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Normative median and ulnar nerve conduction values among a rural aged population

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Abstract.
BACKGROUND: Carpal tunnel syndrome (CTS) is commonly diagnosed with a combination of characteristic symptoms and nerve conduction studies (NCS) across the wrist. Normative NCS values exist, but there is minimal data among older individuals or among rural populations.
OBJECTIVE: To estimate distal median and ulnar sensory, and median motor latencies across the wrist in an older, rural population.
METHODS: Hand symptom questionnaires and three standard NCS were obtained from 1085 participants. Univariate and multiple linear regression analyses were conducted.
RESULTS: Normative NCS values are presented from participants (mean age 57 years) who reported either no CTS symptoms or possible CTS symptoms. Covariates associated with NCS included age, hand temperature, body mass index, and height.
CONCLUSIONS: This large normative NCS data set can be generalized to an older and rural population. Nerve conduction latencies were generally longer in this population than those reported in previous studies.

Keywords: Rural, nerve conduction, normal data, carpal tunnel syndrome, ergonomics

1. Introduction

Carpal tunnel syndrome (CTS) is the clinical illness resulting from compression of the median nerve at the wrist. Estimates of the prevalence of CTS among general populations range from 0.6% to 5.8% [1–3] and higher among working populations [4]. The standardized annual incidence of physician-diagnosed CTS in the US is 542 per 100,000 for females and 303 for males [5].

The diagnosis of CTS is often based on the combination of characteristic symptoms in the median sensory nerve distribution of the hand and nerve conduction study (NCS) results consistent with median mononeuropathy at the wrist. Several NCS measurements are used to localize median nerve impairment consistent with CTS, including median sensory nerve conduction velocity (NCV) across the wrist, and differences in sensory latency between the median and ulnar nerve across the wrist. When using NCS to assist in the diagnosis of CTS, a clinician will compare results obtained from an individual suspected of having CTS to "nor-

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mal" or expected results. Published estimates of expected results from large populations are uncommon.

In order to empirically estimate unbiased lower or upper limits of normal for NCS parameters (i.e., to estimate normative values), measures should be obtained from persons free of pathology that may influence the observed result. According to an American Association of Electrodiagnostic Medicine (AAEM) report [6], normative data used for diagnosing CTS should be obtained from a representative sample of "normal" individuals without CTS. Ideally, the sample would also be large and have sufficient range of important covariates, such as age and gender, so that their effects on the measures can be estimated.

Although normative data for median and ulnar nerve conduction measures across the wrists have been published for worker [7], university student [8], and patient populations [9], there is still a paucity of population-based median and ulnar normative data. Specifically, there is a lack of normative data among persons living in rural locations and older populations. For example, in a literature review [10], the mean participant age of any of the studies cited was less than 50 years for all but one study [11]. With the population aging in most western nations, normative data obtained from samples of older individuals will be needed by clinicians and researchers to provide more accurate criteria for CTS diagnoses.

In addition to the limited information among older individuals, we are not aware of studies of normative NCS results obtained among rural populations, despite the fact that individuals living in rural environments comprise over 20% of the US population [12]. Normative nerve conduction values from rural populations may be different than those obtained from more urban areas as a result of differences in exposure to occupational hazards, such as neurotoxins from farming, comorbid conditions, and access to health care [13,14].

The purpose of this study was to estimate normative wrist to finger median and ulnar sensory latencies, and median motor latencies across the wrist among persons recruited from an older, rural population. A secondary purpose of this study was to estimate the effect of various demographic characteristics on these latency values.

2. Methods

2.1. Subjects

Participants for this study were recruited from among those currently enrolled in a multi-year prospective cohort study of chronic disease and injury among an agricultural population in a single county in rural Iowa, US (the Keokuk County Rural Health Study; KCRHS). Keokuk County has a population of approximately 11,400, which meets the US Census definition of rural [15]. The unit of enrollment for participants in the KCRHS was the household, randomly selected from among all households in the county. Since a primary focus of the KCRHS was agriculturally-related injuries and illnesses, farm households were over-sampled. At the time that the NCS were obtained, 1004 households representing 25% of the county were enrolled in the KCRHS.

