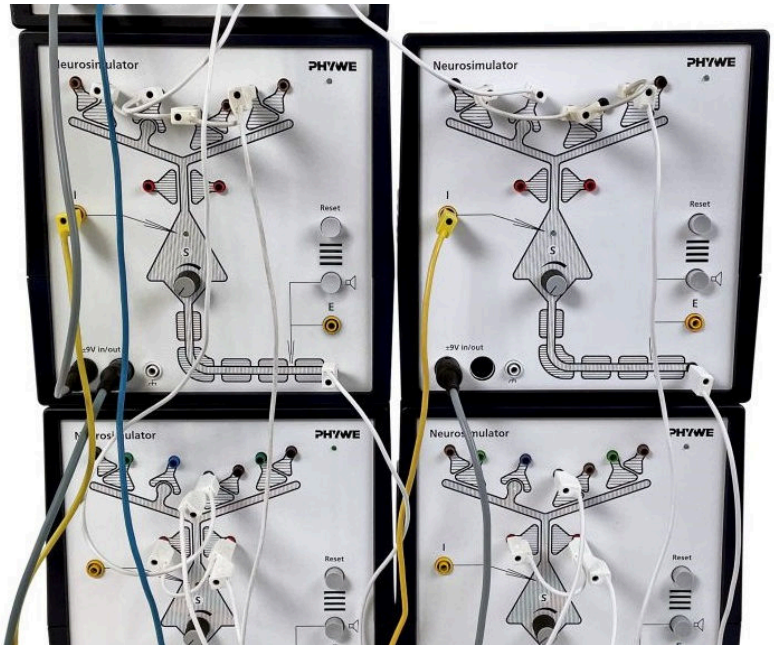
Neural networks with Cobra SMARTsense

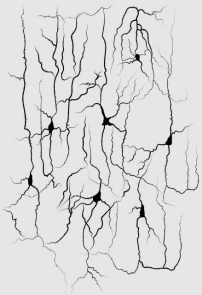


Experiments on the topic of neural networks like short-term memory, body clock and others. In preparation for these experiments, it is strongly recommended that the experiments on nerve cells with one nerve cell and nerve cell interactions with two nerve cells be carried out beforehand. The material required for this is already included in these experiments on neural networks.

Biology | Nervous system, neurobiology

Difficulty level	Group size	Preparation time	Execution time
hard	-	10 minutes	45+ minutes

PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de



PHYWE excellence in science

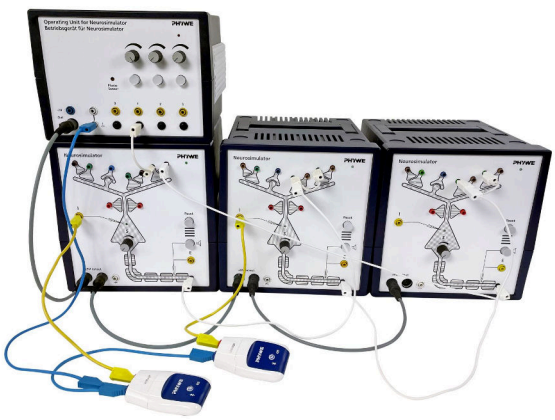
General information

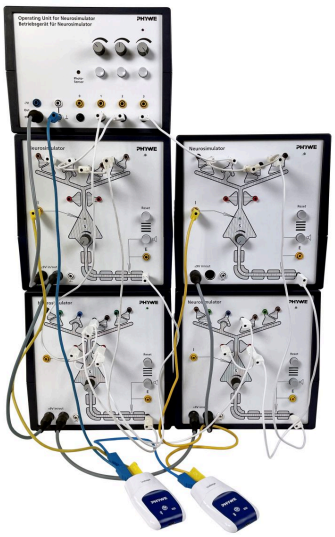
Application

PHYWE excellence in science

The human brain is made up of billions of neurons connected by synapses that transmit information in response to electrical and chemical signals.

These interactions enable the brain to perform complex functions such as memory, perception, movement and thinking.





Typical experiment setups with 3 and 4 nerve cells

PHYWE excellence in science

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

Other information (1/2)

PHYWE excellence in science

Prior knowledge

The two experiments "The nerve cell" (P4010769) and "Interaction of nerve cells" (P4010869) should be done beforehand.

Principle

Teaching system for conducting experiments on the topics of nerve cells, nerve cell interactions and neuronal networks. The two voltage sensors are used to measure the strength of the stimuli acting on the nerve cells as well as the membrane potential (EPSP) resulting from the various interconnections between two nerve cells.

Other information (2/2)

PHYWE excellence in science

Learning objectives

In this experiment, the pupils and students learn what complex possibilities neuronal networks already offer when three or four nerve cells are interconnected. To name just two examples: the internal clock, which determines the sleep rhythm, for example, short-term memory and sensory learning.

Tasks

The experiment consists of 6 examples from the wide world of neural networks that can be carried out independently of each other:

(1) transient (phasic) responses with emphasis on visual sense, (2) neuronal oscillator (e.g. body clock), (3) rotating excitation (short-term memory), (4) cerebral cortex and sensory learning, (5) directional selectivity through unilateral inhibition and self-calibration of paired sensory channels.

PHYWE excellence in science

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

Safety instructions

PHYWE excellence in science

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

PHYWE excellence in science

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

Equipment

Position	Equipment	Item no.	Quantity
1	Set Neurobiology with a nerve cell with Cobra SMARTsense	65963-22	1
2	Neurosimulator	65963-00	3

PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Theory 1

PHYWE excellence in science

Transient (phasic) reactions in the sense of vision

One type of neuron responds only to changed stimulation, not to sustained stimulation. These are called ON and OFF neurons. They respond only to the onset and/or disappearance of a stimulus with an activation that is usually brief and more intense the stronger the stimulus change. These two types of neurons act on other neurons, e.g. ganglion neurons of the visual sensory system. In addition, such neurons also exist in the tactile and olfactory sensory systems. The circuit in this experiment - an example from the visual system - can be used to show the **interconnection of retinal ganglion cells with amacrine cells**:

In the retina, the photoreceptors come into contact with bipolar cells, usually several of which are connected to one ganglion cell each. In addition, the photoreceptor cells are interconnected via horizontal cells and the ganglion cells are interconnected via amacrine cells. Each nerve cell thus receives signals from several sensory cells, and each sensory cell transmits signals to several nerve cells. Receptor potentials build up on the bipolar, horizontal and amacrine cells, whereas action potentials are formed first on the ganglion cells.

