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Development of a carpal tunnel syndrome screening method using structured interviews and vibrotactile testing

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Abstract. Carpal tunnel syndrome (CTS) is a debilitating and expensive health problem. An inexpensive screening method that would differentiate between people who do not have CTS and those that may have CTS would be useful. The screening methodology investigated here had two phases: a structured interview and provocative vibrotactile testing (VT). The control group ($n = 36$) was composed of asymptomatic college students and faculty, the case group was composed of patients currently visiting an occupational medicine clinic for symptoms consistent with CTS. The case group was subdivided into positive and negative for nerve conduction latency, NCL+ ($n = 21$) and NCL− ($n = 13$), respectively. Using a scored, structured interview, 33 of the controls and none of the symptomatic cases were identified as non-CTS. The results from the provocative flexion VT indicated that if the difference between the age corrected baseline and the threshold at 15 minutes is 15 μm or more, the subject was likely to be NCL+ (odds ratio 12.6, 95% CI 3.8 to 41.8). Further research may improve this screening methodology to not only determine whether or not a person has CTS, but also to determine the level of median nerve impingement or damage.

Keywords: Carpal tunnel syndrome, vibrotactile testing, CTS screening, nerve conduction latency

1. Introduction

Carpal tunnel syndrome (CTS) is a problem in the workplace. In 2002, 22,651 cases of work related carpal tunnel syndrome were reported by private industry [10]. Of these, 8,962 cases were reported in manufacturing facilities, 4,560 cases were reported by the service industry, 3,007 cases were reported by retail sales employees, and 6,032 of the cases were reported by businesses engaged in other trades [11]. According to the National Safety Council the average cost for these cases was $17,202 [9]. However, this average cost only includes the medical and indemnity costs associated with each case; it does not include indirect costs, which are often estimated as 2–3 times the direct costs. Only amputation and fractures had longer lost-time costs [9]. In addition to the economic costs (both to the employer and society) associated with CTS, there is often a dramatic decrease in the quality of life for those who suffer from this syndrome.

It is suggested that the development of a screening tool that will inexpensively identify those who have CTS and/or are developing CTS will aid in the treatment of these individuals. By decreasing the cost of evaluations, more employees may be evaluated and proper, timely intervention provided. Ultimately, such a screening tool may reduce the cost of treating CTS by early identification of CTS symptoms accompanied with prompt corrective action.

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1.1. Carpal tunnel syndrome

CTS presents a constellation of symptoms, which include pain, paraesthesia, hand weakness, loss of dexterity, and nocturnal pain, all of which can be debilitating. There also are changes in the tactile threshold in the fingers and a decrease in nerve conduction velocity across the median nerve. These symptoms may be attributed to the compression of the median nerve within the carpal tunnel. If the symptoms are not recognized and treated, permanent damage and disability may result. It is believed that if CTS symptoms can be addressed early in the disease progression, permanent damage may be minimized or avoided [19].

CTS often involves inflammation-related swelling of wrist flexor tendons due to repetitive motion or excessive loading during gripping maneuvers [7]. Tunnel pressure increases during mechanical stress [5,6,12, 13,20] and inflammation creates ischemic conditions of low oxygen, metabolic build up, and decreased pH which compromise metabolically active structures such as median nerve fibers. It is believed that the increased pressure (mechanically or biologically induced) and ischemia, damage the large myelinated axons of the median nerve by injuring the membranes, myelin, and Schwann cell networks. This damage suppresses the action potential transmission and may be manifested by a detectable threshold shift in the fingers.

1.2. Screening process

The goal of any screening process is to differentiate between groups that have similar attributes or levels of an attribute. This process may require more than one step, with each step further refining or differentiating the results of the previous screen. There is often a progression of costs for each level of testing. That is, earlier screening tests are usually simpler, require less invasive procedures and consequently are generally less expensive than the later tests. As the screening process continues, screening tools become more sophisticated, require well trained personnel and often require more time. The better the screening process, the fewer misidentified subjects (false positives and false negatives). Each misidentification has its own costs. False positives increase screening costs, because participants are subject to additional, unnecessary evaluation. False negatives misidentify participants with the disease, resulting in delayed treatment and potential disease progression.