Since 1994, investigators have obtained a substantial amount of information from KCRHS participants in two rounds of data collection. Self-administered questionnaires and personal interviews have been used to collect medical history (including medication use), occupational information, injury history, mental health, and risk behaviors. Additionally, medical screening has been conducted, including the recording of vital signs and administration of standard blood tests (e.g. serum glucose). Investigators have collected anthropometric data including height, weight, and skin fold measurements of the triceps and waist. All data were collected at a single research facility located in the largest town of the county. Characteristics of the KCRHS have been previously described [16,17].

Specific to the current study, the Institutional Review Board at the University of Iowa approved this study and participants provided written informed consent prior to data collection. All individuals participating in the KCRHS between February 2001 and April 2004 and who were age 18 years or older ($n = 1085$) were invited to participate in the current study of median and ulnar NCS.

2.2. Hand symptom diagrams

Participants completed a self-administered hand symptom questionnaire and hand symptom diagram [18, 19]. Participants rated hand or wrist symptoms, such as numbness, tingling, burning, or aching on a 0–10 scale ($0 =$ none; $10 =$ severe) and shaded a hand diagram where the symptoms were located. Participants were also asked about the duration of hand symptoms, nocturnal hand symptoms, and activities that aggravated hand symptoms.

An investigator (DA) blinded to the NCS findings classified the hand diagrams into three CTS symptom categories: 1) classic CTS symptoms (CL-CTS),

2) possible CTS symptoms (P-CTS), and 3) no CTS symptoms [18,20,21]. Symptoms defined as CL-CTS included numbness, tingling, burning, or aching in the palmar aspect of at least two of the first three digits (thumb, index, and long fingers), and P-CTS included those symptoms in no more than one of the first three digits. Classifications were conducted separately for the dominant and non-dominant hands.

2.3. Nerve conduction studies

After participants completed the hand symptom questionnaire, three standard NCS [22,23] measures were obtained over an 8 cm distance across the wrist of all participants: 1) orthodromic palm-wrist median mixed nerve latency (MML), 2) orthodromic palm-wrist ulnar sensory nerve latency (USL), and 3) median distal motor latency (MMot). All NCS were obtained with a Cadwell 5200A nerve conduction stimulator (Cadwell Laboratories, Inc., Kennewick, WA, US) by two registered nurses trained in electrodiagnostic techniques. A fourth NCS parameter, the median-ulnar sensory latency difference (MULD) was calculated by subtracting MML from USL.

To measure MML across the wrist, the stimulating electrode was placed over the mid-palm and the recording electrode was placed on the wrist 8 cm proximal to the stimulating electrode (approximately 2 cm proximal to the distal wrist crease). For the USL, the stimulating electrode was placed over the ulnar aspect of the palm and the recording electrode was placed on the wrist 8 cm proximal to the stimulating electrode. For both the median and ulnar nerves, the sensory latency was defined as the interval (ms) between the stimulus artifact and the peak of the mixed nerve action potential. The MMot was obtained with the stimulating electrode placed over the midpoint of the distal forearm approximately 2 cm proximal to the distal wrist crease and the recording electrode placed over the thenar eminence parallel to the first metacarpal. The motor latency was defined as the interval (ms) between the stimulus artifact and the onset of the compound motor action potential. For all measures, supramaximal stimulation was used and the ground electrode was placed on the dorsum of the participant's hand.

Hand temperature was monitored continuously during the NCS with a surface thermistor (TH-8 Thermalert, Physitemp Instruments, Inc., Clifton, NJ, US) placed in the palmar web space between the thumb and index finger. Although NCS were performed in a warm room and skin temperatures were monitored and recorded, time constraints precluded any efforts to manipulate hand temperature.

