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Prediction Of The Nerve Conduction Abnormalities Frequently Associated With Carpal Tunnel Syndrome From Clinical Features

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PREDICTION OF THE NERVE CONDUCTION ABNORMALITIES FREQUENTLY ASSOCIATED WITH CARPAL TUNNEL SYNDROME FROM CLINICAL FEATURES

by

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ABSTRACT

This study was undertaken to develop a clinically useful model for predicting electrophysiological abnormality in the nerve conduction tests used in the diagnosis of carpal tunnel syndrome (CTS). The prediction model combined commonly recorded clinical history, signs, and symptoms in a multivariate analysis. Electrophysiological abnormality and adjustments for the influencing variables (sex, distance, and temperature) were based on normative nerve conduction values obtained in a control group (n=104). This was the first study in this topic area in which prediction bands were used to adjust the criteria for assigning abnormality to account for influencing variables. The variables used to represent nerve conduction abnormality were selected based on the literature, clinical usage, and investigation of their inter-relationships.

Two hundred and eighty-five subjects with signs and symptoms of CTS who were referred for nerve conduction testing were evaluated by interview and physical examination by an investigator who was blind to the electrodiagnosis. Electrodiagnosis was performed without knowledge of the clinical information. The univariate relationships of the clinical variables with nerve conduction abnormality were

examined by Chi square analyses to determine the variables to be included in the model.

The model most highly predictive of nerve conduction abnormality included the variables Flick sign, nocturnal discomfort, and family history (P=0.910). Two other specifications of abnormality, based on the numbers of abnormal variables, were used to test the robustness of the prediction model with similar results, but symptom duration was also included in the model. Tests such as Tinel's sign and Phalen's test which are often recommended in diagnosing CTS were less useful in this study in the prediction of abnormality than information obtained from the history. It was noted that prediction based upon the inclusion of a number of variables in a multivariate analysis, was better than prediction based upon any single variable. This study strongly suggests that the probability of nerve conduction abnormality can be predicted from clinical signs and symptoms and thus could be particularly useful to clinicians who lack easy access to nerve conduction testing.

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relationships, plots of the nerve conduction variables against each of the other variables that might affect them were obtained for all control subjects and separately for males and females.

Since sex differences and interactions between sex and another variable necessitated adjustments of the abnormality criteria for the sexes, t-tests were used to confirm sex differences and multiple regression analyses were used to confirm interactions between sex and other variables. Instead of reducing the alpha level for multiple testing, the alpha level for each of the tests was 0.05 as it was deemed more important to identify than ignore variables which affected the nerve conduction variables.

Multiple regression analyses were performed for each of the nerve conduction variables to determine the potential effect of hand temperature, age, height, and the distance between the stimulating and recording electrodes, sex, and interaction with sex. The nerve conduction variables which exhibited sex differences were evaluated separately for males and females. If at least 10% of the variance in the nerve conduction variable was accounted for by an independent variable (i.e., the multiple correlation coefficient, $R^2 \geq 0.10$), adjustments to the criteria for abnormality to account for these independent variables were deemed to be necessary.

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CHAPTER I

INTRODUCTION

1.1 Statement of the Problem

Carpal tunnel syndrome (CTS), the most common entrapment neuropathy (Dawson et al., 1983: page 5; Heffernan, 1983), describes a group of symptoms including pain and paraesthesia in the median nerve distribution in the hand (Phalen, 1970; Phalen, 1981). The typical presentation of CTS has been described as bouts of pain and paraesthesia affecting the thumb and two and one half finger distribution of the median nerve in the hand (Ashbury et al., 1985). The problem usually occurs at night causing the patient to waken (Hadler, 1984: page 143; Heffernan, 1983). Relief is obtained by shaking the hand (Hadler, 1984: page 143; Pryse-Phillips, 1984). Often the symptoms are related to pregnancy, occupation, or avocation (Ashbury et al., 1985). Objective and subjective reduction in sensation may occur (Phalen, 1970) and two-point discrimination is often impaired in the median nerve distribution (Hadler, 1984: page 143). Later, thenar atrophy may be observed as well as weakness when using the thumb in opposition (Hadler, 1984: page 144). Atypical cases of CTS also occur where symptoms exist beyond the distribution of the median nerve in the hand, making it somewhat difficult to diagnose.

Nerve conduction studies are frequently used to confirm the diagnosis (Kemble, 1968; Kimura, 1978). Whether the diagnosis of CTS can be made based entirely on clinical grounds or on the results of nerve conduction studies has been the topic of considerable debate (Nieman et al., 1985); some authors support the need for verification of diagnosis through electrophysiological testing (Editorial, 1985) while others support clinical diagnosis (Louis et al., 1985). Little is known about the relationship between nerve conduction study findings and clinical features, specific signs and tests. Even less is known about how effectively clinical features, signs and tests, can predict the results of electrophysiologic tests. If the diagnosis of CTS can be established principally from clinical features, signs and tests, then the need for expensive electrophysiological investigation may be obviated. The cost of performing nerve conduction studies on two or more nerves is $116.00 (includes the technical and professional fee). Management of the entrapment neuropathy or its attendant disability may also be expedited by earlier diagnosis.

The primary purpose of this investigation was to develop a model for predicting electrophysiological abnormality from a set of clinical variables. By categorizing subjects according to presence or absence of electrophysiological abnormality and performing logistic regression analysis

(Schlesselman, 1982), the associations of the clinical symptoms, signs and tests with electrophysiological abnormality were identified; the effect of each clinical variable was adjusted for the effects of the other variables. The model was developed, based on the logistic regression analysis which specifies the probability of, or prediction of, abnormality depending upon a set of clinical variables. Determination of the features that, individually or in combination, are associated with the electrophysiological diagnosis would provide information which could increase the confidence with which a decision could be made with respect to treatment prior to or in the absence of nerve conduction testing.

Two sub-problems had to be addressed to achieve the primary purpose. The first sub-problem was to establish normative values for the electrodiagnostic tests (principally median nerve conduction studies) based on values obtained for a group of control subjects.[1] The normative electrodiagnostic values were adjusted for the effects of other variables, such as temperature and distance between the stimulating and recording electrodes. Values for the indices of median nerve conduction beyond those of the normal range for control

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[1] Each laboratory typically establishes its own normative values which are specific for their own equipment and testing techniques.

subjects are usually considered indicative of CTS.

The second sub-problem was to establish which nerve conduction tests will appropriately discriminate between those experimental subjects with abnormality and those without abnormality on nerve conduction studies. Although nerve conduction studies or electrodiagnostic techniques have been used since 1956 (Simpson, 1956) to investigate patients thought to have CTS, there are numerous nerve conduction tests and there is minimal consensus about which test or tests are the most helpful in diagnosing CTS. There is no accepted electrodiagnostic standard for diagnosing CTS and, often in practice, a clinical judgement is made about the results of the nerve conduction studies (Redmond and Rivner, 1988).

1.2 Basic Assumptions

The study was designed to investigate which of the clinical features, signs and tests are predictive of the diagnosis of CTS. There is no accepted gold standard for diagnosing CTS. For the present purposes, it was assumed that nerve conduction studies, which are used in clinical practice to confirm the diagnosis, can appropriately categorize the study subjects into those without abnormality and those with abnormality indicative of CTS. In essence, this is the criterion employed in clinical practice.

The combination and number of nerve conduction variables

that should be used to determine CTS is debatable. For the purpose of the present investigation, it was assumed that the degree of confidence in the diagnosis of CTS increases with the number of abnormal nerve conduction tests. The primary specification employed for diagnosing CTS was the most conservative and definitive division of subjects into those with clear evidence of abnormality (abnormal findings on all electrodiagnostic tests) and those without abnormality (no abnormal electrophysiological findings). Clinicians often use fewer or less rigorous criteria to classify subjects as having probable or mild CTS, e.g., abnormality on one electrophysiological test. In the present study, consideration was given also to diagnosing CTS based on fewer or less rigorous criteria.

1.3 Scope of Study

The scope of present study was limited to those patients attending the Neurosciences Laboratory, Victoria Hospital Corporation, London, Ontario and, within that group, to those who volunteered to participate in the study. In these respects, the sample was not random. There was no a priori reason to think that these limitations, that influenced subject selection, would have had any systematic influence on the outcome.

The scope of the present study was limited also to those

nerve conduction tests that were routinely performed and used for diagnostic purposes in the Neurosciences Laboratory, Victoria Hospital. Specifically, these tests included distal sensory and motor latencies, sensory and motor conduction velocities, F responses, and comparisons of these values with ipsilateral ulnar nerve values (See Appendix I, Definition of Terms). Other electrodiagnostic tests that have been reported in the literature to be useful in the diagnosis of CTS, such as palmar stimulation to determine the motor and sensory latencies and conduction velocities in the wrist-to-palm segment (Kimura, 1978); and amplitude of the sensory action potential (Jackson and Clifford, 1989) were not used.

The diagnosis of CTS based on electrophysiological criteria could have been specified several ways. The scope of the present study was limited by defining the presence of electrophysiological abnormality, i.e., the CTS diagnosis, in terms of the number of electrodiagnostic tests showing abnormal results. A viable and alternative strategy to approach the question of predicting CTS from clinical features, would have been to use the extent of abnormality (statistical deviance) on one (or more) electrodiagnostic test(s).