Depending upon the costs of misidentification, the first steps may be optimized by having high negative predictive value (NPV) at the cost of a decreased positive predictive value (PPV). While this may identify more subjects requiring additional testing, it will reduce the number of subjects who will be misidentified as not having the attribute in question (false negative).

The goal of this screening process is to determine who should get more sophisticated, time consuming and expensive tests to determine if a person has CTS. A successful tool will ultimately only identify those that are most likely to have CTS and who require more expensive testing to confirm a CTS diagnosis. Given the state of the art in CTS diagnosis, it may be more appropriate to identify individuals who do not have the disease, rather than identify individuals that do have the disease, early in the screening process.

1.3. Study overview

The first step in this process was intended to identify those individuals least likely to have or least likely to be developing CTS (controls). This first step may have a higher negative predictive value (NPV) and specificity with the tradeoff of reduced positive predictive value (PPV) and sensitivity, thus reducing the number of false negatives. The choice of a high NPV at the cost of reducing PPV provides a protective effect for the subjects. This first step was accomplished using a structured interview.

NPV is the percentage of those subjects identified as controls by the test that actually are controls. Specificity is the percentage of actual controls that are identified as controls by the test. PPV is the percentage of those subjects identified as cases by the test that are actually cases. Sensitivity is the percentage of actual cases that are identified as cases by the test.

The second step was to better differentiate between those subjects that may have CTS and those who most likely do not using VT. This test was intended to be more sensitive and have a higher PPV than the structured interview. In this way, the pool of subjects requiring more expensive tests and evaluation such as NCL and physician visits can be reduced.

Simple provocative tests such as Phalan's test and other pressure provocative tests have shown good sensitivity in identifying CTS [17,21]. Provocation was used because provocative postures may increase the pressure within the carpal tunnel, which may lead to increased parasthesia more quickly than in non-provocative postures [1]. Provocative flexion appears to cause a greater

increase in VT threshold for people with CTS than those who do not [2]. For this study, the provocation was wrist flexion and the subject's wrists were positioned in maximum voluntary flexion.

2. Methods and equipment

All procedures were approved by the Univeristy of Utah Institutional Review Board for the use of human subjects. Each participant signed an informed consent form and completed the structured interview, provocative vibrotactile testing and NCL tests, in that order.

2.1. Subjects

Controls were college students and faculty ($n = 36$). Their ages ranged from 18 to 52 years, with an average age of 26.3 $\pm$ 6.9 yrs. These subjects were asymptomatic. Thirty-five of the controls were NCL$-$ and one control tested NCL$+$. The case population was made up of patients (cases) recruited from an occupational medicine clinic. These patients were symptomatic and already being treated for CTS related symptoms. Patients were further divided into NCL$+$ ($n = 21$) or NCL$-$ ($n = 13$) groups. The patient's ages ranged from 19 to 60 years with an average age of 37.0 $\pm$ 11.6 yrs. Twenty-three of the controls were male, 13 were female. Eleven of the cases were male, 23 were female.

This study required: 1) a structured interview, 2) provocative vibrotactile testing, and 3) standard nerve conduction evaluation. The structured interview captured information about health history and current, CTS-related symptoms. The second phase used provocative vibrotactile testing to measure the vibrotactile threshold of the middle fingertip with the wrist in maximum voluntary flexion, and compares the threshold with an age corrected average threshold for neutral postures. Vibrotactile Testing has been used successfully by Jetzer [4] and others to detect vibration sensitivity threshold shifts. The third phase measured the nerve conduction latency (NCL) using a Nervpace 200-VS portable electroneurometer (Neurotron Medical Inc., Pennington, NJ). Experimenters were not blinded to subject status (symptomatic subjects were recruited at an occupational medicine clinic and controls in a university setting), but experimenters only recorded the subject's responses (not their own observations) and VTT and NCL are objective quantitative measures that were recorded last to minimize bias.