2.4. Exclusions

The nerve conduction results for the respective dominant or non-dominant hand of participants whose hand symptom diagrams were classified as CL-CTS were excluded from the normative data set. Since many of those classified with P-CTS may or may not have had CTS, two separate sets of normative analyses were conducted, the first among only participants who reported no symptoms and the second among participants who reported either no symptoms or P-CTS. Additionally, any individual who was previously diagnosed with CTS or who had surgery for CTS was excluded from analyses.

Individuals with diabetes mellitus and rheumatoid arthritis (RA), known risk factors for impaired median nerve function at the wrist, were excluded from all analyses [24–26]. Because of the age of the study participants, a relatively large proportion reported a diagnosis of thyroid disease. Due to the high prevalence, these participants were not excluded; rather, thyroid disease status was included as a covariate in the analysis. Results obtained from hands with skin temperature $< 29°C$ were excluded from analyses [27]. Finally, in order to avoid biasing the normative data sets with results from individuals affected by undiagnosed pathology that increased the risk of impaired nerve function, all nerve conduction measures obtained from participants for whom one or more "no response" was observed were excluded from all analyses.

2.5. Data analysis

After collection of NCS, all waveforms were reviewed by a study investigator blinded to participant characteristics to ensure data quality. Waveforms that did not appear to have a clear nerve or muscle action potential present were not included in the data analysis. Since nerve conduction measures of the hands of individuals are not independent, separate analyses were conducted for the dominant and non-dominant hands [28–30]. Means and 95% confidence intervals were calculated for the four NCS measures (MML, USL, MULD, and MMot). Tests of assumptions of normality (Kolmogorov-Smirnov test, Shapiro-Wilk Test) and skewness were conducted on the NCS data. Natural logarithm transformations were performed on non-normal data and subsequent analyses were performed on the transformed data. For each NCS, the 50^{th}, 90^{th}, 95^{th}, and 99^{th} percentiles were calculated.

To estimate unadjusted (i.e., crude) associations between NCS outcomes and potentially important covariates, linear regression analyses were separately conducted for each of the four NCS outcomes and age, gender, height, weight, body mass index (BMI), waist circumference, triceps skin fold thickness, thyroid condition, and smoking status (never, former, current) [31–35]. Additionally, stratified analyses between age and BMI, and age and gender, were investigated by examining associations between the four NCS outcomes and the appropriate cross product terms in separate regression analyses.

In order to build parsimonious multivariate models, covariates with unadjusted probabilities < 0.15 were entered simultaneously into multiple linear regression models of each of the four NCS outcomes. For collinear covariates, the variable with the stronger age-adjusted association with the outcome was retained for multivariate modeling and the collinear variable was dropped. All analyses were performed with SAS, Version 9.13 for PC (SAS Institute, Cary, NC).

3. Results

3.1. Participants

Approximately one quarter of households (1589 adults) in Keokuk County participated in the parent study (KCRHS). Among these individuals, 1085 were recruited for the current study. Approximately 10% of the sample ($n = 107$) refused NCS and were excluded from further analysis, and an additional 13 individuals were excluded from analysis due to an equipment malfunction. Review of NCS waveforms showed that an unacceptable number of measures obtained by one of the examiners met study quality criteria for analyses and results obtained by this examiner ($N = 373$) were excluded from further analysis. Of the remaining individuals ($N = 596$), 33% were excluded from further analysis due to existing co-morbidities or unattainable NCS (diabetes $N = 43$, rheumatoid arthritis $N = 4$, previous CTS diagnosis or NCS unable to be obtained $N = 153$).

Hand skin temperature was < 29°C for 11 dominant and 12 non-dominant hands; results from these hands were excluded from the analyses. Also excluded from analyses of normative values were results from 115 individuals classified as having CL-CTS (either hand) based on the hand diagram data. The remaining two cohorts included: 1) participants who reported no symptoms consistent with CTS (dominant hand $n = 252$, non-dominant hand $n = 255$), and 2) participants who reported either no CTS symptoms or P-CTS (dominant hand $n = 272$, non-dominant hand $n = 269$).

