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FUNCTIONAL AND CLINICAL ASPECTS OF THE SENSORY SYSTEM

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Annotation: This article describes the anatomical and physiological foundations of the human sensory system, as well as methods of its clinical examination. The article provides a detailed analysis of dermatomes, ascending spinal pathways, and various sensory modalities — light touch, pain, temperature, vibration sense, proprioception, graphesthesia, and stereognosis. Pathological conditions such as sensory disturbances, sensory and cerebellar ataxia, paresthesia, hyperesthesia, and hypoesthesia, as well as methods for their clinical assessment, are also discussed. The article emphasizes the theoretical and practical aspects of neurological examination, including the Romberg test and standardized scoring systems used to evaluate a patient's sensory status. The annotation offers scientifically based recommendations for identifying and assessing sensory system disorders and applying them in neurological practice.

Keywords: Sensory system, neurological examination, dermatomes, proprioception, graphesthesia, stereognosis, Romberg test, sensory ataxia, cerebellar ataxia, nociceptors, mechanoreceptors, dorsal nerve root, facial dermatomes, trigeminal nerve, hyperesthesia, hypoesthesia, paresthesia, allodynia, analgesia, dysesthesia, sensory deficit

Introduction: The sensory system is one of the complex and essential components of the human body, responsible for receiving, transmitting, and interpreting stimuli from the external and internal environment. Along with other systems, particularly the motor system, the sensory system is necessary for the body's adaptation to the external environment, ensuring safety, and performing coordinated movements. The activity of the motor system depends on information from the sensory system, and if sensory input is insufficient, appropriate motor responses do not occur. Therefore, in clinical practice, understanding the functioning of the sensory system, knowing its examination methods, and being familiar with the signs of sensory disturbances are very important [3, 4, 14].

The sensory system operates through various receptors in the human body. The skin, muscles, and tendons are equipped with nociceptors and mechanoreceptors that help detect external stimuli. These receptors transmit signals to the spinal cord via the dorsal nerve roots, where synapses form in the dorsal horn of the gray matter, and the signals ascend through the white matter. Ascending spinal pathways, including the lateral and ventral spinothalamic, dorsal column, spinocerebellar, cuneocerebellar, spinotectal, and spino-olivary tracts, carry different sensory modalities such as pain, temperature, pressure, touch, vibration sense, and proprioception. Information received through these pathways is interpreted by the central nervous system, leading to appropriate motor responses. One of the first steps in clinically examining the sensory system is understanding dermatome maps. A dermatome is an area of skin supplied by a single nerve root, providing not only a theoretical basis but also a practical reference for identifying sensory disturbances [1, 2, 5].

Dermatomes in the trunk are relatively horizontally oriented, while in the extremities they are arranged along a long axis. It should be noted that the C_1 nerve roots do not contribute to a dermatome, and facial dermatomes are supplied by the trigeminal nerve (CN V). Various sensory modalities are assessed in sensory system evaluation: light touch, pain, temperature, vibration sense, proprioception, graphesthesia, and stereognosis. Testing light touch and pain requires patient cooperation, with the patient accurately reporting the perception of stimuli. Temperature sensation can be evaluated using cold and sometimes warm test tubes, while vibration sense is detected with a 128 Hz tuning fork [6, 7, 9, 11].

Proprioception assesses the ability to recognize the position of a body part, whereas graphesthesia and stereognosis test the ability to identify complex stimuli through touch and perception. Additionally, in clinical practice, the Romberg test plays an important role in assessing sensory disturbances. If proprioception is impaired, the patient's voluntary movements, including gait, are significantly affected. The Romberg test allows differentiation between sensory ataxia and cerebellar ataxia, helping to determine balance, movement, and coordination.Another challenge in sensory examination is ensuring that the patient provides accurate reports of sensation. To address this, the International Spinal Cord Society and the American Spinal Injury Association developed standardized scoring systems to evaluate sensory deficits. This system considers indicators such as the presence or absence of sensation, normality, or alteration. Through this, sensory disturbances in patients can be objectively assessed and monitored [8, 10, 13].

