

The Effectiveness of Post-Offer Pre-Placement Nerve Conduction Screening for Carpal Tunnel Syndrome

Ann Marie Dale, PhD, OTR/L, Bethany T. Gardner, OTD, OTR/L, Angelique Zeringue, MS, Robert Werner, MD, MS, Alfred Franzblau, MD, and Bradley Evanoff, MD, MPH

Objective: We evaluated post-offer pre-placement (POPP) nerve conduction studies (NCS) for carpal tunnel syndrome (CTS), testing diagnostic yield and cost-effectiveness. **Methods:** A total of 1027 newly hired workers underwent baseline NCS and were followed for an average of 3.7 years for diagnosed CTS. Measures of diagnostic yield included sensitivity, specificity, and positive predictive value (PPV). Cost-effectiveness of POPP screening was evaluated using a range of inputs. **Results:** Abnormal NCS was strongly associated with future CTS with univariate hazard ratios ranging from 2.95 to 11.25, depending on test parameters used. Nevertheless, PPV was poor, 6.4% to 18.5%. Cost-effectiveness of POPP varied with CTS case costs, screening costs, and NCS thresholds. **Conclusions:** Although abnormal NCS at hire increases risk of future CTS, the PPV is low, and POPP screening is not cost-effective to employers in most scenarios tested.

Carpal tunnel syndrome (CTS) is a common work-related upper extremity musculoskeletal disorder and has the longest time away from work and the highest associated direct costs among upper extremity work-related injuries and musculoskeletal disorders.¹⁻⁴ Direct medical costs are estimated to exceed \$1 billion per year.^{1,3} Carpal tunnel syndrome can also cause significant impairment in functional ability for workers in both work and daily activities.^{2,5,6} Some employers routinely use post-offer pre-placement (POPP) screening, including nerve conduction studies (NCS), to identify workers at higher risk of developing CTS, so that these workers will not be hired into hand-intensive jobs at higher risk of CTS, thus reducing the employer's injury rates and workers' compensation costs.⁷ It is difficult to estimate the number of employers currently utilizing POPP NCS to make hiring decisions; to our knowledge, there are no published scientific reports describing the prevalence of POPP testing by employers. Despite a lack of clear scientific evidence that POPP screening with NCS is sufficiently predictive of future CTS, this practice seems to be widespread on the basis of publications in trade journals, advertisements by health care facilities offering "carpal tunnel testing or screening,"⁸⁻¹⁷ and promotion by device manufacturers.

From the Department of General Medical Sciences (Dr Dale, Dr Gardner, Ms Zeringue, and Dr Evanoff), Washington University School of Medicine; School of Public Health (Ms Zeringue), St Louis University, St Louis, Mo; and Department of Environmental and Health Sciences (Dr Werner and Dr Franzblau), University of Michigan School of Public Health, Ann Arbor.

This study was supported by the Centers for Disease Control and Prevention—National Institute for Occupational Safety and Health (grant # R01OH008017-01) and by the Washington University Institute of Clinical and Translational Sciences Award (grant # UL1 TR000448) from the National Center for Advancing Translational Sciences of the National Institutes of Health.

The contents of this article are solely the responsibility of the authors and do not necessarily represent the official view of the National Institute for Occupational Safety and Health, the National Center for Advancing Translational Sciences, the National Institutes of Health, or NeuroMetrix.

The authors declare that they have no conflicts of interest.

Address correspondence to: Ann Marie Dale, PhD, OTR/L, Department of General Medical Sciences, Washington University School of Medicine, Campus Box 8005, 660 S Euclid Ave, St Louis, MO 63110 (adale@dom.wustl.edu).

Copyright © 2014 by American College of Occupational and Environmental Medicine

DOI: 10.1097/JOM.0000000000000185

Studies of active industrial workers have found a high prevalence of asymptomatic nerve conduction abnormalities, from 15% to 20%.¹⁸⁻²⁶ Available studies indicate that asymptomatic workers with abnormal NCS are at a higher risk of developing CTS than asymptomatic workers whose NCS are normal.^{18,27,28} Nevertheless, the magnitude of the increased risk conferred by nerve conduction abnormalities, the cost-benefit of doing such screening, and the effectiveness of different work placement strategies in preventing CTS all remain to be defined.

Another potential limitation of most existing studies is the possibility of a survivor bias resulting from selection of subjects who have worked for years in a hand-intensive industry; these studies may have evaluated those workers who remained asymptomatic despite work demands and abnormalities of nerve conduction.²⁹ The predictive value of NCS may thus be different among job applicants than among active workers in hand-intensive industries. Only one study to date has screened new employees at the time of hire and followed their development of CTS longitudinally. This study by Franzblau et al²⁸ assessed workers in a single manufacturing plant who received NCS before hire but were hired regardless of the results. Results from this study showed that abnormal NCS conferred a higher risk for a future workers' compensation claim for CTS; however, most of the claims came from workers whose screening NCS were normal at the time of hire, and the cost of worker testing exceeded the potential savings that would have resulted from not hiring workers with abnormal NCS.

For the purposes of screening, it is unclear whether it is preferable to measure median nerve latency via sensory nerve latency, motor nerve latency, or in comparison to ulnar nerve latencies. Different testing techniques and different placement of electrodes can alter the results obtained.³⁰⁻³² Another important issue in screening studies of asymptomatic persons is the need to define what constitutes an "abnormal" test result for working populations. The appropriateness of current normative values is questioned by studies showing higher prevalence of "abnormal" values among asymptomatic populations of active workers than among the general population.^{33,34} It is not clear whether the populations from which normative values were drawn are truly representative of the worker populations in which the tests are being used.

The aim of this study was to determine whether NCS as part of POPP screening for new hires correctly identifies people at risk for CTS across a wide range of industries. This study examined the hypothesis that workers with baseline abnormalities of median nerve conduction would have a higher incidence of CTS than those with normal nerve conduction. In addition, we tested how the prediction yield varied across different case definitions for determining normal and abnormal NCS. Finally, we estimated the cost-benefit of screening from the perspective of the employer.