Table 1
Demographics of participants

Characteristic	Mean (SD) or N (%)
Age (years)	56.7 (15.6)
Gender	
Male	218 (36.6)
Female	378 (63.4)
Height (m)	1.67 (0.09)
Weight (kg)	82.8 (18.2)
Body Mass Index (kg/m^2)	29.5 (5.7)
Right handed	547 (91.8)
Years lived in Iowa	52.5 (18.0)
Years lived in Keokuk County	42.2 (44.8)
Years Lived on a farm	28.0 (24.8)
Place of Residence	
Farm	203 (34.1)
Rural	66 (11.1)
Town	327 (54.9)
Marital status	
Married/co-habitate	463 (77.7)
Widowed	58 (9.7)
Divorced/never/other	75 (12.6)
Education	
High school graduate or some college	480 (80.5)
College graduate or more	116 (19.5)
Smoking status	
Never	375 (63.0)
Former	153 (25.7)
Current	67 (11.3)

The mean participant age was 56.7 years (SD 15.6), the mean height was 1.67 m (SD 0.09), and the mean weight was 82.8 kg (SD 18.2). Other demographic and personal characteristics are presented in Table 1 and are generally similar to results observed among all participants in the second round of the KCRHS (data not shown). Demographic characteristics did not differ significantly between the two examiners ($p > 0.05$), suggesting that systematic biases were not introduced by excluding results obtained by one of the examiners.

3.2. Nerve conduction outcomes

As expected, distributions of all of the NCS measures were right skewed, and the dominant hand USL values were leptokurtotic. Natural logarithm transformations did not appreciably reduce the skewness. Therefore, the reported means and medians were calculated from untransformed results, and percentiles were calculated to better describe the distributions.

Normative values are presented in Table 2 for the NCS measures obtained from participants who reported no CTS symptoms, and in Table 3 for the NCS measures obtained from those with P-CTS or no CTS

Table 2
Normative values (ms) for nerve conduction studies (NCS) obtained from participants who reported no CTS symptoms (CI = confidence interval)

	N	Mean (SD)	95% CI	Median	90^{th}	95^{th}	99^{th}
Dominant hand NCS							
Median sensory	252	2.22 (0.32)	2.18–2.26	2.18	2.68	2.85	3.10
Ulnar sensory	248	1.89 (0.20)	1.87–1.91	1.89	2.14	2.22	2.43
Median motor	247	3.77 (0.61)	3.70–3.85	3.69	4.62	4.95	5.54
Median ulnar latency difference	248	0.32 (0.30)	0.28–0.36	0.29	0.75	0.93	1.17
Non-dominant hand NCS							
Median sensory	251	2.16 (0.27)	2.12–2.19	2.14	2.56	2.68	2.85
Ulnar sensory	251	1.89 (0.20)	1.87–1.92	1.89	2.14	2.19	2.35
Median motor	251	3.69 (0.56)	3.62–3.76	3.61	4.45	4.73	5.37
Median ulnar latency difference	251	0.27 (0.28)	0.23–0.30	0.21	0.63	0.80	1.30

Table 3
Normative values (ms) for nerve conduction studies (NCS) obtained from participants who reported no CTS symptoms or participants with possible CTS symptoms (CI = confidence interval)

	N	Mean (SD)	95% CI	Median	90^{th}	95^{th}	99^{th}
Dominant hand NCS							
Median sensory	271	2.23 (0.33)	2.19–2.27	2.18	2.71	2.89	3.15
Ulnar sensory	268	1.90 (0.20)	1.87–1.92	1.89	2.14	2.22	2.43
Median motor	267	3.80 (0.65)	3.72–3.87	3.69	4.62	4.95	5.88
Median-ulnar latency difference	268	0.33 (0.31)	0.30–0.37	0.29	0.75	0.97	1.18
Non-dominant hand NCS							
Median sensory	265	2.17 (0.30)	2.13–2.20	2.14	2.56	2.68	2.89
Ulnar sensory	265	1.90 (0.20)	1.87–1.92	1.89	2.14	2.22	2.35
Median motor	265	3.69 (0.56)	3.63–3.76	3.61	4.45	4.70	5.37
Median-ulnar latency difference	265	0.27 (0.29)	0.24–0.30	0.21	0.67	0.80	1.30

symptoms. The confidence intervals were most narrow for the USL and widest for MMot.

