# Quantitative cutaneous sensory testing in children and adolescents

John P. Conomy, M.D.
*Department of Neurology*

Karen L. Barnes, Ph.D.
*Division of Research*

Robert P. Cruse, D.O.
*Department of Pediatrics and Adolescent Medicine*

Every time we conceive and express quality as quantity our knowledge increases and along with it, our powers of thinking and acting correctly.

Constantine Tsatsos[1]

A fundamental consideration of every branch of science is the measurement of natural phenomena. Indeed, much of the history of science is inseparable from the history of measurement and quantitation.[2] It has been the goal of the quantitative scientific method since its inception by the Greeks that natural phenomena could be reduced, abstracted, and numerically designated so they could be understood. The applications of this method of abstraction and numerical designation are an implied bulwark of contemporary biomedical science. In the clinical neurosciences, quantitative measurement of the functions of the special senses has had a long and arduous development. Numerical measurement of sensation has been comfortably achieved in some areas, particularly vision and hearing. It is commonplace in the modern era to express visual acuity by numeric designations and to map the visual fields with precisely-sized objects in terms of degrees of arc, and to desig-

nate hearing function in decibels.The skin senses, rich and varied as they are, have eluded numeric designation, and much of what we understand about cutaneous sensation is left to the amplification and vagaries of descriptive language. We have not yet developed reliable scientific methods of measuring such phenomena as touch, light pressure, cutaneous pain, or thermal sensibility, much less more complex cutaneous phenomena, such as rubbing, tickling, wetness, itching, and other compound sensations that are daily human experiences.

Attempts at quantification of skin sensation began more than 100 years ago with the anatomic definition of nonhomogeneous cutaneous zones of tactile discrimination and attempts at relating quantitative stimuli placed upon the skin to behavioral responses associated with that stimulation.[3] The last 10 years have yielded an accelerated growth of precision in the quantitative description of human cutaneous sensory function.[4–7]

An additional methodology for the quantification of cutaneous sensation was introduced in 1974 by Conomy and Barnes,[8] and studies of normal and abnormal cutaneous sensibility in adults were reported subsequently.[9] The purpose of the present study is to report the results of quantitative cutaneous sensory testing in groups of normal and abnormal children and adolescents. As has been shown to be the case with adults, the technique is simple and can be readily understood by children. The technique appears to have use in discriminating those children with abnormal cutaneous sensory function from those who are normal in this regard.

## Methodology

Children were studied in a pleasant laboratory situation. When they were comfortably seated in a large chair, the nature of the testing apparatus and their participation in the test was explained to them. With younger children, this was always carried on in the presence of a parent. The situation was comfortable and amusing for the child. Stimuli were not painful. Once cooperation and comfort were ensured, a response lever was placed in easy reach. The cutaneous areas to be studied were cleansed and coated with conductive jelly. Stimulating electrodes were applied closely to the skin area to be tested and held in place with nonocclusive elastic straps (*Fig. 1*). The stimulating electrodes consisted of 9-

**Fig. 1.** Healthy 11-year-old child undergoing quantitative cutaneous sensory testing. The young subject is seated comfortably in a large laboratory chair. Electrodes are in place about the left forearm (arrow), and the response lever is being manipulated by the contralateral hand.

mm diameter modified electroencephalogram recording electrodes (Grass Instrument Corporation).

The quantitative assessment of cutaneous sensory function we employ is based upon the method of limits and is analogous in sensory neurophysiology to the von Békésy method of audiometry. The subject-operated stimulator provides pulsed, constant-current stimulation of the skin. Each stimulus is a 200-msec train of rectangular pulses at 20 Hz and 0.2-msec pulse duration. Trains are repeated once a second with increments of 0.1 mamp every 2 seconds. For 2 minutes at each site the child signals perceptual responses by pressing the lever. A permanent record of stimulus and nonverbal responses is produced along with an on-line computer analysis of the data (*Figs. 2 and 3*). Statistical analysis includes determinations of mean sensory thresholds, limits of stimulus intensity during detection, perceptual duration, cycle rates, and perceptual persistence indices. Threshold stimulus detection in normal children is accompanied occasionally by such statements as, "I'm being tickled," or "There is a bug on my skin." Each subject serves as his or her own control in the test situation. Instrumentation and statistical analysis have been extensively described in previous publications.[8, 10]

