

In press in *Proceedings of the Association for Biology Laboratory Education (ABLE)*, 2004

Touch and Temperature Senses

by

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Biographical:

Charlie Drewes received a BA in biology from Augustana College (SD) and his MS and PhD in zoology from Michigan State University. Currently, he is a professor in Ecology, Evolution and Organismal Biology at Iowa State University. His research focus is on rapid escape reflexes and locomotion, especially in oligochaete worms. Charlie teaches courses in invertebrate biology, neurobiology and bioethics. During summers, he leads hands-on, residential workshops for high school biology teachers at Iowa Lakeside Lab. In 1998, he received the Distinguished Science Teaching Award from the Iowa Academy of Science and, in 2002, he received the Four-year College Biology Teaching Award from the National Association of Biology Teachers.

Abstract:

This investigation focuses on the sensory biology of human touch and temperature reception. Students investigate quantitative and qualitative aspects of touch-sensory functions in human skin. Values for two-point discrimination are compared to Weber's original data. Also, novel materials and methods are introduced for investigating the functional organization of cold sensory reception in human skin, including: (a) estimation of sensory field size for single cold-sensory fibers, (b) demonstration of the discontinuous distribution of cold-sensory fibers in skin, and (c) estimation of the density of cold-sensitive fibers per unit area of skin. Tactile and thermoreceptor functions are related to underlying neuroanatomy of peripheral and central neural pathways.

Keywords:

Sensory perception, sensory discrimination, mechanoreceptors, thermoreceptors, sensory fields

Running title: Temperature senses

Contents:

General Introduction	3
A. Two-point Discrimination of Touch	6
B. Tactile Localization	7
C. Mapping Temperature Receptors	8
D. Can One Temperature Stimulate Both Cold and Warm Receptors?	11
References	12
Appendix A. Data Sheet for Two-point Threshold Distance	13
Appendix B. Two-point Threshold Values from E. H. Weber's <i>De Tactu</i>	13
Appendix C. Data Sheet for Error of Localization	14
Appendix D. Data Sheet for Cold Point Testing	14

General Introduction

All the sights, sounds, odors, tastes, touch, and other stimuli that we sense in the world around us are detected by special kinds of cells called sense cells. Some sense cells (such as those that detect light) are grouped together to form a sense organ (as the retina of the eye). Other sense cells, such as those that detect touch and temperature, are not grouped into organs but rather they are arranged as separate sensory neurons (Sinclair, 1981; Smith, 2000). The cell bodies of these neurons are located in the dorsal root ganglia near the spinal cord. One branch from each neuron extends into the spinal cord and another extends to the skin, where it branches into tiny terminal endings called receptor endings. Receptor endings from any given sensory neuron are highly sensitive to just one type of stimulus, such as touch. Endings from other neurons are sensitive to other stimulus types, such pressure, heat, or cold, etc. (Figure 1)

Once a touch stimulus is detected by receptor endings in the skin, the neuron responds by initiating electrical impulses (action potentials) that are carried into the spinal cord. Impulses are then relayed to other neurons in the spinal cord and to the thalamus of the brain. From there, the impulses are transmitted to neurons in the somatosensory cortex of the cerebrum (see Figure 2).

It is important to remember that although detection of touch occurs at the receptor endings in the skin, the actual process of perception (that is, conscious realization or awareness) of the stimulus occurs only when certain neurons in the somatosensory cortex of the brain receive the incoming sensory impulses from that part of the body. Furthermore, each part of the body has a corresponding part of the brain devoted to perceiving its touch. As a result, there is a very specific organization of the somatosensory cortex in which the body surface is represented in an upside-down fashion on the surface of the cortex (see Figure 2). Note in these illustrations that some body parts have a greater brain space devoted to the perception of their touch than other parts. For example, large areas of the cortex are devoted to the perception of touch in very sensitive areas, such lips and fingers.