Covariates associated with all NCS outcomes in univariate models with probability < 0.15 were age, gender, height, weight, BMI, waist circumference, skinfold measurements, hand temperature, and smoking status. Among individuals without symptoms, the presence of a thyroid condition was univariately associated with non-dominant USL ($p = 0.10$), and use of estrogenic hormones was associated with the non-dominant MMot ($p = 0.08$). Among those with P-CTS or no symptoms, the presence of a thyroid condition was not significantly associated with any of the NCS ($p > 0.15$). Use of estrogenic hormones was associated with the dominant USL ($p = 0.13$), non-dominant MML ($p = 0.14$), and non-dominant MMot ($p = 0.08$). Substantial collinearity existed between BMI, weight, and waist circumference. Thus, BMI alone was included in the multivariate models. Height was not collinear with BMI and was maintained in multivariate models, since it is a well known covariate for nerve conduction values.

Regression coefficients and associated p-values for multivariate models are in Table 4. For individuals with P-CTS or no symptoms, age and hand temperature were significantly associated with MML, MMot, and USL bilaterally. Hand temperature was not associated with MULD. Body mass index was significantly associated with USL, MMot, and MULD for the dominant and non-dominant hands among individuals with no symptoms, and among the combined group of P-CTS or no symptoms. Among individuals without symptoms of both hands and those with P-CTS in the non-dominant hand, height was associated with MML and MMot.

Stratified analyses indicated that there was a statistically significant relationship between BMI and both USL and MULD for individuals < 50 years old and without symptoms ($p < 0.001$). Specifically, among individuals < 50 years old and without symptoms, USL decreased 0.01 ms for every unit increase in BMI (kg/m^2). In contrast, no such association existed for individuals > 50 years old. For individuals > 65 years old and without symptoms, there was a significant association between gender and MMot; latency was 0.41 ms shorter for females than males in this older age group.

4. Discussion

To our knowledge, this study is the largest normative data set of nerve conduction values for the distal

Table 4

Multivariate intercepts (Int.), regression coefficients (β), p-values (p), and R^2 for nerve conduction studies (NCS) obtained from participants (N) who reported no symptoms*

			Age		BMI		Height		Temp.		Gender		Smoke		
NCS	N	Int.	β	p	β	p	β	p	β	p	β	p	β	p	R^2
Dominant															
Median mixed	250	2.373	0.007	< 0.001	0.006	0.08	0.597	0.05	−0.051	< 0.001	−0.018	0.76	−0.036	0.36	0.21
Ulnar sensory	248	3.087	0.005	< 0.001	−0.005	0.01	0.102	0.56	−0.044	< 0.001	0.035	0.31	0.005	0.83	0.35
Median distal motor	247	4.600	0.011	< 0.001	0.016	0.01	1.092	0.05	−0.112	< 0.001	−0.134	0.23	−0.037	0.61	0.22
MULD	248	−0.865	0.003	0.03	0.012	0.001	0.553	0.07	−0.005	0.65	−0.059	0.33	−0.038	0.34	0.07
Non-dominant															
Median mixed	252	1.781	0.008	< 0.001	0.003	0.38	0.591	0.05	−0.031	0.01	−0.064	0.30	−0.014	0.72	0.17
Ulnar sensory	250	2.943	0.005	< 0.001	−0.005	0.01	0.133	0.43	−0.042	< 0.001	−0.036	0.28	0.016	0.45	0.34
Median distal motor	250	3.723	0.012	< 0.001	0.015	0.04	1.256	0.04	−0.094	< 0.001	0.046	0.70	0.023	0.77	0.17
MULD	250	−1.314	0.003	0.01	0.009	0.02	0.516	0.10	0.012	0.34	−0.106	0.09	−0.027	0.51	0.06

