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# Covariates of Human Peripheral Nerve Function: II. Vibrotactile and Thermal Thresholds

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GERR, F. AND R. LETZ. *Covariates of human peripheral nerve function: II. Vibrotactile and thermal thresholds.* NEUROTOXICOL TERATOL 16(1) 105–112, 1994.—A systematic investigation of covariates of quantitative sensory thresholds was performed on data collected by the U.S. Centers for Disease Control. Vibrotactile and thermal sensory thresholds were obtained from the index finger and great toe of 4,462 male Vietnam-era veterans. The magnitude of effect of skin temperature, height, body mass index, age, race, place of military service, smoking status, alcohol consumption, income, and examiner was estimated for the four outcomes. The major covariates of finger and toe vibrotactile threshold were age, height, body mass index, and examiner. The major covariates of toe thermal threshold were height, income, and examiner, and of finger thermal threshold were age, income, examiner, race, and smoking status. Alcohol consumption had only small effects on vibrotactile thresholds and essentially no effect on thermal thresholds. These results provide an empirical basis for selecting variables to control in studies employing vibrotactile and thermal threshold measures.

Vibrotactile threshold    Thermal threshold    Covariates    Human    Epidemiologic study

MEASUREMENT of sensory thresholds has been proposed as a useful method for evaluating peripheral nervous system dysfunction and disease (3,4,18). These methods allow for rapid, nonaversive, quantitative assessment of the integrity of the somatosensory pathways that convey information induced by stimulation of sensory receptors. They typically rely on psychophysical procedures to provide threshold estimates. Devices for quantification of perception of visual, auditory, vibrotactile, thermal, and electrical current stimulation are currently available commercially.

Two of the most commonly performed measurements of peripheral somatosensory function are vibrotactile and thermal thresholds. These outcomes have been used in several studies of diseases and neurotoxic exposures that affect peripheral nervous system function (2,5,6,10,11,13,14,16,22,24,25,30).

Recently, efforts have been made to estimate the effect of potential covariates such as age and height on sensory threshold measurement. Knowledge of factors that affect these measurements allow for adjustment of results to improve diagnostic utility in the clinical setting. To prevent confounding and biased conclusions and to improve the fit of statistical models in epidemiologic studies, it is common to adjust or control in the data analysis for variables that are associated with the outcomes of interest. Age and height have been suggested as appropriate covariates in studies utilizing vibrotactile thresholds (17,29). Little systematic investigation has been done to identify covariates of thermal thresholds. No systematic investigation using a large study population has been reported concerning which variables should be used as covariates of sensory threshold outcomes.

The Vietnam Experience Study was a large cross-sectional epidemiologic study of a randomly selected group of veterans undertaken by the United States Centers for Disease Control (CDC) "to look for adverse health effects among men who had served in Vietnam" (ref. 7, p. 1). Two groups of men were studied: (a) enlisted men who had served in Vietnam and

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(b) men who had served concurrently but never in Vietnam. An extensive telephone interview was conducted on more than 16,000 subjects, of whom over 4,000 participated in medical examinations. The medical examinations included evaluation of symptoms, physical examinations, and laboratory tests of multiple organ systems. Included in the examinations were measurements of vibrotactile and thermal threshold. The data from this study are available for public use.

In this article, estimates are reported of associations between vibrotactile and thermal thresholds obtained during the Vietnam Experience Study medical examinations and several potential covariates: skin temperature, age, height, body mass index, race, place of military service, alcohol consumption, income category, and examiner. The availability of data from over 4,000 subjects allowed precise estimation of even relatively small associations that might be expected for previously unreported covariates.

## METHOD

Subject eligibility criteria, subject selection procedures, medical examination protocols, and a description of the questionnaire used by the CDC are summarized in a companion paper in this series (23) and are presented in detail in CDC documentation (8,9). Only methods unique to this paper are described.

