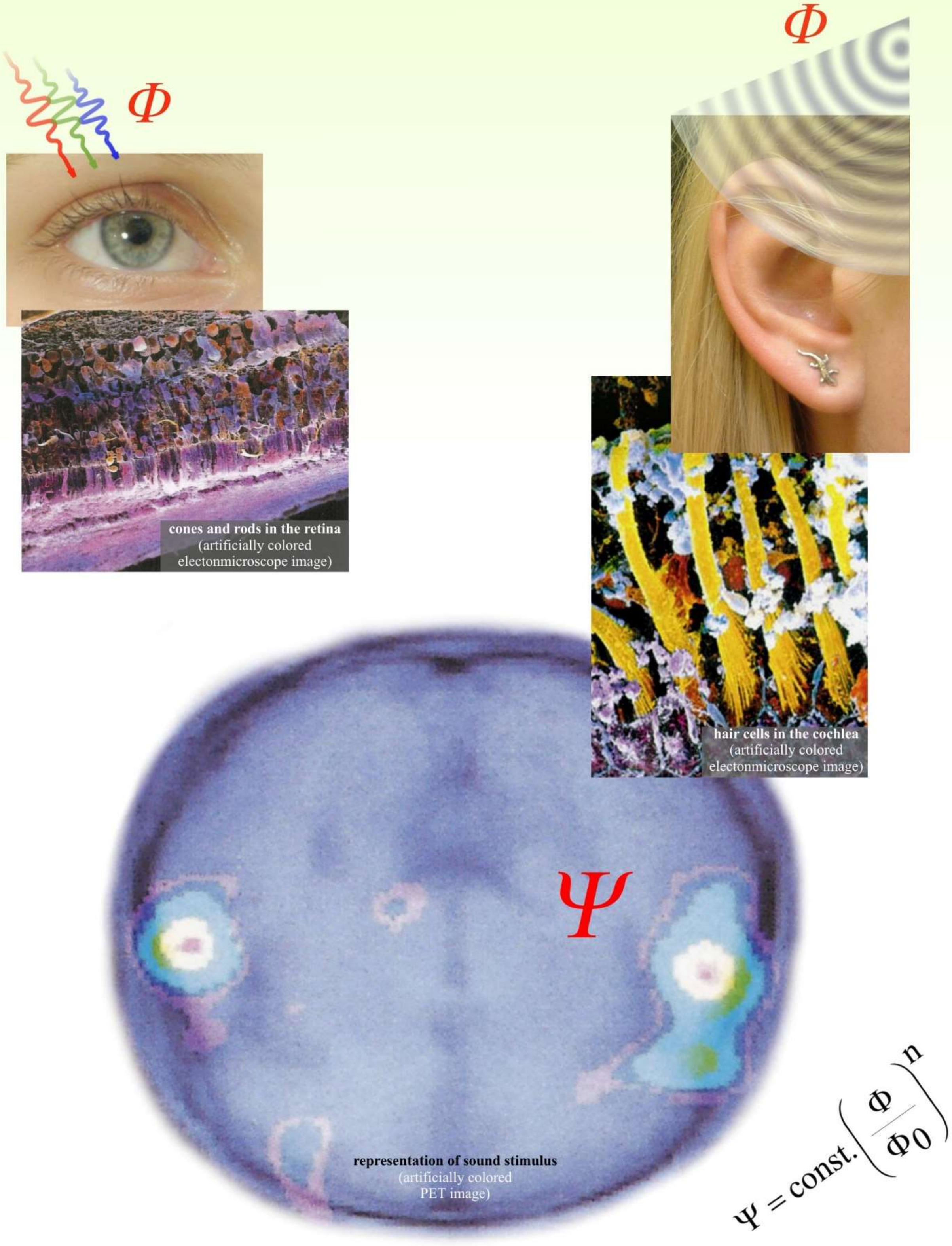
SENSOR

MODEL OF THE SENSORY FUNCTION (PERCEPTION OF LIGHT)

VERIFICATION OF THE STEVENS LAW BY LOUDNESS MEASUREMENT



cones and rods in the retina (artificially colored electonmicroscope image)

hair cells in the cochlea (artificially colored electonmicroscope image)

representation of sound stimulus (artificially colored PET image)

SUMMARY

STIMULUS: An effect on a living organism that evokes some response.

SENSATION: A response to stimuli perceived and recognized by the central nervous system.

SENSORY SYSTEM: Relays the stimulus towards the central nervous system (CNS) where sensation takes place.

RECEPTOR CELL: A specific sensitive cell that receives the stimulus and converts it into receptor potential (a kind of an electric potential).

RECEPTOR POTENTIAL: Local (non-propagating) change of membrane potential of the receptor cell. Its amplitude depends on the stimulus intensity.