1.4 Significance of the Problem

In the first population-based study of CTS which took

place in Rochester from 1961 to 1980, the incidence of CTS was estimated to be 149/100,000 for women and 52/100,000 for men (Stevens et al., 1988). The rates were highest in the age range 45 to 54 years for women and 75 to 84 years for men. In this study, the diagnosis of CTS was confirmed by nerve conduction studies in about half the subjects, the rest of the subjects were diagnosed based on clinical criteria.

An estimate of the prevalence of CTS in the general population was provided in a study conducted recently in the Netherlands (deKrom et al., 1990). Subjects with CTS were identified in a random sample of 500 subjects drawn from the general population. It was not stated how the random sample was selected. Of the 500 subjects, 69 people (14%) experienced nocturnal discomfort and 50 people were willing to participate in the study. CTS was confirmed by nerve conduction studies in 28 subjects, i.e., 6% of 500 subjects.

Although there are no reliable data on the frequency of work-related CTS in the general working population (Cummings et al., 1989), it has been stated that "many industries claim that the incidence of CTS is increasing and that it is one of the most disabling and costly medical problems" (Bleeker, 1987). It is anticipated that the cost to society could be decreased by early or more definitive clinical diagnosis such as that which would be possible based on the model proposed from the results of the present study.

Not only is CTS a very common problem, but it may also be a very debilitating condition. Sometimes clinicians must diagnose and treat CTS without the benefit of nerve conduction studies due to long waiting lists, geographic location, or other reasons. In some instances, treatment does not commence while the patient awaits an appointment for nerve conduction studies, thus leaving the patient uncomfortable and often costing the patient additional time from work. It would be helpful for clinicians and patients alike to know the probability of detecting abnormality on nerve conduction studies given certain clinical signs and symptoms.

There are various reasons for which patients are referred for nerve conduction studies. Some patients appear not to have CTS but are referred to obtain a differential diagnosis. Another subset of patients have compression of the median nerve but have other pathology as well and they require nerve conduction studies to assist in establishing a diagnosis. Some patients who are likely to undergo surgery for CTS have the tests done to confirm the opinion of the surgeon or to provide a baseline from which to chart the patient's progress following surgery. It is possible that physicians could be more selective in their use of nerve conduction studies, with a higher degree of confidence, if there was a better understanding of the relationship of the signs/symptoms with the results of nerve conduction studies.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

The first sections of the literature review briefly describe the anatomy and contents of the carpal tunnel. The clinical features of CTS are reviewed. In the next sections, the use of nerve conduction studies in the diagnosis of CTS is presented. The published normative values of nerve conduction variables and the effects of several variables which have been identified to affect nerve conduction values are indicated. The extent to which nerve conduction studies are a gold standard for diagnosing CTS is examined. The final sections of literature review contain a review of published studies about the relationships between nerve conduction variables and various clinical features, signs, and tests.

2.2 Anatomy of the Carpal Tunnel

The carpal tunnel is a closed space formed dorsally and laterally by the concave arch of the carpal bones and roofed by the transverse carpal ligament which attaches on the ulnar side to the pisiform and hook of hamate and radially to the scaphoid and trapezium. The carpal tunnel contains nine extrinsic digital flexors (the tendon of flexor pollicis longus, the tendons of flexor digitorum

superficialis and flexor digitorum profundus) as well as the median nerve and artery (Robbins, 1963). The median nerve in the carpal tunnel divides to supply the thenar muscles and sensation to the thumb, index finger, middle finger, and radial half of the ring finger (Dawson, 1983: page 13).

CTS is the result of compression of the median nerve within the carpal tunnel by any traumatic or non-traumatic cause of an increase in the volume of the canal contents, a change in the bony structure, or a thickening of the transverse carpal ligament (Robbins, 1963).

2.3 Clinical Features of CTS

CTS occurs most often in the age range of 40 to 60 years and more frequently in women than in men. The female:male ratio has been reported ranging from 1.5:1 (Phalen, 1966; Ragi, 1981) to 5:1 (Kremer et al., 1953).

The typical presentation of CTS has been described at length in numerous articles and textbooks and is summarized here. It consists of attacks of painful tingling in the hand which are severe enough to waken the patient at night. Nocturnal discomfort has been reported in 91% of a series (Tanzer, 1959) and confirmed more recently in 90% of another series (Ragi, 1981). The discomfort may be paroxysmal, intermittent, or continuous (Sunderland, 1968). Pain and paresthesia are classically limited to the median nerve

distribution in the hand, i.e., the thumb, index, middle, and radial half of the ring finger, although many patients complain of diffuse paresthesia in the hand (Le Quesne, 1978; Phalen, 1966; Phalen, 1972; Sandzen, 1981). An early report indicated that no subjective or objective changes occur proximal to the wrist joint (Phalen, 1966). More recent reports refer to accompanying discomfort in the forearm and sometimes reaching the shoulder (Bleeker and Agnew, 1987). Relief of symptoms is obtained by dangling, rubbing, or shaking the hand (Sandzen, 1981).

Sensory abnormalities are confined to the median nerve distribution in the hand. Hypoesthesia was found in 56% (Tanzer, 1959) to 79% of hands (Phalen, 1966); decreased sensation was noted to affect as small a distribution as the tip of the middle finger (Phalen, 1972). Hyperesthesia was observed in only 5% and 9% of hands (Phalen 1966; 1972 respectively). Reduced two-point discrimination was found in 38% of a series (Gelberman et al., 1980).

Thenar atrophy may occur in well established cases. Atrophy was noted in 36% (Gelberman et al., 1980; Phalen, 1972) to 43% of hands (Tanzer, 1959), while weakness was observed in 44% of cases (Gelberman et al., 1980).

Phalen (1966) noted swelling on the volar aspect of the forearm just proximal to the wrist joint in 21% of subjects. This swelling was more obvious in unilateral involvement.

Although Kremer et al. (1953) found that there was rarely a precipitating factor, other authors noted that more severe symptom development was related to a sudden change to more manual labour (Phalen, 1966; Tanzer, 1959). Various occupational groups at risk and risk factors have been identified: e.g., grocery checkers (Barnhart and Rosenstock, 1987), dental hygienists (Bauer, 1985), vibratory tools (Rothfleisch and Sherman, 1978), pregnancy (Voitk et al., 1983; Ekman-Ordeberg et al., 1987). Symptoms often disappeared when patients were on holiday (Heathfield et al.,1957).

Other physical signs used in the diagnosis of CTS are discussed below in relation to the electrophysiological findings.

2.4 Electrodiagnosis of CTS

Nerve conduction studies[2] are frequently performed to confirm the diagnosis of CTS (Gelmers, 1979; Stewart & Eisen, 1978; Bowles et al., 1983; Harris et al., 1979; Gelberman et al., 1980; van Rossum et al., 1980). Electrophysiological data have been obtained in several studies of CTS and their use in the diagnosis of CTS has been investigated and recommended by numerous authors (Hybbinette & Mannerfelt,

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[2]Definitions of some of the terms used in this section are in Appendix I.

1975; Loong, 1977; Cseuz et al., 1966; Melvin et al., 1968; Buchthal and Rosenfalck, 1971; Kimura, 1979). Distal sensory latency (DSL) and distal motor latency (DML) were the variables initially found to be most indicative of CTS. This was shown by Melvin et al. (1973), who investigated which variable of the evoked motor or sensory potentials - latency, amplitude, or duration - was the most significant in detecting pathological axonal change in CTS. Median nerve conduction studies were performed on the dominant wrists of 24 normal volunteers and 19 patients with suspected CTS. By the use of stepwise discriminant function analysis, DSL was identified as the variable most important in differentiating between the groups of subjects. DML by itself was found to be the second best indicator but, because of its high correlation with DSL, was not selected by the discriminant function analysis. In addition to DSL, sensory velocity, sensory duration (elbow), and sensory amplitude (elbow) were selected by the discriminant function analysis to correctly differentiate the subjects with CTS.

Kemble (1968) also noted that DSL and DML as well as other electrophysiological measurements were abnormal in subjects with CTS compared with control subjects. CTS was defined as a hand presenting with pain and/or paresthesia predominantly affecting the fingers innervated by the median nerve and for which no other identifiable cause was evident.

Comparison of the electrophysiological findings of 66 female patients with CTS with 63 females with the same mean age showed that DSL and DML were the variables most affected in CTS as well as the sensory nerve action potential duration at the wrist (SNAP durn wrist), the ratio of proximal to distal sensory nerve velocities (S2/S1), and the log 10 sensory nerve ac .n potential amplitude at the wrist (log 10 SNAP amp wrist).

Several authors have published normative median nerve values for the variables DML and DSL to the index finger (DSL2) which are sometimes referred to as the conventional tests for CTS (Kimura, 1978). These normative values and values for DSL to the fourth finger (DSL4) are reported in Table I. The importance of normative values is that they have been used to identify patients with electrophysiological evidence of CTS. The upper limit of normal range has been used as the value to be exceeded for a diagnosis of CTS (Thomas et al., 1967). More frequently, patients with nerve conduction abnormality were identified by values more than two standard deviations from the mean value of normal control subjects (Kemble, 1968; Di Benedetto et al.,1986). In one study, 2.5 standard deviations from the mean was used to identify subjects with CTS (Uncini et al., 1989).