METHODS

The Predictors of CTS Study, is a prospective, longitudinal study that recruited 1107 subjects from eight employers and three trade unions between July 2004 and October 2006. Subject recruitment took place during company post-offer screenings, new employee orientations, or training classes, depending on each

employer's established hiring procedures. Eligible subjects were newly hired or had become benefits-eligible within the prior 30 days, were at least 18 years of age, worked a minimum of 30 hours weekly, and were able to speak English. Subjects were excluded if they had a prior diagnosis of CTS or peripheral neuropathy, were pregnant at the time of enrollment, or had a contraindication to nerve conduction testing. Subjects were recruited from both low and high hand-intensive jobs and represented a range of industries: construction (carpenters, floor layers, and sheet metal workers), health care (laboratory and hospital technicians), service (food service and housekeeping), and clerical work (computer and clerical workers). Detailed information about recruitment and data collection methods used for this prospective study has been given in several previous articles.³⁵⁻³⁸ The Washington University School of Medicine and the University of Michigan institutional review boards approved this study. All subjects provided written informed consent and were compensated for their participation.

Data Collection Measures

At baseline, all study subjects received a structured physical examination of the upper extremities and bilateral NCS. Subjects also completed surveys at baseline, 6 months, 18 months, 36 months, and annually thereafter. These surveys collected demographic and personal information, work history and physical and psychosocial work exposures, and health information, including the presence of upper extremity symptoms. On each survey, subjects were asked whether they had received a new diagnosis for any medical or musculoskeletal condition, including CTS, in the prior year.

All subjects received NCS of the median and ulnar nerves across the wrist with the NC-stat automated testing device (Neurometrix Inc, Waltham, MA). This device has shown to have good criterion validity compared with traditional electrodiagnostic testing methods in studies performed by the manufacturer and in a study performed by an independent academic group.³⁸⁻⁴⁰ Testing was performed by trained research technicians according to the manufacturer's guidelines, using techniques described in detail in previous publications.^{38,41} The NC-stat device uses preconfigured, nerve-specific electrodes with embedded temperature sensors. Electrodes were placed on the wrist with the distal sensors for the median nerve placed on the third digit and on the fifth digit for the ulnar nerve studies. The distance between the wrist sensors and distal finger sensors was recorded by the research technician. Distal motor latencies (DMLs) and distal sensory latencies (DSLs) were recorded for each nerve, and the median-ulnar differences for sensory latencies (MUDS) were calculated. Latencies were normalized to a skin temperature of 32°C, using the manufacturer's guidelines. Results of NCS were given to each participating worker, but this information was not provided to participating employers; no hiring or job placement decisions were made on the basis of NCS or other study findings.

Statistical Analysis

For this study, the main outcome measure was a diagnosis of CTS by a health care provider, as reported by the worker on any follow-up survey, similar to previous studies of national health surveillance data.⁴²⁻⁴⁴ For calculating time to event and time of follow-up, workers were censored when a diagnosis of CTS was reported, or at the date of the last questionnaire completed for those lost to follow-up or for those without a diagnosis of CTS. Presence or absence of hand symptoms at baseline was not included in our case definition; in a setting where employment may be contingent on the results of POPP screening, workers may have an incentive to underreport symptoms. The analysis in this study was designed to most closely replicate the use of NCS in POPP screening as performed by employers.

Chi-square analyses and *t* tests were used to compare the mean values of the demographic and clinical characteristics, job category, and CTS outcome for workers with normal NCS results at baseline and workers with any NCS abnormality at baseline, including either median DML (greater than 4.5 ms), median DSL (greater than 3.5 ms), or MUDS (greater than 0.5 ms).²⁴ To examine the predictive value of POPP NCS on diagnosis of CTS, bivariate survival analysis was conducted using time from the baseline survey date to the first survey date when CTS was reported. Risk factors were reported as hazard ratios. Significant predictors ($\alpha = 0.05$) were included in the multivariable Cox regression model. The Akaike information criterion was calculated for each NCS parameter separately, and for the composite outcome of any abnormal NCS, to describe which NCS test was the best fit for predicting future CTS.

In addition to determining whether baseline NCS was predictive of CTS diagnosis, we also examined whether prediction varied on the basis of the varying definitions of an "abnormal" NCS result derived from baseline DML, DSL, and MUDS. We used a range of thresholds previously used to identify incident CTS in worker populations and epidemiological studies,^{24,45,46} to show the range of sensitivity and specificity values obtained in POPP screening using different thresholds. We computed measures of diagnostic yield between future CTS diagnosis and baseline NCS, including sensitivity, specificity, positive predictive value (PPV), and negative predictive value. Using different thresholds and NCS tests, we observed how many new workers would need to be screened to correctly identify one future CTS case, and how many workers would be incorrectly identified as a future CTS case. We repeated these analyses for the right hand only, to determine whether testing only one hand could be equally predictive as bilateral testing.

On the basis of these measures, we completed a simple cost-benefit analysis to model a strategy of POPP screening from the perspective of the employer, and compared a strategy of not screening versus a strategy of performing POPP NCS and not hiring workers whose test results were abnormal. In each scenario, we calculated the number of workers who would need to be screened to attain the same number of workers initially hired. The no screening strategy incurred no screening costs at baseline, but we assigned a cost for each case of CTS occurring while employed by the original employer or trade union. The POPP NCS strategy was assigned costs for baseline screening, and costs of future CTS cases that were incurred only for those subjects screening normal at baseline. Cost-benefit analysis used cost estimates of screening and workers' compensation costs from a previous cost-benefit analysis of POPP screening for CTS.⁴⁷ Baseline inputs to our model included a cost per case of CTS of \$20,000, to represent the total cost of a claim, including medical and indemnity costs,⁴⁸ and a cost of screening of \$150. In addition to the base model, we conducted a sensitivity analysis, varying the cost of screening and the cost of treatment, to evaluate the degree to which our model was affected by assumptions for the cost of screening, the cost of a CTS claim, and NCS test characteristics. Different cost estimates for screening were based on published reports of actual screening costs from one employer, which included not only the cost of NCS screening but also other hiring costs such as drug testing, medical evaluations, and administrative costs.²⁸ Different treatment costs were based on published figures for average treatment costs for work-related CTS claims in Washington and Ohio State.^{1,49}