## Study population

A total of 32 children and adolescents are included in this study. Two distinct groups were defined at the outset. The control group consisted of children who were neurologically normal. The study group consisted of those with known neurocutaneous sensory disorders as well as those having illnesses in which such disorders were likely to occur. Children in

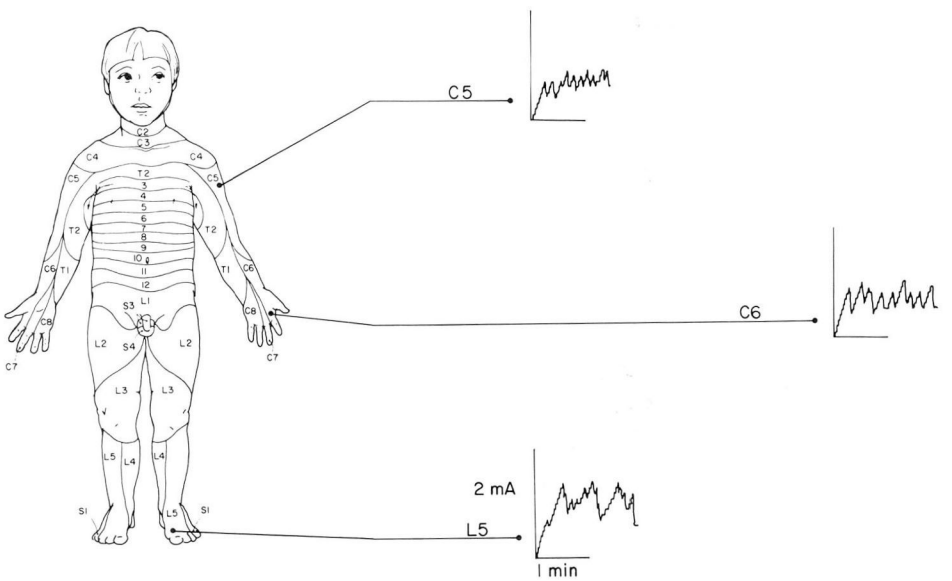


**Fig. 2.** Perceptual response recording in a neurologically normal 7-year-old child. The stimulus sites illustrated are the C5, C6, and L5 dermatomes in a normal child.

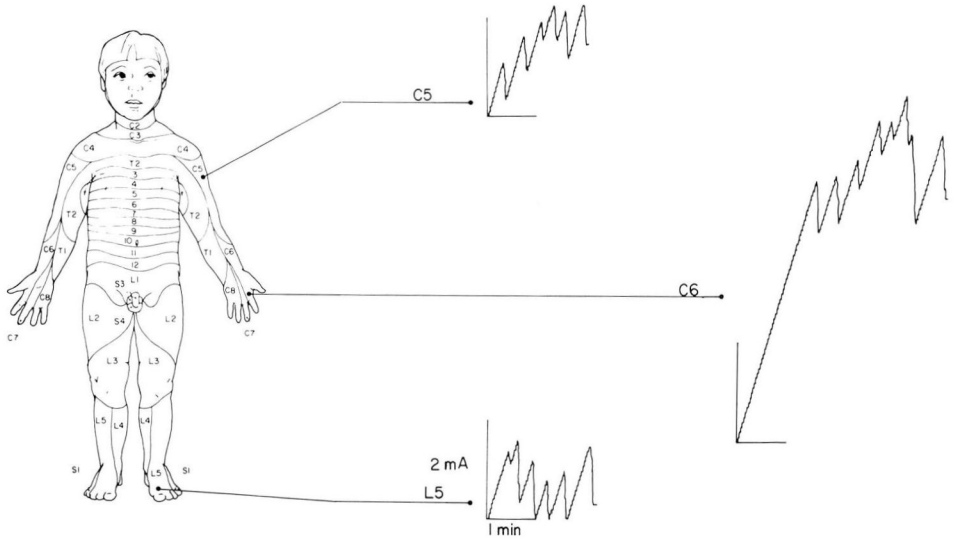


**Fig. 3.** Perceptual response recording in an 8-year-old child with familial neuropathy. Brachial sites show normally low thresholds; distal hand site (C6) shows consistent threshold elevation. Compare same sites to those in *Figure 2*.

both groups were studied after the assent of the child and the informed consent of a parent were obtained.

