

## **TACTILE RESPONSE OF THREE STUDY GROUPS TO FOUR ERGONOMIC RISK FACTORS**

Spencer K. Reese, University of Utah  
Richard F. Sesek, University of Utah  
Robert P. Tuckett, University of Utah  
Donald S. Bloswick, University of Utah

[skr4@utah.edu](mailto:skr4@utah.edu)

### **ABSTRACT**

Carpal tunnel syndrome leads to more average time away from work per case than any other work related injury, including amputations and fractures. This condition is caused by increased pressure in the carpal tunnel and may be aggravated by exposure to ergonomic risk factors. It is therefore desirable to understand the effect of various ergonomic risk factors on the function of the median nerve. This effect may be measured, in part, by a temporary shift in vibrotactile perception threshold. Threshold shifts due to wrist flexion and the combination of flexion with direct pressure, with tendon loading, and with venous occlusion were compared. Test participants included subjects with normal median nerve function, subjects with symptoms of carpal tunnel syndrome, and subjects with diabetic neuropathy. Each group experienced a significant threshold shift associated with each of these provocations. There was, however, little demonstration of significant difference between provocations and groups.

### **INTRODUCTION**

According to the U.S. Department of Labor Bureau of Labor Statistics webpage, carpal tunnel syndrome (CTS) leads to more average time away from work per case than any other work related injury, including amputations and fractures (accessed November, 2003). Symptoms of CTS, caused by entrapment of the median nerve within the carpal tunnel, include numbness in the first three and a half digits of the hand, tingling, weakened grip, and atrophy of the muscles innervated by the median nerve. If not treated, CTS can lead to permanent nerve damage (Pecina, 2001).

Whether industrial exposure to ergonomic risk factors causes CTS or merely aggravates symptoms is debatable. In either case, it is important to minimize risk. Risk factors associated with CTS include non-neutral postures (Marin, 1983; DeKrom, 1990; Werner, 1997), pressure (as from tools or work surfaces) on the palm or wrist (Cobb, 1995; Durkan, 1991; Lundborg, 1982), pinching or gripping (Keir, 1997; Silverstein, 1987), and repetitive or strenuous finger and hand motion (Phalen, 1966; Silverstein, 1987).

Wrist angles, grip forces, and hand activity may be measured to an extent. These may be correlated with symptoms of cumulative trauma disorders to come up with estimated risk levels. However, such correlations do not assess the effect of exposure to risk. Individuals exposed to the same level of risk may experience widely different effects.

Compression of the median nerve often compromises the mechanical sensitivity of the fingertips. Vibrometry provides a means of measuring tactile sensitivity. It is non-invasive and, for most people, more comfortable and less formidable than electrodiagnostic studies. A vibrating probe provides a stimulus and subjects respond by pressing a button if they feel the stimulus. A vibrotactile perception threshold (VPT) is the smallest amplitude of vibration sensed.

When exposed to ergonomic risk factors people may experience a temporary shift in VPT. In this study, threshold shifts were used to quantify the response of subjects to four provocations. These provocations include wrist flexion, wrist flexion combined with direct pressure on the carpal tunnel, wrist flexion combined with loading of the tendons in the wrist, and wrist flexion combined with venous occlusion.

## METHODS

Approval for the use of human subjects was obtained from the University of Utah Institutional Review Board. Subjects were recruited by flyers, newspaper ads, and word of mouth. Forty-three subjects participated in this study. Volunteers included 10 normal subjects with no symptoms of CTS or other neuropathies or nerve damage, 25 subjects diagnosed with CTS or possessing symptoms consistent with CTS (one subject had bilateral CTS and both hands were tested), and 8 subjects with diabetic neuropathy without CTS or other forms of nerve damage. Subjects were compensated for their participation.

During the initial visit, subjects completed a consent form. Sensory nerve conduction was tested antidromically using surface electrodes on the middle finger. Subjects also completed a questionnaire relating to hand and wrist condition and other potential CTS risk factors. Following a training run on the vibrotactile tester, a test routine with one of the four provocations was presented. The other three provocations were presented during different visits, with no more than one provocation presented per day. The order in which the provocations were presented was randomized.

The vibrotactile tester was computer controlled. A 1.0mm diameter probe with 0.64mm gap between the probe and the firm surround had a static skin indentation of 0.3mm. The VPT was an average of 2 complete cycles (2 peaks, 2 “troughs”) and was reported in microns ( $\mu\text{m}$ ). The test sequence averaged 90 seconds in duration.

The test routine began by measuring fingertip, palm, and wrist temperatures. The subjects placed foam earplugs in their ears. A baseline VPT of the middle finger was measured with the wrist in neutral posture. The subjects were then exposed to the provocation and seven measurements were taken at 2.5 minute intervals. Following the last measurement during provocation (beginning 15 minutes after the start of provocation), the subjects had one minute to shake, rub, massage, or otherwise relax their hands. Three or six recovery measurements were

then taken at 2.5 minute intervals (three more measurements were added after several subjects had already been tested).

Provocation A was performed by elevating the vibrotactile tester until the subject was in near maximum unforced flexion (with elbow resting on a foam pad) (see Figure 1).



Figure 1. Provocation A: Flexion

Provocation B was performed by tilting the back of the tester upward, placing the subject in maximum unforced flexion, and resting the fingertips on the tester. A Durkan Gauge (Gorge Medical Products, Hood River, OR) was used to put pressure directly on the carpal tunnel. The force applied to the hand was adjusted to approximately 16.7 N using a scissor stand. A strap placed around the top of the hand helped stabilize the hand (see Figures 2 and 3).