Table I

Published Distal Latencies of the Median Nerve in Normal Subjects

Distal Motor Latency (DML)

Reference Number	Mean (msec.)	S.D.	Range	Distance (cm.)	Sample Size
1	-	-	3.0 - 5.0	-	25
2	3.8	0.5	2.9 - 5.0	6 to 8	50
3	3.8	-	2.5 - 4.5	-	37
4	3.5	-	2.5 - 4.7	7	113
5	3.07	0.46	-	-	63
6	3.8	0.5	3.0 - 4.9	-	55
7	3.4	0.35	-	8	22
9	3.18	0.27	2.6 - 3.8	-	38
10	3.0	0.5	2.1 - 4.0	6.1±0.8	43
	Distal Sensory Latency to Index Finger (DSL2)*				
4	2.8	-	2.1 - 3.5	-	101
5	2.06	0.26	-	-	63
8	2.3	0.2	-	14	30
9	2.47	0.12	2.2 - 2.9	14	38
10	2.4	0.2	1.9 - 2.9	13.3±2.2	43
	Distal Sensory Latency to Ring Finger (DSL4)*				
8	2.4	0.2	-	14	30
10	2.4	0.2	1.9 - 2.9	13.0±1.1	43

* Reported DSL values measured to onset of negative deflection.

References:

1 Simpson, 1956
2 Thomas, 1960
3 Johnson et al., 1962
4 Thomas et al., 1967
5 Kemble, 1968
6 Brown et al., 1976
7 Monga et al., 1985
8 Di Benedetto et al., 1986
9 Jackson & Clifford, 1989
10 Uncini et al., 1989

Differences in the values in Table I can be explained by sample size differences as well as technical and methodological changes that have occurred over the years. Other sources of variability include differences in subjects' hand temperatures at testing, and differences in the distances between stimulating and recording electrodes. Di Benedetto et al. (1986) addressed these issues specifically by providing up-dated normative sensory conduction values which reflected recent techniques and equipment. Standard distances were used and temperatures were maintained above 30°C. using an infrared heat lamp. Values were based on 30 normal subjects; one hand per subject was included in the analyses. Values for DSL2 and DSL4 are included in Table I.

Other electrophysiological tests of the median nerve have been recommended in diagnosing CTS. Felsenthal (1977) investigated whether the latencies of the same nerve in opposite hands and the latencies of paired nerves in the same hand were comparable. Comparisons were made between the median nerve DSL to the index fingers (DSL2) in opposite hands, and between the median nerve DSL2 with the ulnar nerve DSL to the fifth finger (DSL5) within the same hand. Similarly, comparisons were made between the DML values of the median nerves in opposite hands and between the DML values of the median and ulnar nerves in the same hand. The wrists of 50 undiseased volunteers were examined. The distribution

of males and females was not specified. Efforts were made to keep the distance between stimulating and recording electrodes similar among subjects. Hand temperature was not measured. A difference in DSL2 of 0.4 msec., using an antidromic technique, was found when comparing the median nerves in opposite hands or the paired nerves, median with ulnar, in the same hand. For the DML, a difference of 0.6 msec. was found for the median nerves in opposite hands. In the same hand, a difference of less than 1.0 msec. was observed between the paired nerves. The mean difference was 0.4 (SD = 0.28) with a range from 0.0 to 1.2 msec. The cutoff value based on the mean plus two standard deviations was 0.96. Therefore, this study demonstrated that the median nerve distal latencies can be compared with those of the ulnar nerves in the same hand or with the median nerve in the opposite hand.

The relationship between the latencies of the median and ulnar nerves to the ring finger were investigated (Johnson et al., 1981). Both hands of thirty-seven subjects who were normal with respect to diabetes mellitus, peripheral neuropathy, carpal tunnel syndrome were investigated. All control subjects had median nerve DSL values less than 3.7 msec. and ulnar nerve DSL values less than 3.8 msec. Antidromic latencies were obtained using needle stimulation for 34 subjects and surface stimulation for three subjects with no difference in results between the two stimulation

methods. The distance from stimulating to recording electrode was 14 cm. Hand temperature, determined by surface thermistor over the midpalm, was at least 30 degrees Celsius in all subjects. No differences were found between the dominant and nondominant hands. The difference between the median and ulnar distal latencies to the fourth finger were less than 0.6 msec. in all instances and less than 0.3 msec. in 93% of cases. Evidence of the effect of age was present; latency differences between the second and fifth decades were significant in the dominant hand and almost significant in the nondominant hand. The results for the normal control subjects were compared with those of 18 individuals with a history of CTS confirmed by sensory and motor electrophysiological studies. The mean difference in latency between median and ulnar sensory latencies to the fourth finger in subjects with CTS was 1.46 msec. (range 1 to 2.1 msec.). The authors concluded that this technique would provide a useful screening technique for CTS.

Kimura (1978) proposed the use of palmar stimulation as the most sensitive means to improve the determination of abnormal latencies and conduction velocities across the carpal tunnel. The motor and sensory latencies over the wrist-to-palm segment were found to be significantly prolonged in the CTS group while the motor and sensory nerve conduction velocities were significantly reduced. The results of this

study indicated that 25% of the subjects with mild symptoms of CTS would have been undetected by means of traditional methods for determining latencies, i.e., by measuring DML from wrist-to-muscle or DSL to digit.

Other electrophysiological criteria have been recommended in the diagnosis of CTS including measurement of the ratio of the median digital nerve sensory action potential (SAP) with that of the ulnar nerve in the same hand (Loong and Seah, 1971); measurement of median nerve residual latency (Kraft and Halvorson, 1983); and comparison between the median and radial sensory latencies to the thumb (Johnson et al., 1987; Cassvan et al., 1988). These methods will not be presented in detail. The search for the most sensitive or best electrodiagnostic test for CTS has resulted in a proliferation of tests. Efforts have been made by several investigators to determine which of the tests are the most sensitive.

2.5 Recent Studies Evaluating the Relative Merits of Nerve Conduction Tests

Recent reports of studies comparing electrodiagnostic tests provide insight into the value of some of the tests. The nerve conduction test which compares median and ulnar nerve DSL in the fourth finger has been evaluated for its ability to detect abnormality in relation to other nerve conduction tests in two recent studies. In one study, three median-ulnar comparison tests were evaluated, (i) comparison

between the median and ulnar DML, MDML-UDML, (ii) comparison between median nerve DSL to the index finger and the ulnar nerve to the fifth finger, MDSL2-UDSL5, and (iii) comparison between the median nerve and ulnar nerve DSL to the fourth finger, MDSL4-UDSL4 (Uncini et al., 1989). Subjects with mild CTS were compared with a healthy control group which consisted of 43 hands in 33 subjects. In the group of subjects with signs and symptoms of CTS, 42 hands in 32 subjects were used. Subjects with definite CTS based on severe nerve conduction abnormality were excluded. The hands of subjects with CTS symptoms were divided into two groups based on the values obtained for MDSL2; subjects with MDSL2 less than 2.9 msec. (onset) were considered normal or borderline (26 hands); subjects with greater values were considered to have mild abnormality (16 hands). Sensory latencies were tested using orthodromic techniques, with efforts to keep distances between the paired variables similar.

The results of this study illustrated that in the control subjects the mean difference between median and ulnar DSL in the fourth digit was 0.14 msec. (SD=0.11) with a range from 0 to 0.3 msec. (Uncini et al., 1989). The comparison within the fourth digit was observed to be more sensitive in detecting deviation from control values than the other two comparisons; the latter tests were found to be equivalent. The authors of this study noted that when the latency

difference between the median and ulnar nerve was greater than 0.7 msec. in the fourth digit, a double peaked response appeared after stimulation of the fourth digit and was recorded over the median nerve at the wrist. A problem that exists in this study is the use of two hands of subjects within the groups. Because the measurements taken on contralateral hands are not independent, variability among them is potentially reduced which may bias the results.

A second recent study compared five supplemental tests, including median to ulnar nerve DSL comparison in the fourth finger, for their usefulness in detecting abnormality in subjects with symptoms of CTS (Jackson and Clifford, 1989). The supplemental tests that were evaluated were (i) latency following palmar stimulation, Palm (m), (ii) difference between the median and radial nerve DSL values to the thumb, DSL1 (m-r), (iii) difference between the median and ulnar nerve DSL values to the fourth finger measured over 14 cm., DSL4 (m-u), (iv) difference between the median and ulnar nerve palmar latencies, Palm (m-u), (v) ratio of the amplitude of the median and ulnar nerve sensory action potentials for the index and fifth fingers, Amp 2/5. Three patient groups were compared with a control group (Group A) which consisted of hospital staff and patient volunteers. The control group was screened to rule out peripheral neuropathy, diabetes mellitus, excessive alcohol consumption, and exposure to toxins. The

three patient groups were Group B, mildest cases of CTS, subjects with normal conventional nerve conduction studies and EMGs; Group C, more severe cases of CTS, subjects with abnormal conventional nerve conduction studies, and normal EMGs; Group D, most severe cases, abnormal conventional nerve conduction studies, and abnormal EMGs. Conventional nerve conduction studies, used to establish the diagnosis and severity of CTS, were prolonged DML, prolonged DSL2, reduced motor amplitude, and reduced sensory amplitude. In this study, distances were standardized and hand temperature was maintained above 31°C. by warming the hands. One hand per subject was included in the analyses.

