C5 What functions does the skin have? – The skin as a sense organ

The suggested experiments can be carried out by up to eight groups of students. They are particularly suitable as an introduction to the sense of touch from a sensory-physiological point of view. These instructions provide notes for linking the experiments to the curriculum and ideas for further study.

1 Main question

The question of the skin's functions is answered by means of three subexperiments relating to the sensations of touch and temperature.

- In subexperiment 1, students experience with their own bodies that different areas of the skin have different degrees of sensitivity to touch. The students are already familiar with individual variations in skin sensitivity from everyday experience – for example, the way some people are ticklish in specific areas of their bodies while other people are less so.
- Subexperiments 2 and 3 deal with the function of thermoreceptors. Subexperiment 2 illustrates how the number of heat and cold receptors in a specific area of skin differs. Subexperiment 3 demonstrates how the skin does not register absolute temperatures, but only temperature differences. We apply this phenomenon in our day-to-day lives, for example, when we take a cold shower before jumping into a swimming pool so that the water in the pool will feel warmer.
  Subexperiments 2 and 3 also require that students follow a correct methodology, for example, by preparing water at specific temperatures and systematically "processing" the surface of the skin on the back of the hand.

2 Integrating the experiment into the teaching context

2.1 Basic principles

2.1.1 Structure of the skin

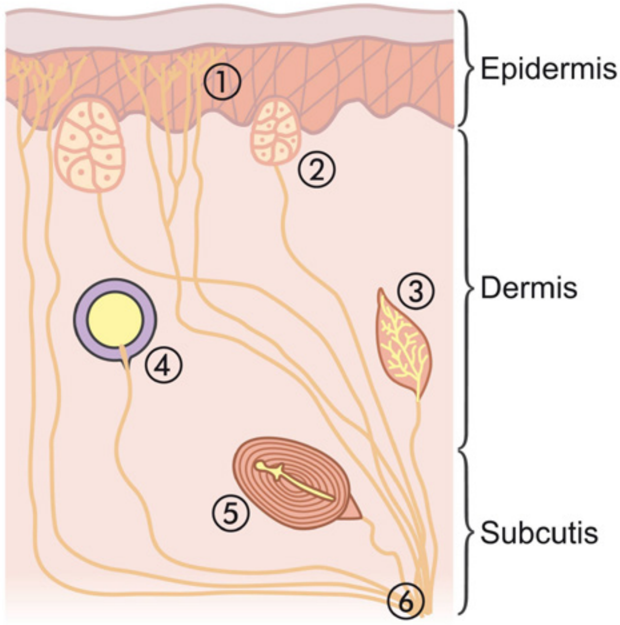
With a total surface area of 1.5 to 2 m^2, the skin is the largest organ of the human body.
It fulfills several functions. The skin …

- is an important sense organ for perceiving cold, heat, touch, pressure, and pain.
- regulates body temperature (by changing the diameter of blood vessels and secreting sweat).
- protects the body from harmful environmental influences (radiation, germs, mechanical influences, etc.).
- stores fat.
- secretes substances (sweat, oil).
- indicates emotions (turns pale, blushes, etc.).

Skin can be roughly divided into three layers:

- Epidermis
- Dermis
- Subcutis

The nerve endings and receptors that react to pain, pressure, and temperature are each located in specific layers of the skin.



① Pain receptor (free nerve endings)
② Meissner's corpuscle (tactile corpuscle)
③ Heat receptor
④ Cold receptor
⑤ Vibration receptor (Pacinian corpuscle)
⑥ Sensory nerve fibers

Fig. 1: Skin receptors.

2.1.2 Sensors in the skin

- **Free nerve endings:** These receptors can sense pain, itch, and tickling. Because pain sensitivity is especially important for survival, free nerve endings extend into the epidermis to enable people to experience ideally all pain stimuli. One cm^2 of skin contains up to 170 free nerve endings. This explains why – other than areas covered by thick calluses – there are no areas of skin where the surface is impervious to pain. The areas that are insensitive on the surface have deeper pain receptors that react to substances released when tissue is damaged.
- **Meissner's corpuscles (tactile corpuscles):** These receptors react to changes in pressures and thus to light touch and shear forces. They are especially numerous in the fingertips and the oral mucosa, i.e., places where we do the most testing of objects and substances in the environment. They are less numerous on our backs. Meissner's corpuscles provide information on the surfaces of objects, which is the basis for subexperiment 1. There are other types of tactile corpuscles.
- **Cold receptors:** These receptors are located in the upper region of the dermis and are responsible for the perception of cold. Unlike a thermometer, they are incapable of measuring absolute temperatures and can perceive only temperature differences. They react to a drop in temperature and trigger a sensation of cold, and are most sensitive at ambient temperatures of around 25 °C. On the back of the hand, there are up to eight receptors per cm^2 of skin; in contrast, there are up to 20 receptors per cm^2 on the tongue.

