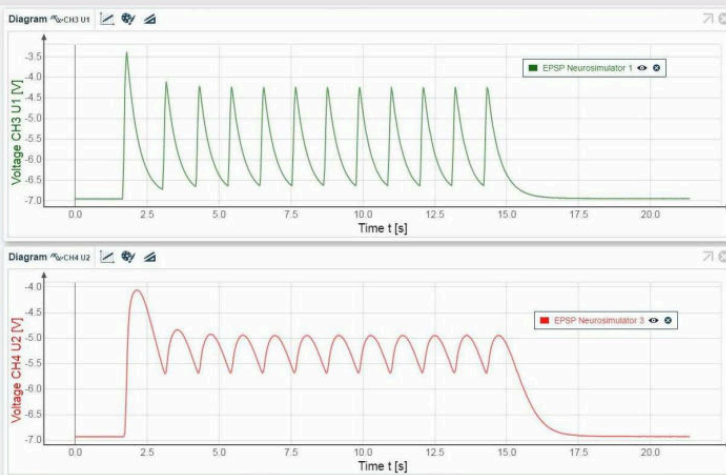
Evaluation

Results 2
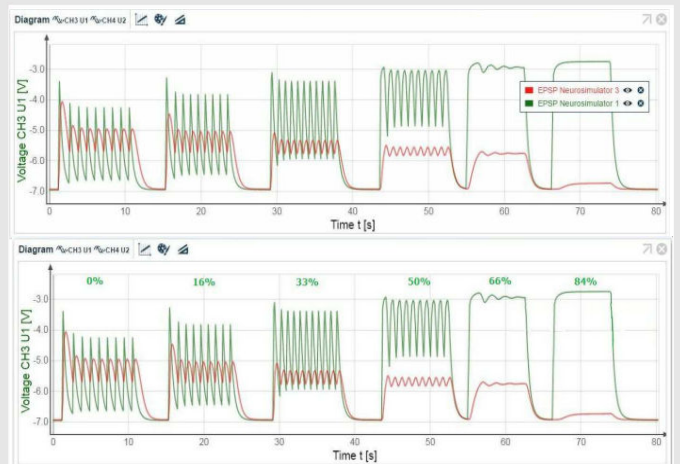

Figure 6: Transient responses

Figure 7: Transient responses with different threshold on Neurosimulator 1

Theory 3

PHYWE
excellence in science

Rotating excitation (short-term memory)

This self-preserving excitation within a neural network is exemplary for short-term memory, because a stimulus is retained for some time within this network. Neurosimulators 1 (on the left) and 2 (in the middle) form a positive feedback loop, i.e. once a short stimulus has been inititated, the signal keeps being transmitted. The third Neurosimulator (on the right) acts as an inhibiting interneuron for Neurosimulator 2. This setup permits studying several variations, by changing stimulus intensity and threshold levels of neurons 1 or 2 and the inhibiting interneuron.

PHYWE
excellence in science

Setup and procedure

Setup 3.1

PHYWE
excellence in science

Notes: Each person presses the button specificly. To get similar signal duration, all parts of this experiment should be performed by the same person.

1. Rotating excitation variation: variation of stimulus duration

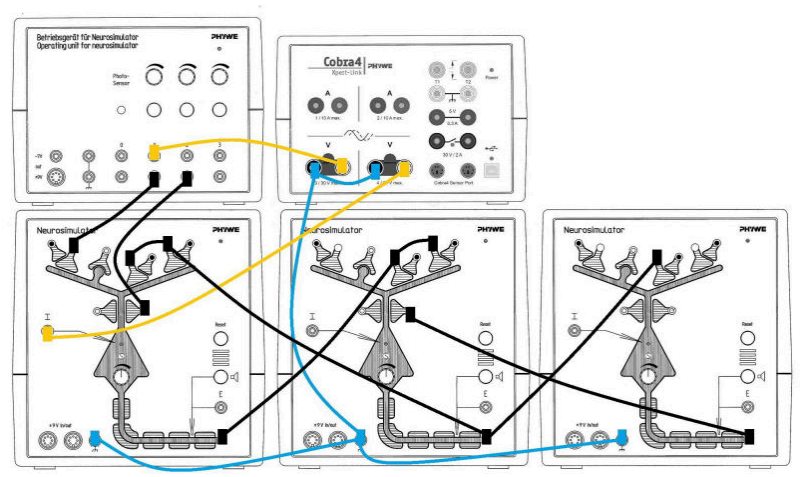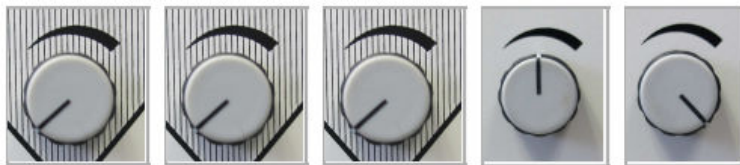- The experiment is set up as per Fig. 8. Two BNC-adapters (plug/socket 4 mm) are needed for voltage measurement.

Figure 8

Setup 3.2

PHYWE
excellence in science

- Neurosimulator 1, knob threshold: 0%

- Neurosimulator 2, knob threshold: 0%

- Neurosimulator 3, knob threshold: 0%

- Operating unit, knob stimulation intensity 1: 50%

- Operating unit, knob stimulation intensity 2: 100%

Procedure 3.1

PHYWE
excellence in science

1.1. Convulsive excitation

○ Start measurement in the measurement window.

○ Press the stimulation button 1 approximately one second.

○ Finish the measurement as soon as the voltage has reached the initial value.

○ Stop the convulsive excitation by pressing the stimulation button 2. Save and evaluate the results.

1.2. Dampening Start measurement in the measurement window.

○ Press the stimulation button 1 less than a second (very short tap, like on a hot stove).

○ Finish the measurement as soon as the voltage has reached the initial value. Save and evaluate the results.

Procedure 3.2

PHYWE
excellence in science

2. Rotating excitation variation: variation of stimulus intensity

○ Start measurement in the measurement window.

○ Press the stimulation button 1 less than a second (very short tap, like on a hot stove).

○ Finish the measurement as soon as the voltage has reached the initial value. Save the results.

○ Repeat the measurement several times. Change minimal the signal intensity for each mesurement: turn minimal the knob for stimulation intensity 1, both directions are possible. Aim is to get diagrams with convulsive excitation and with dampening.