A person's sensitivity to tactile stimulation of the skin may vary, depending on which part of the body is stimulated (Weber, 1978). For example, high sensitivity to touch occurs in areas of the skin such as lips and fingertips. High sensitivity results from two factors: (1) the large brain space devoted to perception of touch in those skin areas, and (2) the high density of touch sensory nerve fibers and receptor endings in those particular skin areas. In contrast, low sensitivity to touch in other areas of the body, such as the trunk and back, results from less brain space in the cortex and a lower density of sensory fibers and receptor endings.

Touch sensory nerve fibers show rapid sensory adaptation to a constant touch stimulus. It is important that touch sensory fibers respond in this way so that we are not distracted by constant

touch stimuli that are otherwise unimportant. For example, although we perceive the touch of our clothes as we put them on or move, we do not feel them once they are on and we are motionless.

This laboratory investigation will focus on the physiology and psychophysics of touch and temperature receptors in human skin. Both quantitative and qualitative features of receptor functions will be explored. The investigation is intended for introductory-level biology or for basic courses in human biology or human physiology.

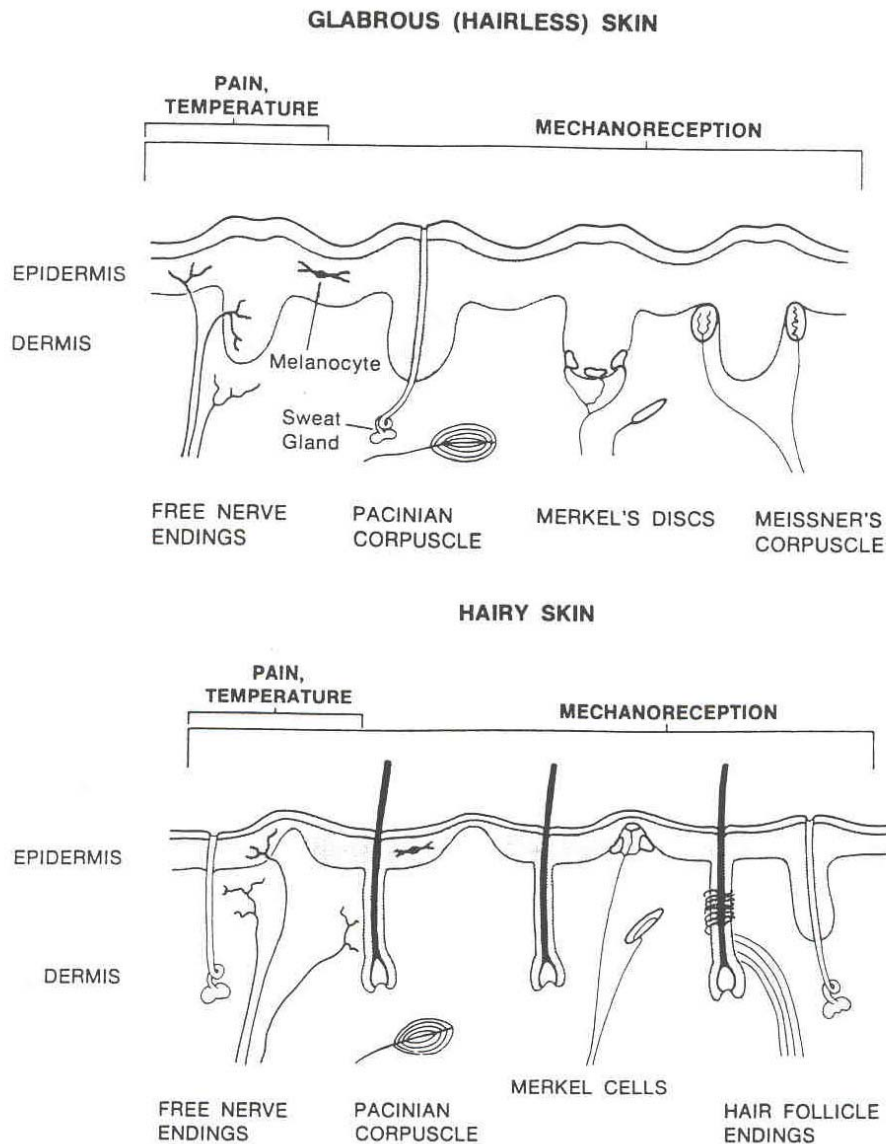


Figure 1. Several types of sensory fiber endings in glabrous and hairy skin of humans.

