Ridge Detection Tactility Deficits Associated with Carpal Tunnel Syndrome

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A ridge detection threshold task was administered to patients diagnosed as having carpal tunnel syndrome for studying performance in an occupationally relevant functional tactile inspection task. Thresholds were compared with a reference group of subjects not having carpal tunnel syndrome symptoms, performing the same task. The threshold detection task used the method of limits for studying the effects of carpal tunnel syndrome, rate of ridge height changes, ridge gradient, and direction of shearing against the skin on ridge detection thresholds for a repeated measures factorial experimental design. Sixteen carpal tunnel syndrome hands and 30 normal hands were studied. Average ridge detection threshold was 0.08 mm for the normal subjects and increased to 0.20 mm for the carpal tunnel syndrome subjects. No significant age effect was observed. These results suggest that workers having carpal tunnel syndrome may not detect an edge or surface defect in a tactile inspection task unless it was more than twice as high as detected by workers without CTS.

Carpal tunnel syndrome (CTS), an upper extremity cumulative trauma disorder, is a major cause of lost time and workers' compensation claims in industries involving manual work.[1–6] The pathophysiology of CTS is clearly and conclusively documented as entrapment of the median nerve at the wrist within the carpal tunnel.[7] The severity of entrapment may vary from extremely mild to profound. The functional deficits that can result from CTS also can vary from extremely mild to profound.

The median nerve is a mixed nerve composed of autonomic, sensory, and motor axons. An individual may have no detectable sensory or motor deficits yet complain bitterly of painful paraesthesias in the hand. This may be due to early selective compromise of the autonomic fibers. The symptoms and functional deficits that result from compression depend on which fibers are compromised. In the early stages of CTS there may be primarily sensory problems. This can result in functional deficits that may directly affect manual work performance.

Efficient, coordinated use of these fingers for precision activities may be significantly impaired if there is a sensory deficit. Grasping and gripping functions of the hand are highly affected by impaired sensibility and degraded motor activity in all cases of peripheral nerve involvement. Compression of the median nerve often results in sensory loss of innervated surfaces of the index finger, the long finger, and the thumb,[8] the fingers used most often in precision hand functions.[9,10] Inability to use them effectively also may result from sensory loss in these fingers.[11] A hand with impaired sensibility may not perform precision motor-sensory tasks rapidly and skillfully even if its muscle functions are good.

Hand function is extremely dependent on sensory feedback. Moberg[12] pointed out that adequate sensory feedback is crucial for hand function. Unfortunately, an understanding of what is adequate sensation is still evolving. Certainly the usual bedside clinical neurologic examination for testing sensory loss in the hand using pinpricks, cotton balls, and tuning forks is not sensitive enough to define minor sensory losses that may be functionally quite significant. Detailed multimodality sensory evaluation includes such quantitative measures as moving two-point discrimination and Semmes-Weinstein monofilament tests. These, however, do not directly

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0096-1736/91/3306-0730$03.00/0

relate to functional tactility tasks often performed in industrial operations, such as tactile inspection for burrs, protrusions, or other rough surfaces.

Two-point discrimination tests have been the major clinical tests used for measuring tactile sensitivity.[13,14] In a study evaluating hand sensibility in patients with idiopathic CTS who underwent carpal tunnel release, only 22% of the hands had abnormal static two-point discrimination.[15] Two-point discrimination tests have been reliable in assessing functional nerve regeneration but not sensitive to the gradual decrease in nerve function created by external compression.[16,17] These findings may be explained by the notion that two-point discrimination and moving two-point discrimination, both highly dependent on cortical integration, are believed to remain intact even if only a few fibers are conducting normally to the correct cortical end-points.[18] Magnitude threshold testing is more likely to show gradual and progressive changes as a greater proportion of nerve fibers are lost while others still maintain the proper central connections.[19]

The Semmes-Weinstein monofilament test was abnormal for 83% of the hands tested in a study of idiopathic CTS patients.[19] The normal range was considered 0.0045 to 0.068 g force. Six weeks after carpal tunnel release surgery, all hands having abnormal monofilament results demonstrated improvement, and 63% had normal ranges.