The results demonstrated that DSL4 (m-u) was the most sensitive of the five tests (Jackson and Clifford, 1989). It detected abnormality in 100% of subjects who had abnormal conventional nerve results and was abnormal in 44% of subjects in Group B, the subjects without abnormal conventional nerve conduction results. DSL1 (m-r) was almost as sensitive a test as DSL4 (m-u), and in combination, the two tests detected abnormality in 73% of Group B subjects.

In another study, orthodromic palm to wrist sensory latency (which was purported to be the most sensitive test) was compared with DML, DSL2, and the comparison between the median nerve DSL2 and ulnar nerve DSL5 in subjects who had clinical evidence of CTS (Monga et al., 1985). Standardized

distances (8 cm. and 14 cm.) were used and measurements were taken at room temperature of 23°C. The variable which compared the median nerve DSL2 and ulnar nerve DSL5 was shown to be as sensitive as the palmar latency when considered together with the conventional techniques of measuring DSL2 and MDML. Considered individually, palmar latency detected minimally more abnormality than the other techniques.

A problem in the studies which use subjects who have a clinical diagnosis of CTS, but do not have abnormality based on conventional nerve conduction tests, was identified by Jackson & Clifford (1989). To compare the relative merits of various nerve conduction tests in diagnosing CTS, a gold standard is needed to confirm the diagnosis. Generally, conventional nerve conduction tests provide a gold standard. As more sensitive tests are sought to identify abnormality in mild or early cases of CTS, the conventional nerve conduction tests which are purported to be less sensitive cease to be an effective gold standard.

The studies reported in this section demonstrate that the variable which compares the DSL of the median and ulnar nerves in the fourth finger is a sensitive test for detecting abnormality in CTS. The variable which compares the DSL2 of the median and DSL5 of the ulnar nerve is nearly as sensitive as measurement of palmar latency.

2.6 Nerve Conduction Criteria used to Diagnose CTS in Published Studies

Nerve conduction tests have been used in numerous studies as the gold standard for diagnosing CTS. The nerve conduction criteria used to diagnose CTS in studies

(a) evaluating the significance of Tinel's sign (Bowles et al., 1983; Gelmers, 1979; Stewart & Eisen, 1978), the Flick sign (Pryse-Phillips, 1984), and provocative tests (Gellman et al., 1986);

(b) evaluating steroid injection, splinting (Harris et al., 1979) and surgical treatment (Gelberman et al., 1980); and

(c) correlating clinical and electrophysiological features (vanRossum et al., 1980; Pavesi et al., 1986) are indicated in Table II.

Prolonged distal latencies of the median nerve were used as the gold standard for diagnosis of CTS (Bowles et al., 1983; vanRossum et al., 1980) or were combined with signs and/or symptoms to diagnose CTS (Gelmers, 1979; Stewart & Eisen, 1978; Harris et al., 1979; Gelberman et al., 1980; Pryse-Phillips, 1984).

Table II

Electrodiagnostic Criteria for CTS
Used as Gold Standard in Published Studies

Reference Number	DML (msec.)	DSL2 (msec.)	Other Criteria
1	>4.5	>2.7	SAP wrist <8.6mV
2	>4.7 or = 0 M-M*>1.0	-	-
3	>4.5 M-M*>1.0	>3.5 M-M*>0.5	-
4	>4.5 M-M*>1.0	>3.5 M-M*>1.0	-
5	>4.5	M-M*>0.5	-
6	>4.7	>3.5 or = 0	-
7	>4.5 M-M*>1.0 M-U*>1.5	>3.5 M-M*>0.5	MSAP Amp*<USAP or<10mV
8	>4.5 M-M*>1.0	>3.5 M-M*>1.0	-
9	>4.5	>3.5	MMAP Amp*<8mV MSAP Amp*<8uV SCV2 wrist<35m/sec
10	>4.0	>3.7	SCV<50m/sec

* M-M Comparison of median nerves between hands.
* M-U Comparison between median and ulnar nerves in same hand.
* MSAP Amp Median sensory action potential amplitude.
* MMAP Amp Median motor action potential amplitude.

References: 1 Stewart and Eisen, 1978; 2 Gelmers, 1979; 3 Harris et al., 1979; 4 Gelberman et al., 1980; 5 vanRossum et al., 1980; 6 Bowles et al., 1983; 7 Pryse-Phillips, 1984; 8 Gellman et al.,1986; 9 Pavesi et al., 1986; 10 Katz et al., 1990

The values in Table II illustrate that investigators have used different nerve conduction tests and different cutoff values as the gold standard for diagnosing CTS, e.g., DSL cutoff values varied from 2.7 to 3.7 msec.; some investigators have compared contralateral median nerves with differing values to be exceeded; some investigators have compared median and ulnar nerves in the same hand. In the earlier studies, published cutoff values were often used. In more recent studies, normative values specific to the laboratory in which the testing was conducted were used. All electrodiagnostic laboratories determine normative distal latency values and establish criteria for diagnosing CTS based on their own equipment and techniques. These values are frequently unpublished. As a result, different laboratories in the same city use their own specific nerve conduction assessment techniques and criteria for the diagnosis of CTS.

2.7 Studies Evaluating the Effects of Variables on Nerve Conduction Values

In establishing normative nerve conduction values, the effects of other variables on the nerve conduction variables have been considered. Kemble (1968) recognized that differences existed in the nerve conduction values of males and females and chose to use a totally female subject group. The effect of distance on latency values has also been acknowledged by some investigators who have used standard

distances. Several studies have been conducted to investigate the effects of some of these variables on the nerve conduction variables.

In a recent study, the effects of height, age, and foot temperature on the conduction velocity and DML of the median nerve were evaluated (Rivner et al., 1990). The DML was evaluated over a standard distance in all subjects of 7 cm. The group consisted of 104 normal subjects ranging in age from 17 to 77 years (mean = 35 years, SD = 14). Subjects were excluded for signs or symptoms of peripheral neuropathy or other condition predisposing to neuropathy. For conduction velocity in this study, an inverse correlation with age was observed. DML was observed to be correlated with height but not with either foot temperature or age. Differences for males and females were not discussed.

The effect of temperature on nerve conduction values was recognized in an early study (Gilliatt and Sears, 1958). For people whose hands felt cold, the arms were warmed in hot water for five to ten minutes before the testing session. In some more recent studies, hands were maintained at a warm temperature using a heat lamp (Di Benedetto et al., 1986).

In a study of the temperature effects on the nerve conduction in normal subjects and subjects with nerve abnormalities including CTS, nerve conduction was measured at mean finger temperatures of 23 and 33°C. respectively (Bolton

et al., 1982). It was noted that both normal and compressed nerves showed a -0.09 msec. change in DSL per degree Celsius rise in temperature. There were differences in the rate of change in DML in normal subjects compared with CTS subjects. In normal subjects, DML changed -0.28 msec. per degree Celsius rise in temperature while in subjects with CTS, DML changed -0.40 msec. per degree Celsius rise in temperature.

The studies in this section indicate that the variables of sex, distance between stimulating and recording electrodes, age, height, and temperature should be considered in relation to the nerve conduction values.

2.8 Relationship between Latencies and Clinical Features

The variables that are most useful in the clinical diagnosis of CTS have not been identified by the earlier studies that have addressed this question. The electrophysiology of the median nerve was compared with symptom duration, clinical manifestations, and hand dominance (Kemble, 1968b). Sixty-six female subjects with a total of 120 hands affected by CTS were included in the study. The definition of CTS was "a hand (or case) presenting with pain and/or paresthesiae, which predominantly affect the fingers innervated by the median nerve, and for which there is no other identifiable cause". The only eligibility criterion cited was normal sensory conduction in the ipsilateral ulnar

nerve. Males were excluded. The distal latencies of the median nerve were not provided nor were the values that were considered prolonged. Whether or not subjects required prolonged distal latencies to be included in the study is not clear. 62% (74) subjects had idiopathic CTS and the rest had CTS believed to be secondary to associated conditions such as rheumatoid arthritis. The following observations were reported: (1) a significant relationship between duration of symptoms (x years) and DML (Y) which persisted when the effect of patient age was eliminated; the relationship was expressed by the regression line $Y = 4.89 + 0.24(x-1.91)$. (2) subjects with objective signs (such as weakness or wasting of abductor pollicis brevis, loss or diminution of pain and/or touch sensation, hyperesthesia in the median nerve distribution) had longer DML and DSL compared with subjects with symptoms only; and (3) more subjects with CTS secondary to associated conditions such as arthritis had objective signs than patients with idiopathic CTS.

No details about the actual symptoms and signs that were related with electrophysiological findings were provided. In addition, the inclusion of both hands of most subjects violates the assumption of independent observations for the analyses. As a result, the error effects were not random which could lead to biased results.

Electrodiagnostic aspects of CTS and their relationship

with some clinical features were reported by Thomas et al. (1967) who followed a series of 300 patients with 476 affected hands at the Mayo Clinic who had a final diagnosis of CTS, an electromyographic examination, and surgical decompression of the median nerve. The following relationships between preoperative clinical and electrophysiological findings were described: (1) conduction abnormalities were observed more frequently in subjects whose symptoms were of longer duration; (2) a relationship was observed between thenar muscle weakness and prolonged DML; and (3) many patients with no clinical evidence of impaired sensory appreciation had abnormal conduction in the afferent fibers of the median nerve.