PHYWE excellence in science

Setup and procedure 1

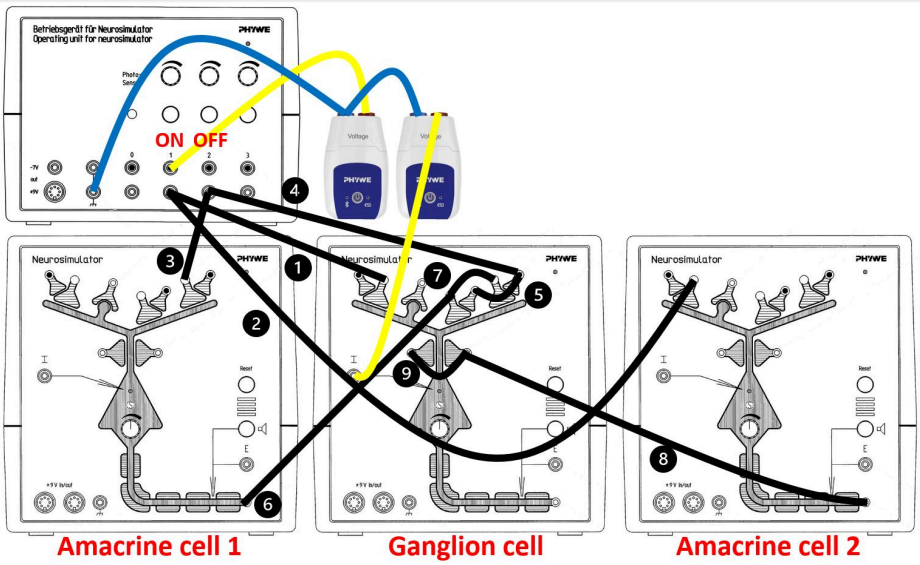
PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Setup 1.1

PHYWE excellence in science

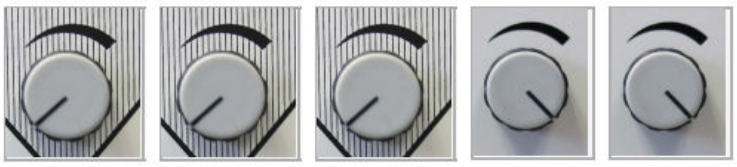
Transient (phasic) reactions in the sense of vision

Set up the wiring as shown in the illustration on the right.



Setup 1.2

PHYWE excellence in science

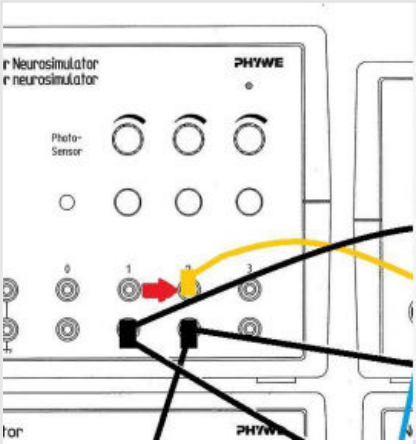


- Neurosimulators 1,2 and 3: Rotary knob firing threshold: 0%
- Power supply: Rotary knob stimulus intensity 1 (stimulus for ON): 100%
- Power supply: Rotary knob stimulus intensity 2 (stimulus for OFF): 100%

PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Procedure 1

PHYWE excellence in science



Cable to be switched during the experiment

- Start measurement.
- Press stimulation button 1 for about 5 seconds. Wait until the voltage has reached the initial value.
- Now plug the yellow cable in the black socket in stimulus channel 1 into the black socket of channel 2 (red arrow in the illustration).
- Press stimulation button 2 for approx. 5 seconds. Wait until the voltage has reached the initial value.
- Press stimulation buttons 1 and 2 for approx. 5 seconds. Wait until the voltage has reached the initial value.
- Stop measurement as soon as the voltage has reached the initial value.
- Save and evaluate results.

PHYWE excellence in science

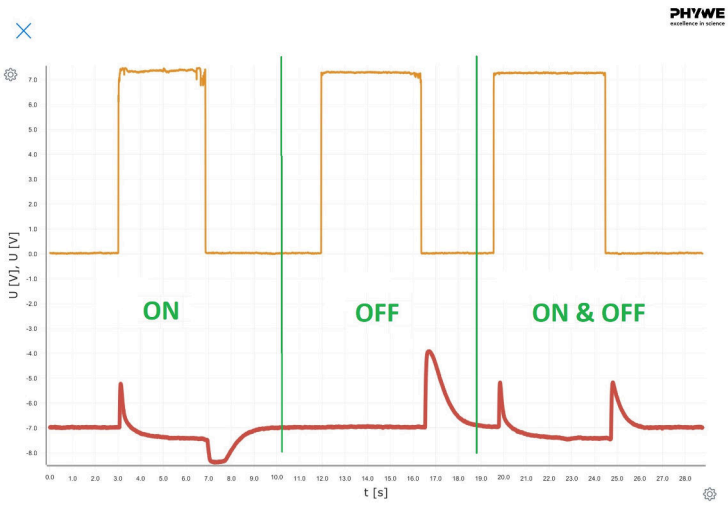
Evaluation 1

PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Result 1.1

ON: Two cells are involved, the ganglion cell and the amacrine cell, which transmits a signal to the inhibitory synapses of the ganglion cell. The lower cells receive a stimulus at one of their excitatory synapses. The membrane potential of the ganglion cell is determined.

At the beginning of the signal, the membrane of the ganglion cell is depolarised for a short time, which leads to a decrease in the membrane potential. Due to the activity of the inhibitory synapses, hyperpolarisation can be observed.

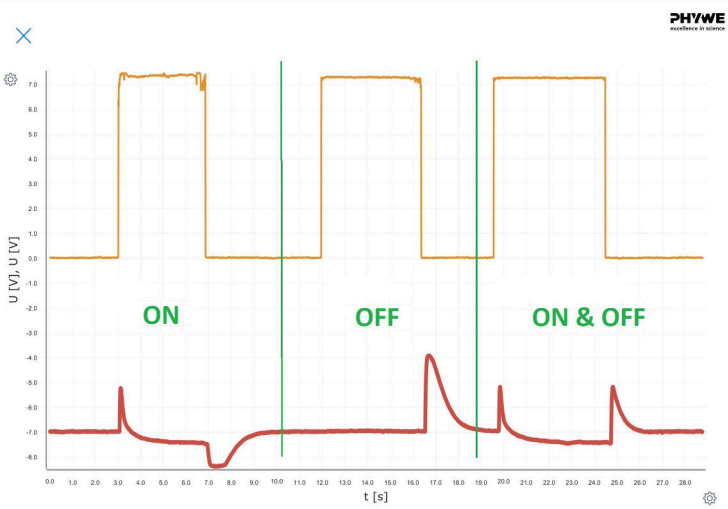


Result 1.2

OFF: Two cells are involved: the ganglion cell and the amacrine cell, which transmits a signal to the veto synapses of the ganglion cell. Both cells receive a stimulus at their excitatory synapses. The membrane potential of the ganglion cell is determined.