Like the motor system, the sensory pathway also plays an essential role in transmitting and interpreting environmental stimuli. Without adequate sensory signals, appropriate motor responses cannot be produced. Both systems work together to ensure optimal perception and response to a constantly changing external environment. As a result, it is equally important for clinicians to understand the internal functioning of the sensory pathway, how it can be assessed, and the signs of sensory impairment. This article begins by reviewing dermatome maps and ascending spinal pathways, as understanding both provides an invaluable foundation. The article then discusses the evaluation of common sensory modalities and which findings are considered abnormal [12, 15].

Materials and methods: Dermatomes do not exist as anatomically distinct, sharply defined regions on the body. They are more theoretical lines used to simplify the understanding of the physiology of cutaneous sensory innervation. On the trunk, dermatomes are arranged relatively in a horizontal plane. However, this pattern changes in the limbs because during embryonic development the limb buds elongate and rotate significantly. As a result, dermatomes of the upper and lower limbs become oriented along long axes (although still forming narrow band-like regions). Some variation exists among different dermatome maps.

There are two important cautions associated with the dermatome principle. First, the C1 nerve roots do not contribute to a dermatome segment. Second, facial dermatomes are supplied by the trigeminal nerve (CN V). The ophthalmic division supplies the upper third of the face, the maxillary division supplies the middle third, and the mandibular division supplies the lower third of the face.

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Below are the dermatome segments and the regions they supply. Only commonly used examination points are listed, but dermatomes can extend along long and narrow regions. Therefore, knowing the full area of each dermatome is useful so that each dermatome can be tested at multiple levels.

Segment — **Supplied Region**

C2 — Covers the occiput and the ears

C3 — Suboccipital region posteriorly, and a portion of the anterior neck

C4 — Supraclavicular fossa, anterior and posterior neck

C5 — Anterolateral surface of the arm, ventrolateral surface of the forearm

C6 — Posterior part of the deltoid, thenar eminence, and the thumb

C7 — Dorsal midline of the hand and wrist, second and third fingers

C8 — Medial surface of the hand, ulnar surface of the wrist, fourth and fifth fingers

T1 — Anteromedial surface of the arm, ventromedial surface of the forearm

T2 — Upper portion of the axilla

T3 — Begins at the mid-clavicular line level and the third intercostal space

T4 — At the nipple line level

T5 — Between the nipples and the xiphoid process

T6 — Horizontal line of the xiphoid process intersecting the mid-clavicular line

T7 — Horizontal line just below the xiphoid process intersecting the mid-clavicular line

T8 — Horizontal line between the xiphoid process and the umbilicus, intersecting the mid-clavicular line

T9 — Upper three-quarters of the horizontal line between the xiphoid process and the umbilicus

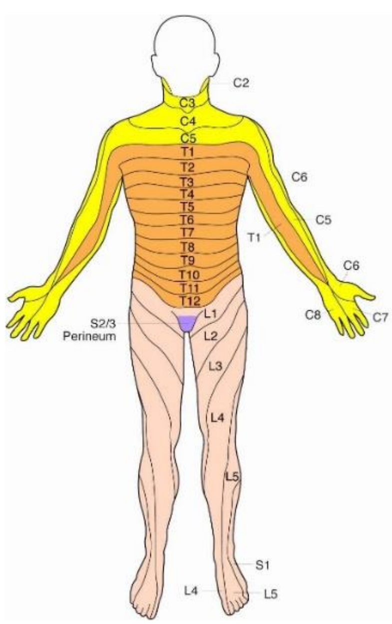

Figure 1: Cervical (C2–C8, yellow): Supplies the neck and upper limb regions. **Thoracic (T1–T12, orange–white):** Innervates the skin of the upper and mid-thoracic back and chest. **Lumbar (L1–L5, pink):** Covers the lower abdomen, thigh, and upper part of the leg. **Sacral (S1–S3, darker shade):** Supplies the knee region, lower leg, and perineum.