○ Save every time the results and evaluate them. Before each measurement stop the convulsive excitation by pressing the stimulation button 2.

Procedure 3.3

PHYWE
excellence in science

Figure 9
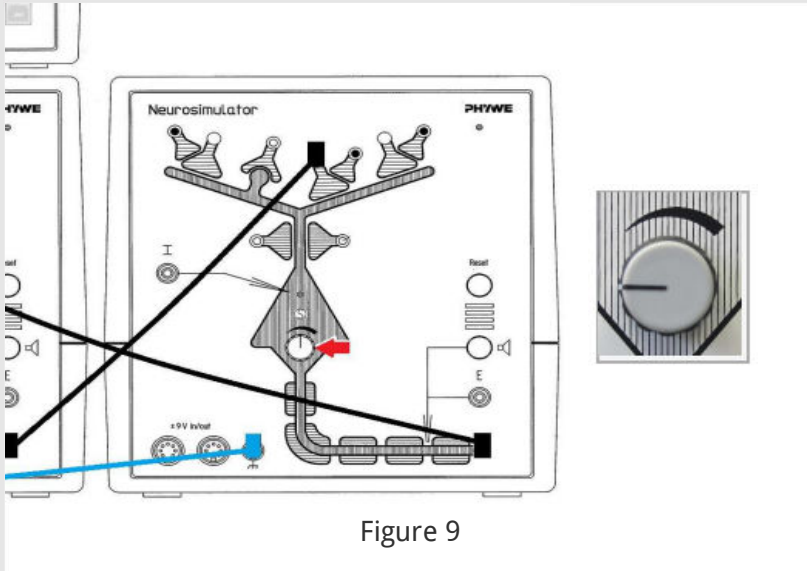
3. Rotating excitation variation: variation of threshold, equilibrium

- Change settings of the threshold knob at the Neurosimulator 3 on 16% (Fig. 9). Neurosimulator 3 is equivalent to inhibitory neuron.

PHYWE
excellence in science

Evaluation

Results 3.1

PHYWE
excellence in science

1. Rotating excitation variation: variation of stimulus duration

1.1 Convulsive excitation

○ Figure 10 and Figure 11 show the first example for convulsive excitation.
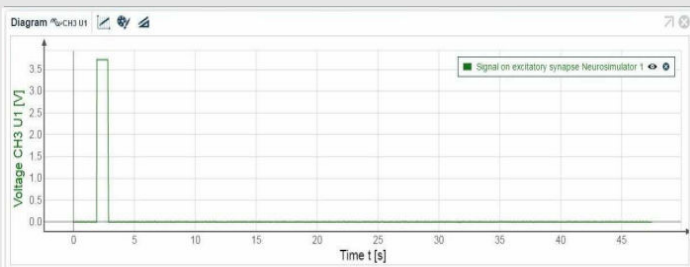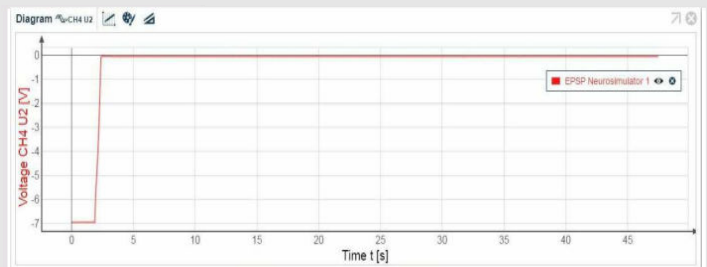
Figure 10

Figure 11

Results 3.2

PHYWE
excellence in science

1. Rotating excitation variation: variation of stimulus duration

1.1 Convulsive excitation

○ Figure 12 and Figure 13 show the second example for convulsive excitation.
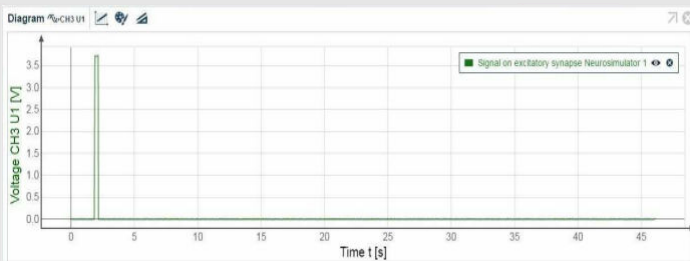
Figure 12

Figure 13

Results 3.3

PHYWE
excellence in science
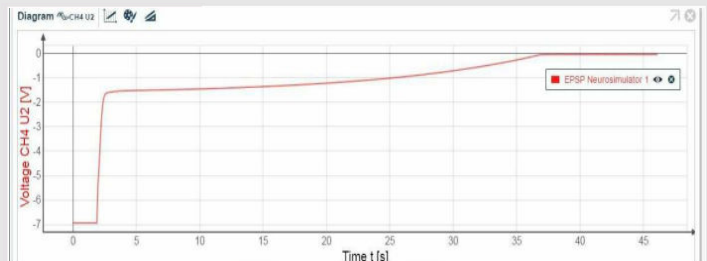
1.2. Dampening

Figure 14 and 15 show an example for dampening.
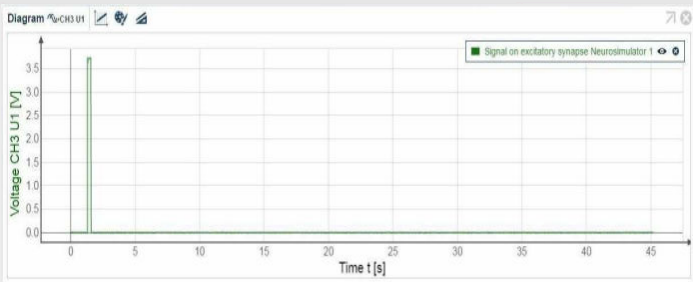
Figure 14

Figure 15

Results 3.4

PHYWE
excellence in science
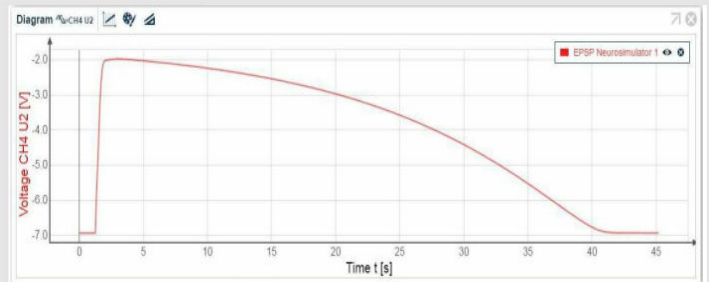
2. Rotating excitation variation: variation of stimulus intensity

Examples of convulsive excitation and dampening using different stimulus intensity. Hint: The most convenient way to read the values (signal intensity Umax and duration t = t2 - t1) is when you use the mouse pointer. Move the mouse pointer along the graph line, as shown in Fig. 16.