*MULD = median-ulnar latency difference; age (yrs); BMI (kg/m^2); height (m); temp. (°C); male = 0, female = 1; never smoked = 0, current or past smoker = 1.

median and ulnar nerves that can be appropriately generalized to an older and rural population. As discussed in previous papers, data can be considered "normative" in several ways [6,7]. Normal values are often defined as those ± 2 standard deviations about the mean. However, this method of defining normal values assumes a normal distribution, which is often absent in bioelectric data [6,36]. In the current study, percentiles were calculated, precluding the need for assumptions about the distribution.

A considerable strength of the current study was the use of a random population-based sample localized to a rural population. In contrast, previous investigations of normative NCS values have examined populations of patients attending neurodiagnostic clinics or samples of convenience, typically in urban areas [7–9,37–39]. In these previous studies, individuals who suspected they were suffering from CTS may have been more likely to participate, leading to selection bias and longer latencies in the normative data set [10]. Previous researchers have commented about the paucity of investigations involving random population-based sample [40].

Specific cutoff values are used to classify NCS as normal or abnormal, although there is inconsistency among medical practitioners making this interpretation [41]. When NCS are normally distributed, values lying within the mean ± 2 SD are considered "normal" [36,42–44]. When the distribution of values is skewed, common with physiologic data, values can be transformed to obtain a normal distribution or values can be reported as percentiles [7,32,36,42]. These normative ranges place the probability of obtaining a false-positive measure at approximately 5% or less. For example, the usual cutoff values for a MULD suggestive of median mononeuropathy are > 0.5 ms to > 0.8 ms [7,45–48]. In the population used in the current study, the MULD would need to be > 0.93 ms before being considered abnormal (95^{th} percentile). A cutoff value of 0.5 ms approximately represents the 80^{th} percentile.

Bingham and colleagues [48], in a study of applicants for various industrial jobs, reported a lower mean MULD (0.19 right, 0.17 left) in participants without CTS symptoms than the current study findings. In fact, the mean MULD for participants with CTS symptoms found by Bingham et al. was more comparable to the participants who reported no symptoms in the current study. The difference in mean age of study participants likely accounts for the inconsistency, since participants in the current study were approximately 25 years older than those in Bingham et al. The cutoff value of 0.93 ms found in the current study is also higher than the 95^{th} percentile reported by Salerno et al. [7] (0.7 ms).

The MULD is often used in population-based studies on CTS. Atroshi and colleagues [49] reported that the MULD had a significantly higher diagnostic accuracy (i.e., greater area under a receiver operating characteristic curve) than many other NCS. Additionally, this NCS is less likely to be affected by hand temperature, height, or other individual characteristics. Although lower levels of sensitivity and specificity for the MULD have been reported by others [10], this NCS has been proposed as a practice standard for the diagnosis of CTS by the AAEM (American Association of Electrodiagnostic Medicine) [10,50].

The AAEM considers MMot a practice guideline, but not a practice standard [50]. The 95^{th} percentile of the MMot (4.95 ms), designating the cutoff value for normal, was longer for this population then that found by many other investigators [51–53]. However, the cutoff value was comparable to normative studies conducted by Buschbacher [54] and Kuntzer [55]. In the current study, the mean value for the MMot was comparable to the mean value obtained from the control subjects in the study conducted by Kuntzer [55]. Interestingly, the mean age of Kuntzer's control subjects was 13 years younger than the current participants.

With the exception of age, hand temperature, and BMI, few variables were significantly associated with the NCS in the current study. In general, latency increases with increasing age [7,31,32,39] and our findings confirm this relationship. Blumenthal et al. [37] clearly indicated that age has a greater effect on electrophysiology than reported symptoms. Rivner et al. [39] reported a correlation coefficient of 0.28 between age and USL among individuals referred to an electrodiagnostic laboratory. In general, the regression coefficients found in the current study were extremely small and would increase latency by approximately 0.08 ms per decade.