Based on findings in 84 hands of 56 subjects with clinical and electromyographic evidence of CTS, it was noted that subjects with lower sensory action potential amplitude and/or sensory conduction velocity had a greater likelihood of sensory deficit (Pavesi et al., 1986). Subjects with atrophy and/or weakness of the thenar muscles had more abnormal DML and motor amplitudes.

Although these studies provided some useful information about the relationship between clinical features and electrophysiological findings, the assumption of independent observations was violated by the inclusion of both hands in the analyses. As a result, the error effects were not random which could lead to biased results.

In a recent study, the value of aspects of the history and physical examination in diagnosing CTS were evaluated (Katz et al., 1990). One hundred and ten subjects who were referred for nerve conduction testing were classified into subjects with CTS and a control group with disorders that could be easily confused with CTS. The electrophysiological criteria for CTS were DML greater than 4.0 msec., DSL greater than 3.7 msec., or sensory velocity less than 50 m/s. Skin temperature was maintained at 34 to 37°C. The prevalence of CTS was 40%. A self-administered hand pain diagram depicting dorsal and palmar views of the hands was developed. Subjects were asked to indicate the location and quality of their discomfort. The diagrams were rated as indicating classic CTS, probable, possible, or unlikely to be CTS by an assessor who was blinded to the results of electrodiagnosis. In addition, an assessment based on an abbreviated history and physical examination was made by a neurologist who was blind to the results of nerve conduction testing. The patient was used in the analyses rather than individual hands.

The results of this study indicate that both the pain diagram and the neurologist's assessment were found to be more highly associated with the diagnosis of CTS than Tinel's sign or Phalen's test in bivariate analyses. These relationships were maintained using multivariate analyses.

2.9 Signs and Tests in the Diagnosis of CTS

Efforts have been made to determine the ability of specific clinical tests and signs to predict the diagnosis of CTS. These include Tinel's sign, Phalen's test, the cuff compression or tourniquet test, and the Flick sign.

2.9.1 Tinel's Sign and Phalen's Test

Tinel's sign is performed by tapping lightly over the median nerve just medial to the palmaris longus tendon at the volar wrist skin crease (Dawson, 1983: page 9; Phalen, 1966). The test is positive when a tingling sensation is elicited in the median nerve distribution in the hand.

Phalen's test is performed by asking the subject to fully flex the wrists with the dorsum of the hands apposed (Phalen, 1966; Hoppenfeld, 1976: page 83). The examiner supports the subject's elbows, with attention to avoid compression of the ulnar nerve, and slight pressure is applied to maintain full flexion of both wrists for up to one minute. The test is positive when numbness or tingling is felt in the median nerve distribution of the hand.

The earliest reports of the usefulness of Tinel's sign and Phalen's test were essentially descriptive and reported sensitivities for Tinel's sign ranging from 61% to 73% and for Phalen's test ranging from 74% to 81% (Phalen, 1966, 1970, 1972). Since the diagnosis of CTS was based on clinical

assessment unconfirmed by nerve conduction studies, a selection bias may have occurred in these investigations.

The nature of the control group and of the group of subjects with CTS affects the sensitivity, specificity, positive and negative predictive values derived for the clinical tests. The results of the studies cited in this section are presented in Tables III and IV.

In three studies, the control groups consisted of subjects with no symptoms of median nerve compression or other hand disorder (Bowles et al., 1983; Gellman et al, 1986; Seror, 1988). These studies provide a reasonable estimate of the sensitivity, but the estimate of specificity is not clinically useful. In one study, the control subjects were not evaluated by electrodiagnostic tests to rule out CTS (Gellman et al., 1986). This may have resulted in a selection bias. In two of these studies the control group and the CTS group included both hands of subjects. Twenty-one hands of 11 control subjects and 28 hands of 17 subjects with CTS were included (Bowles et al., 1983); 40 hands of 20 control subjects were included, and 200 hands of 127 subjects with CTS were included (Seror, 1988). In the third study, only in the CTS group were both hands included; 67 hands of 47 subjects were included (Gellman et al., 1986). The inclusion of both hands in the analyses violates the statistical assumption of independence of observations (Donner, 1984).

Table III

Predictive Ability of Tinel's Sign

Reference (sample size)	Sensitivity	Specificity	Predictive Value Positive	Predictive Value Negative	Prevalence
1 (103)	45	71	61	57	50
2 (90)	43	74	65	54	52
3 (49)	75	95	95	74	57
4 (306)	25	82	58	52	50
5 (113)	44	94	91	56	57
6 (80)	60	77	88	43	73
7 (110)	26	80	42	66	35
8 (49) Right	28	67	47	47	51
8 (44) Left	21	52	25	46	43
9 (110)	60	67	55	72	40

References:

1 Stewart & Eisen, 1978
2 Gelmers, 1979
3 Bowles et al., 1983
4 Woodbury et al., 1984
5 Gellman et al., 1986
6 Heller et al., 1986
7 Golding et al., 1986
8 DeKrom et al., 1990
9 Katz et al., 1990

Table IV

Predictive Ability of Phalen's Test

Reference (sample size)	Sensitivity	Specificity	Predictive Value Positive	Predictive Value Negative	Prevalence
1 (306)	29	78	57	52	50
2 (113)	71	80	82	69	56
3 (80)	67	59	81	41	73
4 (110)	10	86	29	64	35
5 (240)	62	80	94	29	83
6 (48)					
Right (43)	46	48	48	44	52
Left	53	58	50	61	44
7 (110)	75	47	48	74	40

References:
1 Woodbury et al., 1984
2 Gellman et al., 1986
3 Heller et al., 1986
4 Golding et al., 1986
5 Seror, 1988
6 DeKrom et al., 1990
7 Katz et al., 1990

In the studies reported below, electrodiagnosis was used to confirm the diagnosis of CTS. In two studies, the contralateral hand of some of the subjects was included as a

"normal" hand in the control group (Stewart & Eisen, 1978; Gelmers, 1979). As a result, the measurements were neither paired nor independent and, therefore, not appropriate for statistical analysis. In addition, inclusion of the contralateral hand in the control group may have biased the findings since the contralateral hand of a person with CTS may be more likely to be affected by CTS than that of a non-diseased person, i.e., there is less variability within individuals than between individuals.

In two other studies, subjects were divided into those with or without CTS based on electrodiagnosis thus providing control groups with disorders that could be confused with CTS mimicking the clinical situation. However, in one of the studies, 80 hands in 60 subjects were used (Heller et al., 1986), and in the other study 110 hands of 70 subjects were used (Golding et al., 1986). This technique again may have produced measurements that were not independent for statistical analysis.

In summary, the following limitations existed in the studies mentioned above thus affecting the sensitivity, specificity, positive and negative predictive values.

(a) In some studies, the control group did not consist of disorders that could be easily confused with CTS. This limits the clinical value of the results.

(b) In some studies, the diagnosis was not confirmed by a gold

standard, such as electrodiagnosis. The degree of confidence in the presence or absence of abnormality within the groups is limited.

(c) Both hands of some subjects were included either in the control group or in the group of subjects with CTS. Inclusion of both hands of subjects in the same group reduces the variability of measurements due to lack of independence between measurements. This affects the statistics analyses. Inclusion of the contralateral hand of a subject with CTS in the control group, especially when the diagnosis is unconfirmed, reduces the variability among groups. It has been shown that subjects with abnormality in one hand often have bilateral abnormality (Thomas et al., 1967).

In one investigation of the value of Tinel's sign and Phalen's test, all of these concerns were addressed. Nerve conduction studies were used to confirm the diagnosis of CTS (Woodbury et al., 1984). The control group consisted of disorders that would be included in the differential diagnosis of CTS thus reflecting clinical practice. To achieve independence of observations for statistical analysis, the right and left hands were analyzed separately. The sensitivity, specificity, positive and negative predictive values of Tinel's sign and Phalen's test, presented in Tables III and IV, indicate that neither of these tests is predictive of the diagnosis of CTS.

Two recent studies also addressed these areas of concern in the earlier studies. In one recent study evaluating the efficacy of provocative tests in the diagnosis of CTS, subjects were drawn at random from the general population (de Krom et al., 1990). The subjects in this study were not people who went to their physicians due to their symptoms. Therefore, they were likely to be different from those who do consult their physicians. Fifty people who were wakened at night because of tingling in the fingers and who were willing to participate were included in the study sample. All subjects were examined by a neurologist who was blind to the results of nerve conduction studies. Nerve conduction studies were performed and used in combination with typical symptoms of CTS as the gold standard for CTS. Right and left hands were separated for statistical analyses. The predictive values in Table III illustrate that despite the smaller sample size, sensitivities for Tinel's sign were similar to those found in larger studies (Woodbury et al., 1984; Golding et al., 1986). The specificities were lower. The sensitivities observed for Phalen's test in Table IV were in the mid-range of those found in other studies while the specificities were lower.