RESULTS

Of the original 1107 newly hired workers screened in the Predictors of CTS Study cohort, 1027 (92.8%) completed at least one follow-up survey. Five subjects were excluded because baseline NCS results were indeterminate for median DML, DSL, and MUDS. Of the 1022 subjects remaining, 35 had partially missing NCS data and were excluded from analyses requiring the missing parameters, as seen in Tables 1 to 3. Most workers were men (64.5%) with a

TABLE 1. Univariate and Adjusted Predictors of Incident Carpal Tunnel Syndrome at Follow-Up Among All Job Categories

	<i>n</i>	CTS (<i>n</i> = 33)	No CTS (<i>n</i> = 989)	HR (95% CI)	<i>P</i>	Adjusted HR*		AIC
		Mean (SD)	Mean (SD)			(95% CI)	<i>P</i>	
Age, yr	1,022	35.9 (10.4)	30.1 (10.2)	1.04 (1.02, 1.07)	<0.01	—	—	—
Body mass index, kg/m ²	1,022	31.4 (7.4)	28.4 (6.3)	1.06 (1.02, 1.10)	<0.01	—	—	—
		<i>n</i> (%)	<i>n</i> (%)					
Male sex	1,022	13 (39.4)	646 (65.3)	0.33 (0.17, 0.67)	<0.01	—	—	—
Any abnormal NCS findings†‡§	987	20 (60.6)	227 (22.8)	5.42 (2.60, 11.32)	<0.0001	5.36 (2.44–11.75)	<0.0001	374.4
Median DML > 4.5 ms†§	1,000	12 (36.4)	143 (14.4)	2.95 (1.45, 6.01)	<0.01	3.29 (1.50–7.19)	<0.01	413.6
Median DSL > 3.5 ms†§	1,008	19 (57.6)	177 (17.8)	6.57 (3.19, 13.54)	<0.0001	6.44 (2.99–13.86)	<0.0001	370.8
MUDS > 0.5 ms†§	983	19 (57.6)	126 (12.7)	11.25 (5.22, 24.21)	<0.0001	11.36 (4.88–26.43)	<0.0001	336.2

*Adjusted for age, sex, and body mass index.

†Temperature and length adjusted.

‡Median DML > 4.5 ms or median DSL > 3.5 ms or MUDS > 0.5 ms or absent value.

§Thirty-five subjects were excluded due to partially missing nerve conduction data.

AIC, Akaike information criterion; CI, confidence interval; CTS, carpal tunnel syndrome; DML, distal motor latency; DSL, distal sensory latency; HR, hazard ratio; NCS, nerve conduction study; MUDS, median ulnar sensory latency difference.

mean age of 30.3 years and a mean body mass index (BMI) of 28.5 kg/m² (Table 4). A quarter of workers had abnormal POPP NCS at baseline. Subjects with abnormal NCS at baseline were significantly older and more likely to be men and to work in the construction trades. The mean length of follow-up for the cohort was 3.7 (range, 0.4 to 6.2) years. Over the study period, 33 workers reported having received a diagnosis of CTS, with a mean time to first report of diagnosis of 2.4 (range, 0.4 to 5.1) years. Workers with any NCS abnormality at baseline were significantly more likely to report a diagnosis of CTS at follow-up. The overall incidence rate of CTS diagnosis in the cohort was 8.7 per 1000 person years (PYs). The rate of CTS diagnosis was higher among workers with abnormal POPP NCS versus workers with normal POPP NCS (22.2 cases per 1000 PYs vs 4.0 cases per 1000 PYs, rate ratio of 5.5 [95% confidence interval: 2.6 to 11.5]).

Baseline NCS abnormality was a statistically significant predictor of future CTS diagnosis for all nerve test parameters using our predefined cut points of median DML greater than 4.5 ms, median DSL greater than 3.5 ms, or MUDS greater than 0.5 ms (Table 1). Workers with abnormal MUDS were at the highest risk of becoming diagnosed with CTS over the study period, followed by abnormal median DSL, any NCS abnormality, or abnormal median DML. Age, sex, and BMI were statistically significant predictors of CTS diagnosis. There were no substantial changes in the hazard ratios of NCS tests when we repeated these analyses, adjusting for age, sex, and BMI. Using the Akaike information criterion to describe the goodness of fit, MUDS had the lowest Akaike information criterion value and thus was a better predictor of CTS than the screening parameters of any NCS abnormality, median DML, or median DSL.

To examine the effect of defining different NCS cut points for abnormality on the yield of screening, including the PPV and the number needed to test to avoid 1 future case of CTS, we examined the sensitivity and specificity for the cut points shown in Table 2. As expected for a relatively rare condition, specificity and negative predictive value were high (75.9% to 93.1% and 97.5% to 98.8%, respectively); however, sensitivity was low (36.4% to 65.5%) and PPV very low (6.4% to 18.5%). The most sensitive cut point, MUDS greater than 0.5 ms, detected 65.5% of those who would later be di-

agnosed with CTS. Although reasonably sensitive, this measure had a very poor PPV: only 13.1% of those with an abnormal value based on this cut point reported a diagnosis of CTS over the study period. We repeated these analyses using the right hand only; results were similar to the findings of bilateral testing; as expected, sensitivity decreased slightly and specificity improved slightly with unilateral testing.

To assess the preventive effectiveness of POPP NCS for CTS, we calculated the number of job candidates who would need to be screened to avoid 1 future case of CTS among the screened workforce, using the simple methods previously described by de Kort and van Dijk.⁵⁰ Using our predefined cut points, the most sensitive screening parameter, MUDS greater than 0.5 ms, detected only 65.5% of those who would later be diagnosed with CTS, and would have required testing 54 subjects to detect 1 future case of CTS in the workforce. At the same time, the lower specificity of the MUDS greater than 0.5 ms parameter would have inappropriately denied employment to 7 workers among the 54 who would not have developed CTS despite having an “abnormal” NCS test.