Ascending Spinal Pathways The skin, muscles, and tendons contain nociceptors and mechanoreceptors that help detect stimuli from the external environment. These receptors connect to the ascending spinal pathways through the dorsal nerve root. Upon entering the spinal cord, the nerve endings form synapses at various points within the dorsal horn of the gray matter, and then enter the white matter, either ipsilaterally (on the same side) or contralaterally (on the opposite side), depending on the pathway.

There are approximately nine named ascending spinal pathways responsible for transmitting general somatic afferent stimuli. Below are the ascending spinal tracts and the sensory modalities they carry:

Lateral spinothalamic — Pain, temperature

Ventral spinothalamic — Pressure, crude touch

Dorsal column — Vibration sense, proprioception, two-point discrimination

Anterior & posterior spinocerebellar — Unconscious proprioception

Cuneocerebellar — Unconscious proprioception

Spinotectal — Tactile sensation, pain, temperature

Spino-olivary — Additional sensory information relayed to the cerebellum

Results and Discussions: These ascending tracts ensure that sensory information reaches higher centers for processing and integration. Once the signals arrive in the brainstem and thalamus, they are relayed to the somatosensory cortex, where the location, intensity, and quality of the stimulus are interpreted. The integration of these pathways allows the central nervous system to coordinate appropriate motor responses, maintain balance, and perceive the environment accurately. Disruption in any of these tracts may result in specific sensory deficits, such as loss of vibration sense, impaired joint position awareness, altered pain perception, or difficulties in detecting fine touch. Understanding the functional role of each tract is essential for precise localization of lesions during clinical examination and for guiding targeted neurological assessments.

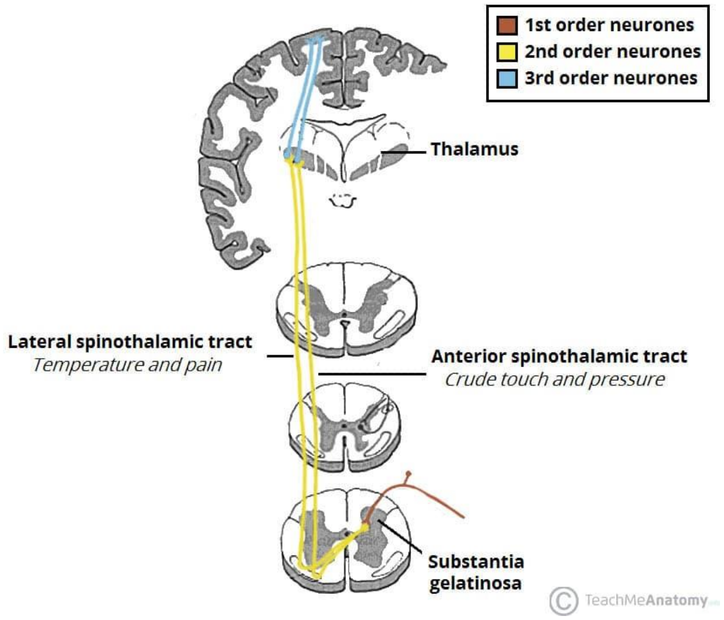

Figure 2. Ascending spinothalamic pathways showing the anatomical course of pain, temperature, and crude touch sensations from the periphery to the thalamus.

Sensory System Examination Despite being conceptually simple, the sensory examination is one of the most time-consuming components of the neurological assessment. The test relies heavily on patient cooperation and their ability to understand the examiner's instructions. Several tools are required: items commonly found on the ward (cotton wisp, Neurotip needles, cold test tubes) and those the clinician must carry (a 128 Hz tuning fork). Before starting, the examiner should clearly explain the procedure and its purpose to obtain informed consent. Adequate exposure of the patient is essential for proper dermatome assessment—this includes uncovering the lower limbs (excluding the perineal region), the chest, and the upper limbs. Perineal and genital dermatomes are generally not examined.

Clinicians must also understand terminology used in sensory assessment. The suffix **-algesia**, derived from the Greek "algesis," refers to the sensitivity to pain. Another common suffix, **-esthesia,** refers to the perception of tactile stimuli. Occasionally, the suffix **-dynia** is encountered, which is synonymous with algesia.