Figure 16

Results 3.5

PHYWE
excellence in science
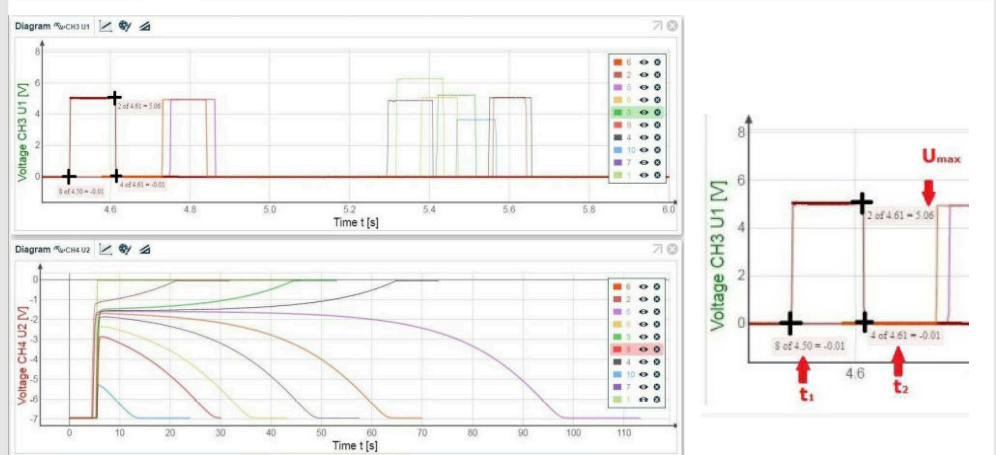
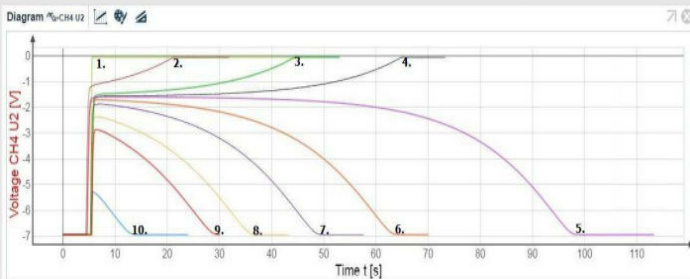Figure 17 and Table 1 show examples of different rotation excitation depending on signal intensity and duration.

Figure 17

Number	signal intensity U_{max}	signal duration $t_2 - t_1$	convulsive excitation	dampening
1.	6.28	0.12	x	
2.	5.05	0.11	x	
3.	5.24	0.10	x	
4.	5.09	0.11	x	
5.	4.96	0.11		x
6.	4.95	0.11		x
7.	4.89	0.11		x
8.	5.08	0.09		x
9.	5.09	0.08		x
10.	3.65	0.10		x

Table 1

Results 3.6

PHYWE
excellence in science

3. Rotating excitation variation: variation of threshold, equilibrium

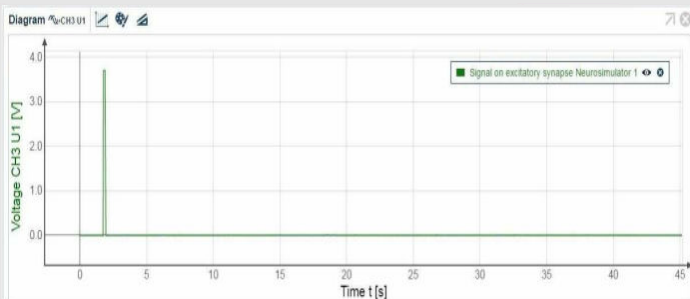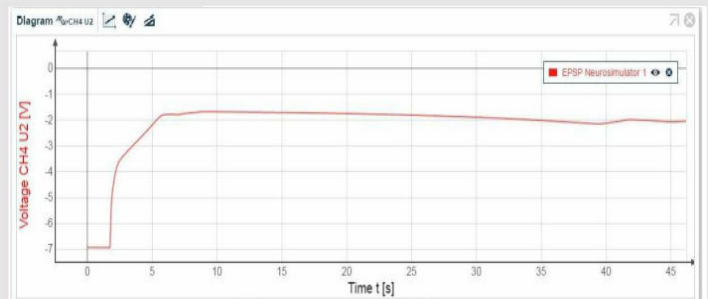Figure 18 and 19 show an example of the measurement.

Figure 18

Figure 19

Theory 4

PHYWE
excellence in science

Cerebral cortex and sensoric learning

This experiment shows that a cortex pyramidal cell can only then respond stimulus-specifically, when it has learned this by means of a preceding correlation of the sensory signal with a non-specific alerting signal. In this way only important signals are stored and processed, and "overloading" of the cerebral cortex is avoided. The optical channel (photosensor) provides the specific signal of a sense organ which excites a thalamic interbrain cell, which in turn excites the Hebbian synapse of a cortex pyramidal cell. The cortex pyramidal cell is also stimutalated by an unspecific stimulus (channel 1). At the same time a stellate cell inhibits the pyramidal cell. These three cell types make up the triad. The processing of sensory signals and their association to motoric programmes occurs in the cerebral cortex of mammals. In addition, the storing of experience takes place here. In an early stage of development, the cerebral cortex is in a diffuse, unformed condition, in which signal processing does not function with the precision that it does in the adult organism. This ability is only slowly acquired in active involvement with the environment. Stimulus processing is also a result of plastic adaption. Coincidence between different stimulations is always necessary hereby, to reach a cortical pyrimidal cell and to stabilize synapses of Hebb's type there by sustained potentiation.

PHYWE
excellence in science

Setup and procedure

Setup 4.1

- The experiment is set up as per Fig. 20.

- Two BNC-adapters (plug/socket 4 mm) are needed for voltage measurement.