At the beginning of the signal, nothing happens. However, the membrane of the ganglion cell is depolarised as soon as the stimulus is switched off.

ON & OFF: Combines the settings of ON and OFF neurons.



PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Theory 2

PHYWE excellence in science

Neuronal oscillator (body clock)

Many animal and human behaviours have rhythmic characteristics. The periodicity of this rhythmicity, which originates 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 any case, neuronal oscillators are necessary as timers for such behaviour. The circuit example shows how individual neurons can bring about **oscillating behaviour** when they are grouped together. The rhythmic behaviour of this neuronal network is based on the **time-delayed negative feedback via a veto synapse**. As a result, the input signal is switched off at regular time intervals. Due to the membrane time constant of the neuronal module (caused by its capacitive properties), there is no abrupt signal drop. With a time delay, which is essentially determined by the signal strength, the small excitation at the veto synapse also leads to such a small inhibition again that the stimulation signal can become effective again. I.e. the inhibition at the veto synapse becomes so weak after some time of increasing inhibition strength that it can no longer inhibit the excitatory synapse.

PHYWE excellence in science

Setup and procedure 2

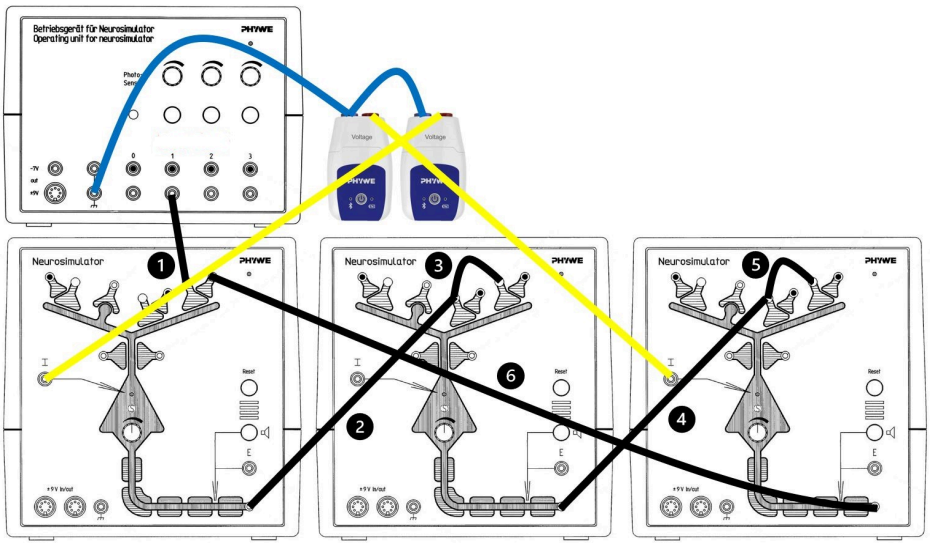
PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Setup 2.1

PHYWE excellence in science

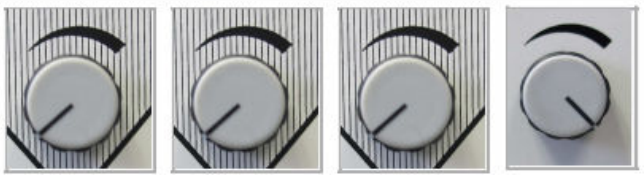
1. Neural oscillator:

Set up the wiring as shown in the illustration on the right.



Setup 2.2

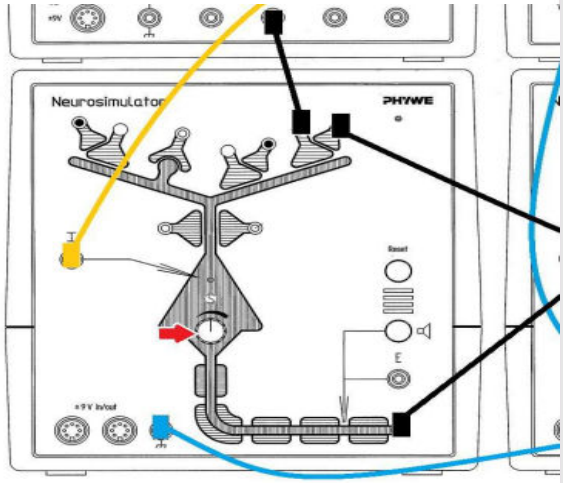
PHYWE excellence in science



- Neurosimulators 1, 2 and 3: Rotary knob firing threshold: 0%
- Power supply: Rotary knob stimulus intensity 1: 100%

PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Procedure 2.1

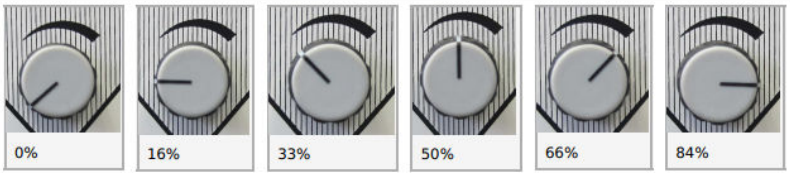


- Start measurement.
- Press stimulation button 1 for about 15 seconds.
- Stop measurement as soon as the voltage has reached the initial value.
- Save and evaluate results.

2. Transient response with different thresholds on Neurosimulator 1

- Change oscillation by different settings of the threshold on neurosimulator 1 (figure left, red arrow).

Procedure 2.2

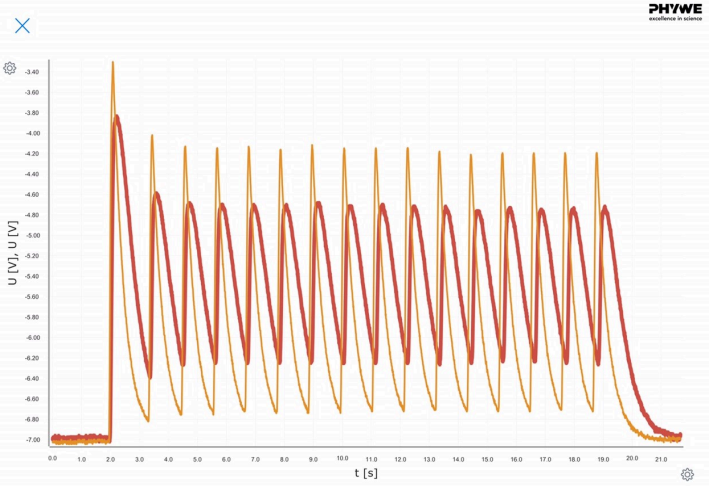


- Start measurement.
- Change the fire threshold in ascending order. Press stimulus button 1 for approx. 5 seconds each time. Wait until the voltage has reached the initial value, then increase the fire threshold again, etc.
- Save and evaluate results.