DYNAMIC COMPRESSION: In the case of weak stimuli, the relative change of the receptor potential is greater than in case of strong stimuli.

DYNAMIC EXPANSION: In the case of weak stimuli, the relative change of the receptor potential is less than in case of strong stimuli.

SENSORY NERVE: A nerve fiber (bundle) that connects a receptor cell to the CNS. It transmits a series of action potentials to the CNS if it is exposed by a receptor potential above the threshold.

ACTION POTENTIAL: A series of short electrical voltage pulses rapidly propagated along the sensory nerve. Its amplitude remains constant during propagation, and the information is encoded by the repetition rate.

AMPLITUDE CODING: The information in the signal is encoded by the magnitude – amplitude – of the signal.

FREQUENCY CODING: The information in the signal is encoded by the frequency of the signal sequence.

WEBER-FECHNER'S LAW: A logarithmic relationship between relative stimulus (ϕ/ϕ_0) and sensation (Ψ): $\Psi = k \cdot \lg(\phi/\phi_0)$, where k is a number specific to the type of sensation.

STEVENS' LAW: A power relationship between relative stimulus (ϕ/ϕ_0) and sensation (Ψ): $\Psi = l \cdot (\phi/\phi_0)^n$, where l and n are numbers specific to the type of sensation. For example, for loudness $n = 0.3$, and for light sensation $n = 0.5$.

In this laboratory practice *we will study and verify the basic psychophysical law describing the relationship between stimulus and sensation. We will learn the transducing and signal-processing function of the sensory system. At first, we will work with the simplified electric model of the eye as a light sensor at the level of* ***receptor potential*** *and* ***action potential*** *("in vivo" measurement is hard to implement at this level). Thereafter we will execute "in vivo" experiments to quantify the relationship between stimuli and sensations. We will compare the subjective loudness sensation to the intensity of the sound stimulus and the sensation of weight to the real weight.*

Further readings:
Damjanovich-Fidy-Szöllősi:
IV/1., IV/2., IV/3.

THEORETICAL OVERVIEW I.

MODEL OF THE SENSORY FUNCTION: RECEPTOR and ACTION POTENCIAL, PERCEPTION OF LIGHT

A simplified block diagram of the sensory system of complex metazoan organisms is shown in Fig. 1. **Receptor cells** of sensory organs are **sensitive specifically** for one type of physical or chemical stimulus (e.g., light, sound, etc.). This stimulus causes a change in the resting potential, resulting in the generation of the **receptor potential**. In the case of weak stimuli, the relative change of the receptor potential could be greater than in case of strong stimuli. This enables us to perceive stimuli across several orders of magnitude with a single organ. This variation of sensitivity is called **dynamic compression** (signal compression). At the other hand, in the case of weak stimuli, if the relative change of the receptor potential is smaller than in case of strong stimuli we call that as **dynamic expansion**. The sensory nerve cell, which is connected to the receptor cell, converts the receptor potential (above a threshold) into the train of uniform electric pulses called **action potentials.** So in this case, the information is encoded not by the magnitude of the action potentials but by its frequency - this is called **frequency encoding**. Action potential reaches the sensory center of the brain, where complex processes produce the sensation. **The strength of sensation corresponds to the frequency of the action potential**.

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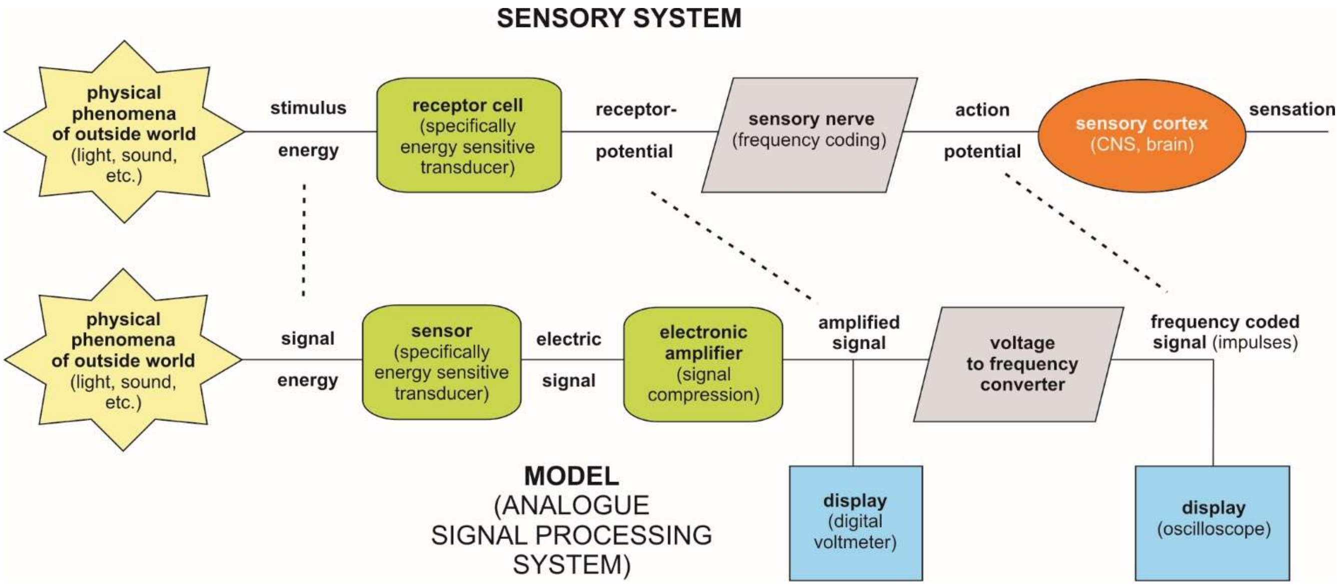