Ridge detection threshold tasks have been used previously for assessing sensory loss at the distal finger tip caused by Raynaud's syndrome,[20,21] temporary threshold shifts due to vibration exposure[22] and sensory recovery after carpal tunnel release surgery.[23] Corlett et al[21] improved on the Renfrew ridge anesthesiometer[24] by constructing a disc containing a ridge on the periphery of a disc. As the disc was rotated by turning a knob, the ridge height increased and subjects responded when the ridge was perceived.

The objective of our present investigation was to measure tactile sensitivity deficits for a stimulus that is occupationally relevant. A ridge detection task was selected as a functional task representative of sensory tasks such as tactile inspection for edges or surface defects. The hypothesis was that workers suffering from carpal tunnel syndrome may experience functional deficits that can affect their performance in tactile activities.

Methods

Apparatus and Experimental Procedure

A microcomputer-controlled aesthesiometer based on Corlett's ridge aesthesiometer was constructed. Details of this apparatus are described by Radwin et al.[22,25] A 9 cm diameter and 2.5 cm wide Teflon disc has a 2.0 mm wide ridge machined along the disc's circumference by eccentrically milling the disc edges, producing a ridge ranging from a minimum height of 0.0 mm to a maximum of 1.2 mm. Three percent of the disc circumference has no ridge.

A direct current motor rotates the disc coupled to a potentiometer for measuring the disc rotation angle which is calibrated against ridge height using a dial indicator gage. A quadratic regression calibration curve is used to determine ridge height associated with the potentiometer output ($R^2 = .99$). The motor direction and speed of rotation are under control of the microcomputer, and the ridge height signal off the potentiometer is digitized using a 12 bit analog-digital converter. The motor and disc assembly is mounted in an acrylic housing that is seated on a cart and glides along a track using four bearings to minimize friction.

Subjects placed the distal phalangeal pad of the index finger against the rotating disc (see Fig. 1). By pushing against the disc, a spring attached to the cart and track was stretched. The spring tension was set at 65 g. Subjects were instructed to push against the disc using only enough force to align a target on the box with a matching target on the track. This method controlled finger force exerted against the disc and kept it constant. The magnitude threshold detection task used the method of limits. Subjects were instructed to press a response push button when the ridge became sufficiently high for perception and release the button when the ridge height was too low for detection. Headphones were worn playing white noise during the trials masking the sounds the motor made, which could have provided rotation speed and direction cues.

A trial commenced after the ridge height was reset to the zero ridge zone. Subjects inserted their index finger through an aperture and the finger was immobilized using a Velcro band. An experimental trial started on sounding of an auditory warning signal, and the disc started rotating. Subjects indicated a rising ridge by pressing the response button. After the button was pressed the disc continued rotating at the same speed and direction for a random period between 1 and 3 seconds until the ridge height was well above threshold. The disc then reversed direction. The response button was released after the ridge was no longer detectable. The disc continued turning at a different

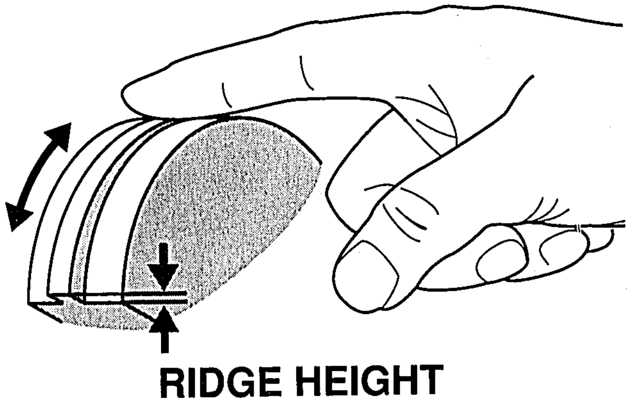


Fig. 1. The ridge, which ran along the periphery of a Teflon disc, sloped upward and downward as the disc rotated against the finger pad.

speed without changing direction past the zero ridge zone and the ridge began to rise again. A similar sequence occurred on the other side of the disc.

Figure 2 illustrates the stimulus presentation sequence. A full cycle included four rising/falling ridge and clockwise/counterclockwise (cw/ccw) threshold determination points. Rising and falling ridge gradients were presented for both cw and ccw directions (see Fig. 2). The disc rotation speed controlled the rate of increasing or decreasing ridge height, and the disc rotation direction controlled the direction of shearing against the skin.