The healthy control group numbered 12 individuals, aged 4 to 20 years (mean 13.7 years). The neurologically abnormal child-adolescent group consisted of 20 individuals, aged 8 to 20 years (mean, 14.9 years). Individuals in the test group consisted of those with diabetes mellitus, a variety of forms of familial diseases of the nervous system, neurologic diseases associated with chronic renal failure, metastatic carcinoma, as well as individuals with postinfectious polyneuropathy, multiple sclerosis, and one who had undergone percutaneous cordotomy for the relief of chronic, intractable pain associated with widespread malignancy.

## Results and discussion

**Normal children and adolescents.** *Table 1* contains the 95% confidence intervals for the test data at each site for those children and adolescents comprising the normal group. *Table 2* contains identical data for individuals in the adult group. The sites utilized for the establishment of normative data and for comparative sites in the test group include the medial portion of the mid-forearm in the T1 dermatome, the skin of the first dorsal interosseous web of the hand in the C6 dermatome, the skin of the anterior thigh in the L3 dermatome, the posterolateral calf in the S2 dermatome, and the dorsum of the foot in the L5 dermatome. Electrode placement is made at standard sites, and positions are based upon standardization from anatomic charts. *Table 1* and all the subsequent tables contain grouped data for threshold maxima during perception (Ymax), threshold minima during perception (Ymin), and mean threshold ($\bar{Y}$). Cycle rates (CR) are expressed in subject-operated cycles per minute and perception duration (PD), the average

**Table 1.** Control group; normal children and adolescents

| Site | Ymax (mA) | Ymin (mA) | $\bar{Y}$ (mA) | CR (cpm) | PD (sec) |
|---|---|---|---|---|---|
| $T_1$ | 0.78–1.34 | 0.41–0.99 | 0.62–1.16 | 5.39–7.61 | 2.93–3.50 |
| $C_6$ | 1.13–2.37 | 0.50–1.94 | 0.83–2.16 | 3.49–6.32 | 2.50–6.91 |
| $L_3$ | 0.83–1.53 | 0.34–1.09 | 0.60–1.30 | 3.77–5.75 | 2.57–3.78 |
| $S_2$ | 0.95–2.01 | 0.43–1.62 | 0.70–1.81 | 4.05–7.00 | 2.74–4.50 |
| $L_5$ | 1.06–2.65 | 0.50–2.09 | 0.76–2.35 | 2.98–5.32 | 2.92–5.48 |

Values expressed are for the 95% confidence intervals obtained from testing a control group of neurologically normal children and adolescents.

**Table 2.** Control group; normal adults

| Site | Ymax (mA) | Ymin (mA) | $\bar{Y}$ (mA) | CR (cpm) | PD (sec) |
|---|---|---|---|---|---|
| $T_1$ | 0.87–1.32 | 0.64–1.06 | 0.75–1.18 | 7.47–11.25 | 2.05–3.07 |
| $C_6$ | 1.19–2.10 | 0.89–1.74 | 1.04–1.91 | 5.51–8.80 | 2.39–3.76 |
| $L_3$ | 0.92–1.43 | 0.59–1.10 | 0.76–1.26 | 5.68–7.99 | 2.83–3.70 |
| $S_2$ | 1.36–2.20 | 0.98–1.83 | 1.18–2.02 | 4.74–7.92 | 2.60–4.12 |
| $L_5$ | 2.91–4.26 | 2.51–3.88 | 2.70–4.06 | 4.74–7.83 | 2.80–4.30 |

Values expressed are for the 95% confidence intervals obtained from testing a control group of neurologically normal adults.

duration of each perceptual cycle is expressed in seconds.