Figure 20

Setup 4.2

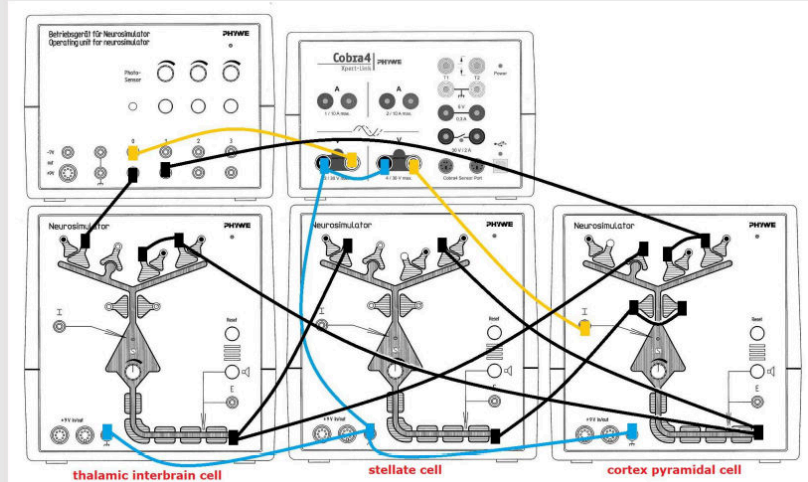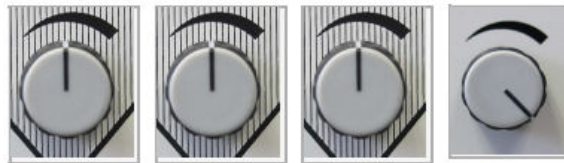- Neurosimulator 1, knob threshold: 50%

- Neurosimulator 2, knob threshold: 50%

- Neurosimulator 3, knob threshold: 50%

- Operating unit, knob stimulation intensity 1: 100%

Procedure 4.1

PHYWE
excellence in science

- To set Hebbian synapse to default, press the reset button on Neurosimulator 3 (cortex pyramidal cell).

- Start measurement in the measurement window.

- Cover the photosensor for 3 second. Wait until the voltage has reached the initial value. Replug the yellow cable on chanel 1 (red arrow, Fig. 21)

Figure 21
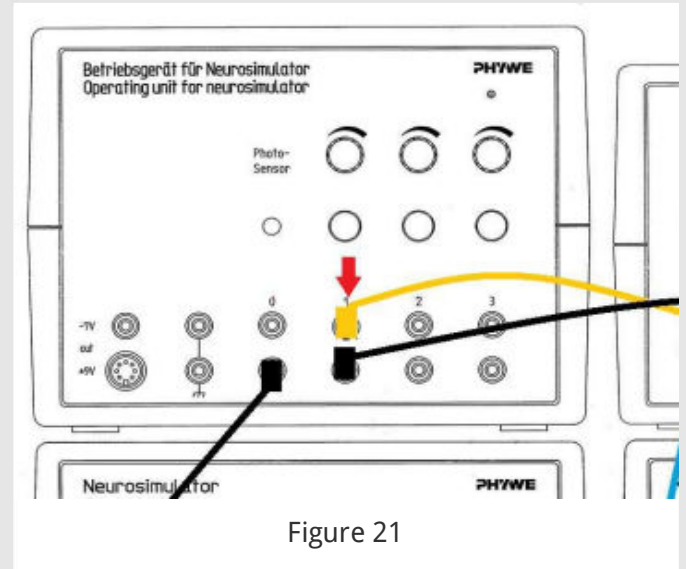
Procedure 4.2

PHYWE
excellence in science

- Press the stimulation button 1 for 3 seconds. Wait until the voltage has reached the initial value. Replug the yellow cable on photosensor (red arrow, Fig. 22).

- Cover the photosensor and press the stimulation button 1 (simultaneously) for 60 seconds. Wait until the voltage has reached the initial value.

- Cover the photosensor for 3 second. Wait until the voltage has reached the initial value. Finish the measurement, save and evaluate the results.

- To set Hebbian synapse to default, press the reset button on Neurosimulator 3 (cortex pyramidal cell).

Figure 22

Evaluation

Results 4.1
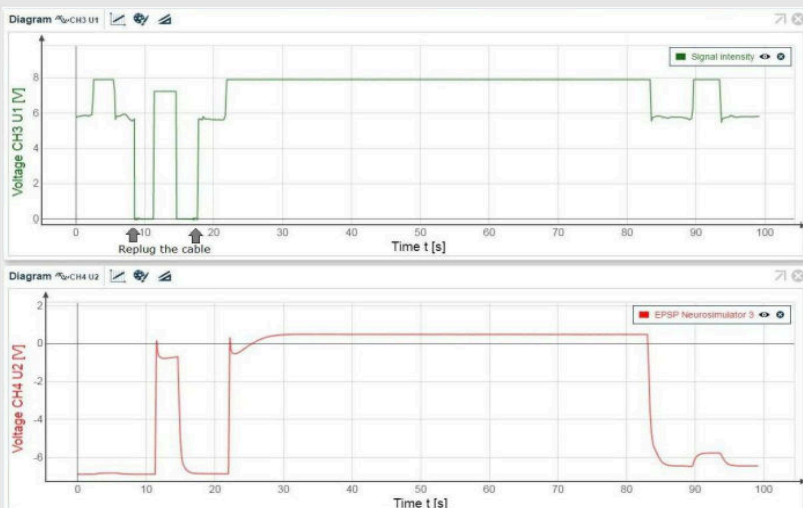
PHYWE
excellence in science
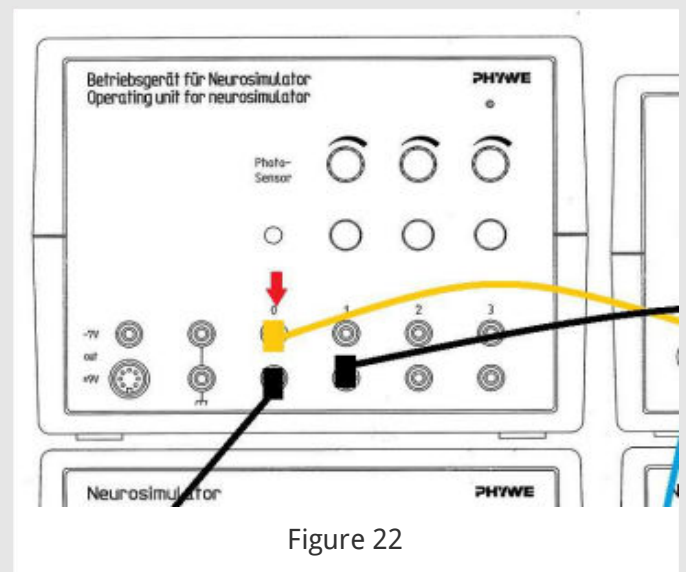
Figure 23: It is cloudy outside