Another recent study was designed to evaluate the value of the history and physical examination findings in diagnosing CTS (Katz et al., 1990). The subjects consisted of patients

referred to a neurophysiology laboratory for diagnostic studies. Physical examinations were performed blind to the results of nerve conduction studies and the nerve conduction studies were performed blind to the findings of the physical examination. The predictive values, presented in Tables III and IV, indicate that both Tinel's sign and Phalen's test were somewhat predictive of CTS. Using multivariate analyses, Tinel's sign was more predictive than was Phalen's test.

The studies reviewed in this section suggest that neither Tinel's sign nor Phalen's test, when considered individually, is sufficiently predictive of CTS to be clinically useful.

2.9.2 **Cuff Compression Test**

Another clinical test used in the diagnosis of CTS is the cuff compression or tourniquet test (Sunderland, 1968: page 719) first described by Gilliatt and Wilson (1953) and recommended by Welply (1961) and Cailliet (1982: page 89).

Gilliatt and Wilson (1953) found that inflation to suprasystolic pressure could detect CTS in cases of severe irritation of the nerve. Within 30 to 60 seconds of inflation, paresthesia was felt in the thumb, index, middle, and perhaps ring finger. This was experienced as an intense tingle or sharp pricks in the thenar pad and palm, and possibly above the wrist in the radial side of the forearm. With less severe nerve irritation, paresthesia did not occur,

but median sensory loss appeared with abnormal rapidity during ischaemia. Numbness of the median nerve digits was detected within 5 to 10 minutes of inflation of the cuff. Having used this method, Johnson et al., (1962) stated the opinion that it provided results that were too subjective although it may be used to substantiate the clinical diagnosis in advanced disease. Welply (1961) indicated that the correct performance of this test was to reduce the pressure to between the systolic and diastolic blood pressures of the patient. In this way, venous distention is produced thus increasing nerve compression and reproducing symptoms. Urbaniak and Roth (1982), who reviewed nerve compression syndromes, also recommended this method of application of the cuff and stated that the test is beneficial.

Cuff compression was one of the tests used in the diagnosis of CTS in a trial evaluating the effectiveness of steroid injection and splinting for CTS (Gelberman et al., 1980). The tourniquet was inflated to suprasystolic pressures for one minute. Forty-one subjects with a total of 50 involved hands were included in the study and in 23 of the hands (46%) positive results were found. Similar application of the cuff compression or tourniquet test was used by Szabo et al. (1984) who observed positive results in 70% of hands of patients with CTS. The study sample was composed of 20 subjects who had 23 involved hands.

Hybbinette and Mannerfelt (1975) reported the late results of surgical treatment in a series of 370 patients with 465 operated hands. In this study, the tourniquet test was used to achieve venous stasis by inflation to 100 mmHg. around the upper arm. In 88% (106) of the 120 arms tested, nocturnal pain was reproduced and it was the impression of the authors that the test was very valuable in establishing the diagnosis. In all of these studies, the observations were not independent because of the inclusion of both hands of some subjects and, therefore, the results could be biased.

The cuff compression test was evaluated in a recent study involving 50 subjects (de Krom et al., 1990). The prevalence of CTS in this group was 52%. The sensitivity and specificity values were 72% and 22% respectively. There were many false positive results. The positive and negative predictive values of 50% and 42% respectively suggest that the test is not clinically useful.

2.9.3 **Flick Sign**

Use of the Flick sign in the diagnosis of CTS was recently reported (Pryse-Phillips, 1984). The question "What do you actually do with your hand(s) when symptoms are at their worst?" resulted in patients making a flicking movement described as similar to that used in shaking down a clinical thermometer. Two hundred and twelve subjects with CTS

confirmed by electrodiagnostic criteria (Table II) were compared with 184 subjects with other median nerve pathologies, thoracic outlet syndrome, ulnar nerve lesions, or cervical radiculopathy, providing a prevalence of CTS for the total group of 54%. The sensitivity and specificity of the Flick sign were found to be 93% and 96% respectively. The positive predictive value was 96% and the negative predictive value was 92%. Based on this report, the flick sign appears to be useful in the diagnosis of CTS.

These results were not confirmed in a recent study of 50 subjects who were selected form the general population (de Krom et al., 1990). The prevalence of CTS was 51%. The sensitivity and specificity were 52% and 63% respectively. The positive and negative predictive values were 59% and 56% respectively. The value of the flick sign remains to be determined.

2.10 Summary of the Literature Review

Nerve conduction studies have been used in reported studies as a gold standard for diagnosing CTS. Normative values must be determined in each laboratory to establish which electrodiagnostic tests will be used and methodological standards based on the actual equipment and techniques generally employed. The variables which potentially affect nerve conduction variables have been identified and should be

standardized or accounted for in relation to the nerve conduction values. The provocative tests that are widely used in clinical practice have not been shown to be predictive of the electrophysiological abnormalities associated with CTS. A recent study suggests that aspects of the history may be predictive of abnormality (Katz et al., 1990). The relationships of clinical features, signs and tests with nerve conduction abnormalities are not well understood.

CHAPTER III

METHODS

3.1 Design

The study was designed in three phases. These phases corresponded to the two sub-problems and main purpose outlined in Chapter I. The initial phase was to establish normative values for the individual electrodiagnostic tests for CTS, based on a group of control subjects. This involved identifying variables which potentially affect the nerve conduction values, i.e., sex, temperature, distance between stimulating and recording electrodes, age, and height. Then, limits of normal distribution were established which accounted for these affecting variables.

The second phase, of determining the electrodiagnostic tests that appropriately discriminate between subjects with abnormality and subjects without abnormality compatible with CTS, involved investigating the inter-relationships of the eleven nerve conduction variables (see Materials and Procedures related to Nerve Conduction Studies) in the control and experimental subjects and deciding how many and which variables to use based on statistical and clinical rationale.

The third phase, of developing a model to predict electrophysiological findings from a set of clinical features, involved evaluation of the associations between the

electrophysiological findings and clinical features in experimental subjects using bivariate analyses followed by logistic regression analysis.[3]

3.2 Control Subjects for Phase I

The control group consisted of consecutive subjects with hand symptoms who were referred to the Neurosciences Laboratory at Victoria Hospital for nerve conduction studies but who had no evidence of CTS or peripheral neuropathy. There were 104 control subjects, 54 females and 50 males, on whom electrophysiological tests (see Methods and Procedures related to Nerve Conduction Studies, page 51) were conducted to determine the distribution of normal values for this study.

The control subjects ranged in age from 16 to 73 years with a mean age for the group of 38.4 years (S.D. 12.1); males were slightly older than females with mean ages (S.D.) of 39.9 (11.8) and 36.9 (12.4) years respectively. The mean height and weight of the group were 168.36 cm. (S.D. 11.7), and 71.7 kg. (S.D. 14.9) respectively. Males were taller and there was less variability in their heights than females; the means (S.D.s) for males and females were 176.6 cm. (7.6) and 160.9 cm. (9.6) respectively. Similarly, males weighed more and there was less variability in their weights than females; the

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[3] A follow-up phase was conducted also. The thesis is based on the earlier phases due to limitations of resources and time.

means (S.D.s) for males and females were 81.2 kg.(11.1) and 63.1 kg. (12.5) respectively.

3.3 Sample Size Determination for Phases II and III

The sample size was based on a single independent variable, an estimate of the proportion of subjects with CTS who have pain that wakens them at night of .91 (Tanzer, 1959). Choosing a difference between subjects with and without CTS of 0.15 as important, with alpha = 0.05, beta = 0.20, and adding 10% for possible attrition, the required sample size was 125 subjects per group (Fleiss, 1981:Table A3). Since approximately half of the subjects referred with suspected CTS actually have the condition (Woodbury et al., 1984), approximately 250 subjects were required.

An alternative method of estimating sample size was made on the basis of a 95% confidence interval around sensitivity and specificity estimates of tests used in the diagnosis of CTS. The 95% confidence interval around a proportion is expressed by

$$\hat{p} \pm 1.96 \ (\hat{p}\ \hat{q}/n)^{1/2}$$ (Colton, 1974: page 160)

where $\hat{p}$ is the estimated proportion, $\hat{q} = (1-\hat{p})$, n is the required sample size, and 1.96 is the value of the critical standard normal deviate z for the 95% confidence interval. Assuming the magnitude of difference tolerated between sample and population proportions is .05, the error of estimate of

the confidence interval is fixed at .05 with 95% confidence,

$$\text{i.e.,} \quad e = 1.96\ (\hat{p}\ \hat{q}/n)^{1/2} \leq .05$$

Solving for n

$$n = (1.96)^2\ \hat{p}\ \hat{q}/0.05^2$$

Using the proportion of cases with nocturnal pain of 0.91 (Tanzer, 1959), the sample size estimate was 126 subjects. Therefore, adding 10% for possible attrition, it was estimated that 140 subjects per group, or 280 subjects were needed.

Either of these estimates would be considered conservative because the inclusion of other independent variables improves the prediction thereby increasing the power. However, for multivariate techniques, the sample size must be large enough to accommodate all the independent variables. A rule of thumb is to include ten subjects for each independent variable in the logistic regression analysis. The estimated sample size of 280 subjects was thus large enough for the proposed logistic regression analyses.