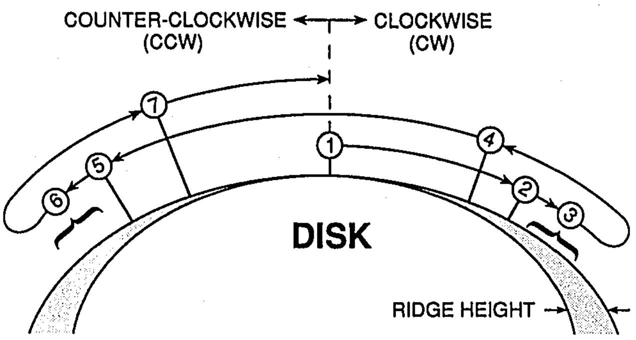
Experimental Design

The experiment consisted of a hierarchical repeated measures factorial design with hand (H) as a random effects variable nested within population (P). All hands were treated as individual members in either the normal or CTS sample. Four ridge rising/falling rates (0.032 mm/s, 0.041 mm/s, 0.048 mm/s, and 0.054 mm/s), two directions (cw and ccw), and two gradients (rising ridge and falling ridge) were included in the experiment. Every hand was treated for all levels of rate (R), direction (D), and gradient (G). The experiment contained a total of 16 conditions presented to all hands in both populations resulting in a P(H) × R × D × G (2 × 4 × 2 × 2) experimental design.

The presentation of rotation speed, initial direction of rotation, and hand tested was counterbalanced as a Latin square between subjects. The 16 experimental conditions were presented as two sets of eight with a 3-minute rest provided between each set of experimental conditions. One set lasted 5 minutes. An initial practice set also was included, and the results of that set were discarded. A single set of trials consisted of three full cycles, but the first cycle was discarded as a practice set.

Hands were categorized into two populations consisting of 30 normal hands and 16 hands of persons diagnosed as having CTS. Fifteen normal subjects, recruited by posting announcements on university bulletin boards, participated in this study. Their ages ranged between 25 and 67 years. Normal subjects were administered a questionnaire to determine whether they were free of hand complaints and did not have any history of hand trauma, toxin exposure, or systemic disease. All subjects except one described themselves as right handed.

Patients with a diagnosis of CTS were recruited from the Froedert Memorial Hand Clinic in Milwaukee, Wisconsin. None had a polyneuropathy or evidence of Raynaud's phenomenon. All had sensory complaints consisting of tingling or numbness in the thumb, index, or middle finger and nocturnal exacerbation of the paresthesias. Furthermore all candidate patient subjects were evaluated for the presence of a focal Tinel's sign over the distal median nerve, a Phelan's sign, stressed Phelan's sign, or reverse Phelan's sign at the time of the experiment following the ridge detection task. Six CTS patients had Semmes-Weinstein monofilament threshold levels determined. Patients chosen for the study had some positive confirmatory findings, either a positive Tinel's, a positive Phelan's, or an elevated monofilament threshold. The 12 CTS patients included five men and seven women. Ages of the CTS sample ranged between 29 years and 60 years. Eleven CTS patients described themselves as right-handed and one as left-handed. Two CTS patients (subjects 16 and 24) were diagnosed as unilateral CTS, however these patients' normal hands were not pooled with the normal reference group.



① START AT ZERO RIDGE HEIGHT.

② SUBJECT PRESSES RESPONSE BUTTON FOR CW RISING THRESHOLD.

③ ROTATE CONTINUOUSLY FOR A 1-3 s RANDOM PERIOD BEFORE SPEED AND DIRECTION CHANGES.

④ SUBJECT RELEASES RESPONSE BUTTON FOR CCW FALLING THRESHOLD AND SPEED CHANGES.

⑤ SUBJECT PRESSES RESPONSE BUTTON FOR CCW RISING THRESHOLD.

⑥ SAME AS ③.

⑦ SUBJECT RELEASES RESPONSE BUTTON FOR CW FALLING THRESHOLD. SPEED CHANGES.

Fig. 2. Sequence for ridge direction/gradient presentation.

Results

Rising ridge and falling ridge thresholds were recorded separately, and the overall ridge detection threshold was computed as the average of all rising ridge and falling ridge threshold responses. Summary statistics of the resulting thresholds are presented in Table 1. Thresholds were analyzed statistically using nested repeated measures analysis of variance for unequal cell sizes and included age as a covariate. Table 2 includes the analysis of variance results, indicating statistically significant effects for population, gradient, and the interactions between population × gradient and rate × gradient. No significant effects were observed for the main effects of direction and speed, or for any other interactions.