Controls were selected to include only asymptomatic subjects in order to determine differences between symptomatic (clinic patients) and asymptomatic subjects.

2.2. Structured interview

The structured interview gathered personal information, medical history, and a description of current symptoms for each subject including: age, weight, height, (to determine the body mass index (BMI)) and pregnancy status. The medical history included questions about wrist or finger fracture, severe cuts or burns, diabetes, ganglion cysts, and previous diagnosis of CTS. Subjects described current symptoms by rating total discomfort. "Total Discomfort" included pain, numbness, parasthesia, tingling, cramping, spasms, stiffness, loss of strength or grip, and diminished sense of touch in the fingers. Discomfort was rated on a scale of 0–10, with 0 representing no discomfort and 10 representing "worst imaginable" discomfort. This information was gathered in a structured interview format to ensure that the discomfort was localized to the median nerve distribution. The original questionnaire had over 60 questions.

2.3. Vibrotactile testing with provocation

VT was chosen because it is easy to administer, relatively inexpensive, can be conducted on site and has been shown to be repeatable [14]. Baseline vibrotactile thresholds (VTTs) were collected for the middle and little fingertips, and the base of the thumb with the wrist in a neutral position. Before data collection began, a short training session was conducted to ensure that subjects understood and were comfortable with the data collection procedure.

A computer controlled vibrometry system was used to determine the VTT. The VTT data were collected using a stair case procedure (similar to a hearing test). After the base line data were collected, the subject's wrist was placed in maximum voluntary flexion (MVF) for 15 minutes (Fig. 1). Every 2.5 minutes the VTT data were recorded for a total of six trials in MVF. The subject was given a one-minute rest period after the final provocative VTT, and then the middle and little fingers and base of the thumb were retested with the wrist in neutral position, for a total of 12 VTT tests. After each test, subjects were asked to rate their wrist pain and discomfort from 0–10. For a more complete description of the equipment and procedures used, see [15].

The intent of the provocative posture is to better differentiate between those persons with CTS and those persons that do not have CTS. This may also provide some insight in the progression of CTS and CTS symptoms. The mechanism for the threshold shift, while not

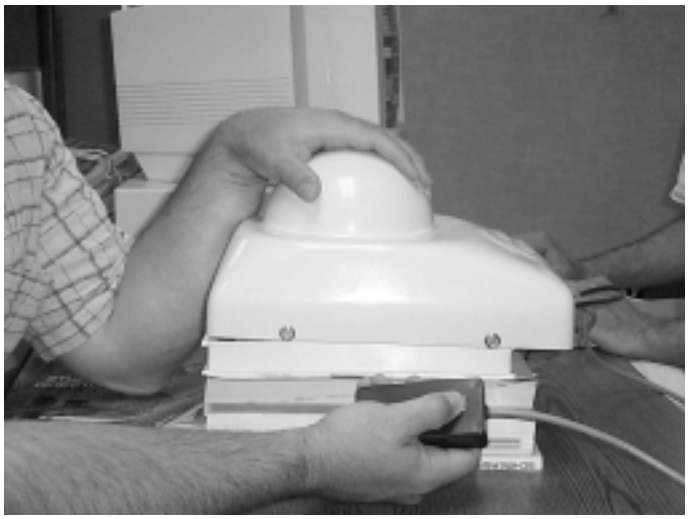

Fig. 1. Illustration of provocative wrist flexion.

well understood, is thought to be increased mechanical pressure within the carpal tunnel and thus increased pressure on the median nerve and possibly a decrease in the circulation through the carpal tunnel [18]. If a subject already has an elevated pressure on the median nerve, the additional provocation may increase this pressure and consequently symptoms, as measured by a threshold shift, will become evident.

The VTT measurement for each subject was compared to the age corrected VTT. The difference between the subject's VTT and the expected VTT for that age was calculated. The direction and magnitude of the difference were used to determine if the subject should be tested further using nerve conduction evaluation.