As is the case with adults, normal adolescents and children show generally low threshold values, rapid cycling frequencies, and reasonably brief durations of perception. Although there is some regional variation in threshold values with slightly higher values being seen in the hand and foot than on the forearm and thigh, thresholds are generally low. This same situation is present in normal, healthy adults.

**Diabetic group (*Table 3*).** Four individuals, aged 11 to 20 years, with juvenile-onset, insulin-dependent diabetes mellitus comprised this group. None had neurologic complaints or any overt clinical evidence of neuropathy. As our own experience and that of other investigators suggest, abnormalities of sensation can be borne out in such individuals when refined methods of sensory testing are employed.[11, 12] These findings support the notion that subclinical disorders of sensation are widespread in diabetes mellitus, even in young patients who do not offer symptoms of sensory disturbance. In our child and adolescent test population, of 100 test functions obtained from a total of 20 sites, abnormalities of threshold functions, perceptual duration, or cycling rates were established 37% of the time when results were compared to the 95% confidence intervals of age-matched controls. In the diabetic children, proximal sites and distal sites were abnormal with nearly equal frequency, suggesting a pan-sensory disturbance rather than a neuropathy affecting the distal portions of the peripheral nerves. The mean values in *Table 3* do not reflect the severe abnormalities seen in the 20-year-old patient in this group.

**Familial hypertrophic neuropathy (*Table 4*).** Two individuals, aged 15 and 20 years, who are members of a family previously reported by Cruse et al,[13] were studied. The neurologic illness in this family is characterized

**Table 3.** Disease group; diabetes mellitus (4 patients)

| Site | Ymax (mA) | Ymin (mA) | $\bar{Y}$ (mA) | CR (cpm) | PD (sec) |
|---|---|---|---|---|---|
| $T_1$ | 1.66* | 1.18* | 1.43* | 5.54 | 3.18 |
| $C_6$ | 2.11 | 1.17 | 1.80 | 6.52 | 4.76 |
| $L_3$ | 1.20 | 0.50 | 0.86 | 4.95 | 4.13* |
| $S_2$ | 1.89 | 0.92 | 1.36 | 4.41 | 4.91* |
| $L_5$ | 2.25 | 1.71 | 1.97 | 5.17 | 5.40 |

Values are expressed as means for the group at each site. Those values marked with an asterisk (*) differ from means established for normal children by two or more standard errors. The same convention is followed in Tables 4–9.

**Table 4.** Disease group; familial hypertrophic neuropathy (2 children)

| Site | Ymax (mA) | Ymin (mA) | $\bar{Y}$ (mA) | CR (cpm) | PD (sec) |
|---|---|---|---|---|---|
| $T_1$ | 1.63* | 1.16* | 1.40* | 4.97 | 2.41 |
| $C_6$ | 2.97* | 2.44* | 2.70* | 4.69 | 2.69 |
| $L_3$ | 2.15* | 1.08 | 1.38* | 4.31 | 2.68 |
| $L_5$ | 4.38* | 3.67* | 4.02* | 4.20 | 2.79 |

by pes cavus, distal muscle weakness, loss of muscle stretch reflexes, hereditary neurosensory deafness, and the early appearance of tic douloureux. Peripheral nerve biopsy of an affected individual disclosed Schwann cell hyperplasia and onion bulb formation. The familial illness is of the autosomal dominant type. Both adolescents in this study had pes cavus, diminution of vibration sense in the feet, and distal suppression, but had no neurologic complaints of any sort related to this familial illness which ordinarily does not become symptomatic before the age of 30 years. Quantitative cutaneous sensory testing disclosed abnormalities in both individuals, predominantly at distal sites in the hands and feet. This pattern of an increasing gradient for demonstration of sensory abnormalities progressing from proximal to distal sites suggests a polyneuropathic illness. The older of the two individuals tested demonstrated the greater degree of deviation from normal.

**Familial neuropathy: "D family type" (*Table 5*).** Of 27 persons known in three generations of the D family, eight have neuropathic disease. The illness is characterized by mild scoliosis, pes cavus, distal muscle atrophy of the hands and feet, distal sensory loss, and mildly raised cerebrospinal fluid protein. Intelligence among affected individuals is superior, and none display cranial nerve or cerebellar abnormalities. Electromyographic studies in affected individuals have disclosed denervation, and nerve conduction studies showed severe slowing. Peripheral nerve biopsies disclosed combined demyelination and axonal loss.