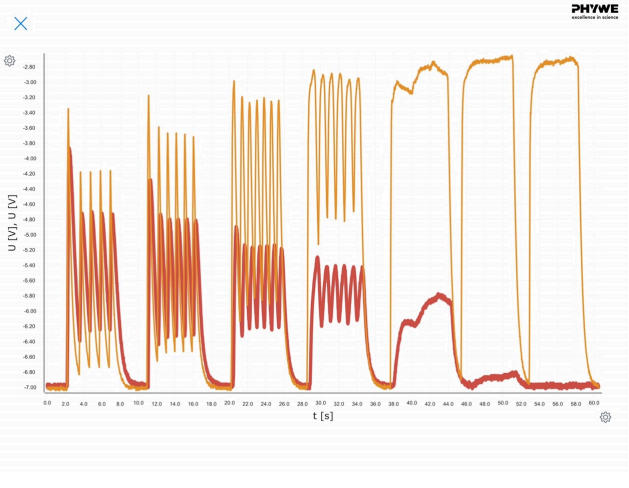
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Evaluation 2

Results 2



Oscillations with inactive firing threshold



Oscillations at different settings of the firing threshold

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

Theory 3

PHYWE excellence in science

Rotating excitation (short-term memory)

This self-perpetuating excitation circling within a neuron group is exemplary for short-term memory, because a stimulus remains in this network for a while. Neurosimulators 1 (left) and 2 (in the middle) form a positive feedback loop, i.e. as soon as a brief stimulus has been triggered, the signal is transmitted further. The third Neurosimulator (right) acts as an inhibitory interneuron for Neurosimulator 2. With this setup, different variations can be investigated by changing the stimulus intensity and thresholds of neurons 1 or 2 and the inhibitory interneuron.

PHYWE excellence in science

Setup and procedure 3

PHYWE excellence in science

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

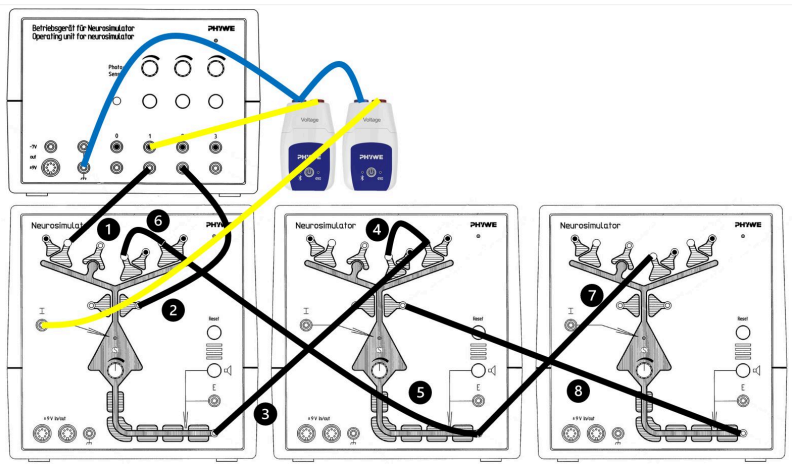
Setup 3.1

PHYWE excellence in science

Notes: Since each person operates push buttons in a slightly different way, to obtain a similar signal duration, all parts of this experiment should be performed by the same person.

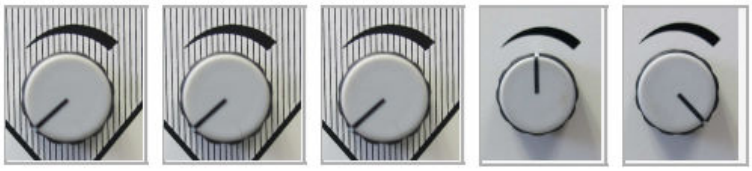
1. Change in rotating excitation: Change in stimulus duration

Set up the experiment as shown in the figure on the right.



Setup 3.2

PHYWE excellence in science



- Neurosimulators 1, 2 and 3: Rotary knob firing threshold: 0%
- Power supply: Rotary knob stimulus intensity 1: 50%
- Power supply: Rotary knob stimulus intensity 2: 100%
- Activate "Additional Y-axis" in the measureAPP

PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Procedure 3.1

PHYWE excellence in science

1.1 Convulsive excitation

- Start measurement and press stimulus button 1 for about one second.
- Stop measurement as soon as the voltage has reached the output value.
- Variation: Repeat the measurement and end the convulsive excitation by pressing stimulation button 2.
- Save and evaluate results.

1.2 Damping

- Start measurement and stimulus button 1 **less** than one second (very short tap, like on a hot cooker top).
- Stop measurement as soon as the voltage has reached the output value.
- Save and evaluate results.

Procedure 3.2

PHYWE excellence in science

2. Change in rotating excitation: Change in stimulus intensity

- Start measurement.
- Press stimulation key 1 for less than one second (very short tap, like on a hot cooker top).
- Stop measurement as soon as the voltage has reached the initial value. Save results.
- Repeat the measurement several times. Minimally change stimulus intensity for each measurement: Turn the knob for stimulus intensity 1 minimally, both directions are possible. The aim is to obtain measurement diagrams with convulsive excitation and with damping.
- Save and evaluate the results each time. Before each measurement, stop the convulsive excitation by pressing the stimulation button 2.

PHYWE excellence in science

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

Procedure 3.3

PHYWE excellence in science

3. Change in rotating excitation: Inhibition

- Start measurement.
- Press stimulation key 1 for approx. one second.
- Press stimulation key 2.
- Stop measurement as soon as the voltage has reached the initial value. Save result.

PHYWE excellence in science

Evaluation 3

PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

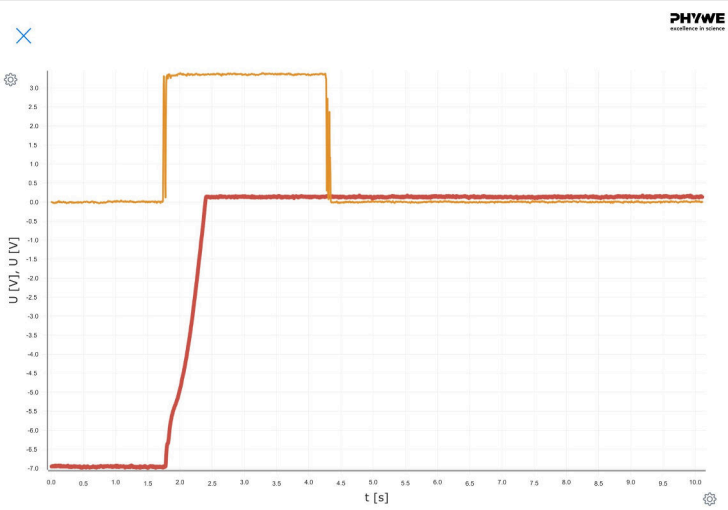
Result 3.1.1

PHYWE excellence in science

1. Variation of the rotating excitation: Variation of the stimulus duration

1.1 Convulsive excitation

The figure on the right shows the first example of convulsive excitation (upper curve: stimulus, lower curve: membrane potential of nerve cell 1).