Depending on author (Patton, 1976; Guyton, 1991; Schmidt, 1986; Smith, 2000), there are various categories of sensory fibers (see Figure 1). These categories often include:

- *Free nerve endings.* Some free nerve-endings are touch-sensitive (mechanoreceptors), while others are strictly pain-sensitive (nociceptors). Still other free nerve endings are temperature-sensitive (thermoreceptors) and these may be either cold-sensitive or heat-

sensitive. Free nerve endings are commonly found in hairy and smooth (glabrous) skin, cornea of the eye, pulp of teeth, mucous membranes, and many other locations.

- *Pacinian corpuscles*. These nerve fiber endings are encapsulated and sensitive to pressure and vibration stimuli.
- *Merkel's discs/Merkel's cells*. These fibers are sensitive to touch and pressure. They are important in localizing touch sensation to different areas of the body. These are found in hairy and smooth skin.
- *Meissner's corpuscles*. These fibers are very sensitive to touch. They are abundant in smooth skin of toes, fingertips, palms, and soles of the feet. They are very important in touch localization and texture discrimination.
- *Hair follicle endings*. These fibers are very sensitive to hair displacement.

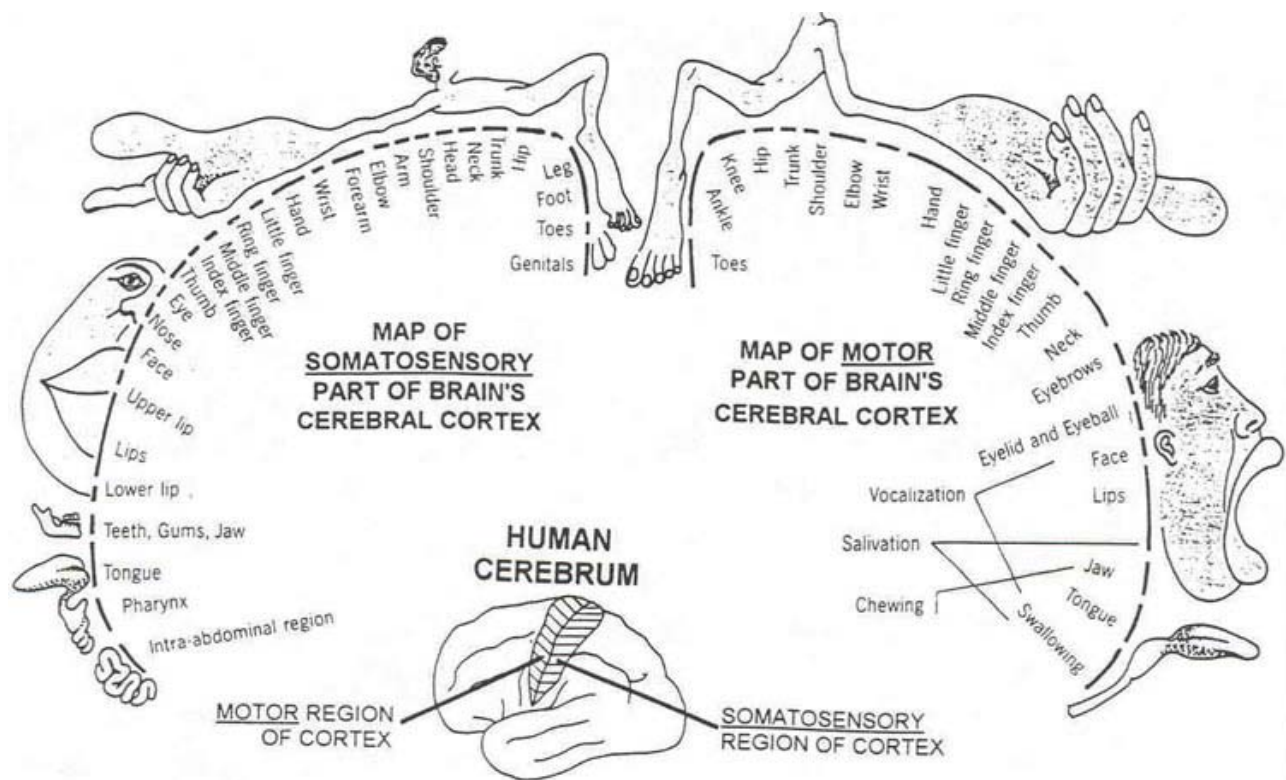


Figure 2. The small diagram in the center shows locations of the somatosensory cortex and motor cortex of the left side of the human cerebrum. The two larger semi-circles show expanded maps of the sensory cortex and motor cortex of the cerebrum. The relative size and position of brain spaces that are devoted to various body parts are indicated on the maps as corresponding pictures and names of body parts. Note that very large regions of the cerebral cortex are devoted to sensory and motor functions of the face and fingers.

A. Two-point Discrimination of Touch

In order for touch at two separated points on the skin to be perceived and discriminated by the brain as two distinct stimuli, the following prerequisites must be met:

- 1) in the skin, *stimulation of at least two spatially separated touch sensitive nerve endings must occur*. This is more likely to happen if the touch stimuli are widely spaced and if the two stimuli occur in sensitive areas of the skin innervated by many touch-sensory endings per unit area. Perception of two stimuli is less likely if the two stimuli are closely spaced or if stimuli are in insensitive areas of skin innervated by few touch-sensory endings.
- 2) in the spinal cord and brain, nerve impulses triggered by the two stimuli must be carried in two separate pathways, resulting in activity in two separate locations in the somatosensory cortex. Such spatial separation of sensory structure and function in the spinal cord and brain is a key feature underlying our ability to discriminate or resolve separate points of touch.

Materials

- Calipers with bristles attached
- Ruler with mm scale