A brother, aged 17 years, and a sister, aged 13 years, underwent quantitative cutaneous sensory testing. Abnormalities of cutaneous perception were demonstrated at distal sites in the hands and feet consistent with polyneuropathic disease.

**Charcot-Marie-Tooth disease (*Table 6*).** Two adolescents with this degenerative neuropathic disorder were

studied at the ages of 17 and 18 years. The sample size is too small for any clear inference or conclusion, but it is striking that the perceptual abnormalities in these individuals relate predominantly to cycle rates and perceptual durations, an abnormal feature of testing shared predominantly, but not exclusively, by children with spinocerebellar degenerations (see below). Those children with well-defined neurologic disease confined to the peripheral nerves tended to demonstrate most abnormalities in threshold functions (Ymax, Ymin, $\bar{Y}$) rather than in cycling rates or perceptual durations.

**Spinocerebellar degenerations (*Table 7*).** Three individuals with spinocerebellar degeneration were studied between the ages of 11 and 16 years. The spinocerebellar degenerations consist of an odd lot of nervous system diseases which are of sporadic or heredofamilial occurrence, in which there is pathologic degeneration of cerebellar tract within the spinal cord, brain stem, or degeneration of the cerebellum itself. A variety of neurologic abnormalities are variably associated with spinocerebellar degeneration and include blindness, dementia, seizures, ocular abnormalities, congenital deformities, movement disorders, and peripheral nerve disease.[14]

The individuals we studied, including a brother and sister from one family, displayed scoliosis, severe pes cavus and distal muscle atrophy, in addition to nystagmus, severe limb ataxia, tremor and truncal titubation. Clinical testing disclosed mild cutaneous sensory deficits, and electrical

**Table 5.** Disease group; "D-type" familial neuropathy (2 children)

| Site | Ymax (mA) | Ymin (mA) | $\bar{Y}$ (mA) | CR (cpm) | PD (sec) |
|---|---|---|---|---|---|
| $T_1$ | 0.34 | 0.01 | 0.17 | 7.64 | 2.49 |
| $C_6$ | 3.33* | 2.87* | 3.18* | 5.47 | 2.65 |
| $L_3$ | 0.34 | 0.02 | 0.19 | 7.13 | 1.77 |
| $S_2$ | 1.01 | 0.44 | 0.71 | 4.50 | 2.29 |
| $L_5$ | 5.69* | 4.52* | 5.11* | 2.95 | 2.75 |

**Table 6.** Disease group; Charcot-Marie-Tooth disease (2 adolescents)

| Site | Ymax (mA) | Ymin (mA) | $\bar{Y}$ (mA) | CR (cpm) | PD (sec) |
|---|---|---|---|---|---|
| $T_1$ | 0.69 | 0.04 | 0.32 | 2.58* | 7.00* |
| $C_6$ | 2.37 | 1.03 | 1.66 | 2.10* | 5.34 |
| $L_3$ | 0.70 | 0.00 | 0.32 | 4.11 | 5.51* |
| $S_2$ | 0.60 | 0.00 | 0.34 | 3.66* | 5.93* |
| $L_5$ | 5.53* | 4.21* | 4.92* | 2.02* | 5.90* |

**Table 7.** Disease group; spinocerebellar degeneration (3 children)

| Site | Ymax (mA) | Ymin (mA) | $\bar{Y}$ (mA) | CR (cpm) | PD (sec) |
|---|---|---|---|---|---|
| $T_1$ | 1.96* | 1.14* | 1.33* | 6.90 | 4.56* |
| $C_6$ | 2.70* | 2.10* | 2.33* | 2.92* | 5.48 |
| $L_3$ | 1.67* | 1.24* | 1.41* | 4.08 | 5.36* |
| $S_2$ | 1.69 | 0.97 | 1.31 | 3.53* | 6.39* |
| $L_5$ | 2.52* | 1.92 | 1.53 | 3.94 | 4.95 |

studies of nerve and muscle showed abnormalities suggestive of peripheral nerve impairment. Quantitative cutaneous sensory testing in this group disclosed threshold abnormalities in both the arms and legs, as well as frequent significant distortions of cycling rates and perceptual duration.