Gender was not associated with NCS in any of the multivariate models. A similar finding was noted by Stetson et al. [32] who suggested that height and wrist measurements were more associated with NCS than gender. However, stratified analyses from the current study indicated an effect of gender on MMot among individuals $>$ 65 years old and without symptoms. The mean latency for males was 4.31 ms compared to 3.90 ms in females, a statistically significant difference ($p = 0.02$). Buschbacher [54] noted similar findings although the difference in latency between males and females was less (males 4.00 ms, females 3.80 ms). The incongruity between the studies is likely due to the effect of age, since Buschbacher used 50 years as the age cutoff rather than 65 years.

A significant negative association was noted between BMI and USL but not MML. Although other investigators have found no relationship between BMI and ulnar NCS [56], Buschbacher [57] reported a significant negative association between BMI (as a continuous variable) and USL. Results from the stratified analysis in the current study confirmed this association; in younger individuals, the USL decreased as BMI increased. Buschbacher suggested that the superficial position of the ulnar nerve may result in decreased nerve temperature and longer latencies in thinner individuals. However, Buschbacher emphasized the limited clinical significance of this finding, a result reinforced by the small β for BMI in the current study (e.g. dominant hand USL, no symptoms $\beta = -0.005$).

As expected, a positive relationship existed between BMI and both the MMot and MULD. Other investigators have reported similar findings [33,35,58]. For example, Werner et al. [33] found that obese individuals had a greater likelihood of CTS compared to those with lower BMIs. More recently, Bland [59] suggested that BMI had a greater effect on reducing the nerve conduction of individuals $<$ 63 years old than in older individuals. Similar findings were noted in the current study, since the relationship between BMI and NCS was not significant in the stratified analysis of individuals $>$ 65 years old.

There was a strong, though nonsignificant, association between height and latency in the current study. The regression coefficients for height and age were similar to those reported by Rivner et al. [39]. Comparably, Stetson et al. [32] reported strong associations between height, and median and ulnar distal latencies. Likewise, Letz and Gerr [31] found height was negatively associated with nerve conduction velocity, but the relationship was stronger for the lower extremity than the upper.

Although smoking status has been included as a covariate in studies on nerve conduction among those with diabetes and peripheral vascular disease [60,61], few studies have considered tobacco use as a separate predictor variable for nerve conduction. Letz and Gerr [31] reported that smokers had reduced motor conduction velocity. Similarly, Nathan et al. [62] found 26% more use of tobacco among industrial workers with CTS than those without CTS. In contrast, no association between smoking and NCS was found in the current study, a relationship noted by other investigators [63,64].

We reported results for the dominant and non-dominant hand separately, which helps adjust for any lack of independence in the data [30]. With few exceptions, the regression estimates from multivariate modeling did not differ substantially between the hands. This finding suggests that handedness does not have a considerable role in nerve conduction of the distal median and ulnar nerves. Carpal tunnel syndrome is commonly bilateral [29], and other normative data confirms that nerve conduction is similar between the dominant and non-dominant hand [65]. One exception to this finding in the current study was that height had a greater effect on latency in the non-dominant hand than the dominant hand, among individuals who reported P-CTS or no symptoms. The reason for this finding is unclear.