In brief, the cohort studied consisted of 4,462 male Vietnam-era veterans who underwent medical examinations at Lovelace Medical Center between June 3, 1985 and September 30, 1986. A large number of health outcome variables were obtained during the examinations, including a brief neurologic physical examination, peripheral nerve conduction measurements, and sensory threshold outcomes. The quantitative sensory measurements were performed on the second day of each subject's 4-day examination period.

### *Sensory Threshold Procedures*

*Vibrotactile threshold examination procedure.* The vibrotactile threshold examination procedure is described in detail elsewhere (9). A brief description follows. An electromechanical vibrometer (Vibratron, Chemo Tech, Inc., New Rochelle, NY) consisting of a controller unit and two identical transducers was used to measure vibrotactile thresholds. (This instrument was a prototype for the Vibratron II available from Physitemp, Inc., Clifton, NJ). Attached to each transducer were hardened rubber posts which protruded through a Plexiglas plate so they could be contacted by either the toe or finger. The device produced vibration at 120 Hz. Voltage applied to the transducer units was read from an analog meter on the face of the controller unit. The voltage applied to the transducers was regulated by turning a knob on the controller unit. A two-alternative forced-choice testing procedure was used to measure vibrotactile thresholds. It was initiated with a stimulation amplitude easily detectable by the subject. The subject was instructed to touch each of the two rods for 1 s and to indicate which of the two rods was vibrating. With each correct determination of stimulus location, the amplitude was reduced by 10% and another trial was administered. A pseudorandom sequence was used to select the rod on which the stimulus would be presented. When the subject was uncertain which post was vibrating, he was required to guess. After the first incorrect response, the procedure required that 2 out of 3 responses be correct before the stimulus intensity was lowered. In addition, at stimulation levels below 2.0 volts, the 2-out-of-3 rule was employed, even if no errors were made. The procedure was terminated when a total of 5 errors were made. The stimulus intensity on the 5 error trials and on the 5 lowest correct trials were pooled, and the highest and lowest values discarded. The threshold in volts was the average of the remaining 8 values. The amplitude of the vibration (in microns) was proportional to the square of voltage applied. Because logarithmic transformation linearized the relationship between age and vibrotactile threshold and stabilized the variance, all thresholds were expressed as the common logarithm of the square of the voltage applied. Higher thresholds indicate poorer sensory acuity.

*Thermal threshold examination procedure.* The thermal threshold examination procedure is described in detail elsewhere (9). A brief description follows. A thermal testing device (Pfizer Thermal Tester, Sensortek, Clifton, NJ; now marketed as the NTE2 Thermal Tester, Physitemp, Clifton, NJ) consisting of two identical "thermal plates" or "stages" and a controller unit was used to measure thermal thresholds. The thermal plates were 4.6 cm × 4.6 cm and were temperature controllable to 0.1°C by manipulating the controller unit. Temperature control of the stages was achieved using a Peltier device and water perfusion. The temperature of each stage and the temperature difference between the stages are displayed digitally on the device. A two-alternative forced choice testing procedure requiring the subject to identify which of the two stages was cooler was used to determine thermal thresholds. The initial difference between stages was chosen to be easily detectable by each subject. The recommended initial difference to achieve this goal was 10°C. During each trial, 1 stage was always set at 25°C. The subject was instructed to touch each stage once for approximately 1 s and to indicate which of the two stages was cooler. With each correct determination of stimulus location, the temperature difference was reduced by 10% and another trial was administered. A pseudorandom sequence was used to select which one of the stages was to be set at a cooler temperature. When the subject was uncertain which stage was cooler, he was required to guess. After the first incorrect response, the procedure required that 2 out of 3 responses be correct before the temperature difference was lowered. The procedure was terminated when a total of 5 errors were made. The temperature differences on the five error trials and on the 5 lowest correct trials were pooled, and the highest and lowest values discarded. The threshold in degrees C was the average of the remaining 8 values. Higher thresholds indicate poorer sensory acuity.

Index finger and great toe skin temperatures were recorded with a digital thermometer at the time of testing.