Figure 2. Provocation B: Flexion and Direct Pressure



Figure 3. Durkan Gauge in Fixture

Provocations C and D were identical to Provocation A except tendon loading was added during Provocation C and venous occlusion during Provocation D. Tendon loading was accomplished by placing loops around the middle segment of the index and ring fingers. The loops were attached to strings with weights on one end and routed over pulleys (see Figure 4). The index finger load was 103.17 g and the ring finger load was 128.22 g. The height of the pulley fixture was adjusted so that the strings would pull approximately orthogonally to the second segment of the fingers. Subjects were instructed to keep the pads of the index and ring fingers against the dome so that the string tension would load the flexor tendons, not just the skeleton.

A pressure cuff was placed around the forearm near the elbow crease during Provocation D (Figure 5). The cuff was pressurized to 15 mmHg to slightly occlude the veins.



Figure 4. Provocation C: Flexion and Tendon Loading

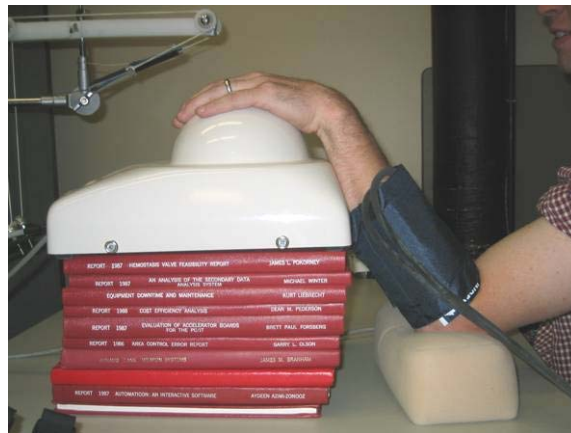


Figure 5. Provocation D: Flexion and Direct Pressure

Three groups of comparisons were made: between the VPT at each time and the baseline VPT for each provocation for each group, between provocations within each group, and between groups for each provocation.

If the data were assumed normal (Kolmogorov-Smirnov test, P-value greater than 0.5), they were compared using t-tests. Non-normal data were compared with nonparametric tests. Natural pairing existed for comparisons within groups, so two-tailed paired t-tests and two-tailed Wilcoxon matched-pairs signed-ranks tests were used. For comparisons between groups, t-tests with Welch correction (allowing for unequal variances) and two-tailed Mann-Whitney tests were used as natural pairing did not exist.

## RESULTS

The average age of the normal group was 29 years (21 to 60 yrs.). The diabetic group ranged from 21 to 70 years of age with an average age of 52. The CTS group averaged 44 years old with a range of 19 to 63 years. An unpaired t-test with Welch's correction showed significant age difference between the normal and CTS groups (difference=15.4 yrs,  $P=0.0032$ ) and between the normal and diabetic groups (difference = 22.8,  $P = 0.0056$ ). The diabetic and CTS groups did not vary significantly in age (difference = 7.4,  $P = 0.2765$ ).

The CTS group was subdivided by sNCV values using a criterion level of 41.26 m/s for normal nerve conduction. The sNCV+ group (slowed nerve conduction) consisted of 17 hands, and the sNCV- group (normal nerve conduction) consisted of 9 hands. The sNCV+ groups was significantly older than the sNCV- group (difference = 18.2, P = 0.0063).

Age predicted VPTs were subtracted from actual VPTs for each subject to correct for age. The age predicted VPTs were given by  $VPT_{predicted} = 0.085 * age + 3.2$ , where *age* was in years and  $VPT_{predicted}$  in microns (Sesek, 2003). The shift at each time was then found by subtracting the baseline measurement from the VPT at that time.

### **Comparison to Baseline**

The VPTs at each time were compared to the baseline VPTs. Tables 1-4 show that there was a trend of decreasing tactile sensitivity throughout the duration of the provocations. For the diabetic group, however, the difference was not shown to be statistically significant at most times during the four provocations.

### **Comparisons Between Groups**

Tables 5-8 show the mean differences between the VPTs of the different groups for each provocation. The sNCV+ group experienced the greatest average shift over the 15 minutes of provocation for each provocation, with the largest shift occurring during flexion alone (Provocation A). The sNCV+ group had significantly higher VPTs than the normal group for each provocation at the 15-minute measurement. The sNCV+ group also had significantly higher VPTs than the sNCV- group at the 15-minute measurement for each provocation except C (flexion and tendon loading).

The reaction of the sNCV- portion of the CTS group to the provocations was similar to the reaction of the normal group except during Provocation C. No significant difference in mean VPTs was demonstrated between these groups.

No significant difference was demonstrated between the diabetic group and the other groups.

### **Comparisons Between Provocations**

The comparisons between groups, summarized in Tables 9-13, show little significant difference between provocations. Normal and diabetic groups did not experience significantly different shifts in VPT between any of the provocations. Fifteen minutes of flexion alone caused a significantly greater shift than flexion combined with venous occlusion in CTS subjects with slowed nerve conduction.

Venous occlusion combined with flexion caused a greater shift than direct pressure combined with flexion at the 2.5 and 5 minute measurements of the sNCV- group. While the shift after 15 minutes of flexion combined with tendon loading (Provocation C) was greater than for the other provocations, this was not shown to be statistically significant.