- The course of the graph for signal intensity depends on the brightness in the room: Figure 23: It is cloudy outside. Figure 24: It is sunny outside. Figure 25: Photosensor is illuminated with flashlight.
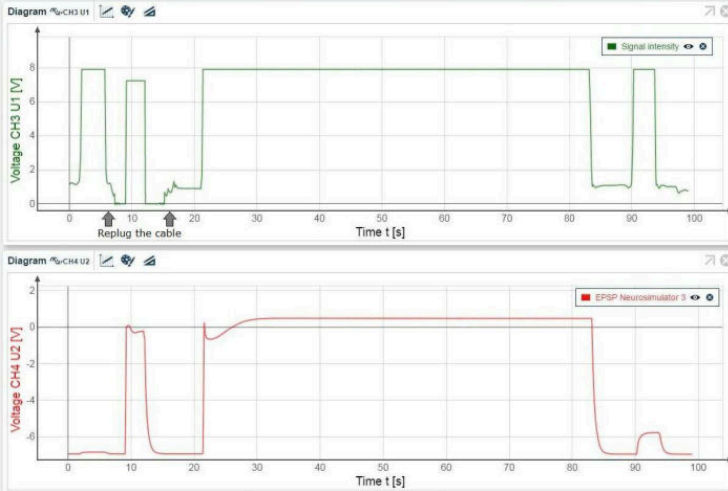
- The results for EPSP are the same.
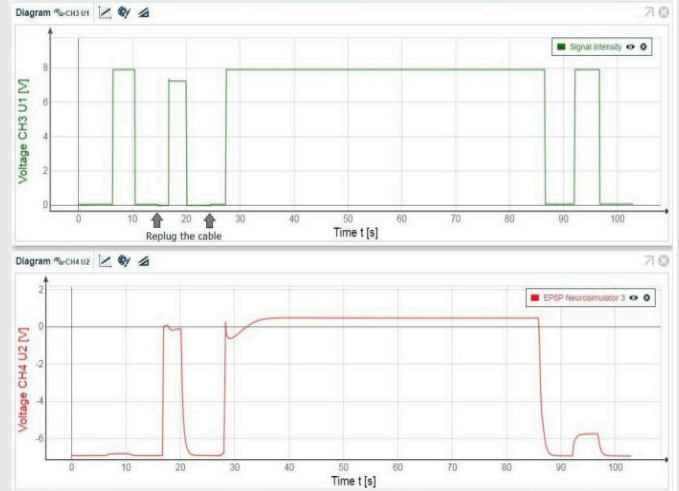
Results 4.2

Figure 24: It is sunny outside

Figure 25: Photosensor is illuminated with flashlight

Results 4.3

In all cases, the results are the same: A cortex pyramidal cell (Fig. 26, area 1.) can only then respond stimulus-specifically (area 4.), when it has learned this by means of a preceding correlation of the sensory signal with a non-specific alerting signal (area 3.).
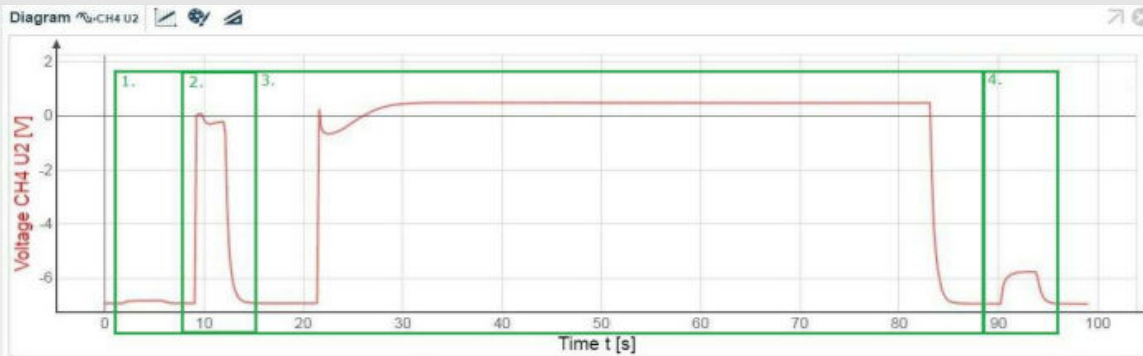

Figure 26

Theory 5

PHYWE
excellence in science

Direction selectivity by unilateral inhibition

Examples: many nerve cells in sensory systems are direction-selective. E.g., certain ganglion cells in the retina respond only when a light stimulus moves in a certain direction but not, however, by movements in the reverse direction. Similar behavior is also known for the sense of touch. This neuronal circuit can be simulated using a circuit with unilateral inhibition between two stimulus channels which are activated successively. Local projection sense organs, e.g. the retina of the eye or the body surface with its touch receptors, are basically capable of coding movements (changes in position in time). One correspondingly also actually finds, in these sense channels, neurons that selectively address stimulus movements (see also On-off response). Some of these cells do not simply react to any movement, but respond only to certain movement directions, while other directions remain unanswered. Their response intensity is as a rule a function of the rate of movement, the direction of movement and - mostly to a low extent - the intensity of the moved stimulus. Such cells are to be found already in the retina of most vertebrates, but only in a few of them on a higher processing level (e.g. anthropoidea).

PHYWE
excellence in science

Setup and procedure

Setup 5.1

- The experiment is set up as per Fig. 27.