### *Questionnaire Information*

Standard questionnaires were administered to all subjects during the telephone interviews as well as during the medical examinations to obtain information about a wide variety of health-related issues. Details of the information obtained by questionnaire are presented in the initial companion paper in this series (23) and the CDC documentation (8,9).

### *Data Analysis*

*Exclusions.* Of the 4,462 potential subjects, 406 (9.1%) were excluded from the present analyses. The rationale was to exclude those subjects with medical conditions that might affect the quantitative sensory outcomes and those with missing or potentially inaccurate covariate measures. The numbers of subjects meeting each of the exclusion criteria are listed in Table 1 of a companion paper (23). The exclusion criteria met most frequently were missing covariate information from the interview, history of diabetes mellitus, fasting blood glucose level > 140 mg/dL, thyroid stimulating hormone level > 8 mIU/L, history of peripheral neuropathy, signs of peripheral neuropathy on examination, unsatisfactory responses during the interview or use of medications identified by the CDC known to be associated with peripheral neuropathy (8). These medications were chloramphenicol, cisplatin, clioquinol, dapsone, diphenylhydantoin, disulfiram, ethionamide, glutethimide, gold, hydralazine, isoniazid, metronidazole, nitrofurantoin, perhexiline maleate, pyridoxine, sodium cyanate, thalidomide, and vincristine.

*Data voiding.* Inspection of initial descriptive statistics revealed several impossible values for some parameters. Therefore, a set of quality assurance void criteria were implemented. An individual data point was voided if it exceeded the void criteria. These void criteria included finger or toe vibrotactile threshold > 50 V and finger or toe thermal threshold > 20°C. In addition, on occasion one or two wild outlier data points identified by visual inspection of plots were voided (e.g., two BMIs > 60.0).

*Statistical methods.* General linear models (28) were fitted separately for the two vibrotactile threshold and the two thermal threshold outcomes. In the 4 analyses, 10 variables were included as potential predictors: skin temperature of the finger or toe as appropriate, height, BMI, age, an indicator variable for race (nonblack/black), an indicator variable for place of service (non-Vietnam/Vietnam), an indicator variable for current smoking status (nonsmoker/smoker), a categorical variable for alcohol drinking intensity level, a categorical variable for annual household income level, and a categorical variable for the examiners administering the threshold measurements. Household income categories were: 1 = <$10,000; 2 = $10,000 to $19,999; 3 = $20,000 to $29,999; 4 = $30,000 to $39,999; 5 > $39,999/year.

## RESULTS

### *Description of Sample Demographics*

Demographic characteristics of the study sample are presented in Table 1. The mean age of the study population was 38 years (SD = 2.5 years). Eleven percent of the population was black, 55% had served in Vietnam, and 45% were cigarette smokers. Twelve percent of the population drank more than 90 beverages containing alcohol per month. Study participants reported a wide range of annual household incomes. Income category 3 ($20,000 to $29,000/year) was the most common. Of the 9 examiners performing vibrotactile threshold measurements, Examiners 6 and 7 performed substantially fewer than the remaining 7. Of the 8 examiners performing thermal threshold measurements, Examiner 6 performed substantially fewer than the remaining 7.

### *Description of Vibrotactile and Thermal Thresholds*

Mean vibrotactile and thermal thresholds are presented for the entire study population in Table 2. Vibrotactile thresholds are higher in the toe than in the finger. Toe thermal thresholds were similar to finger thermal thresholds.

### *Results of General Linear Models*

Parameter estimates from linear models and their associated standard errors of estimate for covariates of finger and toe vibrotactile and thermal thresholds are presented in Table 3. With such a large sample size, in general, an effect observed to be significant at the $p < 0.05$ level could account for as little as 0.1% of the total variance in the dependent variable. Therefore, statistical significance alone is not a useful measure of the strength of associations in this sample. To provide some indication of the relative importance of each covariate, the estimated magnitude of the change in each sensory threshold outcome over a well-defined range of each covariate is presented in Table 4. For the four continuous covariates (temperature, height, BMI, and age), the ranges provided correspond