TABLE 1
Summary of Mean Rising Ridge, Falling Ridge, and Average Ridge Thresholds ± Standard Deviation

Subject	Hand	Age, y	Threshold (mm)		
			Falling Ridge	Rising Ridge	Average Ridge
			Normal Subjects		
1	1	25	0.017 ± 0.014	0.067 ± 0.037	0.042 ± 0.037
1	2		0.046 ± 0.044	0.089 ± 0.040	0.067 ± 0.046
2	3	27	0.088 ± 0.072	0.128 ± 0.034	0.108 ± 0.058
2	4		0.056 ± 0.046	0.135 ± 0.050	0.096 ± 0.061
3	5	25	0.002 ± 0.006	0.125 ± 0.064	0.064 ± 0.077
3	6		0.040 ± 0.034	0.163 ± 0.092	0.102 ± 0.093
4	7	28	0.055 ± 0.044	0.098 ± 0.047	0.076 ± 0.049
4	8		0.031 ± 0.039	0.094 ± 0.037	0.062 ± 0.049
5	9	23	0.041 ± 0.050	0.183 ± 0.074	0.112 ± 0.095
5	10		0.047 ± 0.061	0.131 ± 0.064	0.089 ± 0.074
6	11	31	0.014 ± 0.021	0.111 ± 0.032	0.062 ± 0.056
6	12		0.045 ± 0.039	0.090 ± 0.027	0.068 ± 0.040
7	13	24	0.113 ± 0.053	0.159 ± 0.057	0.136 ± 0.058
7	14		0.125 ± 0.077	0.141 ± 0.031	0.133 ± 0.058
8	15	26	0.066 ± 0.029	0.085 ± 0.022	0.075 ± 0.026
8	16		0.035 ± 0.025	0.090 ± 0.055	0.062 ± 0.050
9	17	24	0.039 ± 0.046	0.152 ± 0.051	0.096 ± 0.075
9	18		0.048 ± 0.061	0.154 ± 0.034	0.101 ± 0.073
10	19	23	0.000 ± 0.000	0.084 ± 0.064	0.042 ± 0.062
10	20		0.000 ± 0.000	0.085 ± 0.022	0.043 ± 0.047
11	21	42	0.116 ± 0.136	0.198 ± 0.117	0.157 ± 0.130
11	22		0.065 ± 0.057	0.154 ± 0.065	0.109 ± 0.075
12	23	46	0.044 ± 0.039	0.077 ± 0.040	0.061 ± 0.041
12	24		0.105 ± 0.075	0.156 ± 0.070	0.131 ± 0.075
13	25	42	0.030 ± 0.029	0.090 ± 0.031	0.060 ± 0.042
13	26		0.043 ± 0.054	0.119 ± 0.065	0.081 ± 0.070
14	27	64	0.052 ± 0.055	0.078 ± 0.040	0.065 ± 0.048
14	28		0.040 ± 0.065	0.070 ± 0.062	0.055 ± 0.063
15	29	67	0.038 ± 0.050	0.118 ± 0.058	0.078 ± 0.067
15	30		0.024 ± 0.046	0.150 ± 0.077	0.087 ± 0.090
			Carpal Tunnel Syndrome Subjects		
16	31	60	0.077 ± 0.081	0.214 ± 0.094	0.146 ± 0.111
17	32	60	0.123 ± 0.124	0.352 ± 0.237	0.238 ± 0.218
17	33		0.286 ± 0.190	0.520 ± 0.110	0.403 ± 0.192
18	34	30	0.246 ± 0.169	0.270 ± 0.144	0.258 ± 0.152
18	35		0.125 ± 0.091	0.255 ± 0.071	0.190 ± 0.104
19	36	29	0.050 ± 0.059	0.355 ± 0.123	0.202 ± 0.183
19	37		0.090 ± 0.087	0.391 ± 0.055	0.240 ± 0.171
20	38	44	0.006 ± 0.012	0.095 ± 0.033	0.050 ± 0.052
20	39		0.008 ± 0.023	0.127 ± 0.101	0.067 ± 0.093
21	40	46	0.113 ± 0.062	0.241 ± 0.137	0.177 ± 0.122
21	41		0.164 ± 0.162	0.265 ± 0.218	0.215 ± 0.193
22	42	31	0.031 ± 0.039	0.118 ± 0.038	0.074 ± 0.059
22	43		0.027 ± 0.042	0.125 ± 0.042	0.076 ± 0.065
23	44	39	0.255 ± 0.162	0.272 ± 0.124	0.264 ± 0.140
23	45		0.334 ± 0.310	0.422 ± 0.292	0.378 ± 0.294
24	46	29	0.153 ± 0.062	0.297 ± 0.190	0.225 ± 0.155