In assessing the validity of POPP NCS for predicting future CTS, the analyses reported earlier followed the full cohort of workers, including those who changed employers, and recorded all cases of CTS during the study period (*n* = 33). We conducted cost-benefit analysis from the perspective of the employer, and thus only the 23 CTS cases that occurred while a subject screened at baseline was still working for the original employer and had complete NCS data were relevant for inclusion in the cost models. In our base case scenario using the criterion of “any NCS abnormality” at baseline, 987 newly hired workers were screened with POPP NCS; 247 workers would have been rejected for hire, a failure rate of 25%. To attain a work pool of 987 workers who tested normal, a total of 1317 workers would need to be screened (987 + 247 replacements from failed screens + 83 additional replacements because of a continuous failure rate of 25% among replacement workers screened). Sixteen of the 23 future CTS cases would have been avoided under a screening strategy, because they occurred in the population of workers testing abnormal at baseline, using this criterion. Seven of 23 CTS cases occurred in the 740 workers screening normal at baseline; we used

TABLE 2. Prediction of Future Carpal Tunnel Syndrome by Different Nerve Conduction Parameters

NCS Cut Point	Nonmissing*		Abnormal NCS	CTS Diagnosis	Cases detected by NCS	Sensitivity, %	Specificity, %	Positive Predictive Value, %	Negative Predictive Value, %	Screened per Case, † n	Noncase Workers Denied Employment per Case, ‡ n
	No. of nonmissing	cases detected									
Median DML >4.2 ms	1,001	249	33	16	48.5	75.9	6.4	97.7	63	15	
Median DML >4.5 ms	1,000	155	33	12	36.4	85.2	7.7	97.5	83	12	
Median DSL >3.5 ms	1,008	196	31	19	61.3	81.9	9.7	98.5	53	9	
Median DSL >3.7 ms	1,005	137	31	18	58.1	87.8	13.1	98.5	56	7	
MUDS >0.5 ms	983	145	29	19	65.5	86.8	13.1	98.8	52	7	
MUDS >0.8 ms	980	81	29	15	51.7	93.1	18.5	98.4	65	4	

*Five subjects had indeterminate baseline NCS results for median DML, DSL, and MUDS. Thirty-five subjects had partially missing NCS data and were excluded from relevant analyses.

†No. nonmissing/cases detected = No. screened per case.

‡(Abnormal NCS – cases detected by NCS)/cases detected = No. of noncases denied employment per case.

§(Abnormal NCS – cases detected by NCS)/cases detected = No. of noncases denied employment per case. CTS, carpal tunnel syndrome; DML, distal motor latency; DSL, distal sensory latency; NCS, nerve conduction study; MUDS, median ulnar sensory latency difference.

a cumulative incidence rate of CTS in the population screening normal at baseline to calculate the expected number of cases in a population of 987 workers screening normal at baseline (10 CTS cases when using the testing criterion of any NCS abnormality). These case counts and the number of workers screened were entered in to our cost model, using base screening costs of \$150 per worker and CTS treatment cost of \$20,000 per case, as shown in Table 3. The NCS failure rate and the number of CTS cases that would have been avoided varied with the sensitivity of the NCS parameter used as the screening criterion. Cost–benefit analysis showed that screening was favored when NCS test sensitivity was high (any abnormal NCS, DSL, and MUDS) and cost of screening was low (\$150). Using the same low screening cost but a less sensitive NCS measure (median DML greater than 4.5 ms), a no screening strategy was favored. With a higher screening cost (\$358), modeled to account for the other costs associated with hiring new workers,²⁸ a no screening strategy was favored in all models, regardless of NCS parameters. These findings were also sensitive to changes in treatment cost for CTS. When the treatment cost for a CTS case was varied (\$13,253 and \$5605), using published workers’ compensation data from Ohio for 1999–2004,⁴⁹ and Washington State,¹ a no screening strategy was favored for all NCS screening parameters except when using a selection criteria of MUDS greater than 0.5 ms with the higher Ohio State costs.

DISCUSSION

The aim of this study was to determine whether NCS performed at the time of hire were predictive of a future CTS diagnosis among a cohort of workers in various industries. Results showed that newly hired workers with abnormal baseline NCS were significantly more likely to report a CTS diagnosis during the study period, which is consistent with previous studies.^{18,27,28} Despite this finding, the predictive validity of such POPP NCS screening is at best low or modest. We tested how the prediction yield varied across different thresholds for defining normal and abnormal NCS and consistently found low PPV across all screening parameters. Post-offer pre-placement NCS screening seems to be widely used by employers, but our cost–benefit models of screening conducted from the perspective of the employer showed that the costs of screening did not outweigh the savings for CTS cases that would have been avoided in the majority of scenarios modeled.

The overall rate of CTS in our cohort was 8.7 cases per 1000 PYs, slightly higher than the rate of 7.8 per 1000 PYs reported by Franzblau et al.²⁸ The slightly higher rate of CTS observed in our study population may be partly attributable to our case definition of CTS diagnoses reported by workers rather than accepted workers’ compensation claims for CTS.²⁸ The rates reported both in our study and in Franzblau et al likely underestimate the true occurrence of disease because of untreated or unreported cases.^{33,51} Not all workers who have symptoms are likely to seek treatment, and of those workers who seek treatment, not all will file a workers’ compensation claim or have an accepted claim. The slightly higher incidence rate in this study may also be attributable to differences in the nerve conduction parameters used to identify abnormalities for workers. Our rate is based on the screening definition of “any NCS abnormality” (median DSL, DML, or MUDS) at baseline, whereas actual test results (latencies, amplitudes, or conduction velocities) were not available in the Franzblau study, and thus prediction models were based solely on test summaries defined as normal or abnormal. In addition, our study had a longer mean follow-up time of 3.7 years versus 2.1 years.²⁸