2.4. Nerve conduction latency

Nerve Conduction Latency (NCL) is currently the "gold standard," but is not a definitive test, for CTS. However, no electro diagnostic test, such as NCL, can correctly identify every CTS case and the clinical judgment of an experienced clinical neurologist remains the best final determinant of this syndrome [17]. While NCL may be a good diagnostic tool, it is not considered a good screening tool because of its expense and relatively poor positive predictive value for screening asymptomatic subjects. Therefore, the results of the NCL were used only to differentiate between NCL+ and NCL− groups not to determine CTS status.

Each subject had his/her NCL tested with the Nervepace 200-VS portable electroneurometer. If the NCL was greater than 310 μs, subjects were then categorized as NCL+ otherwise they were categorized as NCL−. This test is typically preformed at a clinic specializing in hand disorders using specialized equipment and trained personnel. The NCL in our study was conducted by a doctoral student trained in NCL techniques.

3. Developing final structured interview and VT protocol

The data were entered into Excel spread sheet and statistical analyses were performed using both Excel and JMP 5.1. Questions were revisited to reduce redundancy and minimize the number of questions that may be considered sensitive by the subjects, such as, pregnancy status, birth control pill usage, etc. Questions were also reviewed to determine if the questions are well supported in the literature, but did not appear statistically significant in our study. For example, there were only 6 smokers in our study and this might not provide enough power in our study to determine if this is a risk factor. However, because current literature suggests that smoking is a risk factor for CTS [8,16] this question was included in our final questionnaire.

The final questionnaire consists of 14 yes/no risk factors, height and weight (to determine BMI) and 2 subjective ratings of discomfort (0–10). The 14 yes/no questions were:

1. Gender
2. Current Smoker

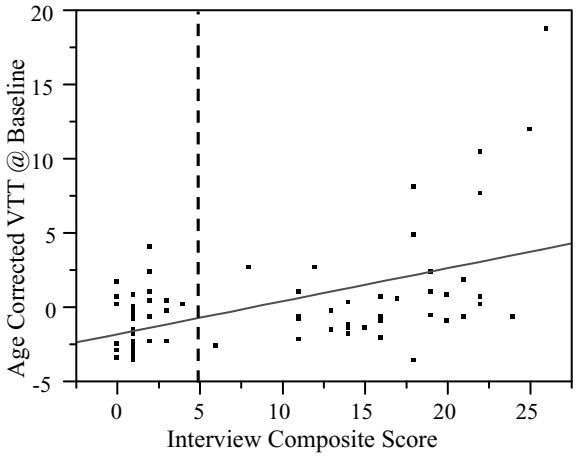

Fig. 2. Age corrected VTT at baseline versus interview composite score. The dashed vertical line represents the interview composite cut off score of 5 discussed later. The solid line represents the regression relationship between the interview composite score and the baseline VTT. The correlation coefficient is 0.50, alpha <0.0001.

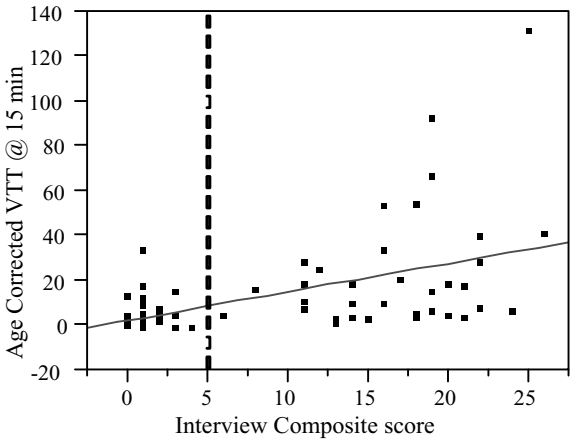

Fig. 3. Age corrected VTT at 15 minutes versus interview composite score. The dashed vertical line represents the interview composite cut off score of 5 discussed later. The solid line represents the regression relationship between the interview composite score and the 15 minute VTT. The correlation coefficient is 0.49, alpha <0.0001.