Inspection General observation should begin as soon as the patient enters the room. Assess their gait, as individuals with sensory ataxia often display abnormal walking patterns. On general examination, skin changes such as **acanthosis nigricans** may indicate diabetes or malignancy, both of which can be associated with sensory disturbances. Conditions such as **Charcot-Marie-Tooth disease** may present with pes cavus, hammer toes, and "inverted champagne bottle" legs. Long-standing **vitamin B12 deficiency** can lead to sensory neuropathies; the presence of neuropathy together with a red, beefy tongue should raise suspicion.

Evaluate for visible scars, as traumatic injuries may damage neurovascular structures and cause sensory deficits. In patients with spinal cord injuries, muscle wasting may accompany sensory loss. While fasciculations, involuntary movements, and tremors are typically associated with motor disorders, they may also appear in mixed sensorimotor deficits.

Light Touch To assess light touch, first take a cotton tip. Show the instrument to the patient to reduce anxiety. Lightly touch the skin over the manubrium or the top of the head as a reference point. Ask the patient how they feel the stimulus and consider this as normal. Then, moving toward the foot, ask the patient to close their eyes. This ensures the stimulus is not seen and reduces the chance of incorrect responses.

Apply stimuli to dermatome regions and ask the patient: Did they feel it or not? Is it the same or different compared to the reference stimulus? Some practitioners continue to assess differences (i.e., increased or decreased sensation). Note: Avoid pushing or scratching with cotton, as this tests another sensory pathway. Examination should proceed from bottom to top (caudocranial), always comparing left and right sides (e.g., left L5 then right L5). Vary the speed of stimulus application so the patient cannot anticipate it. Also, alternate between applying and not applying the stimulus so the patient does not respond automatically with "yes."

Pain Use Neurotip needles to assess superficial pain. Do not use hypodermic needles; use a new Neurotip for each patient and discard after use. Alternatively, a tongue depressor (orange stick) can be split to form a sharp and blunt end. Identify a reference stimulus as in light touch, and apply the sharp and blunt ends. With the patient's eyes closed, test ascending dermatome regions. Avoid pricking the patient; gently let the needle touch the skin. Alternate between sharp and blunt ends. Patients with impaired superficial pain may report blunt or no sensation.

Temperature Temperature sensation is usually assessed with a cold test tube or tuning fork. Show the cold object to the patient as before and set a reference stimulus. Then, moving toward the foot, test each dermatome with the cold tube. Sometimes hot and cold tubes are alternated.

Vibration Sense Vibration is a sensation from a rapidly oscillating object. Assess this using a 128 Hz tuning fork. The tuning fork has two U-shaped prongs attached to a stem with a base. To start, strike the prongs on the thenar eminence to activate vibration. Hold the stem, not the prongs, to avoid damping the vibration. Place the base of the fork on a reference point (manubrium or top of the head). Moving toward the foot, place the fork on the most distal bony prominence (e.g., distal interphalangeal joint of the big toe). Ask the patient to report when vibration starts and stops. If distal points cannot be sensed, move proximally (e.g., metatarsophalangeal joint, medial malleolus, tibial tuberosity, anterior iliac spine). Do not place the fork on soft tissue; vibration is better perceived over bone. For upper limbs, place the fork on the distal interphalangeal joint of the index finger. If sensation is impaired, move proximally (e.g., distal radius, olecranon, clavicle).

Proprioception Proprioception is the ability to determine the position of a body part relative to the environment and other parts of the body. This sensory modality is assessed by checking the patient's joint position. Testing starts from the foot: the examiner holds the sides of the interphalangeal joint of the big toe with the non-dominant hand. The dominant hand holds the distal phalanx and moves it dorsally and plantarly (upward and downward). Ask the patient to close their eyes while moving the phalanx. Perform movements randomly so the patient cannot guess the direction of motion. For the upper limbs, the test is performed on the distal interphalangeal joint and phalanx of the middle finger. If proprioception is normal, testing the next joint is unnecessary. If sensation is impaired, repeat the test on thenext joint. Holding the phalanx as described, including dorsal and plantar sides, reduces partial directional cues.

