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A tactile stimulation device for measuring two-point and gap discrimination thresholds in humans

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A device to measure two-point-discrimination and gap-discrimination thresholds is described. The apparatus is capable of controlled and reliable delivery of forces up to 42.50 g while determining point of skin contact and subsequent depth of skin indentation during threshold determination. Stimulus delivery is controlled by computer software that deactivates a solenoid, allowing a counterbalanced beam with one of two stimulus wheels mounted on its end to rise and stimulate the skin. Depth of skin indentation is recorded by hardware that monitors the output of a photocell reflecting the position of the beam. The apparatus allows complete computer control of all data acquisition and recording.

The two-point threshold is a traditional measure of spatial acuity that has been widely used to assess variation in spatial sensitivity across the body in both normal and patient populations (e.g., Friedline, 1918; Fuchs & Brown, 1984; Gates, 1915; Johnson & Phillips, 1981; Laski, 1916; Loomis, 1979; Tawney, 1895; Weinstein, 1968). However, no readily available device for determining two-point thresholds in a well-controlled manner has previously existed. The traditional device, a hand-held compass, for determining two-point threshold may produce intertrial and interexperimenter variability. This inherent variability may also be compounded by slight rocking of the compass points, producing very noticeable cues, thereby reducing the reported two-point thresholds. Therefore, we designed and produced an apparatus based on the design utilized by Johnson and Phillips (1981), but with the additional capabilities of complete computer automation, as well as data collection, production of a controlled stimulus, and simultaneous measurement of depth of indentation.

The apparatus consists of a counterbalanced beam mounted on a stationary fulcrum support and an XYZ position translator with a base (see Figure 1). The beam is solenoid-driven such that solenoid activation raises one end of the beam, causing the other end, the stimulator arm, to retract from the skin. Release of the solenoid then allows the stimulator arm to float freely upward, contacting the skin with a prescribed force of up to 42.50 g. The force may be adjusted by moving a counterweight along a calibrated scale; checks for accurate counterbalancing may be made using a leveling bubble mounted on the beam. A stepping motor (Airpax, 5V 21Ω/coil, step angle 15°, L82101-P1) is mounted on the stimulator arm; mounted on its shaft is one of two anodized aluminum stimulus wheels (see Figure 2). The two-point-discrimination wheel is 50 mm in diameter, with eight pairs of 0.5-mm-diameter stainless steel pins with flat ends. The pins are embedded around the circumference of the wheel perpendicular to the surface; they protrude from the surface 6 mm. The pins are separated by gaps of 0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, and 3.5 mm. This range was found to include the threshold for discrimination of two points separated by some space from two points separated by 0.0 mm on the pad of the index finger in all persons tested (18–87 years of age), except for those with severe peripheral neuropathies. Pairs are separated by three stepping motor steps of 15° each, or 20 mm. A pair of pins separated by 0.0 mm was utilized rather than a single pin due to the ability of persons to reliably discriminate one point from two points, even when there was no separation between the two points most likely on the basis of intensive cues (Johnson & Phillips, 1981).

The two-point-discrimination wheel represents the usual method of assessing two-point discrimination or spatial

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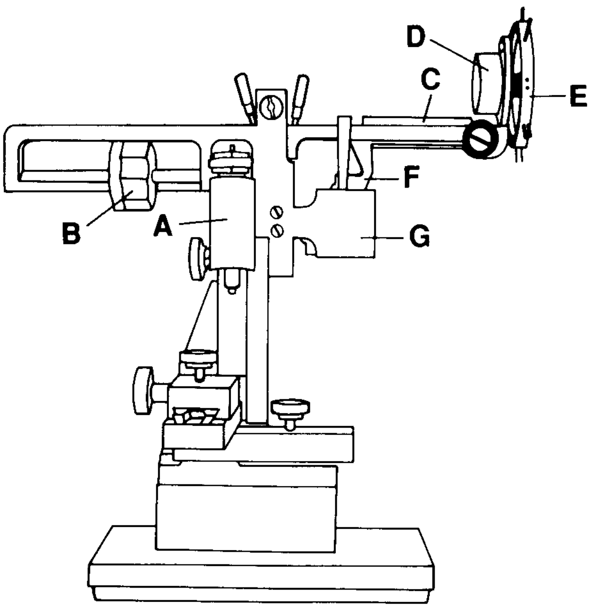

Figure 1. A line drawing of the tactile stimulation device. A = solenoid, B = counterweight, C = leveling bubble, D = stepping motor, E = stimulus wheel (two-point wheel shown), F = photobeam and photocell with impinging vane, and G = dash pot.

resolution. However, persons may discriminate the difference in two-point separation on the basis of size discrimination or other intensive cues (e.g., differences in the total contact area of the stimulus on the skin or the stimulus dimensions, rather than resolution of two distinct points; see Johnson & Phillips, 1981; Loomis, 1979; Loomis & Carter, 1978). A second stimulus was designed to minimize differences in contact area and overall stimulus dimensions as variables between stimuli. The gap-discrimination wheel is 60 mm in diameter, with 12 gaps cut radially into its circumference to a depth of 1 mm. The gaps are 0.2, 0.4, 0.6, 0.8, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, and 4.5 mm wide, centered on a separation of 1½ stepping-motor steps of 15° each, or 10 mm. A 35-mm portion of the wheel circumference surface is left uncut for the 0.0-mm gap. This range of gap sizes was found