A potential limitation of existing studies is the possibility of a survivor bias, resulting from selection of subjects who were working for years in a hand-intensive industry^{18,27}; these studies may have evaluated those workers who remained asymptomatic despite heavy work demands and abnormalities of nerve conduction.²⁹ Jobs in

TABLE 3. Results Comparing the Cost-Effectiveness of a Post-Offer Pre-Placement Nerve Conduction Study Screening Strategy Versus a No Screening Strategy

Strategy	n	Test Sensitivity, %	Test Specificity, %	Screened per CTS Case, n	Noncase Workers Denied Employment per CTS Case, n	Total Cost of Screening Plus Treatment of CTS Cases in the Workforce,* \$		
						Screening Cost = \$150† (Cost per CTS Case = \$20,000)	Screening Cost = \$358‡ (Cost per CTS Case = \$20,000)	Screening Cost = \$150† (Cost per CTS Case = \$13,253§)
Any NCS abnormality¶	987	69.6	76.0	64	14	400,250	674,186	331,869
Screening						460,000	460,000	304,819
No screening								
Median DML >4.5 ms	1,000	40.0	85.1	103	15	558,800	806,736	430,607
Screening						500,000	500,000	331,325
No screening								
Median DSL >3.5 ms	1,008	65.2	81.6	68	12	407,200	666,784	332,983
Screening						460,000	460,000	304,819
No screening								
MUDS >0.5 ms	983	69.6	86.6	64	8	353,850	594,922	293,127
Screening						460,000	460,000	304,819
No screening								

*Total cost of screening = [initial no. screened + (∑ of initial rejected workers + additional replacements by failure rate) × screening cost]. Treatment of CTS cases in the workforce = cost per CTS case × CTS cases not detected by baseline NCS.

†On the basis of base model from Evanoff and Kymes.⁴⁷

‡On the basis of model ID from Franzblau et al.²⁸

§On the basis of average total cost per CTS claim for Ohio State from 1999 to 2004, from Dunning et al.⁴⁹

||On the basis of average total cost per CTS claim for Washington State from 1990 to 1994, from Daniell et al.¹

¶Point of indifference for screening cost = \$199.

Bold type indicates the preference for screening or no screening favored for the different scenarios.

CTS, carpal tunnel syndrome; DML, distal motor latency; DSL, distal sensory latency; NCS, nerve conduction study; MUDS, median ulnar sensory latency difference.

TABLE 4. Demographic and Clinical Characteristics for the Entire Cohort at Baseline and Workers With Normal and Abnormal Nerve Conduction Studies at Baseline

Characteristic	Entire Cohort (n = 1022)	Normal NCS* (n = 740)	Abnormal NCS*† (n = 247)	P‡
Age, mean (SD), yr	30.3 (10.3)	29.1 (9.6)	34.2 (11.5)	0.0002
Body mass index, mean (SD), kg/m ²	28.5 (6.4)	28.0 (6.2)	30.0 (6.8)	0.08
Sex, n (%)				0.03
Women	363 (35.5)	277 (38.4)	74 (30.0)	
Men	659 (64.5)	463 (62.6)	173 (70.0)	
Industry, n (%)				<0.0001
Construction	424 (41.5)	281 (38.0)	133 (53.9)	—
Clerical	366 (35.8)	308 (41.6)	43 (17.4)	—
Service/technical	232 (22.7)	151 (20.4)	71 (28.7)	—
Diagnosis of CTS, n	33	11	20	<0.0001
PYs of follow-up	3,777.5	2,733.0	900.3	—
Diagnosis of CTS/1000 PYs	8.7	4.0	22.2	—

*Thirty-five subjects were excluded because of partially missing NCS data.

†Temperature and length adjusted, absent values considered abnormal. Abnormal NCS = Any of the following: median distal motor latency greater than 4.5 ms or median distal sensory latency greater than 3.5 ms or median-ulnar sensory latency difference greater than 0.5 ms.

‡Used *t* tests for continuous data and chi-square tests for categorical data, comparing those with normal and abnormal NCS at baseline.

CTS, carpal tunnel syndrome; NCS, nerve conduction study; PYs, person years.

hand-intensive industries often have high turnover rates, creating a natural selection bias against workers at greater risk of developing CTS. This study and that of Franzblau et al²⁸ avoid this potential bias that the predictive value of NCS may be different among job applicants than among active workers in hand-intensive industries, and thus more closely models the use of NCS as a screening tool during POPP testing. Results from this study included workers from a wide variety of industries and employers, while Franzblau's study included workers from a single employer.

To determine whether the prediction yield of screening for future CTS cases could be improved, we evaluated six definitions of an "abnormal" NCS result from baseline DML, DSL, and MUDS, using published thresholds previously used in working populations.^{45,46} Our results showed that the percentage of future CTS cases that were correctly predicted was highly dependent on the definition used to define an abnormal screening result. The sensitivity and specificity and positive and negative predictive values of POPP NCS have varied, in part because different criteria were used to define normal and abnormal NCS measures.^{18,28} The increased risk of CTS diagnosis in our study varied widely, depending on the measure chosen to define an abnormal result from a hazard ratio of 2.95 (95% confidence interval: 1.45 to 6.01; *P* < 0.01) for median DML (greater than 4.5 ms) to 11.25 (95% confidence interval: 5.22 to 24.21; *P* < 0.0001) for abnormal MUDS (greater than 0.5 ms). As with any diagnostic test, there are explicit trade-offs between sensitivity and specificity as seen with use of different criteria for defining abnormal NCS. As parameter cut points used to predict the outcome of future CTS diagnosis were made more specific, the employers in the study would have assumed more risk of potentially hiring workers with greater risk of developing CTS, whereas when the cut points were more sensitive, more healthy workers would have been inappropriately excluded from employment. Our study showed very different results between different nerve tests and different criteria for defining abnormality. Carpal tunnel syndrome POPP screening is often based on testing only the median nerve; in this study, we found the highest sensitivity and specificity using the median ulnar difference. In our experience, POPP testing programs in industry have not formally considered the effects of different cut points or nerve conduction

testing techniques in assessing the likely yield and cost-benefit of their screening programs nor have such programs acknowledged the very low PPV of POPP testing.