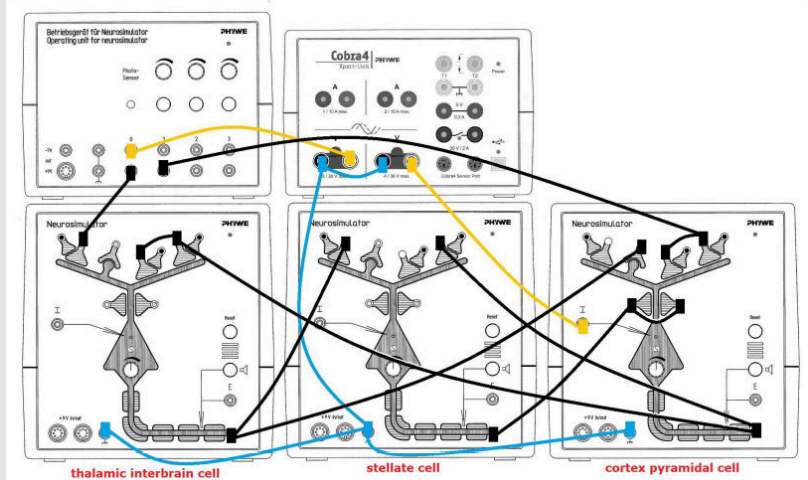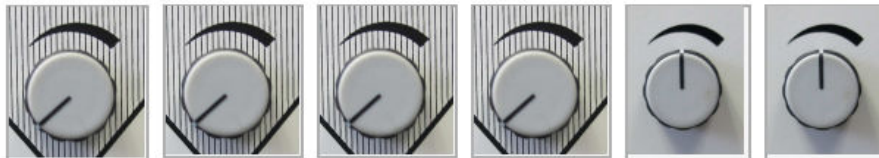- Two BNC-adapters (plug/socket 4 mm) are needed for voltage measurement.

Figure 27

Setup 5.2

- Neurosimulator 1, knob threshold: 0%

- Neurosimulator 2, knob threshold: 0%

- Neurosimulator 3, knob threshold: 0%

- Neurosimulator 4, knob threshold: 0%

- Operating unit, knob stimulation intensity 1: 50%

- Operating unit, knob stimulation intensity 2: 50%

Procedure 5

PHYWE
excellence in science

- Only acoustic monitor of ganglion cell (Neurosimulator 4) is switched on.

- Next, by sending a stimulus only from stimulus channel 1, increase threshold level of the ganglion cell so that no action potential is audible (acoustic monitor of ganglion cell). Check if action potential is audible when stimulus channel 2 is activated. There should not be an acoustic signal as well.

- Part 1: Start measurement in the measurement window. Press the stimulation button 1 and immediately after that (nearly simultaneous) press the stimulation button 2. Finish the measurement. Save and evaluate the results.

- Part 2: Start measurement in the measurement window. Press the stimulation button 2 and immediately after that (nearly simultaneous) press the stimulation button 1. Finish the measurement. Save and evaluate the results.
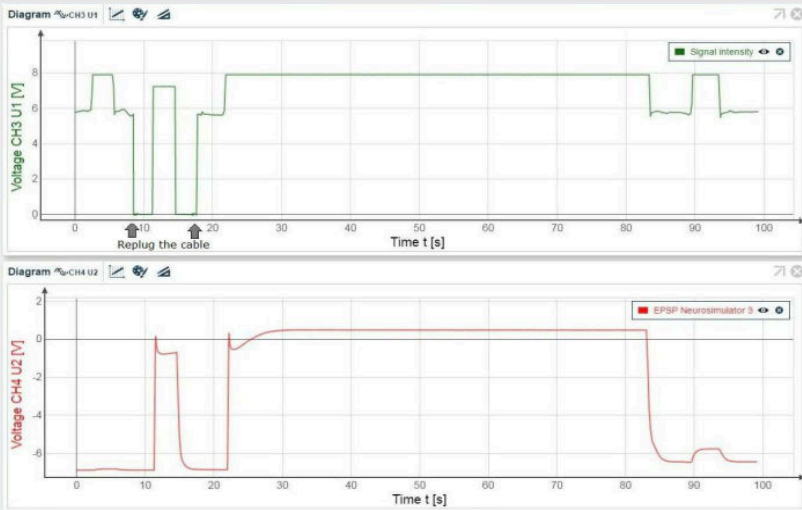
PHYWE
excellence in science

Evaluation

Results 5.1

Figure 28

○ Part 1: No action potential (AP) is generated, see Figure 28.

Results 5.2

Figure 29

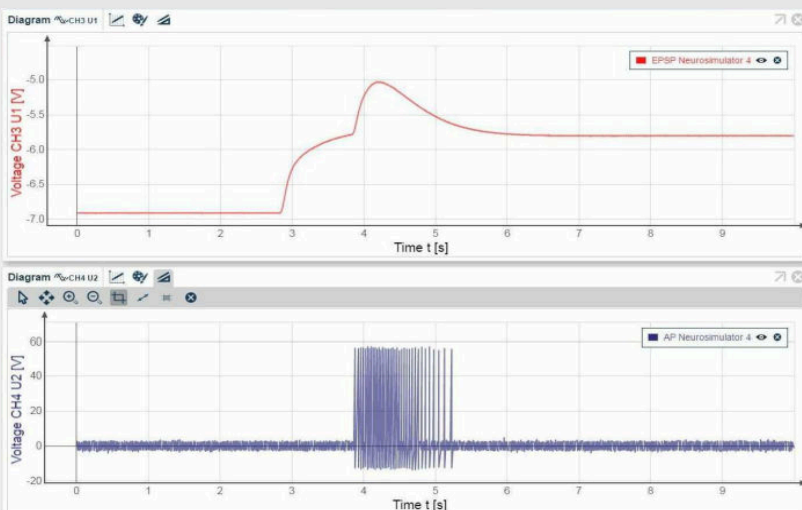○ Part 2: Action potential (AP) is generated, see Figure 29.

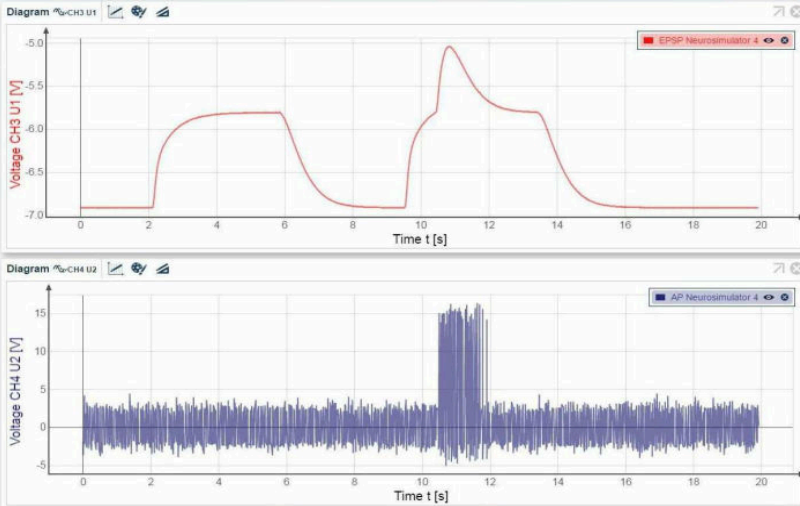# Results 5.3

PHYWE
excellence in science

Figure 30: Measurement at 10 kHz

Different settings in measureLAB can be used depending on the used computer. The result is always clear, but the quality of the diagram depends on the settings.