Fig. 1. *Structure of the sensory system at the level of receptor and action potentials and its corresponding electric model.*

The lower part of Fig. 1 represents the block diagram of one possible electronic model of the sensory system, which will be shown during the practice. Detailed description is given later in the light sensor model section.

THE LIGHT SENSOR MODEL and MEASUREMENT

Receptor cells of the retina are the rods and cones. The model of the photoreceptor shown here corresponds to the cones that are responsible for daylight vision.

The instrument in our measurement is a model of the retina, thus the physical signal energy is represented by light (Fig. 1, lower part). The electronic amplifier subsequent to the **photoreceptor** amplifies and compresses the electronic signal corresponding to the light stimulus. Here we can measure the signal corresponding to the **receptor potential**. The subsequent voltage-to-frequency converter generates the pulse train similar to the **action potential**. Therefore, a digital oscilloscope can show changes in the modeled receptor and action potential for changes in luminosity.

HOW THE SENSOR MODEL WORKS

The light sensor of the model equipment is a silicon photodiode located behind the input aperture (center of the iris) inside the box (Fig. 2).

In the first phase of signal processing the electric signal of the photodiode is **amplified** and **compressed** by a special amplifier (analog multiplying circuit at square root mode, that corresponds to a power function of exponent n = 0.5). Direct current of the **RECEPTOR POTENTIAL** can be measured at this stage.

In the second part of the signal processing the receptor potential is converted into a train of square pulses by a so-called **voltage-to-frequency converter**. The pulse frequency is proportional to the receptor potential at any time.

Finally, a shape-forming circuit generates a signal similar to the real **ACTION POTENTIAL**, that can be visualized on the screen of the oscilloscope.

For the sake of simplicity, the light sensor model does not include the stimulus threshold and the pain threshold characteristics, otherwise common for living systems.

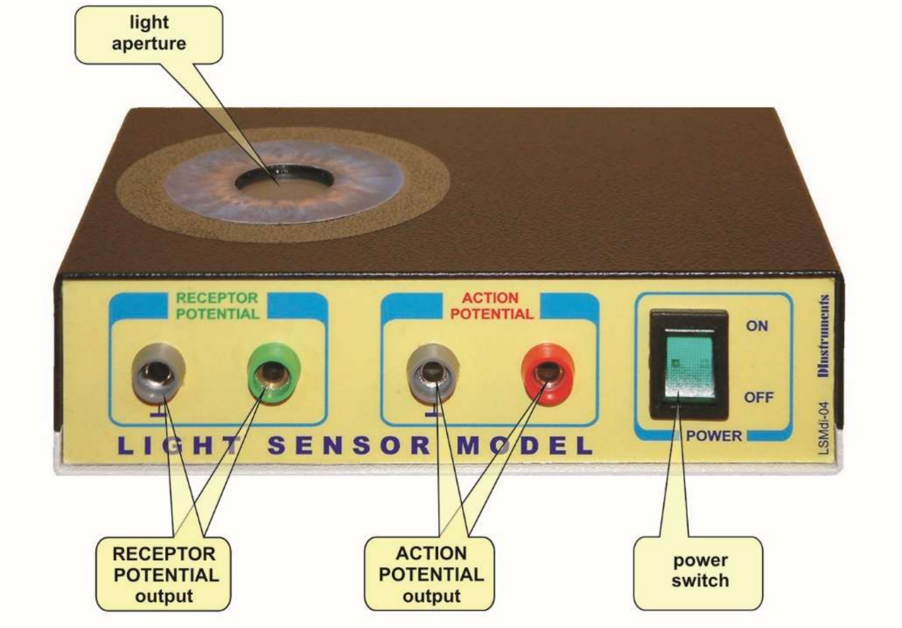

Fig. 2. *Light sensor model.*

During the measurement, we change the intensity of the stimulus - the intensity of light - and observe its effect on the modelled receptor potential and action potential. Our aim is to present and interpret the amplitude and frequency coding.