Result 3.1.2

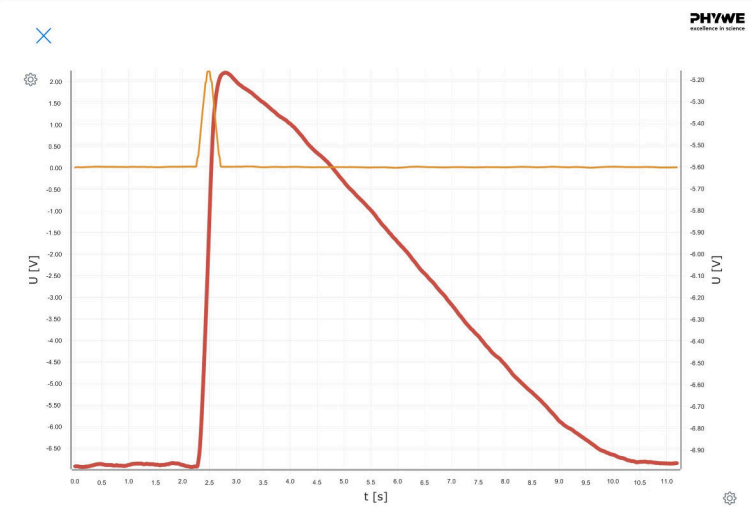
PHYWE excellence in science

1.2 Damping

The illustration on the right shows an example of attenuation after a very short stimulus.

In this experiment, the stimulus channel is medium strong and only a short stimulus impulse is given. The nerve membrane is depolarised, but the stimulus is too weak and the membrane potential returns to baseline.

Since the threshold of the interneuron is low, its inhibition increases the attenuation of the neuron-neuron cycle.



PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Result 3.2

PHYWE excellence in science

2. Change in rotating excitation: Change in stimulus intensity

The table shows examples of different values for convulsive excitation and attenuation depending on stimulus intensity and duration.

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

Result 3.3

PHYWE excellence in science

3. Change in rotating excitation: Inhibition

Depending on the length of the inhibitory stimulus (red arrow in the figure on the right), the convulsive excitation subsides more or less quickly.

PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Theory 4

PHYWE excellence in science

Cerebral cortex and sensory learning

This experiment shows that a cortical pyramidal cell can only react in a stimulus-specific way if it has learned to do so through a previous correlation of the sensory signal with a non-specific alarm signal. In this way, only important signals are stored and processed, and an **overload of the cerebral cortex** is avoided. The photosensor provides the specific signal of a sensory organ, which is a **thalamic interbrain cell** which in turn excites the Hebbian synapse of a **cortex pyramidal cell**. The cortex pyramidal cell is also excited by a non-specific stimulus (channel 1). At the same time, a **stellate cell** inhibits the pyramidal cell. These **three cell types** form the **triad**. The mammalian cerebral cortex is where sensory signals are processed and linked to motor programmes. In addition, this is where **experience storage** takes place. In an early stage of development, the cerebral cortex is in a diffuse, unformed state in which signal processing does not function with the precision that it does in the adult organism. This ability is only slowly acquired through active engagement with the environment. Stimulus processing is also a result of **plastic adjustment**. In this process, coincidence between different stimuli is always necessary to reach a cortical pyramidal cell and stabilise Hebbian synapses there through sustained potentiation.

PHYWE excellence in science

Setup and procedure 4

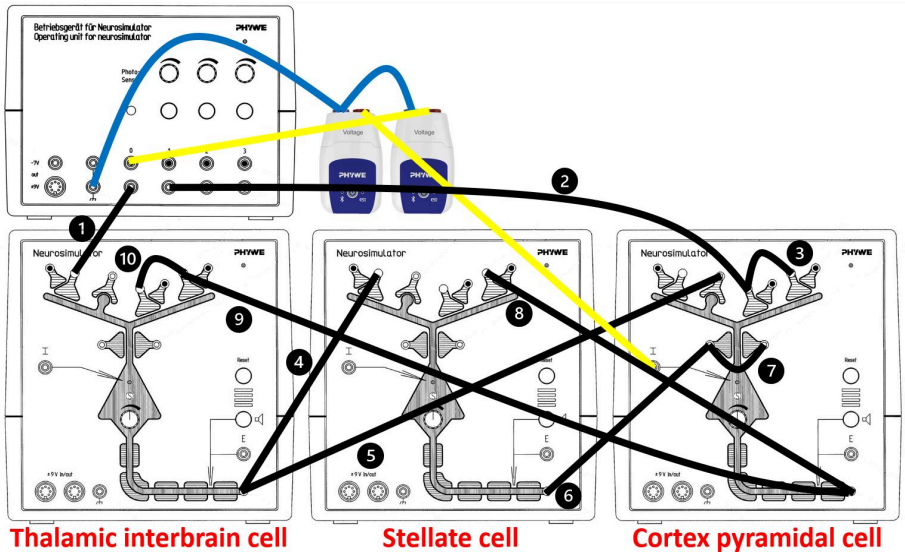
PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Setup 4.1

PHYWE excellence in science

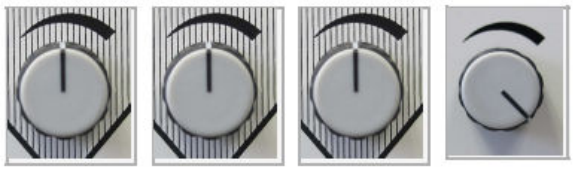
Set up the experiment as shown in the illustration on the right.

The yellow cable is first connected to the measuring channel of the **photosensor**.