Table 1. Provocation A: Comparison to Baseline

Time (min)	Normal			CTS			CTS, sNCV+			CTS, sNCV-			Diabetic		
	Diff. $\pm$ SEM ( $\mu$ m)	p-value	Diff. $\pm$ SEM ( $\mu$ m)	Diff. $\pm$ SEM ( $\mu$ m)	p-value	Diff. $\pm$ SEM ( $\mu$ m)	Diff. $\pm$ SEM ( $\mu$ m)	p-value	Diff. $\pm$ SEM ( $\mu$ m)	Diff. $\pm$ SEM ( $\mu$ m)	p-value	Diff. $\pm$ SEM ( $\mu$ m)	Diff. $\pm$ SEM ( $\mu$ m)	p-value	
															Diff. $\pm$ SEM ( $\mu$ m)
0	3.2 $\pm$ 1.1	0.0184	2.5 $\pm$ 1.6	2.7 $\pm$ 2.4	0.1201	2.2 $\pm$ 0.9	2.2 $\pm$ 0.9	0.0349	1.3 $\pm$ 2.1	0.5549					
2.5	5.2 $\pm$ 0.7	< 0.0001*	8 $\pm$ 3.8	10.6 $\pm$ 5.7	0.0032*	3.2 $\pm$ 1.2	3.2 $\pm$ 1.2	0.0254	3.2 $\pm$ 2.1	0.1730					
5	6.3 $\pm$ 0.9	< 0.0001*	13.9 $\pm$ 6.5	18.7 $\pm$ 9.7	< 0.0001*	5 $\pm$ 1.8	5 $\pm$ 1.8	0.0263	8.4 $\pm$ 4.7	0.1144					
7.5	6.4 $\pm$ 1	0.0001	27.9 $\pm$ 14.1	40 $\pm$ 21.2	< 0.0001*	5 $\pm$ 1.9	5 $\pm$ 1.9	0.0294	16.2 $\pm$ 7.7	0.0736					
10	6.6 $\pm$ 1.5	0.0017	36.3 $\pm$ 14.8	52.1 $\pm$ 21.8	< 0.0001*	6.4 $\pm$ 1.8	6.4 $\pm$ 1.8	0.0083	23.9 $\pm$ 12.1	0.0896					
12.5	8.7 $\pm$ 1.7	0.0005	68.6 $\pm$ 23.7	101.7 $\pm$ 33.8	< 0.0001*	6.1 $\pm$ 1.7	6.1 $\pm$ 1.7	0.0077	21.1 $\pm$ 8.6	0.0444					
15	9.7 $\pm$ 2.2	0.0018	87.9 $\pm$ 28.4	131.1 $\pm$ 39.8	< 0.0001*	6.4 $\pm$ 1.9	6.4 $\pm$ 1.9	0.0111	41.5 $\pm$ 26.1	0.1556					

Table 2. Provocation B: Comparison to Baseline

Time (min)	Normal			CTS			CTS, sNCV+			CTS, sNCV-			Diabetic		
	Diff. $\pm$ SEM ( $\mu$ m)	p-value	Diff. $\pm$ SEM ( $\mu$ m)	Diff. $\pm$ SEM ( $\mu$ m)	p-value	Diff. $\pm$ SEM ( $\mu$ m)	Diff. $\pm$ SEM ( $\mu$ m)	p-value	Diff. $\pm$ SEM ( $\mu$ m)	Diff. $\pm$ SEM ( $\mu$ m)	p-value	Diff. $\pm$ SEM ( $\mu$ m)	Diff. $\pm$ SEM ( $\mu$ m)	p-value	
															Diff. $\pm$ SEM ( $\mu$ m)
0	0.7 $\pm$ 0.7	0.2889	10.1 $\pm$ 6.9	15.4 $\pm$ 10.6	0.0422*	0.7 $\pm$ 0.7	0.7 $\pm$ 0.7	0.3375	5 $\pm$ 3.3	0.1688					
2.5	2.4 $\pm$ 1.3	0.0969	10.7 $\pm$ 6.5	16.3 $\pm$ 9.9	0.0042*	0.8 $\pm$ 0.6	0.8 $\pm$ 0.6	0.2112	7.2 $\pm$ 3	0.0488					
5	3.7 $\pm$ 1	0.0050	13.7 $\pm$ 5.6	20.2 $\pm$ 8.3	0.0219	2.1 $\pm$ 1	2.1 $\pm$ 1	0.0681	15.1 $\pm$ 7.6	0.0885					
7.5	4.3 $\pm$ 1.3	0.0075	28.8 $\pm$ 14	42.7 $\pm$ 21.2	< 0.0001*	4 $\pm$ 0.9	4 $\pm$ 0.9	0.0018	28.8 $\pm$ 16.5	0.1251					
10	6.1 $\pm$ 1.5	0.0026	64.5 $\pm$ 24	98.2 $\pm$ 35.1	< 0.0001*	4.6 $\pm$ 1.3	4.6 $\pm$ 1.3	0.0078	24.7 $\pm$ 8.8	0.0269					
12.5	6.4 $\pm$ 2	0.0116	70.5 $\pm$ 24.1	106.7 $\pm$ 34.7	< 0.0001*	6.1 $\pm$ 1.7	6.1 $\pm$ 1.7	0.0064	42.1 $\pm$ 25.3	0.1409					
15	8.7 $\pm$ 3.5	0.0356	75.7 $\pm$ 24.5	115.3 $\pm$ 34.9	0.0051	5.3 $\pm$ 1.5	5.3 $\pm$ 1.5	0.0074	55.6 $\pm$ 43.8	0.2454					