Post-offer pre-placement screening with NCS seems to be widely used by employers, but only two published studies have evaluated its cost-benefit to employers. Evaluation of POPP screening by using cost data from a manufacturing plant²⁸ found that the cost of screening outweighed potential savings from averting workers' compensation costs for CTS. A cost-benefit modeling study⁴⁷ found that POPP screening for CTS would not be cost-beneficial for most employers, though could be cost-beneficial under circumstances where there was a high cost per case and high incidence of CTS. Using these published models, we compared the cost of screening the workers in our cohort and not hiring those with abnormal baseline NCS versus a policy of no screening. Our results were consistent with these previous studies, showing that POPP NCS screening would not have been cost-beneficial to the employer in most screening scenarios. When the cost of screening was high, a no screening strategy was favored in all cases. As Franzblau et al²⁸ described, there are a number of other potential costs associated with screening in addition to a nerve conduction test, which will vary depending on each employer's hiring practices. These costs may include a medical physical examination, drug test (which may or may not be done concurrently with other POPP screening), and administrative costs associated with new hire paperwork and orientation. In addition, we assigned the same cost of screening regardless of NCS parameter; however, screening parameters that require testing of both the median and ulnar nerves (MUDS) would likely cost more than median nerve testing only (DML and DSL). Our simplified cost model did not account for screening costs in subsequent years of hiring to replace workers lost to turnover and, thus, may not have fully captured costs of pursuing a POPP screening strategy.

Cost of treatment for CTS is also highly variable. A 2005 study of work-related CTS claims in Washington State¹ found a median cost per claim of \$5605 over a 5-year period, though costs for individual cases ranged from \$359 to \$79,265, depending on whether surgery was performed and when the CTS diagnosis occurred in the course of the claim. Our base cost of \$20,000 per diagnosed case is

very likely to be an overestimate of the costs of CTS to employers, because not all diagnosed cases would be claimed under workers' compensation and not all would be surgical cases. The lower costs seen in Ohio and Washington State are more likely to reflect true costs of CTS claims under workers' compensation.

The main limitation of this study was the use of self-reported CTS diagnosis as the outcome. Because this study was designed to replicate employer practices, CTS diagnosis was a more appropriate outcome than an epidemiological case definition, which would have included workers who had symptoms and abnormal NCS findings but who never sought treatment or filed a workers' compensation claim. A similar case definition of self-reported CTS has been used in several previous studies of national health surveillance data.⁴²⁻⁴⁴ Survival models were censored at survey date because the actual date of diagnosis was not available. The use of an absolute latency for defining an abnormal NCS consistent with CTS has been criticized because many factors such as age, temperature, comorbidities, and BMI can influence the absolute latency of the median nerve.⁴⁵ Comparison on the median and ulnar latencies controls for these confounding factors, and our analysis demonstrated that this model was the strongest predictor of future CTS. We included all three definitions of abnormal NCS because they are still widely used in clinical practice.

Our model showed that screening could be favorable only if the average treatment cost was high and the screening cost was low. As discussed in other articles,^{47,50} for screening to be cost-beneficial the prevalence of the disorder must be high among new hires and the incidence high after hire. High employee turnover also increases the cost of screening and decreases potential employer cost savings, because screened workers may leave employment before developing the disease of interest.⁴⁷ Our results highlight the sensitivity of the cost-benefit model to the cost of screening, the cost per CTS case, and the sensitivity of the screening test. This relationship highlights the need for employers who utilize POPP screening to pick appropriate test cut points for their workforce rather than a clinical or general population. Finally, the cost-benefit of screening should be considered within the larger societal context of not hiring otherwise qualified workers. Because of the low PPV of POPP NCS screening for future CTS, data from this study showed that each workplace case of CTS avoided for the employer would come at the cost of inappropriate denial of employment or job placement for 4 to 15 workers who would not develop CTS during the course of their employment. This raises another consideration for employers, the several court cases claiming that employers violated the Americans with Disabilities Act or other laws when applicants were excluded from production jobs on the basis of POPP testing for future risk of CTS. Although some past cases were settled in favor of the employer (Equal Employment Opportunity Commission vs Woodbridge Corporation, 8th Circuit No. 01-L045, August 24, 2001; Equal Employment Opportunity Commission vs Rockwell International Corporation, 7th Circuit Nos. 00-1897 and 00-2034, March 8, 2001), the Equal Employment Opportunity Commission recently won a discrimination case against an employer who excluded a worker from employment on the basis of perceived risk of future CTS.⁵² Although this case was based on violation of the Genetic Information Nondiscrimination Act, at least one other lawsuit in progress addresses discriminatory aspects of POPP screening by median NCS.

CONCLUSIONS

Although abnormal NCS at the time of hire is strongly associated with increased risk of future CTS, the predictive value of such testing is poor, even when using optimal criteria as screening thresholds. The cost of screening and rejecting large numbers of healthy workers from employment is high and, in most cases, seems to outweigh potential employer cost savings from reducing the in-

cidence of CTS in a given workforce. The social costs of rejecting otherwise qualified healthy workers from employment should also be considered. In all scenarios described earlier, the vast majority of workers with "abnormal" screening results did not develop CTS and, thus, would be inappropriately placed or denied employment on the basis of a test with demonstrably poor PPV for future disease. Post-offer pre-placement screening for CTS seems to be widely used, despite ongoing uncertainty about ideal screening procedures, appropriate cut points for screening versus diagnosis of clinical median neuropathy, and cost-benefits of the procedure for employers. Employers should be cautious in implementing any broad worker screening programs without careful consideration of the costs and benefits of such programs. Available evidence shows that POPP screening for CTS is poorly predictive of future disease, and published studies to date have failed to show that this practice is effective. Occupational health professionals should not endorse screening programs that are not based on evidence of benefit to workers' health.