- **Heat receptors:** These receptors are also located in the dermis. They react to a rise in temperature and are thus involved in sensing heat. On the back of the hand, there is less than one receptor per cm^2 of skin on average. Overall, there are few fewer heat receptors than cold receptors.
- **Frequency encoding of nerve signals:** Both types of thermoreceptors are constantly sending impulses to the brain. The particular receptors transmit an impulse to dendrites of the subsequent nerve cell. The impulse passes through the cell body to the axon, which conveys it to the end-bulbs. From there, a transmitter transfers the impulse to the adjacent cell. In this way, the information makes its way to the brain. The frequency of the impulses depends on the temperature. Heat and cold receptors change the impulse frequency in response to cold and heat stimuli: cold receptors send more action potentials per unit of time as the temperature decreases. Heat receptors do the opposite, i.e., they send more action potentials as the temperature increases. After a certain amount of time, the frequencies of the action potentials sent by cold and heat receptors adjust to the prevailing temperature. No additional temperature change is perceived until there is another change in temperature (in subexperiment 3, when both hands are submerged in the middle bowl containing lukewarm water). At this point, more action potentials are sent and the receptors in the “warm hand” register cold water while those in the “cold hand” register warm water.
- **Vibration receptors (Pacinian corpuscles):** These receptors are involved in sensing fast vibrations and react to changes in the shape of the skin. They’re mostly located in the transitional area between the dermis and the subcutis.

2.1.3 Relating the experiments to students’ own experience and integrating them into the curriculum

Students up to 12 to 14 years of age generally think of “skin” as a homogeneous layer that surrounds the body. They are unaware of its multilayer structure. Often it is not until they begin using skincare products and cosmetics that adolescents start to pay more attention to the structure and function of their skin. A meaningful part of instruction might be to counteract the partial information and half truths of the industry with knowledge of the extremely diverse functions of the skin, which is more than just a surface for applying cosmetics.
The experiments can be used in two ways: Either as simple demonstrations without any previous knowledge on the part of the students in order to elicit their questions (“Why is it so easy to feel differences in sandpaper here and so hard there?” “Why does the water feel cold to one hand and warm to the other?”). In this case, the experiments can serve as a basis for further study of the structure of the skin.

Or the class can learn about the structure and functions of skin layers beforehand so that students will already be familiar with the three-layer structure and the existence of different sensory receptors in the skin. The experiments then serve to clarify or apply theoretical knowledge that they’ve already acquired.

2.2 Relevance to the curriculum

Depending on how the experiments are integrated into the teaching context (see 2.1.3), they are suitable for students aged 12 and up or aged 15 and up. Detailed knowledge of how the different pressure and thermoreceptors function and of their neurological dependencies is reserved for the older age group. The contents are relevant only for biology class.

Topics and terms: epidermis, dermis, subcutis, sensitivity, receptors, pain receptors, Meissner's corpuscles (tactile corpuscles), cold receptors, heat receptors, vibration receptors (Pacinian corpuscles), free nerve endings, action potentials, dendrites, cell bodies, axons, end-bulbs, transmitters

2.3 Skills

The students will …

- learn the three-layered structure of the skin.
- be able to name the structures in the human skin that are responsible for the perception of tactile and thermal stimuli.
- safely organize the necessary apparatus and materials in preparation for the experiment.
- color-code heat and cold receptors on the skin.
- determine the number of heat and cold receptors in a defined area of skin.
- describe changes in heat and cold sensations over the course of an experiment.
- determine the duration of specific temperature sensations on both hands.
- explain the occurrence of seemingly contradictory temperature sensations on both hands.
- compare their results with those of other students.

2.4 Explaining the experiment in the teaching context

2.4.1 Subexperiment 1: How does the skin react to touch?

This subexperiment demonstrates that the number of tactile corpuscles differs depending on the skin area. Whereas the fingertips and lips are highly sensitive to touch, the skin on the back is less so. At the same time, there are individual variations among different test subjects. By conducting the experiment in two rounds, the students can discover which skin regions are able to distinguish only coarser differences (60 and 120 grit sandpaper) and which can perceive finer differences (80 and 100 grit sandpaper) (also see 3.1)

2.4.2 Subexperiment 2: How does the skin perceive cold and heat?

Students learn that the concentration of cold receptors on the back of the hand is much higher than the concentration of heat receptors. It is interesting for them to learn on their own bodies that cold and heat are not perceived by the skin as a whole; rather, there are very specific points where these sensations can be felt.

Fig. 2: Sample result from subexperiment 2.