TABLE 1

DEMOGRAPHIC AND OTHER CHARACTERISTICS OF THE STUDY SAMPLE ($n$ = 4056)

| | Mean | (SD) |
|---|---|---|
| Height (cm) | 176.3 | (6.74) |
| Body mass index (kg/m$^2$) | 26.8 | (4.36) |
| Age (year) | 38.3 | (2.50) |
| Finger temperature (°C) | 31.4 | (1.91) |
| Toe temperature (°C) | 29.7 | (1.91) |
| Race (% Black) | 11.4 | |
| Place of service (% Ever Vietnam) | 55.1 | |
| Current smoking (%) | 44.8 | |
| Alcohol drinking category (%) | | |
| Never-drinker | 9.9 | |
| 0 drinks/month | 14.5 | |
| 1–29 drinks/month | 37.6 | |
| 30–89 drinks/month | 26.0 | |
| 90–179 drinks/month | 8.4 | |
| >179 drinks/month | 3.6 | |
| Household income category (%) | | |
| 1 – <$10,000/year | 9.4 | |
| 2 – $10,000–$19,999/year | 18.2 | |
| 3 – $20,000–$29,999/year | 27.9 | |
| 4 – $30,000–$39,999/year | 22.4 | |
| 5 – >$39,999/year | 22.1 | |
| Examiner (%) | Vib. | Thermal |
| 1 | 12.3 | 15.0 |
| 2 | 13.0 | 13.2 |
| 3 | 13.8 | 14.4 |
| 4 | 13.3 | 12.5 |
| 5 | 15.2 | 14.6 |
| 6 | 5.4 | 6.0 |
| 7 | 1.6 | – |
| 8 | 13.8 | 12.6 |
| 9 | 11.6 | 11.6 |

TABLE 2

DESCRIPTIVE STATISTICS OF THE VIBROTACTILE AND THERMAL THRESHOLD VARIABLES

| | Finger | | Toe | |
|---|---|---|---|---|
| Threshold | Mean | (SD) | Mean | (SD) |
| Vibrotactile (volts) | 2.20 | (0.95) | 5.35 | (2.95) |
| Vibrotactile (log[volts$^2$]) | 0.61 | (0.35) | 1.33 | (0.47) |
| Thermal (°C) | 0.82 | (0.71) | 0.85 | (1.14) |
| Thermal (log[°C]) | −0.18 | (0.28) | −0.23 | (0.35) |

TABLE 3

PARAMETER ESTIMATES AND THEIR SIGNIFICANCE LEVEL FOR COVARIATES OF PERIPHERAL SENSORY THRESHOLDS

| | Vibrotactile (log[V²]) | | Thermal log[°C]) | |
|---|---|---|---|---|
| | Finger | Toe | Finger | Toe |
| Skin temperature | 0.00726* | −0.00090 | 0.01995§ | −0.00048 |
| Height | 0.00337§ | 0.02737§ | 0.00047 | 0.00543§ |
| BMI | 0.00342† | 0.00798§ | 0.00491§ | 0.00330† |
| Age | 0.00925§ | 0.02324§ | 0.00324 | 0.00259 |
| Race | 0.07015§ | 0.07669‡ | 0.03634† | 0.06723§ |
| Place of service | 0.01684 | 0.01542 | 0.01519 | 0.02125* |
| Smoking status | 0.01703 | 0.03064* | 0.043698§ | 0.04385§ |
| Alcohol category | | | | |
| 0 | −0.05157* | −0.01130 | 0.00878 | 0.03129 |
| 1–29 | −0.05448† | −0.05182* | −0.00663 | −0.00007 |
| 30–89 | −0.05330† | −0.04115 | −0.00628 | 0.01886 |
| 90–179 | −0.02008 | −0.03803 | −0.02475 | −0.00116 |
| >179 | −0.01261 | −0.01881 | −0.05840* | −0.00865 |
| Never | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| Income category | | | | |
| 1 | 0.04941* | 0.07934† | 0.04812† | 0.09363§ |
| 2 | 0.04451* | 0.07827‡ | 0.04104† | 0.08789§ |
| 3 | 0.00831 | 0.03639 | 0.02699* | 0.02960 |
| 4 | 0.00237 | 0.02808 | 0.01839 | 0.03757* |
| 5 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| Examiner | | | | |
| 1 | 0.00505 | −0.04452 | 0.01256 | −0.03523 |
| 2 | −0.00876 | −0.00134 | −0.02445 | −0.01776 |
| 3 | −0.01126 | 0.09509‡ | 0.03864* | −0.01332 |
| 4 | −0.18011§ | −0.03370 | 0.07480§ | −0.03733 |
| 5 | −0.05113* | 0.09694§ | −0.05216† | −0.07759† |
| 6 | −0.03818 | 0.05764 | 0.05584† | −0.00439 |
| 7 | 0.14431† | 0.25673§ | | |
| 8 | 0.04842* | 0.03954 | 0.13303§ | 0.19242§ |
| 9 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |

*Signifies $p < 0.05$; †$p < 0.01$; ‡$p < 0.001$; §$p < 0.0001$.

to the empirical 5th and 95th percentiles of the covariate in this sample. The range of each covariate is provided in parentheses and the estimated change in each outcome over that range is presented in the Table 4. For the three dichotomous variables (race, place of service, and smoking status), the values in the table represent the mean estimated differences in outcome between the dichotomized groups. For the three categorical variables (drinking intensity group, household income, and examiner), the results provided are the largest estimated mean differences in outcome between any two categories. The purpose of Table 4 is to provide a guide to the magnitude of change in each outcome measure over the range of covariate values likely to be encountered in general practice (with the exception of age, which was restricted in range in this cohort).

*Temperature.* Skin temperature had a small positive effect on index finger vibrotactile threshold and a moderate positive effect on index finger thermal threshold (i.e., higher temperature was associated with poorer vibrotactile and thermal thresholds). It was not significantly related to toe vibrotactile threshold or toe thermal threshold.

*Height.* Height was significantly associated with both finger and toe vibrotactile threshold. The relationship between height and great toe vibrotactile threshold is depicted in Fig. 1. The effect was substantially larger for the toe than for the finger. Over the 5th to 95th percentile range of height observed in this study, index finger and great toe vibrotactile threshold varied by 0.07 and 0.60 log[V²], respectively. Height was significantly associated with great toe thermal threshold but not with finger thermal threshold. The relationship between great toe thermal threshold and height is depicted in Fig. 2. Over the 5th to 95th percentile range of height observed in this study, great toe thermal threshold varied by 0.12 log[°C].

*Body Mass Index.* BMI was significantly associated with finger and toe vibrotactile threshold as well as finger and toe thermal threshold.

*Age.* Age was significantly associated with both index finger and great toe vibration threshold. The relationship between great toe vibrotactile threshold and age is depicted in Fig. 3. The effect was substantially larger for the great toe than for the index finger. Over the 5th to 95th percentile range of age observed in this study, index finger and great toe threshold varied by 0.08 and 0.21 log[V²], respectively. Age was not significantly associated with finger or toe thermal threshold.

*Race.* Black race was significantly associated with higher

TABLE 4

MAGNITUDE OF CHANGE OVER RANGE OF COVARIATE

| | Vibrotactile ($\log[V^2]$) | | Thermal ($\log[°C]$) | |
|---|---|---|---|---|
| | Finger | Toe | Finger | Toe |
| Skin temperature (32.0 to 34.5°C) | 0.02 | 0.00 | 0.08 | 0.00 |
| Height (165 to 187 cm) | 0.07 | 0.60 | 0.01 | 0.12 |
| Body mass index (20.9 to 34.3 kg/m²) | 0.05 | 0.11 | 0.07 | 0.04 |
| Age (34.0 to 43.0 years) | 0.08 | 0.21 | 0.03 | 0.02 |
| Race (nonblack-black) | 0.07 | 0.08 | 0.04 | 0.07 |
| Place of service (Never Vietnam-Ever Vietnam) | 0.02 | 0.02 | 0.02 | 0.02 |
| Smoking status (current nonsmoker-smoker) | 0.02 | 0.03 | 0.04 | 0.04 |
| Alcohol drinking category (range) | 0.05 | 0.05 | 0.07 | 0.04 |
| Income category (range) | 0.05 | 0.08 | 0.05 | 0.09 |
| Examiner (range) | 0.32 | 0.30 | 0.19 | 0.27 |