Graphesthesia and Stereognosis Graphesthesia is the ability to recognize letters or numbers traced on the skin without visual input. Stereognosis is the ability to recognize three-dimensional objects by touch alone. Both tests are usually performed on the upper limbs. In graphesthesia testing, the patient closes their eyes, and letters or numbers are traced on the fingers or palm using a round object. If graphesthesia is normal, the patient can correctly identify the drawn character or number. In stereognosis testing, the patient closes their eyes, and a simple object such as a pen, coin, or key is placed in their hand. If stereognosis is normal, the patient can correctly identify the object. Both hands are tested during this process.

Romberg Test If proprioception is impaired, voluntary movements—including walking—are significantly affected. Cerebellar lesions (vascular or space-occupying) also disrupt balance, movement, and motor coordination. The first condition is called **sensory ataxia**, and the second is **cerebellar ataxia**. The

Romberg test is designed to differentiate between these two conditions. During the test, the patient stands with a narrow base and closes their eyes. The examiner stays close to prevent falls. The patient attempts to maintain balance with eyes closed.

In *sensory ataxia*, walking is relatively normal with eyes open, but stance and gait become unstable, unsafe, and unsteady with eyes closed because the body cannot determine its position relative to the environment, and visual input compensates. In *cerebellar ataxia*, removing visual input does not change the gait or stance because the problem originates from impaired proprioceptive integration.

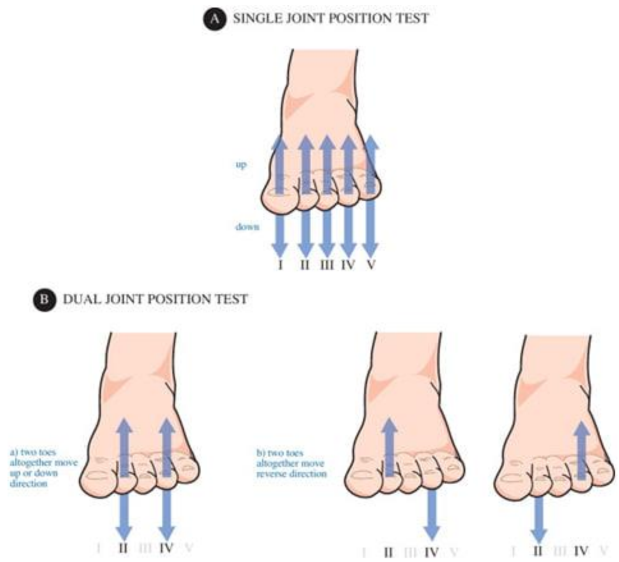

Figure 3. Proprioception test: The patient closes their eyes while the toe is moved up and down, and reports the direction of movement.

Conclusion: The sensory system is a complex mechanism in the human body necessary for receiving, transmitting, and interpreting information about the environment and the internal state of the body in the central nervous system. Through this system, stimuli from different parts of the body—such as pain, temperature, touch, pressure, vibration, proprioception, and complex cortical sensations—are detected and evaluated. A clear understanding of the anatomical and functional aspects of sensory pathways, such as dermatomes, ascending spinal tracts, and specific sensory modalities, facilitates precise localization of sensory deficits during clinical examination. Examination methods—including light touch, pain tests, temperature sensation, vibration sense, joint position sense (proprioception), graphesthesia, and stereognosis—serve to assess the patient's sensory status. It is important to note that sensory testing often relies on the patient's subjective responses, making their active participation crucial. Therefore, examiners are advised to approach the process with motivation and care, fully inform the patient, and optimize examination conditions.

Overall, a deep understanding of sensory system function and fair evaluation provides a foundation for neurological diagnosis and effective patient management. Clinicians should apply this knowledge effectively to assess sensory pathways, detect deficits, and select appropriate interventions or guidance.

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