THEORETICAL OVERVIEW II.

SENSORY FUNCTION: RELATIONSHIP BETWEEN STIMULUS and SENSATION

The relationship between stimulus and sensation is described by the so-called psychophysical laws. In the following, we present two theories.

1. Weber-Fechner law: the base concept of the law is that the *relative change of the stimulus* is proportional to the *change in sensation intensity*. Thus, the **sensation intensity** (Ψ) is proportional to the **logarithm** of the **relative stimulus** (ϕ/ϕ_0):

$$\Psi = k \cdot \lg\left(\frac{\phi}{\phi_0}\right), \quad (1)$$

where k is specific parameter to a given perception mode (so called **modality**).

2. Stevens' law: the base concept of the law is that the *relative change of the stimulus* is proportional to the *relative change in sensation intensity*. Thus, the **sensation intensity** (Ψ) is proportional to the **power** of the **relative stimulus** (ϕ/ϕ_0):

$$\Psi = l \cdot \left(\frac{\phi}{\phi_0}\right)^n, \quad (2)$$

where l and n are specific parameters to a given modality.

In the following measurements, we aim to examine the validity of the two types of psychophysical law and to estimate their parameters for two modalities.

1. LOUDNESS MEASUREMENT

We will measure the relationship between the objective sound intensity and the subjective psychophysical loudness.

Items used in the experiment:
- arbitrary waveform generator in harmonic mode (sinusoidal)
- headphones

Measurement involves two people, the operator and the subject.

PLAN OF THE 1st MEASUREMENT

1. Set the generator to sine wave (**SIN**) of 1000 Hz frequency (**FREQUENCY, 1k**), and connect the headphones to the output. The operator adjusts the **COARSE** knob of the generator to 10^{-2}, and the **FINE** knob to 1. The corresponding resulting physical intensity causes the reference loudness that is "one unit". This reference should be remembered well by the subject, so let her/him listen to the sound for a long enough time, approximately 15 seconds. Repeat the reference loudness sound during the measurement if the subject asks it.

2. Subsequently, the operator carefully adjusts the amplitude to different levels according to the given table in a way that the subject does not see the actual value (**COARSE, FINE** knobs). The subject estimates the **loudness of the sound** with a **positive number in terms of the reference sound**. Accordingly, if the sound appears 10 times louder than the reference sound, then the number is 10. If the sound appears half as loud as the reference, then the relative loudness will be 0.5.
Because several measurements are performed in the classroom at the same time, it is recommended that the subject write down the estimated loudness levels rather than pronouncing them aloud. This way the background noise in the room can be minimized.
Perform 20 different loudness measurements ranging from the threshold of hearing to the loudest possible, following the given table. In this order loud and soft sounds alternate by chance. This way the errors originating from routine can be minimized.

2. WEIGHT SENSATION MEASUREMENT

It is very common in surgery, for example, to interpret the degree of adhesion on a 3 or 5-grade subjective scale during abdominal surgery. Here, the dripping or fused organs are separated by hand or surgical retractors, which is a similar effort process as the "weight lifting" performed during our measurement.

The task of the measurement is to examine the relationship between physical weight and subjective psychophysical sense of weight (lighter, heavier). Measurements show that estimating the weight of an object or the force required to move that object is not a simple task and often very misleading.
Items used in the experiment:

— For each pair of students, seemingly identical plastic jars of different weights.

During the measurement, everyone measures and records individually. Couples must not look at the other's estimations as this may affect the result of the measurement.

Fig. 3. *Weight sensation measurement. Proper holding of jars.*

PLAN OF THE 2^nd^ MEASUREMENT

1. Grab the box labeled "R" (Reference) from the weight series and lift it with one hand. Be careful to *hold the box from the side* (do not place it on the palm of your hand or hold it from above - see Fig. 3).
2. Use the other hand to lift up a numbered box and estimate how many times lighter or heavier than the Reference jar is, similar to loudness measurement. Where there are two numbers in the measurement table, the two boxes marked with the number should be stacked and with the lower one held up.

EVALUATION OF DATA (1st and 2nd measurements)

For loudness measurement at first the *course* and *fine* setting values have to be multiplied (U [rel.unit] = U_{coarse} [rel.unit] · U_{fine} [rel.unit]) to get the signal amplitude, then we take the square of it, because the square of the amplitude is proportional to the intensity (the stimulus in our case).
For weight measurement, the weights of jars are given after the measurement.

Evaluation is similar in both cases:
1. Calculate the relative stimulus intensity.

2. Plot the estimated value of sensation as a function of relative stimulus intensity.

3. Add a logarithmic and a power function to the graph and examine which law gives better correlation.

4. Determine the parameters of the functions.