Table 3. Provocation C: Comparison to Baseline

Time (min)	Normal			CTS			CTS, sNCV+			CTS, sNCV-			Diabetic		
	Diff. $\pm$ SEM ( $\mu$ m)	p-value	Diff. $\pm$ SEM ( $\mu$ m)	Diff. $\pm$ SEM ( $\mu$ m)	p-value	Diff. $\pm$ SEM ( $\mu$ m)	Diff. $\pm$ SEM ( $\mu$ m)	p-value	Diff. $\pm$ SEM ( $\mu$ m)	Diff. $\pm$ SEM ( $\mu$ m)	p-value	Diff. $\pm$ SEM ( $\mu$ m)	Diff. $\pm$ SEM ( $\mu$ m)	p-value	
															Diff. $\pm$ SEM ( $\mu$ m)
0	2.8 $\pm$ 0.9	0.0168	0 $\pm$ 1.3	0.5 $\pm$ 1.9	0.2076*	1 $\pm$ 0.7	1 $\pm$ 0.7	0.1660	-3.9 $\pm$ 4.4	0.4055					
2.5	3.4 $\pm$ 1.1	0.0118	5.1 $\pm$ 1.4	6.4 $\pm$ 2.1	0.0016	2.9 $\pm$ 1.2	2.9 $\pm$ 1.2	0.0381	-3.8 $\pm$ 7.2	0.6149					
5	4.7 $\pm$ 0.7	< 0.0001*	14.2 $\pm$ 6	18 $\pm$ 9.1	0.0001*	7.4 $\pm$ 4.1	7.4 $\pm$ 4.1	0.1081	5.4 $\pm$ 3	0.1117					
7.5	8.2 $\pm$ 1.8	0.0016	30 $\pm$ 12.9	40.4 $\pm$ 19.4	< 0.0001*	11.6 $\pm$ 7.3	11.6 $\pm$ 7.3	0.1528	15.6 $\pm$ 9	0.1251					
10	8.1 $\pm$ 2.1	0.0035	31.6 $\pm$ 14.9	45.2 $\pm$ 22.7	< 0.0001*	7.3 $\pm$ 3.5	7.3 $\pm$ 3.5	0.0688	24.2 $\pm$ 10.1	0.0474					
12.5	7.1 $\pm$ 1.6	0.0014	39.6 $\pm$ 15.9	50.5 $\pm$ 23.4	< 0.0001*	20.2 $\pm$ 14.1	20.2 $\pm$ 14.1	0.1900	21.4 $\pm$ 8.9	0.0467					
15	9.2 $\pm$ 2	0.0014	63.5 $\pm$ 22	70.9 $\pm$ 25.3	< 0.0001*	50.2 $\pm$ 43.4	50.2 $\pm$ 43.4	0.0078*	24.1 $\pm$ 19.9	0.2640					

Table 4. Provocation D: Comparison to Baseline

Time (min)	Normal			CTS			CTS, sNCV+			CTS, sNCV-			Diabetic		
	Diff. $\pm$ SEM ( $\mu$ m)	p-value	Diff. $\pm$ SEM ( $\mu$ m)	Diff. $\pm$ SEM ( $\mu$ m)	p-value	Diff. $\pm$ SEM ( $\mu$ m)	Diff. $\pm$ SEM ( $\mu$ m)	p-value	Diff. $\pm$ SEM ( $\mu$ m)	Diff. $\pm$ SEM ( $\mu$ m)	p-value	Diff. $\pm$ SEM ( $\mu$ m)	Diff. $\pm$ SEM ( $\mu$ m)	p-value	
															Diff. $\pm$ SEM ( $\mu$ m)
0	3 $\pm$ 0.6	0.0010	4.5 $\pm$ 1.1	5.7 $\pm$ 1.6	0.0005	2.3 $\pm$ 0.8	2.3 $\pm$ 0.8	0.0200	7 $\pm$ 8.6	0.4381					
2.5	4.3 $\pm$ 1	0.0016	11.4 $\pm$ 3.6	15 $\pm$ 5.4	< 0.0001*	4.7 $\pm$ 1.2	4.7 $\pm$ 1.2	0.0057	7.1 $\pm$ 7.4	0.3649					
5	5.6 $\pm$ 1.1	0.0007	12.8 $\pm$ 2.9	16.8 $\pm$ 4.2	< 0.0001*	5.1 $\pm$ 1.1	5.1 $\pm$ 1.1	0.0018	10.5 $\pm$ 10.1	0.3324					
7.5	5.1 $\pm$ 1.3	0.0043	15.6 $\pm$ 6.6	20.4 $\pm$ 10	< 0.0001*	6.5 $\pm$ 1.7	6.5 $\pm$ 1.7	0.0044	21 $\pm$ 15.7	0.2215					
10	5.8 $\pm$ 1.5	0.0033	25.9 $\pm$ 13.9	35.9 $\pm$ 21	< 0.0001*	7 $\pm$ 1.9	7 $\pm$ 1.9	0.0066	34.3 $\pm$ 25.3	0.2185					
12.5	9.1 $\pm$ 2.2	0.0024	34.7 $\pm$ 15	48.2 $\pm$ 22.4	< 0.0001*	9.2 $\pm$ 2.6	9.2 $\pm$ 2.6	0.0081	14.9 $\pm$ 9.2	0.1514					
15	8.5 $\pm$ 2.2	0.0039	36.4 $\pm$ 11.7	50.9 $\pm$ 16.9	< 0.0001*	9.1 $\pm$ 2.5	9.1 $\pm$ 2.5	0.0070	23.8 $\pm$ 15.3	0.1629					