- 1. Figure 30: Measurement at 10 kHz (low quality)

- 2. Figure 31: Measurement at 50 kHz

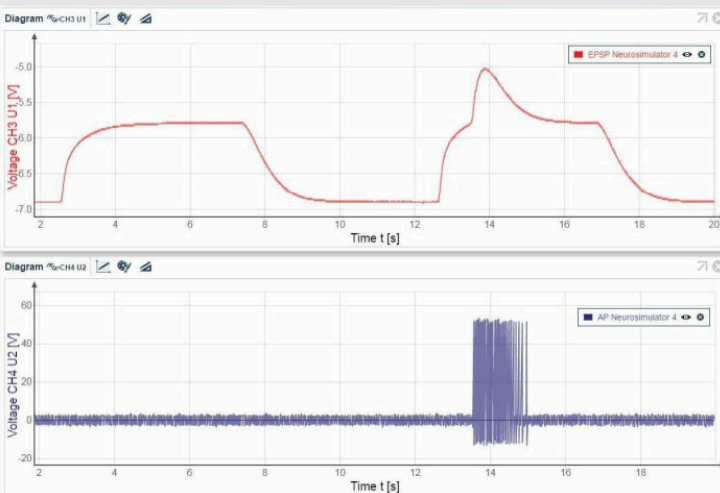- 3. Figure 32: Measurement at 100 kHz (high quality)

Results 5.4

PHYWE
excellence in science

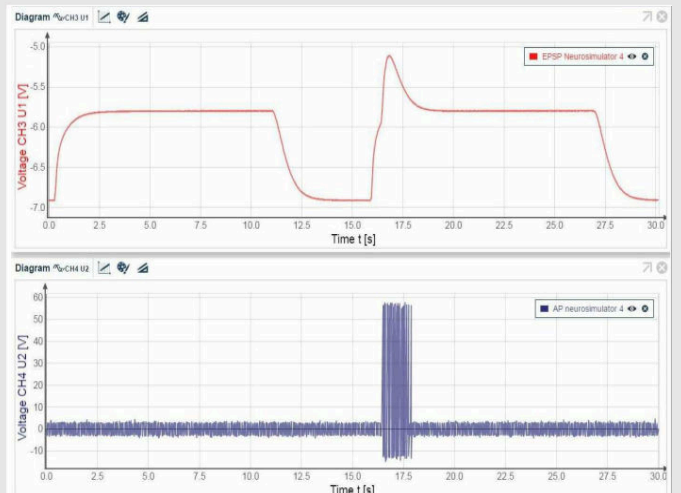

Figure 31: Measurement at 50 kHz

Figure 32: Measurement at 100 kHz

Results 5.5

PHYWE
excellence in science

In Figure 33 you see an example of the measurement at 100 kHz: enlarged area of AP.
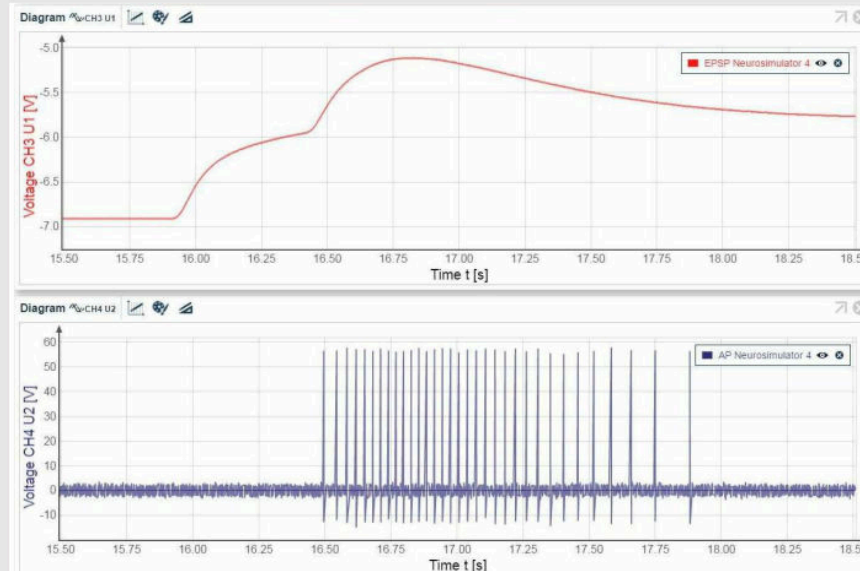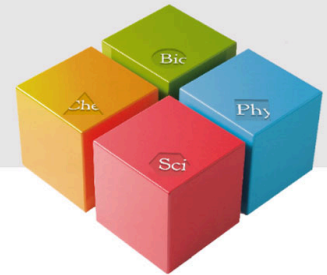

Figure 33

Theory 6

PHYWE
excellence in science

Self-calibration of paired sensory channels

Example: embryonal formation of axis-symmetrical species is not perfect, resulting in slight irregularities of the symmetry. Irregularities of sensory epithelia, e.g. in the equilibrium organ, can be compensated by the nerve system: Hebbian principle offers the possibility to adjust the output signals so that they are symmetrical when the sensory organs are asymmetrical. Experimental setup: There are two sensory neurons and two interneurons (two sensory neuron-interneuron pairs). Asymmetric signals are sent to the Hebbian synapses of the two sensory neurons. A signal generated by the photosensor of the operating unit is sent to the two interneurons, which forward the signal through their efferent axon to their sensory neuron partner where the signal is amplified by branching the signal. Both sensory neurons inhibit their own interneurons.

Setup and procedure

Setup 6.1

- The experiment is set up as per Fig. 34.

- Two BNC-adapters (plug/socket 4 mm) are needed for voltage measurement.