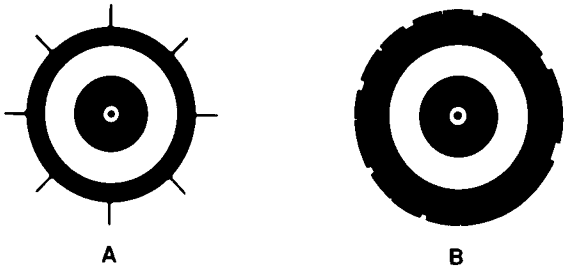

Figure 2. (A) Two-point-discrimination wheel with eight sets of pins separated by distances ranging from 0.0 to 3.5 mm. (B) Gap-discrimination wheel with 13 gaps ranging from widths of 0.0 to 4.5 mm. For both A and B, anodization is shown in black and non-anodized slip-ring touch sensor is the large white inner ring.

to include the threshold for discrimination of a gap from a smooth surface on the pad of the index finger in all persons tested (18-87 years of age), except for those with severe peripheral neuropathies. The only remaining variable between stimuli to be discriminated is the presence or absence of edges, which may also be an intensive cue.

The stimulus wheels described are those currently in use. However, because wheels are mounted only on the motor shaft using a set screw, the design of the apparatus allows the use of multiple interchangeable stimulus wheels of various sizes and stimulus configurations. The only constraints on stimulus design are that the area of the body to be stimulated must be positioned horizontally above the apparatus due to the physical requirements of the counterbalanced beam, and stimuli must be separated by stepping motor steps of at least one half step.

Each of the two stimulus wheels weighs 14.05 g and includes brush and slip-ring touch sensors. The brush and slip-ring touch sensors consist of a circuit between a controller box, the brush (a copper blade attached to the stepping-motor housing), which contacts the slip ring (the nonanodized portion of the stimulus wheel), the pin tips of the two-point wheel or the perimeter surface of the gap wheel, and the skin of the subject's index finger pad, with a ground lead from the skin of the subject to the controller box. The circuit remains open when the stimulus wheel is not in contact with the skin, closing upon contact, with subsequent output to the computer via the controller box, indicating skin contact.

The position of the stimulator arm is monitored continuously by a photocell mechanism attached to the fulcrum support. A vane extends from the stimulator arm and impinges upon the path between the photobeam and photocell, modifying the output of the photocell, as the stimulator arm moves. Activation of the touch sensor indicates the point in the travel of the stimulator arm at which the stimulus contacts the finger and triggers recording of the photocell output by a high-speed 16-channel data-acquisition-and-control card (Metra Byte, DAS 16-F). Recording continues until the touch sensor is deactivated, indicating the point at which the stimulus is no longer in contact with the skin. Depth of skin indentation is computed from the difference between photocell output at the point of skin contact and the output indicating the maximum point in the travel of the stimulator arm and is stored by the computer for data analysis. The stepping motor and solenoid are entirely controlled by computer software, such that all aspects of stimulus presentation and withdrawal are controlled.

An anodized aluminum paddle is mounted on the stimulator arm, just in front of the fulcrum and adjacent to the photocell mechanism vane. Just below the paddle, a dash pot filled with a mineral oil and petroleum jelly solution is mounted on the fulcrum support. The paddle moves back and forth in the dash pot as the stimulator arm moves, functioning as a bounce-dampening device.

The entire apparatus is clamped to a table, on which is mounted a structurally stabilized contoured fiberglass arm-and-hand support. A small oval stimulation window has been cut into the index finger portion of the support, allowing the stimulus wheels to contact the finger pad either transverse to or parallel to the longitudinal axis of the finger. The subjects rest their entire arm (from elbow to fingertips) in the support while seated in an adjacent chair. The subject's arm and hand are secured by Velcro straps in order to minimize movement. A thermostatically controlled heat lamp, with its thermistor located on the dorsum of the hand, is set to maintain digital skin temperature at 33°C.

Once the subject is seated comfortably in the chair with his/her arm secured in the support and the heat lamp turned on, the apparatus can be readied for stimulus trials. The stimulus force must first be set to the desired force by adjusting the counterbalance weight. The apparatus is then positioned using the XYZ position translator so that the release of the solenoid allows the stimulator arm to float upward such that the stimulus contacts the skin of the finger pad only, while missing the support. Once the stimulus is in contact with the skin, it must be leveled, using the leveling bubble on the beam in order to produce a stimulus of consistent contact and force across the finger pad with differing pin separations or gap widths. The solenoid may then be activated, withdrawing the stimulator arm, and the wheel positioned so that the 0.0-mm pin separation (two-point wheel) or the 0.0-mm gap (gap wheel) will contact the skin upon release of the solenoid. The stepping motor and the solenoid may then be placed under software control in order to stimulate the finger pad with any pin separation (two-point-discrimination wheel) or gap (gap-discrimination wheel) in the desired sequence, while controlling the stimulus and simultaneously recording depth of indentation.

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