\*indicates p-value from nonparametric comparison

Highlighted cells indicate significance at 0.05 level

Table 5. Provocation A: Comparison BETWEEN GROUPS

Time (min)	All CTS minus Normal		sNCV+ minus Normal		Normal minus sNCV-		sNCV+ minus sNCV-		Diabetic minus Normal		sNCV+ minus Diabetic		Diabetic minus sNCV-		CTS minus Diabetic	
	Diff.	p-value	Diff.	p-value	Diff.	p-value	Diff.	p-value	Diff.	p-value	Diff.	p-value	Diff.	p-value	Diff.	p-value
0	-0.6	0.7412	-0.5	0.8601	1.0	0.5037	0.4	0.8485	-1.9	0.4505	1.4	0.9304*	-0.9	0.7006	1.4	0.6653
2.5	0.5	0.4800*	5.4	>0.9999*	2.0	0.1564	7.4	0.1313*	-2.0	0.4035	7.4	0.3152*	0.1	0.9809	7.4	0.3152*
5	7.6	0.8460*	12.4	0.4978*	1.3	0.5427	13.6	0.0593*	2.1	0.8695	10.3	0.5486*	3.4	0.5163	10.3	0.5486*
7.5	21.4	0.8250*	33.5	0.1082*	1.4	0.5153	35.0	0.0291*	9.8	0.2493	23.8	0.3048*	11.2	0.2007	23.8	0.4063*
10	29.7	0.0684*	45.5	0.0047*	0.2	0.9478	45.6	0.0035*	17.3	0.1999	28.2	0.4747*	17.4	0.1979	28.2	0.4747*
12.5	59.9	0.1476*	93.0	0.0144	2.6	0.2991	95.6	0.0123	12.5	0.1995	80.6	0.1029*	15.0	0.1312	80.6	0.1029*
15	78.2	0.1289*	121.4	0.0078	3.3	0.2800	124.7	0.0065	31.8	0.2640	89.6	0.0732	35.1	0.2215	89.6	0.0732

Table 6. Provocation B: Comparison BETWEEN GROUPS

Time (min)	CTS minus Normal		sNCV+ minus Normal		Normal minus sNCV-		sNCV+ minus sNCV-		Diabetic minus Normal		sNCV+ minus Diabetic		Diabetic minus sNCV-		CTS minus Diabetic	
	Diff.	p-value	Diff.	p-value	Diff.	p-value	Diff.	p-value	Diff.	p-value	Diff.	p-value	Diff.	p-value	Diff.	p-value
0	9.4	0.4652*	14.7	0.1888	0.1	0.9379	14.7	0.1867	4.2	0.2411	10.4	0.3620	4.3	0.2338	5.1	0.7575*
2.5	8.4	0.6092*	13.9	0.1139*	1.5	0.3045	15.5	0.0272*	4.8	0.1767	9.1	0.9761*	6.3	0.0787	3.6	0.3306*
5	10.0	0.6275*	16.5	0.0688	1.6	0.2653	18.1	0.0478	11.3	0.1834	5.1	0.6543	13.0	0.1351	-1.4	0.4752*
7.5	24.5	0.0260*	38.5	0.0011*	0.3	0.8312	38.8	0.0004*	24.5	0.1828	16.9	>0.9999*	24.9	0.1771	0.0	0.2716*
10	58.4	0.0327*	92.1	0.0193	1.4	0.4829	93.5	0.0078	18.6	0.0764	73.5	0.0594	20.0	0.0599	39.8	0.8855*
12.5	64.1	0.0260*	100.4	0.0006*	0.2	0.9307	100.6	0.0011*	35.7	0.2031	64.7	0.1046*	35.9	0.2001	28.4	0.5150*
15	67.0	0.0124	106.6	0.0082	3.3	0.3978	110.0	0.0066	46.9	0.3214	59.7	0.3032	50.2	0.2894	20.1	0.6963

Table 7. Provocation C: Comparison BETWEEN GROUPS

Time (min)	all CTS minus Normal		sNCV+ minus Normal		sNCV- minus Normal		sNCV+ minus sNCV-		Diabetic minus Normal		sNCV+ minus Diabetic		Diabetic minus sNCV-		CTS minus Diabetic	
	Diff.	p-value	Diff.	p-value	Diff.	p-value	Diff.	p-value	Diff.	p-value	Diff.	p-value	Diff.	p-value	Diff.	p-value
0	-2.7	0.1709*	-3.3	0.1430	-1.8	0.1450	-1.5	0.4668	-6.7	0.1825	3.4	0.5012	-4.9	0.3078	3.9	0.5225*
2.5	1.7	0.3552	3.0	0.2257	-0.6	0.7176	3.6	0.1549	-7.3	0.3551	10.2	0.2119	-6.7	0.3935	9.0	0.2647
5	9.5	0.7877*	13.3	0.2857*	2.7	0.5369	10.6	0.3286*	0.7	0.8166	12.6	0.3826*	-1.9	0.7090	8.7	0.6356*
7.5	21.8	0.7150*	32.2	0.1199	3.4	0.6650	28.8	0.1822	7.4	0.4434	24.8	0.2610	4.1	0.7315	14.4	0.8855*
10	23.4	0.3209*	37.1	0.0309*	-0.8	0.8367	37.9	0.0174*	16.1	0.1624	21.0	0.4092	16.9	0.1514	7.3	0.7263*
12.5	32.5	0.1392*	43.4	0.0847	13.1	0.3824	30.2	0.2809	14.3	0.1561	29.0	0.2622	1.2	0.9425	18.1	0.9665*
15	54.3	0.1653*	61.7	0.0279	41.1	0.5490*	20.6	0.0543*	15.0	0.4779	46.8	0.1605	-26.1	0.8148*	39.3	0.2904*