**Chronic renal failure (*Table 8*).** Two individuals, aged 11 and 16 years, who were chronically uremic on the basis of chronic renal failure, were studied. Neither had neurologic complaints, but were suspected of possibly having subclinical neuropathy, because of the known association of chronic renal disease with peripheral neuropathy.[15] Only the older of the two individuals tested displayed distortions of statistical parameters suggestive of impaired cutaneous sensibility at distal sites in the foot.

**Guillain-Barré syndrome (*Table 9*).** This disorder is believed to be of postinfectious etiology most commonly.[16] It is a paralytic disorder in which nerve roots are attacked by circulating lymphocytes. The illness is generally reversible provided that patients are skillfully nursed through the prerecovery phases.[17] In patients with Guillain-Barré syndrome, motor deficits predominate. Sensory complaints are common (numbness, paresthesias), but dense sensory abnormalities are uncommon and, in fact, militate against the diagnosis of the disorder.[18]

The individual we studied was 20 years old, mildly affected, and clearly beginning to recover at the time that studies were performed. He complained of mild, intermittent paresthesias in his feet. Quantitative cutaneous sensory studies were abnormal for nearly every parameter at every site studied.

## Conclusions

Our experience suggests that the method we employ for the quantitative study of cutaneous sensation is adaptable without modification for use in children. Young children, at least by the age of 4, are capable of understanding the nature of the test

**Table 8.** Disease group; chronic renal failure (2 children)

| Site | Ymax (mA) | Ymin (mA) | $\bar{Y}$ (mA) | CR (cpm) | PD (sec) |
|---|---|---|---|---|---|
| $T_1$ | 0.77 | 0.07 | 0.43 | 4.48* | 4.10* |
| $C_6$ | 1.30 | 0.18 | 0.70 | 2.55* | 4.94 |
| $L_3$ | 0.67 | 0.16 | 0.40 | 4.77 | 3.76 |
| $S_2$ | 1.33 | 0.18 | 0.79 | 3.92* | 3.69 |
| $L_5$ | 3.23* | 2.14* | 2.70* | 3.47 | 3.78 |

**Table 9.** Disease group; Guillain-Barré syndrome (1 patient)

| Site | Ymax (mA) | Ymin (mA) | $\bar{Y}$ (mA) | CR (cpm) | PD (sec) |
|---|---|---|---|---|---|
| $T_1$ | 2.49* | 2.01* | 2.28* | 3.88* | 4.70* |
| $C_6$ | 2.51* | 1.94* | 2.24* | 3.27* | 5.51 |
| $L_3$ | 2.88* | 2.24* | 2.58* | 2.85* | 8.26* |
| $S_2$ | 6.15* | 5.30* | 5.70* | 2.24* | 11.84* |
| $L_5$ | 6.12* | 5.08* | 5.63* | 1.92* | 11.73* |

Absolute values are expressed and compared to means for normal children and adolescents.

and participating in it. Although the number of comments received, particularly from younger children, suggest some feature of minor cutaneous annoyance associated with testing, the method is not painful, is well tolerated, and in fact for many children is amusing. Most children and adolescents perform as reliably as adults in this test. The method appears to have some use in the establishment or confirmation of cutaneous sensory disorders in children and may be useful in situations where such confirmation might not otherwise be obtained.

Our studies to date show little variation in threshold functions among normal children, adolescents, and adults, although there is some trend toward distal threshold elevations as age progresses. When age-matched controls are employed and statistical confidence intervals established, those with abnormalities of cutaneous sensation may be separated from those with normal sensation by this quantitative technique and subsequent statistical analysis. Studies in normal children and adolescents and those with a variety of neuropathies and central nervous system lesions presented here show clear separation between normal and abnormal groups. Quantitative sensory testing in young persons with diabetes, renal disease, Guillain-Barré syndrome, hereditary neuropathies, and spinocerebellar degenerations yield clear clinical-physiologic correlations.

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