3. Have you ever dropped things with this hand because of a lack of sense of touch in your fingers?
4. Have you ever had any surgery on this hand or wrist?
5. Have you ever been diagnosed with tendonitis in the wrist or fingers of this hand?
6. Any acute or chronic trauma to the hand or wrist?
7. During the **past year** have you had any pain or discomfort in your elbow?
8. During the **past year** have you had any pain or discomfort in your forearm?
9. During the **past year** have you had any pain or discomfort in your wrist?
10. During the **past year** have you had any pain or discomfort in your hand or fingers?
11. **Right now**, do you have any pain or discomfort in your elbow?
12. **Right now**, do you have any pain or discomfort in your forearm?
13. **Right now**, do you have any pain or discomfort in your wrist?
14. **Right now**, do you have any pain or discomfort in your hand or fingers?
    Height and weight were recorded and used to determine if body mass index (BMI) was greater than 25.
15. a. Height
    b. Weight
    The two rated questions were phrased as follows:
16. How would you rate the level of pain and discomfort symptoms right now in your hand? Pain and discomfort include: pain; numbness; tingling; cramping; spasms; or stiffness; loss of strength or grip; and diminished sense of touch in the fingers.
    Left: (None) 0—1—2—3—4—5—6—7—8—9—10 (Worst Imaginable)
    Right: (None) 0—1—2—3—4—5—6—7—8—9—10 (Worst Imaginable)
17. Do you *currently* have problems with hand, wrist, or finger discomfort *when going to sleep* and/or *during sleep*: ____ Yes ____ No. If so, please rate the symptoms in each hand. Pain and discomfort include: pain; numbness; tingling; cramping; spasms; or stiffness; loss of strength or grip; and diminished sense of touch in the fingers.
    Left: (None) 0—1—2—3—4—5—6—7—8—9—10 (Worst Imaginable)
    Right: (None) 0—1—2—3—4—5—6—7—8—9—10 (Worst Imaginable)

The interview was scored. Those questions that asked about the presence or absence of a risk factor were scored as 1 point if the risk factor was present; otherwise it was assigned a zero score. The rated discomfort was scored as the number reported (0 to 10). A composite score was generated using the sum of all of these scores. The range of possible scores is 0 to 35 with higher scores indicating a greater level of symptoms and risk factors.

Because the VTT of the middle fingertip was most sensitive [3] and predictive, only the middle finger data

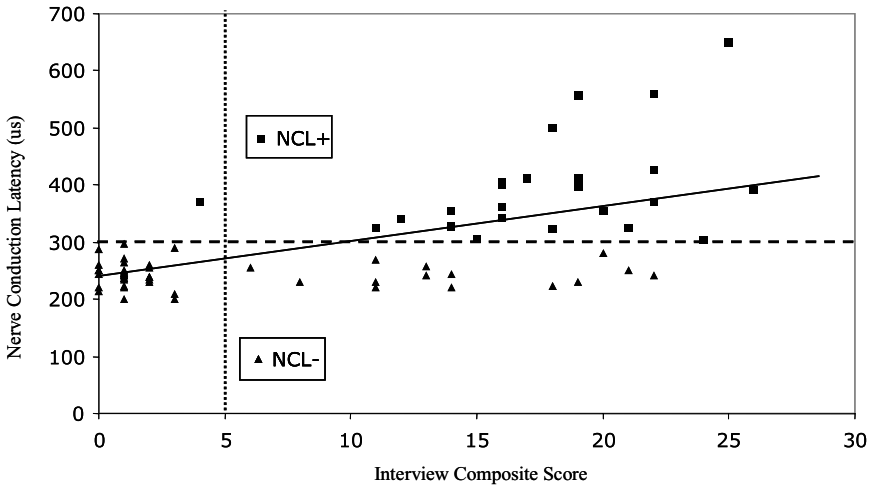

Fig. 4. NCL in microseconds versus interview composite score. The dashed vertical line represents the interview composite cut off score of 5 discussed later. The dashed horizontal line represents the NCL cut off point of 310 microseconds. The solid line represents the regression relationship between the interview composite score and NCL. The correlation coefficient is 0.63, alpha <0.0001.

were used. It is proposed that only data for the middle finger need to be collected for this screening methodology.