Table 8. Provocation D: Comparison BETWEEN GROUPS

Time (min)	CTS minus Normal		sNCV+ minus Normal		sNCV- minus Normal		sNCV+ minus sNCV-		Diabetic minus Normal		sNCV+ minus Diabetic		Diabetic minus sNCV-		CTS minus Diabetic	
	Diff.	p-value	Diff.	p-value	Diff.	p-value	Diff.	p-value	Diff.	p-value	Diff.	p-value	Diff.	p-value	Diff.	p-value
0	1.5	0.2421	2.7	0.1370	-0.7	0.5283	3.4	0.0783	4.0	0.6515	-1.3	0.7108*	4.7	0.6013	-2.5	0.7800
2.5	7.1	0.0970*	10.7	0.0684	0.3	0.8369	10.3	0.0793	2.8	0.7170	7.9	0.4031	2.5	0.7503	4.3	0.9208*
5	7.2	0.0500*	11.3	0.0058*	-0.5	0.7519	11.8	0.0018*	4.9	0.6427	6.3	0.0657*	5.4	0.6096	2.3	0.3299*
7.5	10.5	0.0805*	15.3	0.0239*	1.4	0.5225	13.9	0.0662*	15.9	0.3451	-0.6	0.9072*	14.5	0.3874	-5.4	0.5425*
10	20.0	0.0373*	30.0	0.0039*	1.2	0.6368	28.9	0.0290*	28.4	0.2999	1.6	0.8613*	27.2	0.3193	-8.4	0.3939*
12.5	25.6	0.1011*	39.0	0.1019	0.1	0.9775	38.9	0.0388*	5.7	0.5656	33.3	0.2664*	5.6	0.5744	19.8	0.5425*
15	28.0	0.0373*	42.5	0.0026*	0.7	0.8486	41.8	0.0077*	15.3	0.3528	27.1	0.1943*	14.7	0.3738	12.7	0.6261*

\*Indicates p-value from nonparametric comparison  
 Highlighted cells indicate significance at 0.05 level

Time (min)	A minus B		A minus C		A minus D		B minus C		B minus D		C minus D	
	Difference ± SEM (µm)	p-value	Difference ± SEM (µm)	p-value	Difference ± SEM (µm)	p-value	Difference ± SEM (µm)	p-value	Difference ± SEM (µm)	p-value	Difference ± SEM (µm)	p-value
0	2.5 ± 1.3	0.0842	0.4 ± 1.6	0.8038	0.2 ± 1.0	0.8392	-2.0 ± 1.3	0.1413	-2.3 ± 1.0	0.0555	-0.2 ± 1.1	0.8448
2.5	2.9 ± 1.5	0.0856	1.8 ± 1.3	0.1969	0.9 ± 0.9	0.3342	-1.1 ± 1.6	0.5171	-2.0 ± 1.6	0.2449	-0.9 ± 1.7	0.6217
5	2.6 ± 1.4	0.0971	1.6 ± 1.0	0.1530	0.7 ± 1.0	0.4950	-1.0 ± 1.1	0.3762	-1.9 ± 1.3	0.1844	-0.9 ± 1.2	0.4781
7.5	2.2 ± 1.6	0.1987	-1.7 ± 1.9	0.3727	1.3 ± 1.2	0.3080	-3.9 ± 1.8	0.0644	-0.8 ± 1.9	0.6687	3.1 ± 2.1	0.1742
10	0.5 ± 2.2	0.8145	-1.6 ± 1.9	0.4327	0.7 ± 1.5	0.6233	-2.1 ± 3.1	0.5116	0.2 ± 2.1	0.9224	2.3 ± 2.6	0.4068
12.5	2.3 ± 2.2	0.3140	1.6 ± 1.7	0.3794	-0.5 ± 2.6	0.8636	-0.7 ± 1.9	0.7102	-2.8 ± 3.0	0.3814	-2.0 ± 2.4	0.4195
15	1.1 ± 3.0	0.7308	0.6 ± 2.0	0.7903	1.3 ± 2.9	0.6710	-0.5 ± 4.2	0.9088	0.2 ± 3.6	0.9569	0.7 ± 2.7	0.7987

Time (min)	A minus B		A minus C		A minus D		B minus C		B minus D		C minus D	
	Difference ± SEM (µm)	p-value	Difference ± SEM (µm)	p-value	Difference ± SEM (µm)	p-value	Difference ± SEM (µm)	p-value	Difference ± SEM (µm)	p-value	Difference ± SEM (µm)	p-value
0	-3.7 ± 4.6	0.4479	5.2 ± 5.6	0.3832	-5.7 ± 7.2	0.4540	8.9 ± 6.5	0.2162	-2.1 ± 9.6	0.8376	-10.9 ± 12.1	0.3977
2.5	-3.9 ± 4.0	0.3587	7.1 ± 8.5	0.4333	-3.9 ± 5.5	0.5015	11.0 ± 9.3	0.2762	0.0 ± 8.0	0.9964	-10.9 ± 13.1	0.4322
5	-6.7 ± 4.9	0.2171	3.0 ± 4.8	0.5572	-2.1 ± 6.4	0.7568	9.6 ± 8.3	0.2820	4.6 ± 5.9	0.4615	-5.0 ± 9.6	0.6151
7.5	-12.6 ± 13.4	0.3763	0.6 ± 7.4	0.9376	-4.8 ± 12.2	0.7043	13.2 ± 8.5	0.1631	7.8 ± 5.8	0.2218	-5.4 ± 7.0	0.4612
10	-0.8 ± 9.6	0.9368	-0.4 ± 10.2	0.9726	-10.4 ± 24.7	0.6864	0.4 ± 4.8	0.9318	-9.6 ± 18.0	0.6111	-10.0 ± 17.1	0.5751
12.5	-20.9 ± 17.0	0.2583	-0.3 ± 3.4	0.9294	6.3 ± 11.8	0.6120	20.6 ± 18.2	0.2934	27.2 ± 27.1	0.3490	6.6 ± 12.6	0.6173
15	-14.1 ± 18.3	0.4674	17.4 ± 13.6	0.2409	17.7 ± 32.1	0.5980	31.4 ± 28.0	0.2989	31.8 ± 49.8	0.5442	0.3 ± 30.8	0.9919