vibrotactile thresholds for both the upper and lower extremities. The magnitude of the association was similar for both the upper and lower extremities. Black race was also significantly associated with higher thermal thresholds for both the upper and lower extremities. The effect was larger for the toe than for the finger. Mean finger and toe thresholds for black subjects were about 0.04 and 0.07°C higher than corresponding thresholds for nonblack subjects.

*Place of service.* No significant associations were observed between place of service and the two vibrotactile threshold outcomes. Toe thermal thresholds were significantly poorer among Vietnam veterans than among Veterans serving in other locations. The magnitude of the effect was very small.

*Smoking status.* A small positive effect of smoking was observed for great toe vibrotactile threshold. A nonsignificant positive effect was observed for finger vibrotactile threshold. Modest positive effects of smoking were observed for finger and toe thermal threshold.

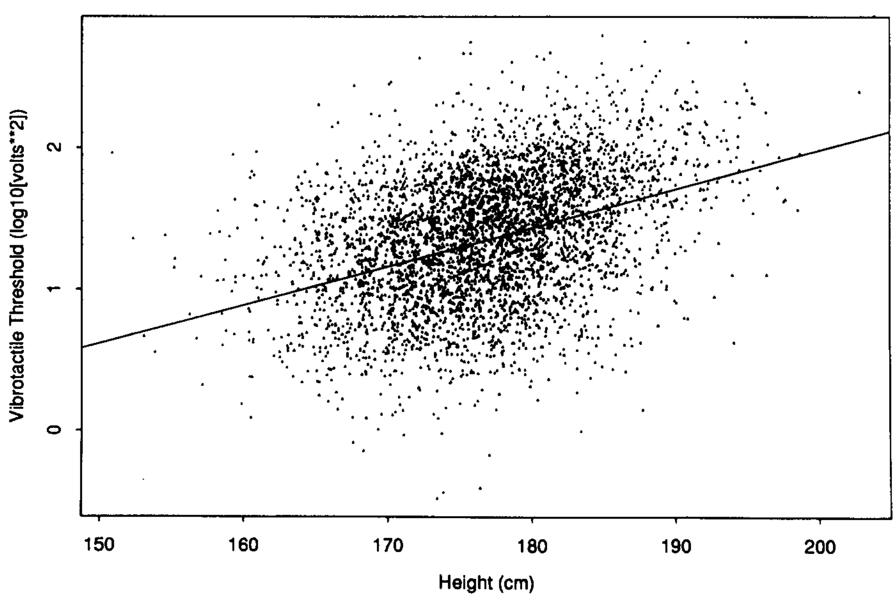


FIG. 1. Great toe vibrotactile threshold as a function of height.