Overall average ridge detection threshold was 0.08 mm (SD = 0.07 mm) for the normal subject sample and increased to 0.20 mm (SD = 0.18 mm) for the CTS subjects. The average falling ridge threshold among all hands studied was 0.08 mm (SD = 0.11 mm), and the average rising ridge threshold for all hands was 0.17 mm (SD = 0.14 mm).

The interaction effect between population × gradient is plotted in Figure 3. Normal subject average rising ridge thresholds were 0.07 mm greater than were average falling ridge thresholds, and average rising ridge thresholds for the CTS group were 0.14 mm greater than were average falling ridge thresholds.

The interaction effect between rate × gradient is plotted in Figure 4. Average rising ridge thresholds values increased for increasing rotation speed, and falling threshold values decreased as rotation speed increased. Average rising ridge thresholds increased from 0.15 mm (SD = 0.13 mm) at the 0.032 mm/s rising ridge rate to 0.18 mm (SD = 0.12 mm) at the 0.054 mm/s rising ridge rate. Alternatively, average falling ridge thresholds decreased from 0.09 mm (SD = 0.12 mm) at the 0.032 mm/s falling ridge rate to 0.06 mm (SD = 0.10 mm) at the 0.054 mm/s falling ridge rate.

Average ridge detection thresholds are plotted against age in Figure 5. Linear multiple regression

TABLE 2
Analysis of Variance Results

Effect	Sum of Squares	*df*	Mean Square	*F*	*P*
Covariate					
Age	0.015	1	0.015	0.21	.6454
Between Factors					
Population	2.082	1	2.082	30.49	.0000*
P(Hand)	2.936	43	0.068		
Within Factors					
Rate	0.009	3	0.003	0.65	.5816
R × P	0.011	3	0.004	0.87	.4601
R × P(H)	0.585	132	0.004		
Direction	0.008	1	0.008	2.96	.0922
D × P	0.002	1	0.002	0.55	.4604
D × P(H)	0.124	44	0.003		
Gradient	1.837	1	1.837	139.71	.0000*
G × P	0.200	1	0.200	15.25	.0003†
G × P(H)	0.578	44	0.013		
R × D	0.070	3	0.023	1.99	.1189
R × D × P	0.068	3	0.023	1.93	.1271
R × D × P(H)	1.541	132	0.012		
R × G	0.106	3	0.035	4.74	.0036‡
R × G × P	0.007	3	0.002	0.32	.8118
R × G × P(H)	0.980	132	0.007		
D × G	0.031	1	0.031	1.67	.2033
D × G × P	0.007	1	0.007	.39	.5364
D × G × P(H)	0.835	44	0.019		
R × D × G	0.023	3	0.008	0.97	.4086
R × D × G × P	0.010	3	0.003	0.40	.7548
R × D × G × P(H)	1.063	132	0.008		

* $P < .0001$.
† $P < .001$.
‡ $P < .01$.

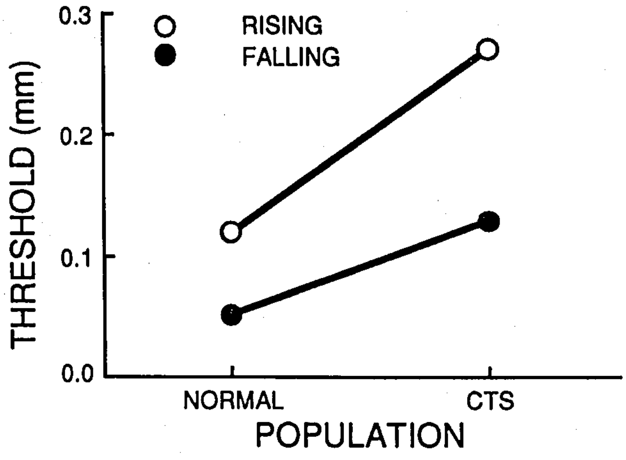


Fig. 3. Plot of interaction between population × gradient.