3.4 Experimental Subjects for Phases II and III

Patients referred for nerve conduction studies with suspected CTS and who consented to participate were included in the study. Approximately three half-days a week were devoted in the Neurosciences Laboratory to nerve conduction studies of people suspected of having CTS. (Occasionally

other people were scheduled into this time also according to the departmental scheduling requirements). The interviewer attended the designated carpal tunnel sessions. All subjects were approached first by the technician performing the nerve conduction studies, who informed them of the study and that it involved people who were being evaluated for CTS. For those who were willing to be approached following their nerve conduction studies, the purpose and procedures were explained by the interviewer, a letter of explanation was provided (Appendix II), and an informed consent (Appendix III) was obtained.

Exclusions according to the criteria were:

1. Previous carpal tunnel release of the hand being investigated (4 people).

2. Generalized peripheral neuropathy (2 people).

3. Inability to communicate effectively in English (7 people).

4. Age greater than 80 years (11 people).

Refusals to participate were due primarily to the time commitment, i.e., the fact they could not stay that day (12 people), or the fact that they were unable to return for follow-up (14 people). Because these people refused participation, no information about them was obtained to determine the extent to which their lack of participation may have biased the group. However, there was no a priori reason to think that the method of self-selection for participation

would have produced a biased group of subjects.

Two hundred and eighty-five subjects participated in the study which was undertaken from November 21, 1985 to February 3, 1987. There were 94 males (33%) and 191 females (67%) with a mean age of 44 years (S.D. 13.7 years; range 16 to 80 years). The mean height of subjects was 165.9 cm. (S.D. 9.4 cm.); the mean weight was 73.3 kg. (S.D. 16.8 kg.). Two hundred and sixty-one (261) of the subjects were right-handed, 91.6%, while the remaining 8.4% were left-handed. The majority of subjects (56.5%) had less than grade 11 education, 15.1% had completed grade 12 to 13, and 28.4% had further education.

There was variability in the duration of symptoms of the group. The mean duration of symptoms was 24.9 months (S.D. 44.3 months). 26.7% of the subjects had symptoms on the right side only; 14.4% had symptoms on the left only. Of the 168 subjects (58.9%) with bilateral symptoms, 40.0% had worse symptoms on the right, 18.9% had worse symptoms on the left.

The subjects reported the following pre-existing conditions (number in parentheses):
pregnancy (2), diabetes (10), previous wrist fracture (17), hypothyroid (10), rheumatoid arthritis (5), osteoarthritis (17), fibrositis (3), polymyalgia rheumatica (1), cervical degenerative disc disease (1), anklyosing spondylitis (1), systemic lupus erythematosis (1).

Subject referrals came from the following sources: Family physicians 67.7%, General surgeons 7.0%, Neurosurgeons 7.7%, Orthopedic surgeons 4.9%, Plastic surgeons 1.1%, Internists 6.7%, Neurologists 4.2%, Physiatrists 0.4%, Unknown 0.4%.

3.5 Protocol for Data Collection - Experimental Subjects

All subjects were evaluated by one individual who obtained a history and performed a physical examination related to the complaint of CTS. The evaluator was a physical therapist experienced in history-taking and physical examination. The physical examination procedures were discussed and reviewed by the Neurologist involved with this study. The evaluation was done blind to the results of nerve conduction studies and reported on a standard assessment form (Appendix IV). The clinical predictors (see page 54) derived from this evaluation were subsequently used in the univariate and logistic regression analyses.

Subjects underwent nerve conduction studies which were performed in a standardized manner by the technical staff of the laboratory, as described below. Data were collected about median nerve conduction in both hands of all subjects but the information about only the symptomatic or more symptomatic hand was included in the statistical analyses to ensure that all observations were independent. If a subject

was unable to distinguish a more symptomatic hand, the dominant hand was used.

3.6 Materials and Procedures related to Nerve Conduction Studies

Conventional nerve conduction studies were conducted in the Electromyography Laboratory of the Neurosciences Department at Victoria Hospital Corporation, London, Canada. Electrodiagnostic tests were performed on the median nerves bilaterally and the ulnar nerve of the more symptomatic hand. Only the ulnar contribution to the fourth finger of the contralateral hand was investigated. A standard EMG machine was used with stimulus duration of 0.1 msec. and amplifier frequency settings of 20 to 5000 Hz. (3 dB down). Palmar skin temperature was monitored using a surface thermistor. The temperature measurements were used to provide temperature adjustments to the criteria for abnormality for the nerve conduction tests.

The electrophysiological tests were:

Distal latencies:

(1) median nerve distal motor latency (MDML),

(2) median nerve distal sensory latency to the index finger (MDSL2),

(3) median nerve distal sensory latency to the fourth finger (MDSL4),

Conduction velocities:

(4) median nerve motor conduction velocity of the forearm (MMCV),

(5) median nerve sensory conduction velocity to the index finger (MSCV2),

(6) median nerve sensory conduction velocity to the fourth finger (MSCV4),

Sensory conduction velocity comparisons:

(7) sensory conduction velocity comparison between the median nerve to the index and the ulnar nerve to the fifth finger (SCVM2U5),

(8) sensory conduction velocity comparison between the median nerve to the fourth and the ulnar nerve to the fourth finger (SCVM4U4),

Distal sensory latency comparisons:

(9) distal sensory latency comparison between the median nerve to the index and the ulnar nerve to the fifth finger (DSLM2U5),

(10) distal sensory latency comparison between the median nerve to the fourth and the ulnar nerve to the fourth finger (DSLM4U4),

F response comparison:

(11) F responses comparisons between the median and ulnar nerves (DIFFRESP).

Motor conduction studies were performed to obtain estimates of forearm motor conduction velocity and distal

motor latency (DML). These were performed by supramaximal stimulation of the median nerve at the wrist and elbow through saline soaked pads (cathode spaced 2.5 cm. from anode). Responses were recorded using Teca silver chloride dot surface electrodes placed over the abductor pollicis brevis with the reference electrode placed at the MCP of the thumb.

Antidromic sensory conduction studies were conducted to obtain sensory conduction velocity and distal sensory latency (DSL), (Bolton and Carter, 1980). These were performed by supramaximal stimulation of the median and ulnar nerves at the wrist through saline soaked pads spaced 2.5 cm. apart. The nerve responses were recorded using Teca ring electrodes with G1 placed over the MCP joint crease and G2 placed over the DIP joint crease of the index, fourth, and fifth digits respectively.

Distal motor and sensory latencies were calculated from onset of stimulus artifact to onset of negative deflection. Forearm motor conduction velocity was calculated by dividing the forearm distance (distance between the two points of stimulation) by the difference between the proximal and distal motor latencies. Sensory conduction velocities were calculated by dividing the distance from the wrist to the proximal crease by the associated distal sensory latency. The F response was determined by stimulation of the median nerve at the wrist and recording the response from the abductor

pollicis brevis.

3.7 The Dependent Variable for Phase III

The dependent variable in the present study was the detection of the electrophysiological abnormality frequently associated with CTS. In the clinical situation, symptoms and/or signs of compression of the median nerve at the wrist are determined and confirmed by nerve conduction studies. In this study, all subjects had symptoms and/or signs of CTS or of disorders that could be easily confused with CTS. Because the relationship of symptoms and signs to abnormal nerve conduction studies was being investigated, only the results of nerve conduction studies were used to categorize the subjects into those with abnormality and those without abnormality. The actual criteria used to assign abnormality are presented in the results for Phase II.

3.8 The Clinical Predictors for Phase III

The clinical predictors were obtained from self-reported information and from a physical examination.

<u>Self-reported information</u>

Duration of symptoms in months.

Frequency of hand symptoms: all the time, at some point every day, from time to time.

Nocturnal pain: Do you have discomfort in your hand(s) that wakens you at night? Yes or no.

Flick sign: What do you do with your hands when you symptoms are at their worst? The test was positive if the subject made or described a flicking movement similar to that used in shaking down a clinical thermometer.

Clumsiness: Have you noticed that you drop things more often than you used to? Yes or no.

Hand numbness that is compatible with CTS:

0. no numbness, or numbness that was not in the median nerve distribution of the hand;

1. numbness within the median nerve distribution of the hand, the first three and a half digits;

2. numbness involving all five digits, i.e., non-specific;

3. numbness involving some of the median nerve distribution of the hand, i.e., digits 2, 3, 4, 5 or digits 3, 4, 5.

A second variable for hand numbness was created and used in completely separate analyses. The charts of subjects with any hand numbness were reviewed and classified as either having numbness that could possibly be compatible with CTS (1), or unlikely to be CTS (0). This classification was based on the subject's description of the problem, i.e., whether the symptoms started in the hand or at the elbow, whether the symptoms radiated proximally or distally, if the symptoms were

vague or specific, etc., and clinical evaluation of the relationship of reported symptoms to the known distribution of the median nerve.

Hand pain that is compatible with CTS: Two variables were created for pain using clinical criteria similar to those used for numbness.

Family history: The subject was asked if anyone in the family ever had a problem like they were having. The subject was considered to have a family history if a family member had been diagnosed with CTS or had undergone surgical release of the carpal tunnel.

Occupation was categorised for predisposition to CTS:

Not likely predisposing: 1. Minimal hand use - e.g. teacher, priest, administrator, manager, supervisor, security guard, counsellor, post office worker, sales clerk, bookkeeper, purchasing clerk. 2. Some hand use, not repetitive, frequent, or heavy - e.g. homemaker, babysitter, technician, dental assistant.