ACKNOWLEDGMENT

We would like to acknowledge the efforts of the staff and technicians who organized and conducted the subject testing as well as provided assistance on this manuscript. In particular, we would like to thank Jaime Strickland, Carla Farrell, Blake Badillo, Nina Smock, Annie Kinghorn, Jeff Krato, countless students, and the large number of subject volunteers. For this study, nerve conduction testing materials were donated by NeuroMetrix.

REFERENCES

1. Daniell WE, Fulton-Keohoe D, Chiou LA, Franklin GM. Work-related carpal tunnel syndrome in Washington State workers' compensation: temporal trends, clinical practices, and disability. *Am J Ind Med.* 2005;48:259-269.
2. Foley M, Silverstein B, Polissar N. The economic burden of carpal tunnel syndrome: long-term earnings of CTS claimants in Washington State. *Am J Ind Med.* 2007;50:155-172.
3. Wasiak R, Pransky G. The impact of procedure type, jurisdiction, and other factors in workers' compensation on work-disability outcomes following carpal tunnel surgery. *Work.* 2007;28:103-110.
4. Bureau of Labor Statistics. Nonfatal occupational injuries and illnesses requiring days away from work, 2011: Bureau of Labor Statistics, United States Department of Labor. Available at <http://www.bls.gov/news.release/archives/osh2.11082012.pdf>. Published 2013. Accessed December 19, 2013.
5. Beaton DE, Kennedy CA. Beyond return to work: testing a measure of at-work disability in workers with musculoskeletal pain. *Qual Life Res.* 2005;14:1869-1879.
6. Burt S, Deddens J, Crombie K, Jin Y, Wurzelbacher S, Ramsey J. A prospective study of carpal tunnel syndrome: workplace and individual risk factors. *Occup Environ Med.* 2013;70:568-574.
7. Werner RA. Evaluation of work-related carpal tunnel syndrome. *J Occup Rehabil.* 2006;16:207-222.
8. Anonymous. Pre-placement test for CTDs challenged. *CTD News.* 1995;4:1-7.
9. Pruitt R. Pre-placement evaluation: thriving within the ADA guidelines. *Am Assoc Occup Health Nurses J.* 1995;43:124-130.
10. Memphis Orthopaedic Group. Pre-employment screening. Available at <http://memphisorthogroup.com/services/pre-employment-screening/>. Published 2012-2013. Accessed September 19, 2013.
11. Sure Hire Inc. *Carpal Tunnel Syndrome: What Employers Need to Know*. Leduc, AB: Sure Hire Inc; 2009. Available at <http://www.surehire.ca/media/SureNews%20Volume%202%20Issue%203.pdf>. Accessed September 19, 2013.
12. WorkSTEPS. *New Hires: Pre Employment Screening*. Austin, TX: WorkSTEPS Inc; 2012. Available at <http://www.worksteps.com/services/new-hires/>. Accessed September 19, 2013.
13. Medical Center of the Palm Beaches. Occupational medicine. Available at <http://thetotalmd.com/services/occupational-medicine/>. Published 2013. Accessed April 17, 2014.