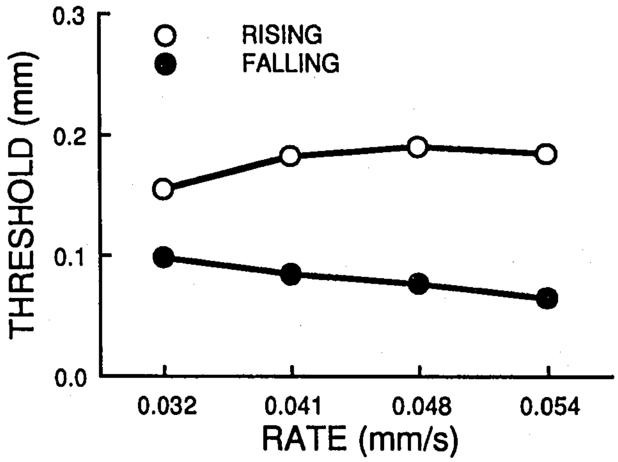


Fig. 4. Plot of interaction between rate × gradient for mean ridge detection thresholds.

using average threshold as the dependent variable and age as an independent variable, including an indicator variable for population, indicated that the effect of age did not significantly contribute to the variance (F(1,42) = 0.014, $P > .05$). Furthermore, the magnitude of the age coefficient was less than the resolution of the instrument. The resulting regression model was threshold (mm) = 0.072 + 0.00 age + 0.11 P (R^2 = .44), where P = 0 for normal subjects and P = 1 for CTS subjects (F(2,43) = 16.57, $P < .001$).

Only seven of 11 CTS hands tested had elevated Semmes-Weinstein monofilament thresholds (>2.83). There was no correlation, however, between rising ridge thresholds and monofilament thresholds (r = .231), falling ridge thresholds and monofilament thresholds (r = .064), and average ridge thresholds and monofilament thresholds (r = .164) among CTS hands.

Discussion

Average ridge detection thresholds for the CTS group was 0.12 mm greater than for the reference group, representing a 150% threshold increase above the normal reference population. The CTS sample thresholds

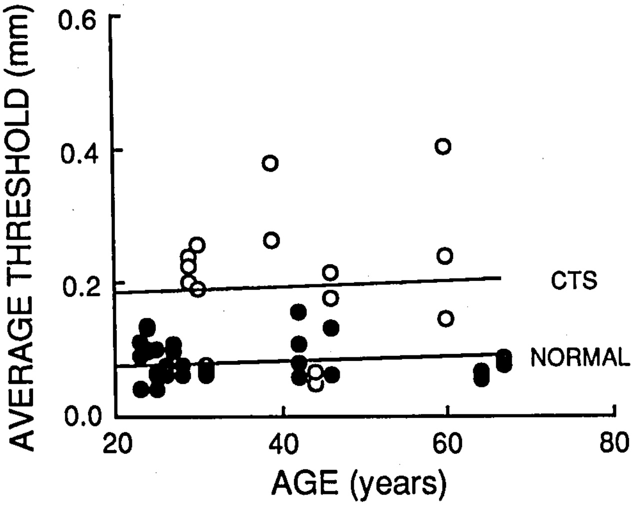


Fig. 5. Mean ridge detection threshold plotted against age. The filled targets represent normal subject thresholds and the empty targets represent CTS subject thresholds.

also had greater variability than did the normal sample thresholds. Although average thresholds were higher for the CTS sample, individual CTS hands had threshold values within the range of the normal sample (see Table 1).

Average thresholds for normal hands ranged from 0.04 mm to 0.16 mm. Among CTS hands, the lowest threshold was 0.05 mm, and the greatest threshold was 0.40 mm. The lowest falling ridge threshold for the normal group was 0.00 mm, and the greatest falling ridge threshold was 0.13 mm. The lowest falling ridge threshold among CTS hands was 0.01 mm, and the greatest falling ridge threshold was 0.33 mm. Ten CTS hands had falling ridge thresholds that overlapped the normal subject group falling threshold range. The lowest rising ridge threshold among the normal group was 0.07 mm, and the greatest rising ridge threshold among the normal group was 0.20 mm. The lowest rising ridge threshold among CTS hands was 0.10 mm, and the greatest rising ridge threshold was 0.52 mm. Only four CTS hands had rising thresholds overlapping the normal rising ridge threshold range.