- Data Sheet for Two-point Threshold Distance (Appendix A)

Procedure for two-point discrimination

1. Work in groups of two or three, with one person being the *subject* and the other(s) being the *examiner* and the *data recorder*. The subject should be seated with eyes closed.
2. Start with the tips of the caliper bristles about 80 mm apart. The examiner should lightly touch the two bristle tips, at the same instant, to the back of the subject's hand. The subject should state whether he/she perceived the touch as a single point or as two separate points.
3. Reduce the spacing between bristles by 10 mm and repeat step 2. Repeat testing again and again using a gradually smaller spacing each time. Occasionally, and without the subject's knowledge, the experimenter should touch the subject with only one bristle. This will help prevent the subject from knowing (or second-guessing) whether or not a double-point stimulus was always delivered.
4. Eventually, a critical distance between the two bristles will be found that the subject consistently reports as one point rather than two points. This is the *two-point threshold distance* for that particular body region in the subject. Find this value in mm for the back of the hand and record it on the Data Sheet.
5. Now move to the next area of the body, as listed on the Data Sheet and repeat steps 2 through 4. Depending on the area being tested, you may need to begin with smaller spacing. Also, when testing body areas with small two-point threshold distances, it is advisable to use

relatively small changes in bristle spacing for each test (1 mm change, for example). Report values to the nearest mm.

6. Switch roles and repeat the stimulus testing and data collection procedures for each subject.

Questions and analysis relating to two-point discrimination

1. Assuming that small, two-point threshold distances are associated with high densities of touch sensory endings, which body areas seem to have the highest density of touch sensory endings?
2. Which areas have the lowest density of sensory endings? Compare your two-point threshold values to reference values shown in Appendix B. These values were obtained by the famous German physiologist, E. H. Weber (1795-1878), who is considered to be the “father of psychophysics.”
3. Explain why it would be advantageous to an animal's survival to have different touch receptor densities in different regions of the body.
4. Using your data, try to predict the density of touch receptor endings in the following areas: lips, thigh, back, toes, and forehead. List these in order, starting with the least sensitive.

B. Tactile Localization

Tactile localization is the ability to relocate (by memory) a spot on the skin that has just been touched. Generally, the ability to accurately relocate the stimulus site increases in body areas with the greatest density of touch sensory endings and the greatest amount of brain space devoted to that body area.