Although not specifically tested, the CTS symptom definition had minimal effect on the normative values. As expected, latencies were slightly longer in those

Table 5

Multivariate intercepts (Int.), regression coefficients (β), p-values (p), and R^2 for nerve conduction studies (NCS) obtained from participants (N) who reported no symptoms or possible CTS symptoms*

			Age		BMI		Height		Temp.		Gender		Smoke		
NCS	N	Int.	β	p	β	p	β	p	β	p	β	p	β	p	R^2
Dominant hand															
Median mixed	270	2.567	0.007	< 0.001	0.005	0.11	0.459	0.12	−0.050	< 0.001	−0.011	0.85	0.004	0.91	0.21
Ulnar sensory	268	3.138	0.005	< 0.001	−0.005	0.01	0.087	0.59	−0.045	< 0.001	0.044	0.17	0.012	0.56	0.36
Median distal motor	267	4.725	0.011	< 0.001	0.015	0.02	0.898	0.13	−0.106	< 0.001	0.158	0.18	0.042	0.58	0.18
MULD	268	−0.705	0.003	0.01	0.011	0.001	0.422	0.16	−0.004	0.75	−0.060	0.31	−0.004	0.91	0.06
Non-dominant hand															
Median mixed	263	2.029	0.006	< 0.001	0.005	0.06	0.567	0.03	−0.039	< 0.001	−0.041	0.42	0.026	0.43	0.19
Ulnar sensory	263	2.775	0.004	< 0.001	−0.004	0.05	0.210	0.24	−0.040	< 0.001	0.015	0.67	−0.002	0.94	0.25
Median distal motor	263	4.295	0.009	< 0.001	0.010	0.08	1.181	0.02	−0.101	< 0.001	0.122	0.23	0.008	0.90	0.19
MULD	263	−0.720	0.002	0.04	0.009	0.004	0.357	0.20	0.001	0.94	−0.056	0.31	−0.024	0.50	0.05

*MULD = median-ulnar latency difference; age (yrs); BMI (kg/m^2); height (m); temp. (°C); male = 0, female = 1; never smoked = 0, current or past smoker = 1.

with P-CTS or no symptoms (Table 3) than individuals with no symptoms alone (Table 2). The MMot was most susceptible to changes due to the symptom definition.

There are limitations of this normative study that may have affected the results. Since the results of the second examiner were deleted, selection bias was possible. The second examiner may have differentially tested individuals with poorer nerve conduction. Excluding these results from the study would have had the likely effect of shorter mean latencies. However, no significant difference in mean NCS values was noted between the two examiners. Test review bias was possible in this study since the electrodiagnostic equipment did not automatically mark onset latencies [66]. Observer bias was also possible, but was minimized two ways. First, the examiners were blinded to the three CTS categories based on the hand diagram. Second, the investigator who performed the categorization was blinded to the results of the NCS. The exclusion of any individual where a single NCS was unable to be obtained (possibly suggesting a nerve block) may make our results more conservative.

An additional limitation is due to the latency measurement. Since peak sensory latencies were examined in this study, it is possible that the results may not be useful to clinics or laboratories that calculate onset latencies. Hennessey et al. [65] indicated that onset latencies are easier to determine, especially if the signal has a broad peak. However, Sander and colleagues [45] indicated that peak latencies have similar distributions to onset latency.

Inclusion of individuals with comorbidities associated with CTS may have altered the NCS. Atcheson et al. [24] noted that approximately 33% of individuals with CTS also had a comorbidity known to be associated with CTS, regardless of case definition. In the current study, the effect of comorbidities on the NCS was minimized by excluding individuals with diabetes and RA from the normative data sets. Thyroid conditions and hormone replacement therapy were included as covariates, but were not associated with any of the nerve conduction measurements in the multivariate models.

5. Conclusions

In summary, appropriate normative data considers the demographic characteristics of the population of interest. The individuals who participated in the current study were older than those who participated in many other normative studies. Additionally, this rural population was likely exposed to unique workplace factors that may have influenced their NCS. Latencies were generally longer in this population than those reported by other investigators. Similar to other studies, factors such as age, height, BMI, and hand temperature were associated with NCS. It is essential for clinicians and researchers to use appropriate normative values when making their determinations.

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Abbreviations

AAEM	American Association of Electrodiagnostic Medicine
BMI	body mass index
CTS	carpal tunnel syndrome
KCRHS	Keokuk County Rural Health Study
NCS	nerve conduction studies
NCV	nerve conduction velocity
RA	rheumatoid arthritis
SD	standard deviation

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