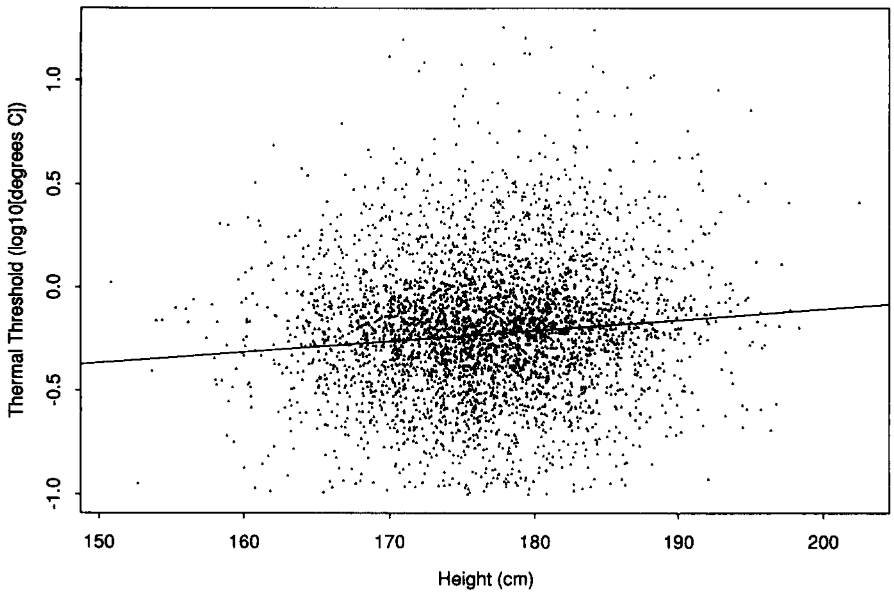


FIG. 2. Great toe thermal threshold as a function of height.

*Alcohol consumption.* The parameter estimates in Table 3 for alcohol consumption category are presented relative to the Never-drinker group. Lower values were observed for both finger and toe vibrotactile threshold for every alcohol consumption category when compared to the Never-drinker category. For the great toe, the negative association was significant only for subjects who reported consumption of 1–29 drinks per month. For the index finger, significant negative associations were observed for those drinking no alcohol at the time of study, consumers of 1–29 drinks per month, and consumers of 30–89 drinks per month. No consistent pattern was observed between finger or toe thermal threshold and alcohol consumption category. Only the group drinking >179 drinks per month had significantly lower finger thermal thresholds than the Never-drinker category.

*Income category.* The parameter estimates for income category are presented relative to the highest income category. In general, vibrotactile and thermal thresholds were higher for the lower income categories. The parameter estimates for income category were larger for toe vibrotactile and thermal thresholds than for finger thresholds. The largest difference in toe vibrotactile threshold between any two income categories was 0.08 log[$V^2$]. The largest difference in toe thermal threshold between any two income categories was 0.09 log[°C].

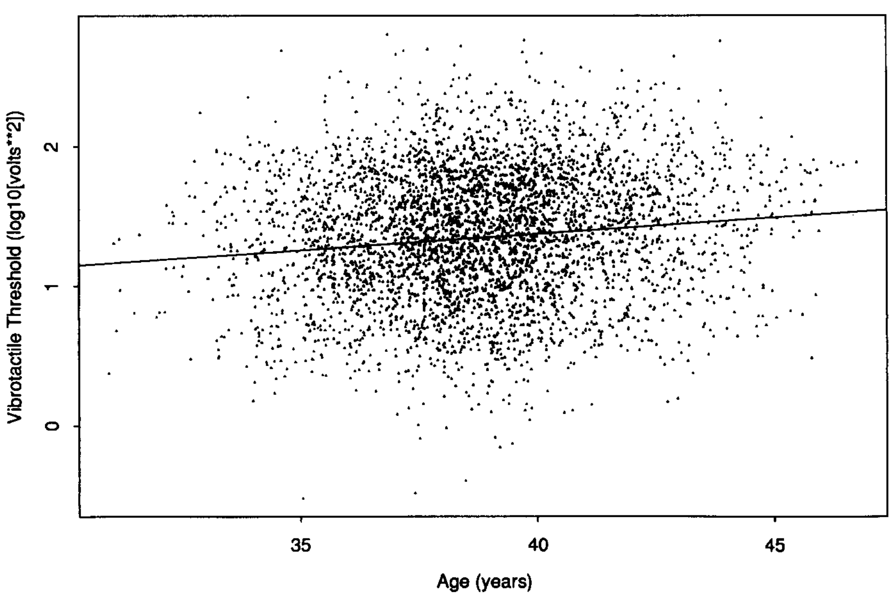


FIG. 3. Great toe vibrotactile threshold as a function of age.