Time (min)	A minus B		A minus C		A minus D		B minus C		B minus D		C minus D	
	Difference ± SEM (µm)	p-value	Difference ± SEM (µm)	p-value	Difference ± SEM (µm)	p-value	Difference ± SEM (µm)	p-value	Difference ± SEM (µm)	p-value	Difference ± SEM (µm)	p-value
0	-7.4 ± 6.1	0.6338*	2.7 ± 1.7	0.1412	-2.0 ± 2.2	0.3819	10.1 ± 7.2	0.2635*	5.5 ± 6.9	0.5249*	-4.6 ± 2.1	0.0359
2.5	-2.6 ± 3.2	0.4908*	3.0 ± 3.6	0.4148	-3.4 ± 2.6	0.2009	5.6 ± 6.2	0.7915*	-1.0 ± 4.0	0.0342*	-6.6 ± 4.2	0.2411*
5	0.4 ± 2.5	0.8634	0.0 ± 8.4	0.9957	1.2 ± 6.2	0.1358*	-0.5 ± 6.8	0.9439	0.8 ± 5.5	0.2752*	1.3 ± 5.5	0.8151
7.5	-0.2 ± 18.9	0.9158*	-1.4 ± 16.0	0.9304	12.2 ± 10.7	0.5995*	-1.2 ± 17.8	0.9789*	12.9 ± 17.1	0.8740*	14.1 ± 8.7	0.3525*
10	-27.4 ± 27.1	0.5782*	5.5 ± 18.6	0.7693	10.4 ± 13.6	0.4227*	32.9 ± 27.4	0.5782*	38.0 ± 27.7	0.5249*	5.1 ± 18.9	0.7112*
12.5	0.0 ± 25.0	0.9789*	30.9 ± 25.0	0.2276	33.9 ± 25.1	0.4082*	30.9 ± 27.4	0.1817*	34.9 ± 22.0	0.1817*	3.9 ± 12.9	0.5424*
15	15.3 ± 27.8	0.2635*	27.6 ± 30.9	0.3810	51.5 ± 23.3	0.3533*	12.2 ± 31.4	0.7003	38.2 ± 22.9	0.3029*	26.0 ± 17.3	0.5782*

Time (min)	A minus B		A minus C		A minus D		B minus C		B minus D		C minus D	
	Difference ± SEM (µm)	p-value	Difference ± SEM (µm)	p-value	Difference ± SEM (µm)	p-value	Difference ± SEM (µm)	p-value	Difference ± SEM (µm)	p-value	Difference ± SEM (µm)	p-value
0	-12.5 ± 9.3	0.2012	3.5 ± 2.7	0.2154	-3.0 ± 3.4	0.3888	15.9 ± 11.1	0.1721	9.6 ± 10.8	0.8209*	-6.4 ± 3.1	0.0580
2.5	-5.4 ± 4.9	0.2932	4.5 ± 5.7	0.4374	-4.4 ± 3.8	0.2699	9.9 ± 9.6	0.7057*	0.6 ± 6.3	0.9266	-9.3 ± 6.4	0.1675
5	-1.0 ± 3.8	0.8037	1.2 ± 13.0	0.9253	1.8 ± 9.5	0.8489	2.2 ± 10.6	0.8373	2.9 ± 8.6	0.7394	0.7 ± 8.4	0.9323
7.5	-0.9 ± 29.9	0.9767	1.5 ± 24.8	0.9530	19.5 ± 16.2	0.3289*	2.4 ± 27.8	0.9330	21.6 ± 26.8	0.4037*	19.2 ± 13.1	0.1644
10	-43.9 ± 42.2	0.3151	9.1 ± 29.2	0.7599	16.2 ± 20.8	0.4475	53.0 ± 42.5	0.2315	60.7 ± 42.7	0.1754*	7.8 ± 29.9	0.7989
12.5	0.0 ± 39.5	0.9998	56.3 ± 37.1	0.1501	53.5 ± 37.9	0.2247*	56.3 ± 41.3	0.1930	56.3 ± 33.5	0.1136	0.0 ± 76.5	0.6322*
15	23.3 ± 43.8	0.6021	67.7 ± 38.8	0.1011	80.2 ± 33.9	0.0310	44.4 ± 41.6	0.3024	61.9 ± 34.8	0.0953	17.5 ± 13.2	0.2050