Setup 4.2

PHYWE excellence in science



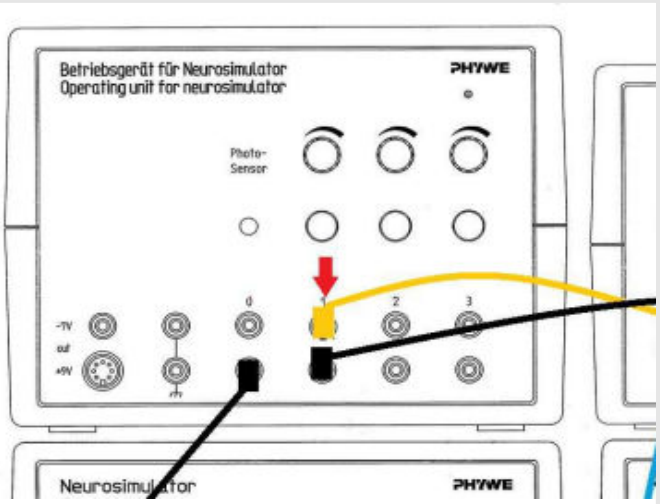
- Neurosimulators 1, 2, 3: Rotary knob firing threshold: 50%.
- Power supply: Rotary knob stimulus intensity 1: 100%

PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Procedure 4.1

PHYWE excellence in science

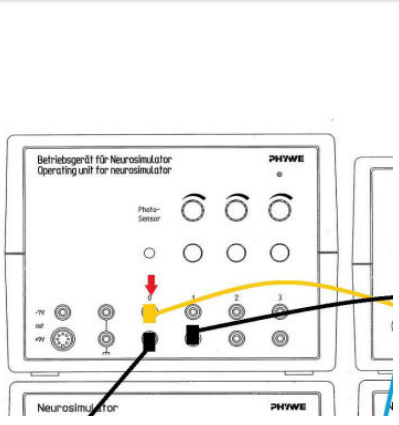
- To set the Hebbian synapse to the default values, press the reset button on neurosimulator 3 (cortex pyramidal cell).
- The yellow cable is plugged into the measuring channel of the p**hotosensor**.
- Start measurement.
- Cover the photosensor for 3 seconds. Wait until the voltage has reached the initial value.
- Yellow cable on s**timulus channel 1** (red arrow in the illustration on the right).



Procedure 4.2

PHYWE excellence in science

- Press stimulation button 1 for approx. 3 seconds. Wait until the voltage has reached the initial value. Reconnect the yellow cable to the measuring channel of the **Photosensor** (red arrow in the illustration on the right).
- Cover the photosensor and press stimulus button 1 (simultaneously) for 60 seconds. Wait until the voltage has reached the initial value.
- Cover the photo sensor for 3 seconds. Wait until the voltage has reached the initial value. Finish the measurement, save and evaluate the results.
- To reset the Hebbian synapse to the default value, press the reset button on neurosimulator 3 (cortex pyramidal cell).



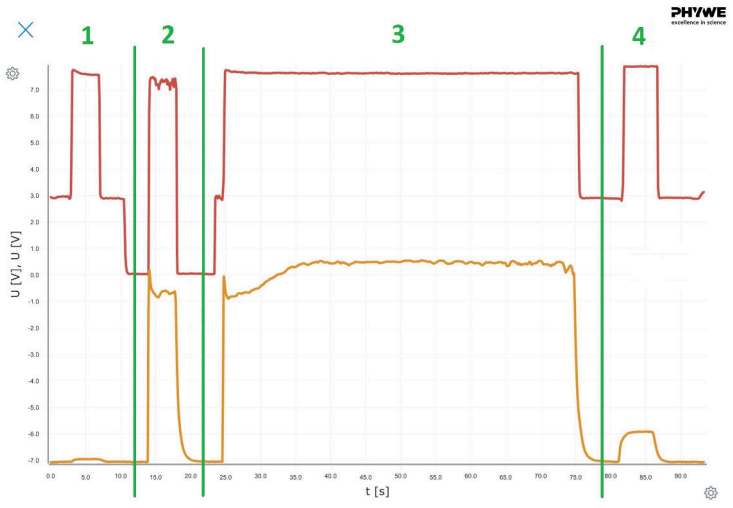
PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

PHYWE excellence in science

Evaluation 4

Result 4

PHYWE excellence in science



The excitation by the specific stimulus (photosensor, measuring range 4) after simultaneous actuation of the photosensor and stimulus button 1 is greater than in measuring range 1 and decays more slowly than the excitation by stimulus button 1 in measuring range 2.

Conclusion: A cortex pyramidal cell (measuring range 1) can only react in a stimulus-specific manner (measuring range 4) if it has learned to do so through a previous correlation of the sensory signal with a non-specific alarm signal (measuring range 3).

PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Theory 5

PHYWE excellence in science

Directional selectivity through unilateral inhibition

Examples: Many nerve cells in sensory systems are direction-selective. For example, certain ganglion cells in the retina only react when a light stimulus moves in a certain direction, but not when it moves in the opposite direction. A similar behaviour is also known for the sense of touch. This neural circuit can be simulated by a circuit with one-sided inhibition between two stimulus channels that are activated one after the other. Local projection sensory organs, e.g. the retina of the eye or the surface of the body with its tactile receptors, are basically able to encode movements (changes in position over time). Accordingly, neurons are actually found in these sensory channels that respond selectively to stimulus movements (see also on-off response). Some of these cells do not simply respond to every movement, but respond only to certain directions of movement, while other directions remain unresponsive. Their response intensity is usually a function of the speed of movement, the direction of movement and - usually to a lesser extent - the intensity of the stimulus being moved. Such cells are already found in the retina of most vertebrates, but only in a few of them at a higher processing level (e.g. anthropoids).

PHYWE excellence in science

Setup and procedure 5

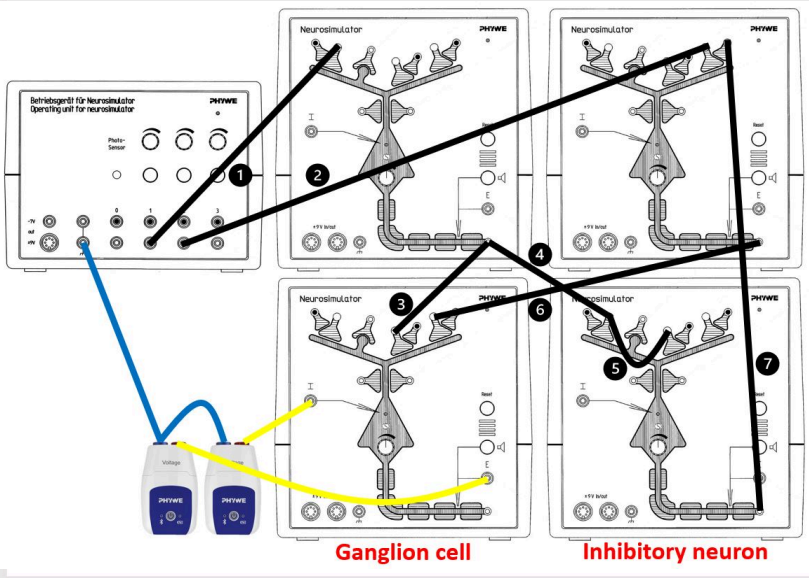
PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Setup 5.1

PHYWE excellence in science

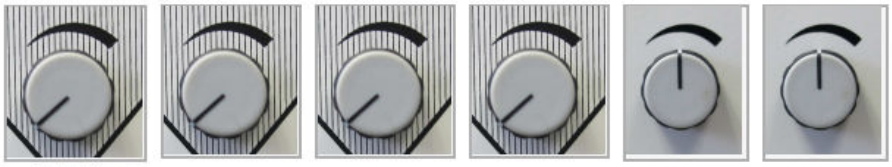
Set up the experiment as shown in the illustration.