Materials

- Stiff brush bristle
- Metric ruler
- Data Sheet for Error of Localization (see Appendix C)

Procedure for tactile localization

1. Work in groups of two to three, with one person as “subject’ and the other(s) as ‘examiner’ and ‘data recorder.’ The subject should be seated with eyes closed and his/her hand resting, motionless on a flat surface.
2. The examiner then positions the bristle tip over a selected point on the palm and touches that point so that the subject feels it. [IMPORTANT: The experimenter must keep track visually of the exact point where the touch was made, but not let the subject see or know.]
3. Next, give the bristle to the subject and, with eyes now open, have the subject touch the spot where he/she thinks the touch was made. The subject should hold the probe in that spot.

4. Measure and record the distance in mm between the spot of the original touch, selected by the experimenter, and the relocated spot, selected by the subject. Record this result (to the nearest mm) as the “error of localization” for trial 1 on the Data Sheet for Error of Localization (see Appendix.C)
5. Repeat steps 2-4 three times (same body region). Then, calculate an average error of localization.
6. Now, repeat the procedure and obtain an average error of localization for the fingertip and for the inside of the forearm.
7. Switch roles and repeat the procedure for a different subject.

Questions and analysis relating to tactile localization

1. Which area(s) had the lowest average error of localization?
2. Did areas with low average error of localization also have small two-point thresholds? Why would you expect these two results to coincide closely?

C. Mapping Temperature Receptors

Besides touch sensory nerve fibers, skin contains thermosensory fibers with receptor endings that are highly sensitive to temperature (Sinclair, 1981; Smith, 2000). Some thermosensory fibers specifically respond to warmth (warm receptors); others respond to cold (cold receptors). Endings for cold-sensitive or warm-sensitive nerve fibers are located just beneath the skin surface.

The terminals of an individual temperature-sensitive fiber do not branch profusely or widely. Rather, the endings of each fiber form a small, discretely sensitive point, which is separate from the sensitive points of neighboring fibers. The total area of skin occupied by the receptor endings of a single temperature-sensitive nerve fiber is relatively small (~ 1 mm in diameter). In addition, the density of these thermo-sensitive points varies greatly in different body regions. For example, there are up to 15-25 cold points per square centimeter in the lips, 3-5 cold points per square centimeter in the finger, and less than 1 cold point per square centimeter in some broad areas of the trunk.

In most areas of the body there are three to ten times as many cold-sensitive points as warm-sensitive points. It is well established from physiological and psychological testing that warm-sensitive nerve fibers and cold-sensitive fibers are distinctively different from one another in both structure and

function. Both kinds of fibers seem to terminate as free nerve endings in the skin.

Materials

- Flexible, clear metric (mm) ruler
- Clean, white sheet of paper
- Data Sheet for Cold Point Testing (see Appendix D)
- Scissors
- Permanent marker (broad-tipped)
- Extra-fine-tipped marking pen (or fine-tipped ballpoint pen)
- Masking tape
- Roll of drywall joint tape (mesh style tape with 2 mm x 2 mm square grid openings)
- Blunt metal probes (approximately 1 mm tip diameter) with thermally insulated handles
- Large coffee can full of dry, fine sand (cooled in refrigerator)
- Large coffee can full of dry, fine sand (warmed on hotplate) [NOTE: Imbed metal ends of probes in the cool (or warm) sand for at least 10 min before testing. To stabilize sand temperature during testing, place cooled or warmed cans on an insulated surface, such as Styrofoam.]

Procedure for estimating the sensory field size for a single cold point

1. The *tester* should remove a probe from the cold sand, holding onto it by the insulated handle to reduce the rate of warming. Make sure the probe is dry and has no sand adhering to it. Even though it is insulated, the probe will warm up quickly and should be replaced in the cool sand after about a minute or two. Next, gently touch the tip of the probe to a single spot on the ventral (inside) surface of the subject's lower arm. If the subject does not immediately report a clear-cut sensation of cold, then lift and move the probe to another location, a very short distance away, until the subject reports a cold sensation. Note the precise spot where the cold was reported and, using a fine-tipped marking pen, make a small "reference" point on the cold-sensitive spot. Replace the probe, temporarily, in the cold sand.
2. Now, use the fine-tipped marking pen to make a matrix-like array of very tiny dots surrounding the reference point. Each point should be about 1 mm apart, as shown in Fig. 3.