4. Results

The scores for the structured interview ranged from 0 to 26. For the overall population the average score was 9.5 ± 8.6. The average score for the control group was 2.1 ± 3.1, with a range from 0 to 14. The average score for the case group was 17.4 ± 4.5, with a range from 8 to 26.

The age corrected baseline VTT ranged from -3.6 to 18.8 μm, the overall average was 0.3 ± 3.8 μm. The age corrected VTT at 15 minutes ranged from -1.3 to 131.2 μm. The mean VTT at 15 minutes was 13.9 ± 22.3 μm. Results for both baseline and 15 minutes are presented in Table 1. Data are presented for controls and cases with cases further divided into NCL$-$ and NCL$+$ groups.

Using a Student t-comparison, baseline means for cases and controls were significantly different ($p = 0.0011$). The means at 15 minutes for the cases and controls were also significantly different ($p = 0.0003$). NCL$-$ and NCL$+$ cases were significantly different ($p = 0.0001$) at 15 minutes.

The correlations between the various screening components were calculated. The correlations between the composite interview score and the baseline age corrected VTT was 0.50 (95% CI 0.30–0.66) (Fig. 2). The correlation between composite interview score and the VTT at 15 minutes was 0.49 (95% CI 0.29–0.65) (Fig. 3). The correlation between the composite score and the NCL was 0.63 (95% CI 0.46–0.75) (Fig. 4). The correlation between the VTT at 15 minutes and NCL was 0.69 (95% CI 0.54–0.80) (Fig. 5).

5. Proposed screening methodology

The proposed screening methodology seeks to take advantage of differences between the symptomatic and asymptomatic groups at each stage of the sequential screening.

Using a structured interview cut off score of five, 33 of the controls ($n = 36$) and none of the cases ($n = 34$) were below the composite questionnaire score, resulting in a specificity of $33/36 = 0.92$ (95% CI 0.85–0.92) and an NPV of $33/33 = 1.00$ (95% CI 0.93–1.00). The population that would be identified by the composite questionnaire score to be further tested would include all of the cases (100% sensitivity) and 3 false positives. This has a sensitivity of $34/34 = 1.0$ (95% CI 0.93–1.00), and a PPV of $34/37 = 0.92$ (95% CI 0.85–0.92) (see Table 1). If a subject scores lower than 5 on the structured interview, continued workplace surveillance and the encouragement of early reporting of symptoms is recommended. If the subject scores a 5 or higher on the structured interview further testing, including VTT to differentiate the level of symptoms, is suggested. A cut off score of 5 was selected to allow the presence of some risk factors that may be related to other conditions (non-CTS) or simply idiopathic in nature. CTS

Table 1
Vibrotactile Threshold Results at $T = 0$ (Baseline) and $T = 15$ Minutes

	Baseline		15 Minutes	
	Mean (μm)	Range (μm)	Mean (μm)	Range (μm)
Overall	0.3 ± 3.8	-3.6 to 18.8	13.9 ± 22.3	-1.3 to 131.2
Controls	-1.1 ± 1.8	-3.6 to 4.0	4.7 ± 6.9	-1.3 to 33.4
All Cases	1.7 ± 4.7	-3.6 to 18.8	23.9 ± 28.5	0.6 to 131.2
NCL$-$ Cases	-0.4 ± 1.7	-3.6 to 2.6	9.1 ± 7.8	0.6 to 27.8
NCL$+$ Cases	3.0 ± 5.4	-2.2 to 18.8	33.6 ± 32.8	3.1 to 131.2