The measuring channel for the action potentials in the ganglion cell can be connected to an oscilloscope. Alternatively, both voltage sensors can be connected to a computer via USB to increase the measuring frequency (5000 Hz per channel instead of 500 Hz with Bluetooth operation). However, the easiest way to carry out the experiment is to use the acoustic monitor to display the action potentials.



Setup 5.2

PHYWE excellence in science



- Neurosimulators 1, 2, 3, 4: Rotary knob firing threshold: 0%
- Power supply: Rotary knob stimulus intensity 1 and 2: 50% each

PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Procedure 5

PHYWE excellence in science

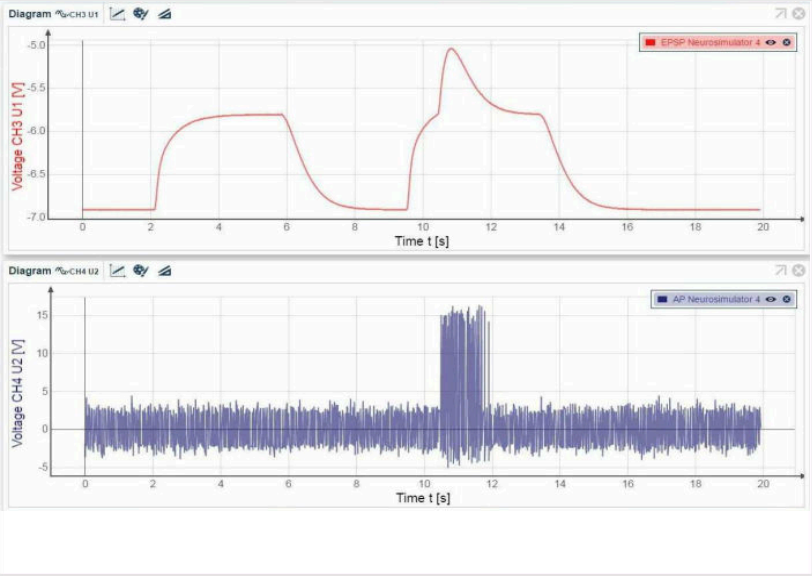
- Activate only the acoustic monitor of the ganglion cell (Neurosimulator 4).
- Then increase the threshold of the ganglion cell by emitting a stimulus only from stimulus channel 1 so that no action potential is audible (acoustic monitor of the ganglion cell). Check whether an action potential is audible when stimulus channel 2 is activated. No acoustic signal should be heard.
- Part 1: Start measurement. Press **stimulus button 1** and immediately afterwards (almost simultaneously) press **stimulus button 2**. End measurement. Save and evaluate results.
- Part 2: Start measurement. Press **stimulus button 2** and immediately afterwards (almost simultaneously) press **stimulus button 1**. End measurement. Save and evaluate results.

PHYWE excellence in science

Evaluation 5

PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Result 5.3



Measurement with the measureLAB software, which can also be used.

Only in the second part of the measurement is an action potential (AP) generated, the consequence of direction selectivity.

Theory 6

Self-calibration of paired sensory channels

Example: The embryonic formation of axisymmetric species is not perfect, resulting in slight irregularities in symmetry. Irregularities of the sensory epithelia, e.g. in the organ of equilibrium, can be compensated for by the nervous system: Hebb's principle offers the possibility of adjusting 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). Asymmetrical signals are sent from stimulus channel 2 and stimulus channel 3 to the Hebbian synapses of the two sensory neurons (here: stimulus intensity 50% and 100% respectively). A signal originating from stimulus channel 1 of the operating unit is sent to the two interneurons, which transmit the signal via their efferent axon to their sensory neuron pair, where the signal is amplified by branching. Both sensory neurons inhibit their own interneurons.

Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

PHYWE excellence in science

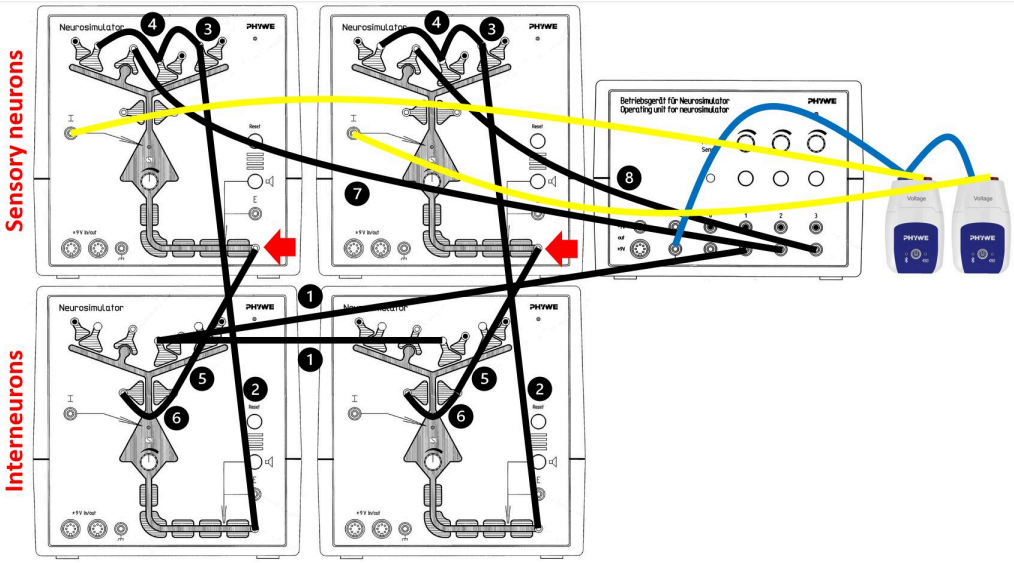
Setup and procedure 6

Setup 6.1

PHYWE excellence in science

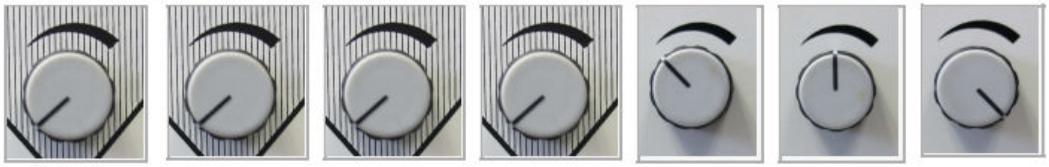
Self-calibration of paired sensory channels:

- Set up the wiring as shown in the illustration on the right.
- For the second measurement, leave one of the two cables marked with the red arrows unplugged.



PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Setup 6.2



- Neurosimulator 1, 2, 3, 4: Rotary knob firing threshold: 0%
- Power supply: Rotary knob stimulus intensity 1: 33%
- Power supply: Rotary knob stimulus intensity 2: 50%
- Power supply: Rotary knob stimulus intensity 3: 100%

Procedure 6.1

Self-calibration of paired sensory channels

- Start measurement.
- Press stimulation key 1, wait 1 to 2 seconds, keep key pressed and additionally press stimulation keys 2 and 3 simultaneously.
- Press and hold the three stimulus buttons simultaneously for a longer time (e.g. 30 seconds).
- End measurement when the voltage has reached the initial value.
- Save and evaluate results.

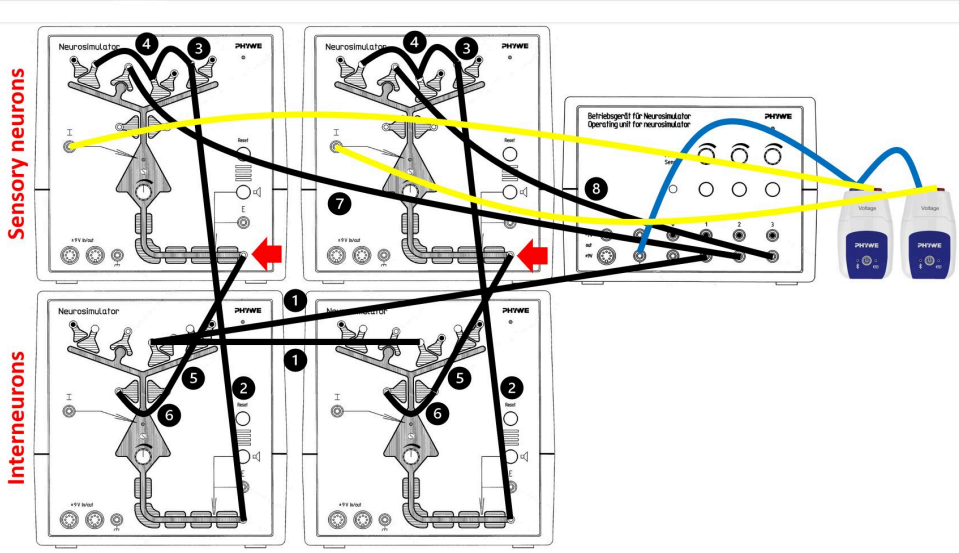
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Procedure 6.2

PHYWE excellence in science

No self-calibration

- Remove one of the cables marked with a red arrow from the black socket.
- Otherwise, perform the same procedure as for the experiment "Self-calibration of paired sensory channels".



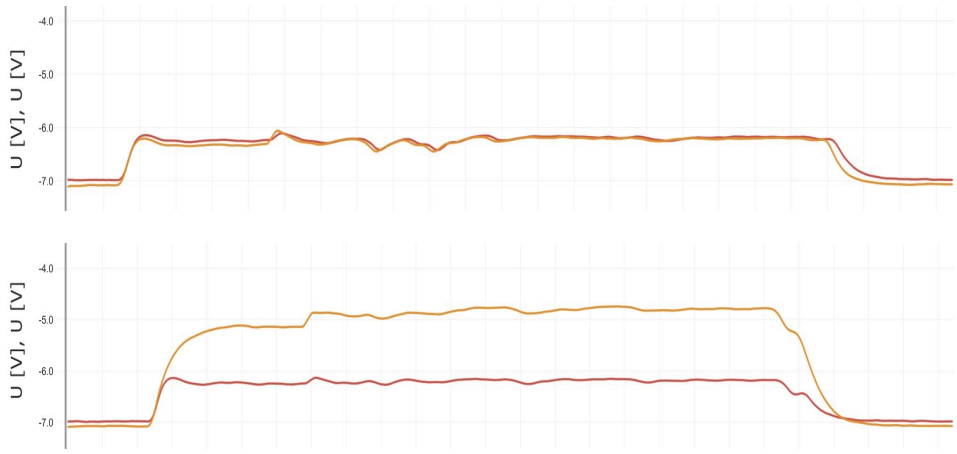
PHYWE excellence in science

Evaluation 6

PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Result 6.1

The figure shows examples for the measurement **with** (above) and **without** (below) self-calibration of paired sensory channels. Measurement time 25 seconds.

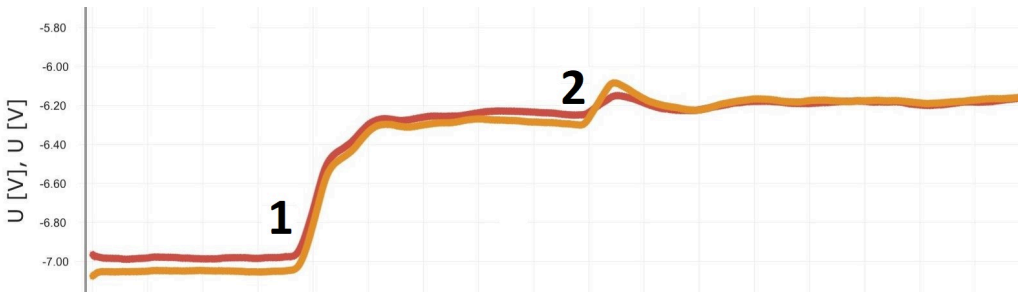


Result 6.2

The illustration on the right shows the start of self-calibration:

Action 1: Pressing the stimulus button 1

Action 2: Stimulus button 1 remains pressed, additional simultaneous pressing of stimulus buttons 2 and 3



Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

PHYWE excellence in science

Outlook

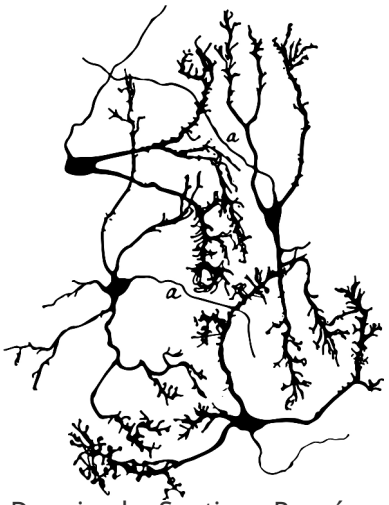
Outlook

PHYWE excellence in science

Additional neural networks

More circuits can be created with data from various research projects. An internet search term such as "synaptic potentiation" yields a considerable amount of scientific papers. Their neuronal models can be converted into neurosimulator circuits.

Please note that if you want to use more than 4 Neurosimulators, you need another power supply to supply power to the additional Neurosimulators, i.e. 1 additional power supply per 4 Neurosimulators.



Drawing by Santiago Ramón y Cajal (1852 - 1934)

PHYWE excellence in science

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de