The results of this investigation indicated that as a population, the CTS ridge detection thresholds were greater than reference group thresholds. Although the mean performance between the two groups were significantly different, there appeared to be overlap between specific subjects in the two groups. This overlap indicates that some members of the reference group may have poorer performance in the ridge-detection task than do some CTS subjects. Threshold differences between individual subjects in the reference group may represent the limits of normality. Similarly, individual differences between CTS subjects may have been due to differences in the level of severity of the disorder.

Rising ridge thresholds were consistently greater than falling ridge thresholds. This was likely due to reaction time delays using the method of limits paradigm, which tends to result in greater response values for increasing stimulus magnitude and lower response values for decreasing stimuli than for the actual threshold value. When using this paradigm, the actual threshold is obtained using the mean value of upper and lower threshold responses. These differences may be minimized by reducing the rate of change of the stimulus. The disc rotation speeds used were selected as the lowest practical values for controlling ridge rising and falling rates without greatly affecting the threshold values. A further reduction in speed, however, would have increased the time for administering the experiment. Four disc rotation speeds were used to discourage subjects from adopting a strategy of timing their responses. The counterbalanced presentation sequence for the ridge rising/falling rate was too complicated for subjects to predict.

Falling ridge thresholds are further lowered by residual sensation. This was also observed in previous investigations using this stimulus for threshold testing.[21,23] The reason for having a no-ridge zone was to minimize residual sensation before measuring the rising ridge threshold when the falling ridge threshold was low.

Average thresholds for normal subjects tested in this study were similar to values reported by Corlett et al[21] for young adults using a manually operated ridge aesthesiometer. They found the mean rising threshold for the right index finger of normal students was 0.13 mm (SD = 0.05 mm) and 0.11 mm (SD = 0.05 mm) using the left index finger. Corlett and his colleagues found the falling ridge threshold were below the measurement resolution of their apparatus, resulting in zero in many cases.

The age range for the CTS patients in this study was 29 years to 60 years. The age for the normal subjects overlapped the CTS patients ranging from 25 years to 67 years. Because age may be an essential factor when dealing with sensory function, it was necessary to ensure that the threshold differences observed between the two samples was not confounded with age. No significant age effects, however, were observed in this study. Haines et al[26] did not observe any age effects when testing depth sense thresholds for 91 workers having a mean age of 41 years.

Absence of correlation between the Semmes-Weinstein monofilament and ridge detection task may have occurred because the two tasks require different sensory modalities. The monofilament threshold task is a pressure stimulus, the ridge detection threshold task involves detecting an edge stimulus. Furthermore the monofilament test may lack control of stimulus presentation and is highly prone to individual examiner error. Automated testing, such as the one used in this study, may overcome these difficulties.

Marsh[23] studied CTS patients using the Corlett aesthesiometer before and after surgical intervention. Marsh reported reductions in rising ridge thresholds were observed after surgery for patients having CTS, however no comparisons were made between the magnitude of the threshold measured against a normal reference group. The results of our investigation agree with the findings reported by Marsh for increased ridge detection thresholds for CTS patients. Furthermore we provide statistical evidence that ridge detection thresholds for CTS subjects, on the average, are significantly greater than ridge detection thresholds for a normal reference group.

The results of this investigation suggest that on the average, workers suffering from CTS may not detect a surface in a tactile inspection task unless it is more than twice as high as detected by workers without CTS. Although the ridge detection task was similar to activities often performed in tactile inspection tasks, ie, detecting surface defects or ridges during industrial operations such as surface finishing, further studies are necessary to correlate the ridge detection threshold with performance in actual industrial tasks. Because the ridge detection task involves a stimulus similar to the stimulus for these types of industrial tasks, it is reasonable to assume the sensory modalities involved are the same. This tool needs to be validated if it is to be used as a functional assessment for disability. That is the subject of future investigations.

Acknowledgments

The authors thank the staff at Froedert Memorial Hospital Hand Rehabilitation Clinic for use of the clinic for this study. This project was supported in part by grants from the Veterans' Administration and by the Wisconsin Alumni Research Foundation.

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