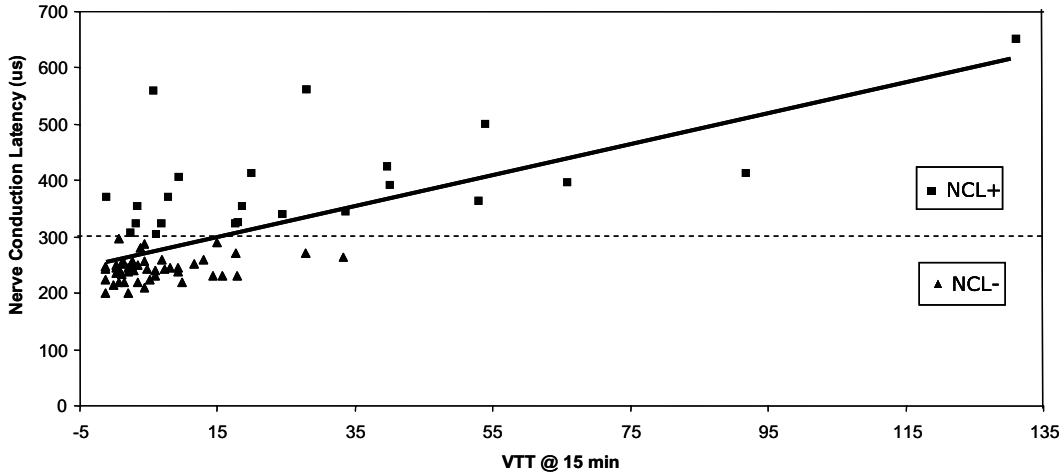

Fig. 5. NCL in microseconds versus the age corrected VTT score at 15 minutes. The dashed horizontal line represents the NCL cut off point of 310 microseconds. The solid line represents the regression relationship between the 15 minute VTT and NCL. The correlation coefficient is 0.69, alpha <0.0001.

is multi-factorial and no single risk factor or symptom alone is indicative of the disorder. A cut off value of 5 allows some variation away from "normal," asymptomatic conditions. For example, if the presence of any risk factor alone (a structured interview score of 1 or more) was used, the structured interview would generate significantly more false positives and thereby increase the costs of screening by moving more subjects into the second phase of testing.

The maximum difference between the age corrected baseline and the threshold measured during the entire 15 minute provocative flexion trial was calculated. If this difference was 15 μm or more, then the subject was more likely to be NCL$+$ than NCL$-$. The associated odds ratio was 12.6, 95% CI 3.8 to 41.8 (Table 2).

The screening process is illustrated in Fig. 6.

6. Discussion

While VTT has been shown to differentiate symptomatic from asymptomatic subjects, and NCL$+$ from NCL$-$, it does not appear to be helpful (beyond the initial interview) in this study in differentiating the false positive from the cases. This may be because the effectiveness of the structured interview allowed only 3 false positives to move to the next stage. This differentiation may be a reflection of the relatively dichotomous control and case populations. That is, our study did not include asymptomatic workers with a long industrial work history, who might be incorrectly classified by the structured interview.

When the difference between the age corrected baseline and the threshold measured during the entire 15-minute provocative flexion trial was 15 μm or more then the subject was more likely to be NCL+ than NCL$-$. This may indicate a more progressed level of CTS development in cases with NCL$+$ than those with NCL$-$ and suggests that VTT may be useful to differentiate individuals with varying levels of symptoms associated with CTS. As the ability to differentiate the disease progression improves, the information gained may not only aid in the care of the subject but also help prioritize allocation of resources to improve jobs. Such improvement may be based upon the risk assessment models suggested by You [22].