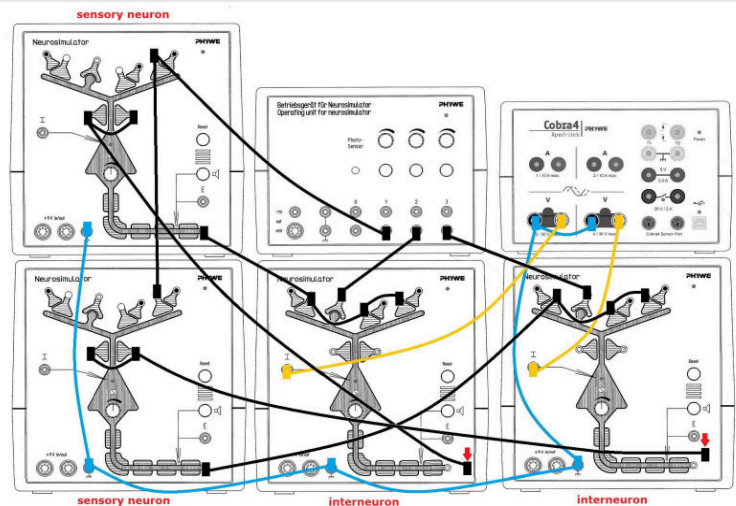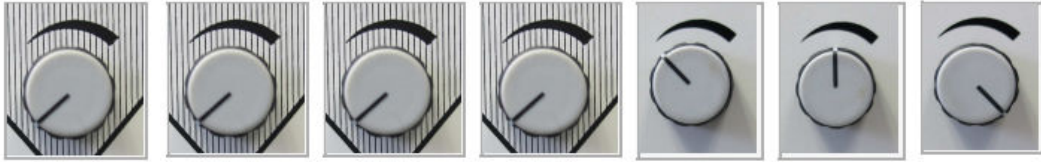- Leave two cable unplugged (red arrows).

Figure 34

Setup 6.2

PHYWE
excellence in science

- ○ Neurosimulator 1, knob threshold: 0%, Neurosimulator 2, knob threshold: 0%

- ○ Neurosimulator 3, knob threshold: 0%, Neurosimulator 4, knob threshold: 0%

- ○ Operating unit, knob stimulation intensity 1: 33%

- ○ Operating unit, knob stimulation intensity 1: 50%

- ○ Operating unit, knob stimulation intensity 1: 100%

Procedure 6.1

PHYWE
excellence in science

- ○ Start measurement in the measurement window.

- ○ Press the stimulation button 1, wait for 1-2 seconds and press additionally simultaneously buttons 2 and 3.

- ○ Keep the three buttons pressed for approximately 40 seconds.

- ○ Finish the measurement if the voltage has reached the initial value.

- ○ Save and evaluate the results

Procedure 6.2

Self-calibration of paired sensory channels

- Plug one loose cable back into the black socket (red arrows, Fig. 35).

- Start measurement in the measurement window.

- Press the stimulation button 1, wait for 1-2 seconds and press additionally simultaneously buttons 2 and 3.

- Keep the three buttons pressed for approximately 40 seconds.

- Finish the measurement if the voltage has reached the initial value. Save and evaluate the results.
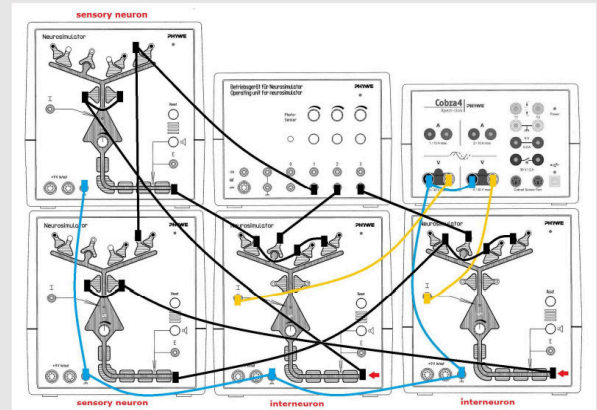

Figure 35

Evaluation

Results 6.1

PHYWE
excellence in science

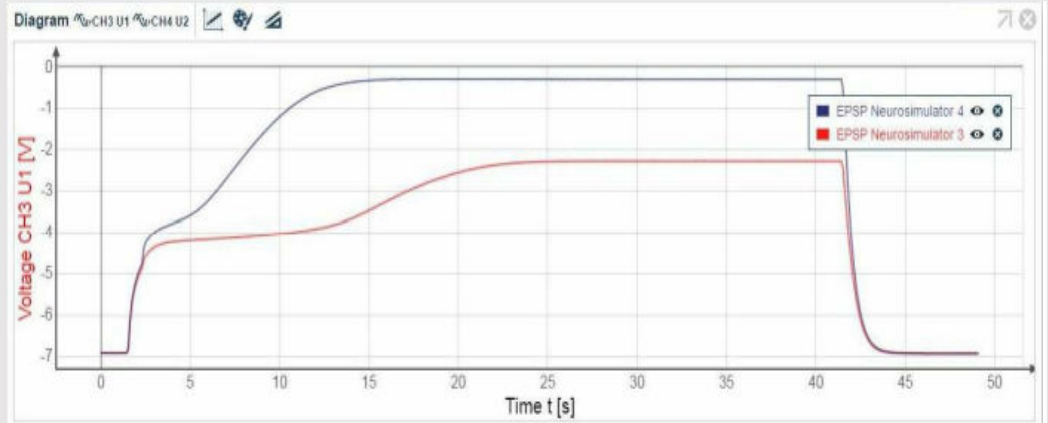- In Figure 36 you see an example of the measurement of no self-calibration of paired sensory channels.

Figure 36

Results 6.2

PHYWE
excellence in science

- In Figure 37 you see an example of the measurement of the self-calibration of paired sensory channels.

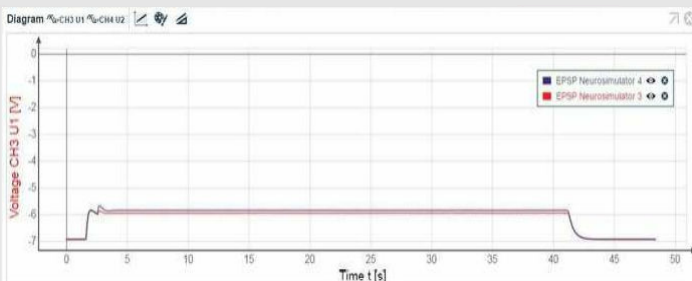- Figure 38 shows: Enlarged section: beginning of self-calibration.

Figure 37

Figure 38