Time (min)	A minus B		A minus C		A minus D		B minus C		B minus D		C minus D	
	Difference ± SEM (µm)	p-value	Difference ± SEM (µm)	p-value	Difference ± SEM (µm)	p-value	Difference ± SEM (µm)	p-value	Difference ± SEM (µm)	p-value	Difference ± SEM (µm)	p-value
0	1.6 ± 1.1	0.1992	1.2 ± 1.0	0.2772	-0.1 ± 1.3	0.9317	-0.3 ± 0.5	0.5126	-1.7 ± 0.9	0.1063	-1.3 ± 1.0	0.1987
2.5	2.3 ± 1.2	0.0904	0.3 ± 1.1	0.7726	-1.5 ± 1.9	0.4496	-2.0 ± 1.0	0.0725	-3.8 ± 1.1	0.0091	-1.8 ± 1.7	0.3334
5	2.9 ± 2.0	0.1775	-2.3 ± 4.4	0.6096	0.0 ± 2.3	0.9851	-5.3 ± 3.6	0.1765	-3.0 ± 1.1	0.0313	2.3 ± 3.6	0.5384
7.5	1.0 ± 2.2	0.6511	-6.6 ± 7.9	0.6523*	-1.5 ± 2.6	0.5823	-7.6 ± 7.0	0.3120	-2.6 ± 1.7	0.1625	5.0 ± 6.1	0.4294
10	1.8 ± 2.0	0.4023	-0.9 ± 3.8	0.8223	-0.6 ± 1.8	0.7561	-2.7 ± 3.0	0.4016	-2.4 ± 1.5	0.1483	0.3 ± 2.2	0.9008
12.5	-0.1 ± 2.2	0.9805	-14.1 ± 14.6	0.9453*	-3.2 ± 2.4	0.2315	-14.1 ± 13.2	0.3177	-3.1 ± 2.3	0.2165	11.0 ± 12.4	>0.9999*
15	1.1 ± 1.9	0.5900	-43.8 ± 44.0	0.7344*	-2.7 ± 1.6	0.1287	-44.9 ± 42.6	0.2031*	-3.8 ± 2.2	0.1292	41.1 ± 43.3	0.3702

\*indicates p-value from nonparametric comparison  
 Highlighted cells indicate significance at 0.05 level

## CONCLUSIONS

The ergonomic risk factors of wrist flexion, direct pressure on the carpal tunnel, tendon loading, and venous occlusion cause a decrease in sensitivity in the area of the hand innervated by the median nerve. This was demonstrated in subjects without CTS or other forms of neuropathy or nerve damage as well as in subjects with CTS (with both normal and slowed nerve conduction). Subjects with diabetic neuropathy also experienced a decrease in sensitivity, though the shift was not statistically significant in many cases from the baseline.

Subjects with CTS with slowed nerve conduction experienced the greatest temporary VPT shifts. The shift was significantly higher than that of the normal group following 15 minutes of each provocation. The subjects with CTS and normal nerve conduction, however, reacted about the same to the provocations as the normal group.

Addition of other ergonomic risk factors to flexion did not seem to have a significant effect. The effect of these risk factors alone was not tested. It is possible that the addition of risk factors partially alleviated the effect of flexion.

The effect of direct pressure, tendon loading, and venous occlusion may be studied further. The magnitude of these risk factors was not varied. It is possible that increasing the magnitudes will increase the temporary VPT shift. The magnitude of flexion was near maximal for the subject, while the magnitude of the other risk factors was probably far from maximal for most subjects. Future studies may show magnitudes of other risk factors that lead to an equivalent VPT shift to that caused by near maximum flexion.

Quantification of the effect of ergonomic risk factors may be more useful than merely analyzing the exposure. The ability to measure a change in tactile sensitivity due to ergonomic risk factors was demonstrated. Future studies may apply VPT measurements to assess the effect of actual work tasks.

Small sample sizes might have contributed to the inability to show significant difference between groups. Power studies were not performed to estimate the number of subjects required to demonstrate significance. The data from this study will help in determining sample size in future studies.

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## REFERENCES

- Bureau of Labor Statistics (BLS) [database on the Internet]. U.S. Department of Labor. – [cited 2003 Nov]. Available from: <http://www.bls.gov/search/search.asp>.
- Cobb TK, Kai-Nan A, Cooney WP. Externally applied forces to the palm increase carpal tunnel pressure. *J Hand Surg [Am]*. 1995;20A(2):181-5.
- DeKrom MCRFM, Kester ADM, Knipschild PG, Spaans F. Risk factors for carpal tunnel syndrome. *Am J Epidemiol*. 1990;136(6):1102-10.
- Durkan JA. A new diagnostic test for carpal tunnel syndrome. *J Bone Joint Surg*. 1991;73A(4):535-8.
- Keir PJ, Wells RP, Ranney DA, Lavery W. The effects of tendon load and posture on carpal tunnel pressure. *J Hand Surg [Am]*. 1997;22A(4):628-34.
- Lundborg G, Gelberman RH, Minter-Convery M, Lee YF, Hargens AR. Median nerve compression in the carpal tunnel – Functional response to experimentally induced controlled pressure. *J Hand Surg [Am]*. 1982;7(3):252-9.
- Marin EL, Vernick S, Friedmann LW. Carpal tunnel syndrome: median nerve stress test. *Arch Phys Med Rehabil*. 1983;64:206-8.
- Pecina M, Krmpotic-Nemanic J, Markiewitz A. Tunnel syndromes: peripheral nerve compression syndromes. Boca Raton, FL: CRC Press; 2001.
- Phalen GS. The carpal-tunnel syndrome: seventeen years' experience in diagnosis and treatment of six hundred fifty-four hands. *J Bone Joint Surg*. 1966;48A(2):211-28.
- Reese SK, Sesek RF, Tuckett RP, Bloswick D. Measuring the effects of ergonomic risk factors on tactile sensation. 1<sup>st</sup> Annual Regional National Occupational Research Agenda (NORA) Young/New Investigators Symposium, Salt Lake City, Utah, June 2003.
- Sesek RF, Tuckett RP, Bloswick DS, Khalighi M. Prolonged wrist flexion. In press 2003.
- Silverstein BA, Fine LJ, Armstrong, TJ. Occupational factors and carpal tunnel syndrome. *Am J Ind Med*. 1987;11:343-58.
- Werner R, Armstrong TJ, Bir C, Aylard MK. Intracarpal canal pressures: the role of finger, hand, wrist and forearm position. *Clin Biomech*. 1997;12(1):44-51.