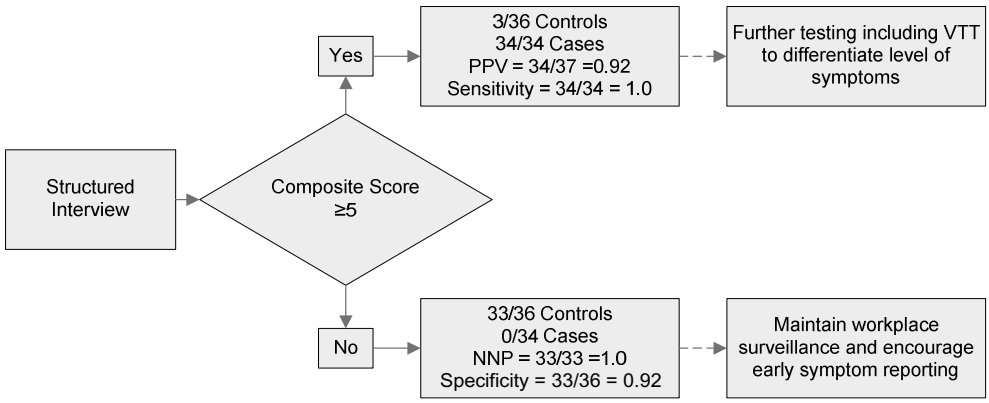

Fig. 6. Flowchart illustrating structured interview and results using a cutoff point of 5.

Table 2
2 by 2 matrix of subject status and structured interview score below 5 and greater than and equal to 5

	Subject Status	
	Symptomatic	Asymptomatic
SI >= 5	34	3
SI <5	0	33

Table 3
2 by 2 matrix of subject NCL status and structured interview score below 15 and greater than and equal to 15

	Subject NCL Status	
	NCL +	NCL −
SI >=15	21	14
SI <15	1	34

This screening methodology appears to successfully differentiate between participants that do not have CTS and those that may. This methodology is relatively easy and inexpensive to perform. If it is possible to better describe the progression of symptoms to advanced or "full blown" CTS, this methodology may be used to alert health care providers, so that patients can be treated for the symptoms of CTS before the syndrome advances to more severe and expensive level. If this methodology is applied in a facility, safety and health personnel and management may be proactively alerted to departments and job types that may be causing CTS symptoms if risk factor indicators tend to cluster in employees within these areas. This information can be used to prioritize ergonomic improvement within the facility. While the work environment may not be the only contributing factor, it is one over which the employer typically has the greatest control. Other risk factors such as the personal characteristics of the workers themselves (e.g., BMI, smoking, etc.) can be influenced (such as with smoking cessation incentive programs), but not changed directly.

7. Recommendations

The structured interview cutoff points used for this study were chosen because they resulted in high negative predictive value (100% in this study). This provides a protective effect for workers. This means that not all of the subjects that do not have CTS are removed from the next screening step (false positives), but it ensures that relatively few (zero in this study) of the subjects that actually have CTS are falsely defined as negative. While these results indicate that a screening methodology comprising of a questionnaire and VTT may differentiate between those that do not have CTS and those that do, further research may increase the usefulness of this methodology by increasing the sensitivity of the structured interview and VT. Also, a much larger sample including a more diverse control group that better matched the symptomatic group in terms of age, gender, and work exposures is recommended.

The current calculation of the interview/questionnaire score may be too simplistic. It is possible that certain risk factors are more predictive of CTS than others. If this is true, each factor should be weighted accordingly. Also, it is possible that these risk factors may interact and that the scoring should reflect these interactions.

When the test population of the controls increases to include asymptomatic workers with greater age and work experience range, it may become possible to identify those workers who are developing CTS and implement corrective action before the CTS is fully developed and more expensive to treat. That is, if the work histories and injury status of the cases and controls become more continuous, it may become possible to de-

termine different stages of CTS and help ergonomists to determine those physical factors most likely to result in CTS.

As the fundamental understanding of risk factors for CTS and their interactions improves, the results from the questionnaire and the VT may become more sensitive and ultimately we may be able to create a model that differentiates between different levels of nerve impingement and damage that leads to CTS.

8. Conclusion

By using this screening method to differentiate between those subjects who do not have CTS and those that may have CTS, the costs to diagnose CTS will decrease by reducing the number of subjects needing nerve conduction latency (NCL) testing and evaluation by a physician. This decrease in testing costs can lead to more focused testing and the possibility of early intervention.

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