14. Direct RehabMed. Occupational medicine and business health. Available at <http://www.directrehabmed.com/pages/programs-and-services/-occupational-medicine.php>. Published 2005–2007. Accessed September 19, 2013.
15. Austin Adams MD. *Occupational Medicine*. Smyrna, TN: Austin Adams MD; 2013. Available at <http://www.austinadamsmd.com/childhood-adulthood-reflection.html>. Accessed September 19, 2013.
16. FAMC–Fremont Area Medical Center. *Work Health Services*. Fremont, NE: FAMC–Fremont Area Medical Center; 2013. Available at <http://www.famc.org/landing.cfm?id=555636>. Accessed September 19, 2013.
17. Cevene Care Clinic. Because illnesses and injuries do not occur on your schedule. Rockford, IL: Cevene Care Clinic; 2013. Available at <http://www.cevenecareclinics.com/services.cfm?id=2>. Accessed September 19, 2013.
18. Nathan PA, Keniston RC, Myers LD, Meadows KD, Lockwood RS. Natural history of median nerve sensory conduction in industry: relationship to symptoms and carpal tunnel syndrome in 558 hands over 11 years. *Muscle Nerve*. 1998;21:711–721.
19. Werner RA, Franzblau A, Albers JW, Buchele H, Armstrong TJ. Use of screening nerve conduction studies for predicting future carpal tunnel syndrome. *Occup Environ Med*. 1997;54:96–100.
20. Werner RA, Franzblau A, Albers JW, Armstrong TJ. Influence of body mass index and work activity on the prevalence of median mononeuropathy at the wrist. *Occup Environ Med*. 1997;54:268–271.
21. Bingham RC, Rosecrance JC, Cook TM. Prevalence of abnormal median nerve conduction in applicants for industrial jobs. *Am J Ind Med*. 1996;30:355–361.
22. Schottland JR, Kirschberg GJ, Fillingim R, Davis VP, Hogg F. Median nerve latencies in poultry processing workers: an approach to resolving the role of industrial “cumulative trauma” in the development of carpal tunnel syndrome. *J Occup Med*. 1991;33:627–631.
23. Kearns J, Gresch EE, Weichel CY, Eby P, Pallapothu SR. Pre- and post-employment median nerve latency in pork processing employees. *J Occup Environ Med*. 2000;42:96–100.
24. Silverstein BA, Fan ZJ, Bonauto DK, et al. The natural course of carpal tunnel syndrome in a working population. *Scand J Work Environ Health*. 2010;36:384–393.
25. Rosecrance JC, Cook TM, Anton DC, Merlino LA. Carpal tunnel syndrome among apprentice construction workers. *Am J Ind Med*. 2002;42:107–116.
26. Nathan P, Meadows K, Doyle L. Occupation as a risk factor for impaired sensory conduction of the median nerve at the carpal tunnel. *J Hand Surg Br*. 1988;13B:167–170.
27. Werner RA, Gell N, Franzblau A, Armstrong TJ. Prolonged median sensory latency as a predictor of future carpal tunnel syndrome. *Muscle Nerve*. 2001;24:1462–1467.
28. Franzblau A, Werner RA, Yihan J. Preplacement nerve testing for carpal tunnel syndrome: is it cost effective? *J Occup Environ Med*. 2004;46:714–719.
29. Bleeker M. Use of screening nerve conduction studies for predicting future carpal tunnel syndrome. Letter in. *Occup Environ Med*. 1997;54:622.
30. Werner R. Electrodiagnostic evaluation of carpal tunnel syndrome and ulnar neuropathies. *PM R*. 2013;5:S14–S21. Available at http://ac.els-cdn.com/S1934148213001561/1-s2.0-S1934148213001561-main.pdf?_tid=c54807ac-68f0-11e3-8dbf-00000aab0f27&acdnat=1387487086_d2b5a40f149a5505e5be8965b7b42b05.
31. Letz R, Gerr F. Covariates of human peripheral nerve function: nerve conduction velocity and amplitude. *Neurotoxicol Teratol*. 1994;16:95–104.
32. Chaudry V, Cornblath DR, Mellits ED, et al. Inter- and intra-examiner reliability of nerve conduction measurements in normal subjects. *Ann Neurol*. 1991;30:841–843.
33. Atroshi I, Gummesson C, Johnsson R, Ornstein E, Ranstam J, Rosen I. Prevalence of carpal tunnel syndrome in a general population. *JAMA*. 1999;282:153–158.
34. Salerno DF, Werner RA, Albers JW, Becker MP, Armstrong TJ, Franzblau A. Reliability of nerve conduction studies among active workers. *Muscle Nerve*. 1999;22:1372–1379.
35. Johnson AM, Dale AM, Strickland JR, Venditti P, Evanoff BA. Employers’ concerns regarding research participation. *Int J Occup Environ Health*. 2008;14:11–17.
36. Gardner BT, Dale AM, Vandillen L, Franzblau A, Evanoff BA. Predictors of upper extremity symptoms and functional impairment among workers employed for 6 months in a new job. *Am J Ind Med*. 2008;51:932–940.
37. Dale A, Strickland J, Symanzik J, Franzblau A, Evanoff B. Reliability of hand diagrams for the epidemiologic case definition of carpal tunnel syndrome. *J Occup Rehabil*. 2008;18:233–248.
38. Armstrong T, Dale A, Al-Lozi M, Franzblau A, Evanoff B. Median and ulnar nerve conduction studies at the wrist: criterion validity of the NC-stat automated device. *J Occup Environ Med*. 2008;50:758–764.
39. Leffler CT, Gozani SN, Cros D. Median neuropathy at the wrist: diagnostic utility of clinical findings and an automated electrodiagnostic device. *J Occup Environ Med*. 2000;42:398–409.
40. Kong X, Gozani SN, Hayes MT, Weinberg DH. NC-stat sensory nerve conduction studies in the median and ulnar nerves of symptomatic patients. *Clin Neurophysiol*. 2006;117:405–413.
41. Evanoff B, Zeringue A, Franzblau A, Dale AM. Using job-title-based physical exposures from O*NET in an epidemiological study of carpal tunnel syndrome. *Hum Factors*. 2014;56:166–177.
42. Luckhaupt SE, Dahlhamer JM, Ward BW, Sweeney MH, Sestito JP, Calvert GM. Prevalence and work-relatedness of carpal tunnel syndrome in the working population, United States, 2010 National Health Interview Survey. *Am J Ind Med*. 2013;56:615–624.
43. Tanaka S, Wild DK, Cameron LL, Freund E. Association of occupational and non-occupational risk factors with the prevalence of self-reported carpal tunnel syndrome in a national survey of the working population. *Am J Ind Med*. 1997;32:550–556.
44. Blanc PD, Faucett J, Kennedy JJ, Cisternas M, Yelin E. Self-reported carpal tunnel syndrome: predictors of work disability from the National Health Interview Survey Occupational Health Supplement. *Am J Ind Med*. 1996;30:362–368.
45. Salerno DF, Franzblau A, Werner RA, Bromberg MB, Armstrong TJ, Albers JW. Median and ulnar nerve conduction studies among workers: normative values. *Muscle Nerve*. 1998;21:999–1005.
46. Werner RA, Franzblau A, Gell N, Hartigan AG, Ebersole M, Armstrong TJ. Incidence of carpal tunnel syndrome among automobile assembly workers and assessment of risk factors. *J Occup Environ Med*. 2005;47:1044–1050.
47. Evanoff B, Kymes S. Modeling the cost-benefit of nerve conduction studies in pre-employment screening for carpal tunnel syndrome. *Scand J Work Environ Health*. 2010;36:299–304.
48. Washington State Department of Labor and Industries. Work-related musculoskeletal disorders of the neck, back, and upper extremity in Washington State, 1997–2005. In: Silverstein B, Adams D, eds. *Technical Report Number 40-11-2007 December 2007*. Olympia, WA: Sharp Program; 2005.
49. Dunning KK, Davis KG, Cook C, et al. Costs by industry and diagnosis among musculoskeletal claims in a state workers compensation system: 1999–2004. *Am J Ind Med*. 2010;53:276–284.
50. de Kort W, van Dijk F. Preventive effectiveness of pre-employment medical assessments. *Occup Environ Med*. 1997;54:1–6.
51. Rempel D, Evanoff B, Amadio PC, et al. Consensus criteria for the classification of carpal tunnel syndrome in epidemiologic studies. *Am J Public Health*. 1998;88:1447–1451.
52. US Equal Employment Opportunity Commission. Fabricut to Pay \$50,000 to settle EEOC disability and genetic information discrimination lawsuit: federal agency files first suit enforcing genetic discrimination law against fabric distributor that requested family medical history, refused to hire woman. US District Court for the Northern District of Oklahoma (Civil Case No.: 13-CV-248-CVE-PJC). Available at <http://www.eeoc.gov/eeoc/newsroom/release/5-7-13b.cfm>. Published 2013. Accessed March 21, 2014.