*Examiner*. Considerable variability attributable to which of the 9 examiners performed the vibrotactile measurements and eight examiners who performed the thermal thresholds was observed for both the finger and toe. The parameter estimates in Table 3 are presented relative to 1 examiner, chosen arbitrarily. The largest differences in vibrotactile thresholds between any 2 examiners was 0.32 log[$V^2$] for the index finger and 0.30 log[$V^2$] for the great toe. The largest differences in thermal thresholds between any 2 examiners was 0.19 log[°C] for the finger and 0.47 log[°C] for the great toe.

## DISCUSSION

The medical examinations of the Vietnam Experience Study generated the largest set of vibrotactile and thermal thresholds collected according to a common protocol ever reported. In this population-based study of relatively healthy, young, adult males, the major covariates of vibrotactile thresholds were height, BMI, age, and examiner. Race, smoking status, and income were also related to vibrotactile threshold but not as strongly as the covariates mentioned above. The association between alcohol consumption and vibrotactile thresholds was small and all alcohol consumption categories had lower vibrotactile thresholds when compared to the Never-drinker category. Skin temperature was marginally related to finger vibrotactile threshold and not significantly related to toe vibrotactile threshold. Place of military service was not significantly related to vibrotactile threshold.

The most important covariates of toe thermal threshold were height and examiner. Other significant covariates of toe thermal threshold were income, race, BMI, smoking status, and skin temperature. Place of military service was slightly but significantly associated with toe thermal threshold. The most important covariates of finger thermal threshold were examiner, skin temperature, income, race, and smoking status.

Age has been demonstrated to be an important covariate of vibrotactile threshold (12,15,17,20,21,22,27,29,31). Fewer studies have been published in which the association between height and vibrotactile threshold was evaluated. When included as a covariate, height was significantly related to great toe threshold in several studies (15,17,22,29). The current study appears to be the first to demonstrate a significant association between height and finger threshold. In addition, the associations between vibrotactile threshold and BMI, race, smoking status, and income have not been previously reported. The relatively large differences observed between examiners suggests the need for rigorous training and evaluation of inter-examiner reliability of new test procedures.

No statistically significant covariates of thermal threshold are available in the literature. In one study of 100 normal subjects, investigators noted that an apparent increase in thermal threshold was observed with increasing subject age but that the trend was not significant (1). In another study of 156 normal subjects, no significant associations were observed between age, height, BMI or skin temperature and lower extremity thermal threshold (29). Estimation of the effect of age was somewhat limited in the current study because of the restricted range of this variable. At this time, no clear mechanism for the nontrivial effects of race and income on toe thermal threshold is available.

The absence of adverse effects of alcohol consumption on sensory thresholds was notable and contrary to conventional wisdom. However, when evaluated in other studies, alcohol consumption among subjects who have not been diagnosed as alcoholic has not been associated with poorer vibrotactile thresholds (15,26,29). No association between alcohol consumption and thermal thresholds was observed in a study of normal subjects (29). The relationship between alcohol consumption and measures of neurological function are described in detail in a companion paper (19).

No biological mechanism is readily available to explain many of the associations observed in the current study. Indeed, the previously unreported associations observed in the current study should be considered hypothesis-generating and confirmed in future studies, rather than taken as conclusive evidence of an effect.

Additional research should address development of protocols and training methods that are less prone to interexaminer differences. Because the vibrotactile threshold results of the current study were reported in units of voltage applied to the vibrator, they cannot be compared directly to the results of other studies using other vibrotactile instruments. However, the pattern of results and relative magnitude of effects of the covariates should be generalizable to similar groups of subjects. In future studies, vibrotactile thresholds should be reported in universally accepted units such as microns of peak-to-peak displacement (18).

These results suggest that age, height, BMI, race, and income are the most important variables to be considered as covariates of vibrotactile threshold outcomes in epidemiologic studies. Height, race, and income appear to be the most important covariates of thermal threshold outcomes. Because the study was performed on males of a limited age range who had been screened for health at the time of entry into military service, caution is required when generalizing the results to other groups. Clinicians using vibrotactile and thermal thresholds during evaluation of individual patients should also consider the effect of covariates when determining normality of results in the clinical setting.

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