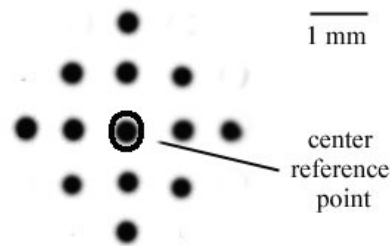


Figure 3. Matrix of dots used to estimate area of sensitivity for one cold-point.

- 3. Now, use the cold probe to touch the reference dot once again to confirm its cold sensitivity. Then, touch each dot that is adjacent to the reference dot. The idea is to determine the spatial limits of cold sensitivity for one cold point. Typically, the dimensions of a cold point will be approximately 1-2 mm across. Do your results confirm this? If so, this result will help you interpret and validate results obtained in the next section.**

Procedure for estimating density of cold points

- 1. Work in groups of two or three. One person will be the *tester*. If your group size is two, then the second person is both the subject and *data recorder* (the subject uses one arm to write with, while the other is held motionless for testing). With a group of three, the second person is subject and third person is *data recorder*.**
- 2. Cut off a 2-inch by 3-inch rectangle of drywall tape and place it flat on a piece of paper. Using the broad-tipped, permanent marker, outline the boundaries for an 8-unit by 8-unit grid, as shown in Fig. 4. Thus, an 8x8 array of squares is bounded by the marks. This array corresponds to the 8x8 grid shown on the Data Sheet in Appendix D.**
- 3. Now, carefully remove the marked drywall tape and transfer it to the ventral (inside) surface of the subject's lower arm. Make sure the entire adhesive surface of the tape is pressed flat against the subject's arm. The subject should not move his/her arm during testing. If needed, secure the edges of the drywall tape to the arm with masking tape.**

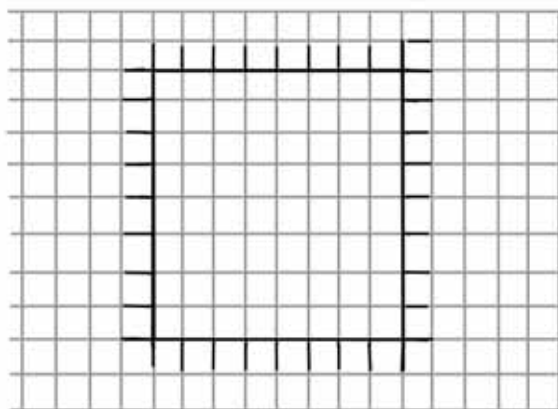


Figure 4. Short piece of drywall tape with marked 8-unit x 8-unit grid, which demarcates the 64 squares that will be tested for cold point sensitivity.

- 1. Just before your group begins testing, the *tester* should remove a cooled probe from the sand, holding it by the insulated handle to reduce the rate of warming. Though insulated, the probe warms up rather quickly, so it should be replaced in the cool sand after a few minutes.**
- 2. With the subject's eyes closed and arm resting motionless on a flat surface, the *tester* should *briefly* touch the probe tip to the upper left corner square in the 8x8 grid. After this brief touch, pull the probe away from the skin. Have the subject report whether he/she felt cold or touch. The *data recorder* should immediately record the result as a dot for touch, or C for cold, in the corresponding square of the Data Sheet for Cold Point Testing (Appendix D).**
- 3. As quickly as possible, repeat step 2 for each square, working from left to right across the first row of squares, and then doing the same for the second row, and so on, until all 64 squares have been touched. If the team is properly communicating and coordinating, only two or three probes will be needed for testing all 64 squares and this testing should take only 3-4 minutes. If testing is delayed, the probe may become too warm and it may be necessary to obtain another cold probe. If so, replace the probe in the cold source for later use.**
- 4. OPTIONAL: Test for warm points using an insulated probe that has been imbedded in warm-hot sand. Since probes will cool quickly, it is important to do all testing within one minute after a probe is removed from sand. Repeat steps 2-3, with the subject reporting whether he/she feels warm or**

touch. The *data recorder* then records a dot for touch, or W for warm, on the Data Sheet. [NOTE: To test all 64 squares in the grid, it may be necessary to use several probes. Replace used probes in the sand.]