2.4.3 Subexperiment 3: How does the skin distinguish between different temperatures?

Subexperiment 3 proves that cold and heat receptors do not register absolute temperatures, but only temperature differences. At the beginning of the experiment, both the heat receptors on the left hand and the cold receptors on the right hand are sending increased action potentials to the brain. Following an adjustment period (within a range of minutes), the heat and cold receptors adapt. When the hands are then submerged into the mixture of hot and cold water in the middle bowl, both hands detect a new temperature difference. The action potentials from both hands increase once again and generate sensations of heat and cold, respectively. Because the thermoreceptors convey temperature differences rather than absolute temperatures, the mixed water feels cold to the previously warm hand and warm to the previously cold hand.
The temperature sensation of the hand that was in the warm water persists longer than that of the "cold" hand, firstly because hands have more cold receptors, and secondly because cold receptors adapt more quickly than heat receptors. In evolutionary terms, cold seems to pose a greater threat to humans than heat.

2.5 Experimental variations

The three subexperiments are suitable for work in pairs. They can also be conducted in the context of learning at stations. However, note that subexperiment 2 requires a certain amount of concentration on the part of the test subject, so the possibility of distractions coming from other students should be kept to a minimum.
As a supplement to subexperiment 1, a simple experiment can be used to discover the distance between tactile sensors. A student carefully places the two points of an unbent paper clip on the skin of the test subject and gradually brings them closer and closer together to determine at what point the test subject feels only one point of contact, i.e., can no longer distinguish between the two separate sensations. The results of this experiment will vary widely depending on the region of the body (see 2.1.2).
To save classroom time, subexperiment 2 can be limited to a specific area of the back of the hand. In this case, the test subject first outlines an area of, for example, 3 x 3 cm (nine squares of 1 x 1 cm each) on the back of their hand. The nine squares can then be "processed" systematically.
The more extreme the temperature difference between the two bowls of water, the more impressive subexperiment 3 will be.

3 Additional information on the experiment

You will find additional media for preparing or for further study of this experiment on the Siemens Stiftung Media Portal:
https://medienportal.siemens-stiftung.org

4 Notes on conducting the subexperiments

4.1 Facilities

The experiments can be carried out in any classroom.

4.2 Time required

	Preparation and execution	Analysis, questions
Subexperiment 1	20 min.	15 min.
Subexperiment 2	30 min.	15 min.
Subexperiment 3	10 min.	15 min.

4.3 Safety aspects

The students may conduct the experiments only in the presence and under the supervision of the teacher. The teacher is to point out to the students that the provided materials may be used only according to the respective instructions.
For these experiments, watch out for the following potential dangers and make your students aware of them:

- Working with a flame can result in burns or fires. Before a lighter is used for the first time, the teacher must check that it is working properly and, above all, adjust the flame height.
- For subexperiment 2, be careful that the nail does not become too hot or it may cause injury.
- Make sure that no damage can occur to water-sensitive materials and apparatus.
- The students should have as much space as possible on their tables in order to avoid accidental spillage of water during subexperiments 2 and 3.
- For subexperiment 3, make sure the water in the hot-water bowl (left-hand bowl) does not exceed 45°C, to prevent scalding. Use the thermometer!

4.4 Apparatus and materials

Required materials that are not supplied, for each student group:

- Cloth or scarf to be used as a blindfold
- 1 small bowl for dipping a nail in (ice-)cold water
- 3 large bowls for filling with water and submerging hands
- Hot (approx. 45°C) and cold water, ice cubes if desired
  If the warm water does not come from a tap in the classroom, the teacher must prepare it in an electric kettle and distribute it at the correct temperature.
- 1 blue and 1 red felt-tipped pen
- 1 towel for drying hands
- 1 watch
- 1 lighter (if possible, a gas igniter) or matches

Supplied:

The apparatus and materials supplied are sufficient to allow **eight** groups of students to conduct the experiments simultaneously.

Safety-relevant materials and apparatus must be tested for proper functioning before being handed out to the students.

The following materials included in the kit are needed for **one** group of students:

Material	Quantity
Bowl, plastic	1x
Digital thermometer*	1x
Nail (steel, “iron”)	1x
Sandpaper, 60, 80, 100, and 120 grit	1 sheet each
Scissors	1x
Tea light	1x

*Remove the plastic sleeve before the first use. Press the “on/off” button to turn on the thermometer. After completing the experiment, turn off the thermometer again (press “on/off” again). Press the “°C/°F” button to switch between the Celsius and Fahrenheit temperature scales.

Fig. 3: Apparatus and materials supplied for one group of students.

4.5 Cleanup, disposal, and recycling

All apparatus and nearly all materials from the kit can be reused. Therefore, after the students have completed the respective experiment, they should put the apparatus and materials back in the appropriate boxes and return them to the kit. This practice will ensure that you and your colleagues will find everything again quickly the next time the kit is used.
Apparatus that become dirty during the experiment, such as cups, bowls, spoons, and test tubes, should be cleaned before being returned to the kit. We recommend that you have the students do this immediately after they have completed the experiment.
Also make sure that the apparatus are in working order for the next time. For example, recharge used accumulators immediately. (It makes sense to charge the accumulators even if they will not be used for an extended period.)
Materials that cannot be reused, such as used pH test strips and filter paper, should be disposed of properly.
The waste that accumulates during this experiment can be disposed of in the regular trash or poured down the sink.