5. Repeat the entire testing procedure for cold receptors on another subject, as _____ time _____ permits.

Questions and analysis relating to cold points and warm points

1. Measure the dimensions of the square-holes in the drywall tape. Also measure the distance from the center of one square hole to the center of an adjacent hole in the tape. Compare these dimensions to the estimated width of the cold point, as determined by procedures shown in Fig. 3. If a subject reports the sensation of cold when each of two adjacent holes is stimulated, how many cold points are likely to be involved? Explain your answer.
2. Using information from the preceding step, make your best estimate of the total number of cold points in the 8x8 grid.
3. Now, measure the length and width of the 8x8 grid area (to the nearest millimeter). Multiply the length by the width to determine *grid area*. Express the *grid area* value in units of square centimeters.
4. Next, divide the estimated number of cold points in the grid by the *grid area* to obtain an estimate of *cold point density*. Record values for cold-point density for each subject. Make sure to include correct units.
5. What percentage of the grid squares appears insensitive to cold? Do your data suggest that these *cold-insensitive* areas are sensitive to other stimuli? Explain.
6. OPTIONAL: Using procedures above, determine the number and location of warm points within the grid area. Then, estimate the density of warm points and compare to cold point locations and density.

D. Can One Temperature Stimulate Both Cold and Warm Receptors?

Many sensory nerve fibers respond well to the sudden onset of a stimulus, but then respond less, or stop responding altogether, when the stimulus remains constant. This decrease in the level of response despite continued stimulation is called sensory adaptation. One result of sensory adaptation is that our perceived

sensation of cold is greater while skin temperature is falling, as compared to when skin temperature is constantly cool. Similarly, we feel warmer when the temperature is rising as compared to constantly warm conditions. As an everyday example of thermal adaptation, the water in a swimming pool feels much colder when we first enter it, as compared to after we've been in it a while. Likewise, hot water in a tub feels hotter at first than after we've been in it a while. Thus our sensations of temperature are more influenced by *relative changes in temperature* (in one direction or the other, depending on thermoreceptor type), rather than by the absolute value of temperature.

Materials

- Three small pails, each 2/3 full of water (or deep dish pans, or aquaria)
[NOTE: Water temperatures are adjusted as follows: container-A ~ 10° C, container-B ~ 45° C, container-C ~ 21° C (room temp)]
- Towel
- Crushed ice and/or hot plate, if needed and desired

Procedure

1. Place the pails in the following order on a table (left to right): cold, room, and warm.
2. Have the subject place one hand in warm water and the other in cold water for 1 minute.
3. After one minute, the subject should place both hands in the center container (room temperature) and immediately report the sensation in each hand.
4. Does the sensation change after keeping both hands in room temperature water for 1 min?

Questions relating to thermal adaptation

1. What temperature change occurred and what thermoreceptors were stimulated when the left and right hands were initially placed in the cold and warm water tanks, respectively.
2. Explain what temperature change then occurred in each hand when it was then moved to the center container at room temperature.

3. Which sensory receptors most likely respond when the left hand is put in the center container? Which receptors respond when the right hand is placed in the center container?

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Appendix A. Data Sheet for Two-point Threshold Distance

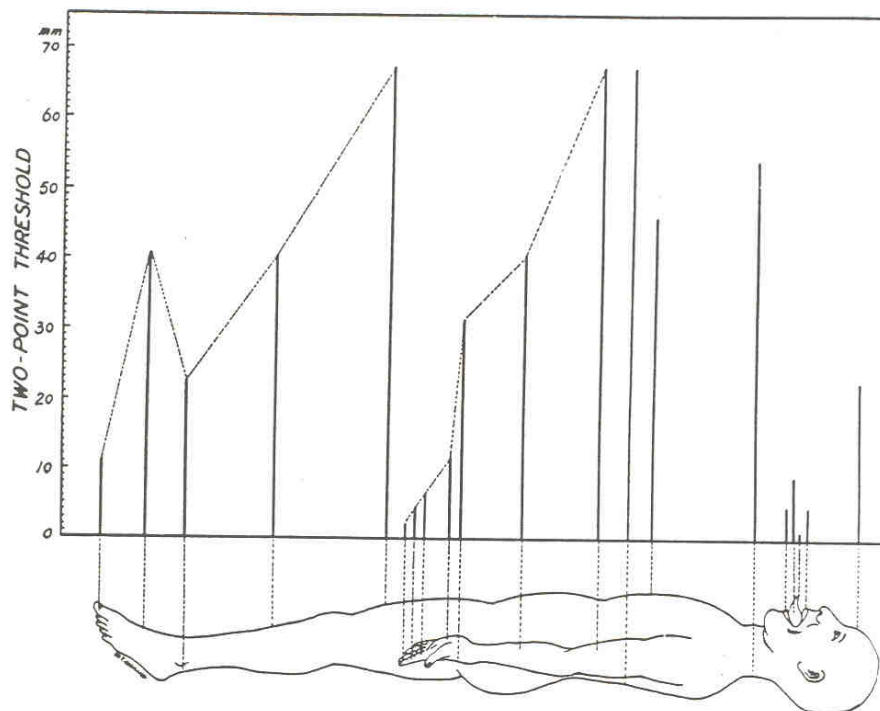
Record threshold distance in millimeters (mm).

Body area tested	Subject 1	Subject 2	Subject 3	Subject 4	Mean
Back of hand					
Palm of hand					
Index fingertip					
Forearm (non-hairy surface)					
Upper arm (outer surface)					
Shin					
Back of neck					

Appendix B. Two-point threshold values from E. H. Weber's *De Tactu*, 1834

Values below are converted from original units (Paris lines) to millimeters.

tip of tongue	2 mm	midback	29 mm	back of knuckles	16 mm
lower lip	4 mm	lower shoulder blade	61 mm	tip of 2nd finger	1 mm
upper lip	4 mm	side of chest	34 mm	front mid thigh	41 mm
tip of nose	7 mm	mid front of back	40 mm	mid shin	27 mm
skin on cheekbone	18 mm	side of stomach	47 mm	mid calf	40 mm
mid forehead	22 mm	mid upper arm	36 mm	Foot top surface	27 mm
ear	20 mm	forearm underside	23 mm	sole of big toe	13 mm
back of neck	27 mm	palm of hand	13 mm	tips of toes	9 mm



Adapted from Weber, 1978.

Appendix C. Data Sheet for Error of Localization

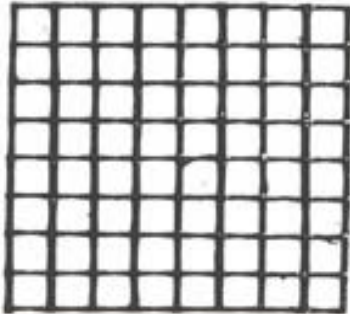
Record threshold distance in millimeters (mm).

Palm of hand				
	Trial #1	Trial #2	Trial #3	Average Error
Subject 1				
Subject 2				
Subject 3				
Fingertip				
	Trial #1	Trial #2	Trial #3	Average Error
Subject 1				
Subject 2				
Subject 3				
Inside of forearm				
	Trial #1	Trial #2	Trial #3	Average Error
Subject 1				
Subject 2				
Subject 3				

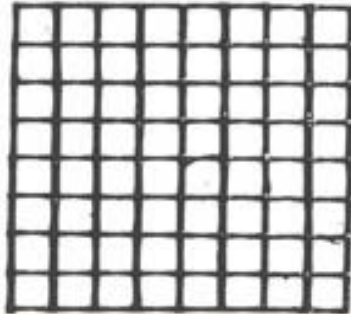
Appendix D. Data Sheet for Cold Point Testing

These grids can also be used for warm point testing (optional). Record one of the following symbols in each square of the grid: **C** = cold point; **•** = touch (or **W** = warm point)

Subject 1



Subject 2



Subject 3