Not known to be predisposing: 3. More hand use - e.g. waitress, nurse, cleaner/janitor, painter, electrician, glazier, picture framer. 4. Heavy hand use - e.g. farmer, plumber, carpenter, roofer, furniture maker, welder, mechanic.

Predisposing occupations: 5. Fine finger activities - e.g. cashier, grocery checker, typist, telephone

operator, bank teller, computer worker, food preparer, hair dresser, seamstress, secretary. 6. Heavier activities - e.g. factory/assembly line workers, butchers. 7. vibration - e.g. bus/truck driver, shovel operator.

Information was ascertained about the subject's previous job if the symptoms dated to the time before the present job or if the subject was retired. If the previous job was predisposing, coded 5 to 7, the subject was coded according to the previous job.

Recreational activities were categorized into activities that were considered not likely to be predisposing for CTS, e.g., photography, volunteer work, flower arranging, stamp/coin collecting, housework, studying; activities that might be predisposing, i.e., crafts such as knitting, crocheting, needlepoint, rug hooking; and sports. When this variable was dichotomised, sporting activities, which included numerous activities that did not involve use of the hands, were added to the non-predisposing recreational activities.

Physical examination

Atrophy of abductor pollicis brevis: Obvious flattening of the thenar eminence was considered evidence of atrophy.

Light touch sensation was tested by determining if the subject, whose eyes were closed, felt the touch of a wisp

of cotton on the skin of the hand similarly within the median nerve distribution as elsewhere. This variable was coded as follows:

0. not impaired, or impaired outside the median nerve distribution of the hand;

1. impairment within the median nerve distribution of the hand, the first three and a half digits;

2. impairment involving all five digits, i.e., non-specific;

3. impairment involving some of the median nerve distribution of the hand but also extended beyond the median nerve distribution, i.e., digits 2, 3, 4, 5 or digits 3, 4, 5.

Pin prick sensation was tested by asking the subject to discriminate between the sharp and dull ends of a pin with the eyes closed. This variable was coded in the same way as light touch.

Hyperaesthesia was hypersensitivity to light touch in the median nerve distribution of the hand. This variable was coded as impaired (1) or not impaired (0).

Two point discrimination was tested by asking the subject to discriminate between a single point or two points applied to the fingers. A calibrated compass, the ends of which had been dulled, was used. Two point discrimination was considered to be impaired if the subject could not

discriminate points 4 to 5 mm. apart at the fingertips and up to 6 mm. apart at the proximal phalanx. Impairment was confirmed by checking the area three times. This variable was coded in the same way as light touch.

Weakness of abductor pollicis: A subject was considered to show evidence of weakness if weakness was evident on the following test. With the forearm supinated, abduction of the thumb at 90 degrees to the plane of the palm. Resistance to thumb abduction was applied by the examiner. Weakness was evidenced if the examiner was able to break the subject's hold.

Tinel's sign was performed by tapping lightly with a Queen's Square reflex hammer over the median nerve just medial to the palmaris longus tendon at the volar wrist skin crease (Phalen, 1966). The test is positive when a tingling sensation is elicited in the median nerve distribution on the hand.

Phalen's test was performed by asking the subject to fully flex the wrists with the dorsum of the hands apposed (Phalen,1966; Hoppenfeld, 1976: page 83). The examiner supported the subject's elbows, with attention to avoid compression of the ulnar nerve, and slight pressure was applied to maintain full flexion for up to one minute. The test was positive when numbness or tingling was felt

in the median nerve distribution of the hand.

Cuff compression test was performed by inflation of a blood pressure cuff around the subject's upper arm to suprasystolic pressure (Gilliatt and Wilson, 1953), followed by reduction of the pressure to between systolic and diastolic pressure of the subject (Welply, 1961). The test was positive if, within 30 to 60 seconds, paraesthesia was felt within the median nerve distribution of the hand.

3.9 Statistical Analyses

The statistical analyses are presented in sequence to address the three phases, i.e., the two sub-purposes and then the primary purpose of the study.

3.9.1 Phase I

The first sub-purpose was to establish normative values for the electrodiagnostic variables based on control subjects. For each of the electrodiagnostic variables, criteria for assigning abnormality, which took into account the variables found to affect the electrodiagnostic variables, were developed. More specifically, after descriptive statistics were obtained for the nerve conduction variables, the potential effect of other variables (hand temperature, age, sex, height, and the distance between the stimulating and recording electrodes) was investigated. To observe the

relationships, plots of the nerve conduction variables against each of the other variables that might affect them were obtained for all control subjects and separately for males and females.

Since sex differences and interactions between sex and another variable necessitated adjustments of the abnormality criteria for the sexes, t-tests were used to confirm sex differences and multiple regression analyses were used to confirm interactions between sex and other variables. Instead of reducing the alpha level for multiple testing, the alpha level for each of the tests was 0.05 as it was deemed more important to identify than ignore variables which affected the nerve conduction variables.

Multiple regression analyses were performed for each of the nerve conduction variables to determine the potential effect of hand temperature, age, height, and the distance between the stimulating and recording electrodes, sex, and interaction with sex. The nerve conduction variables which exhibited sex differences were evaluated separately for males and females. If at least 10% of the variance in the nerve conduction variable was accounted for by an independent variable (i.e., the multiple correlation coefficient, $R^2 \geq 0.10$), adjustments to the criteria for abnormality to account for these independent variables were deemed to be necessary.

For the variables requiring adjustment, 95% prediction bands were placed around the regression line using the formula

$$\hat{Y} \pm t(v, 0.95)\ s\ \{1 + x_*'(x'x)^{-1}\ x_*\}^{1/2}$$

(Draper and Smith, 1981: adapted from equation 1.4.12, page 30). Abnormality of distal latencies indicative of CTS is a prolonged value while abnormality of conduction velocity suggestive of CTS is a reduced velocity. Therefore, the limit of normal distal latencies was cut off by the upper prediction band and the limit of normal conduction velocities was cut off by the lower prediction band.

For the nerve conduction variables that did not require adjustment, the percentile technique (Feinstein, 1977) was used to determine the values that would be considered abnormal. Many investigators in this area have used the Gaussian distribution rather than the percentile technique to assign abnormality, designating the central 95% as normal and cutting off the upper and lower 2.5% as abnormal. Since the data for the control subjects did not conform to the normal distribution, it was deemed preferable to use the percentile technique.

The percentile technique required that the observed values for each of the nerve conduction variables be ranked in ascending order. Since prolonged distal latency values are suggestive of CTS, the values for the upper 5% of the ranked group were considered abnormal. For conduction velocities,

the lowest 5% of the ranked group were considered abnormal. Similar percentiles were created for the variables comparing median and ulnar values, i.e., SCVM2U5, SCVM4U4, DSLM2U5, DSLM4U4. For conduction velocity comparisons, the ulnar nerve values were subtracted from the median nerve values and the lowest 5% were considered abnormal. For latency comparisons, the ulnar nerve values were subtracted from the median nerve values and the highest 5% were considered abnormal.

3.9.2 Phase II

Using the criteria for abnormality established by the prediction bands and percentile techniques, the raw values of the eleven nerve conduction variables of the study subjects were recoded to abnormal versus normal. The number of subjects with abnormality for each nerve conduction variable was determined. The number of subjects with abnormality for each electrodiagnostic test was determined before and after the adjusted criteria were applied. The effect of adjustment was noted.

The second sub-purpose was to evaluate the experimental subjects and determine how to reduce the information on eleven nerve conduction variables to categorize experimental subjects appropriately into those with abnormality and those without abnormality. Initially, the intention had been to categorize subjects using eight variables and to use mainly conduction

velocities rather than distal latencies for the reason specified in Appendix V.

The extent to which the nerve conduction variables were related to each other, particularly the relationships between the conduction velocities and their associated distal latencies, was examined using Pearson product moment correlation coefficients.

Factor analysis was performed to further evaluate the extent to which the eleven variables were measuring the same things and to represent the relationships among the sets of variables parsimoniously. Within this analysis, the variables and factors were expressed in standardized form with mean of 0 and standard deviation of 1, thus, the total variance for the model was the sum of the variance for each variable (in this instance 11). The number of factors obtained by the principal components extraction method was based on the criterion that the eigenvalue, representing the total variance explained by the factor, was greater than one. Since the variance of each variable is 1, a factor with variance of less than 1 represents less of the variance than the variable itself.

Prior to eliminating variables, the number of abnormal nerve conduction tests per subject were counted. Comparisons were made between the numbers with abnormalities using all eleven variables, using five distal latency variables, and

using five conduction velocity variables.

For the most conservative and definitive specification of abnormality, subjects were divided into those without abnormality on any test, and those with abnormalities on all tests. Subjects with abnormalities on some but not all tests, i.e., the subjects who are in the grey area of diagnosis, were excluded from this conservative analysis but included in inclusive analyses, more representative of clinical reality.

3.9.3 Phase III - The Model

The primary purpose of the study was to develop a model for predicting the electrophysiological abnormalities associated with CTS based on a set of clinical features. The relationship of each independent variable with electrophysiological abnormalities was evaluated first by contingency tables and assessment of the association by the chi square test of independence. Additional information about each variable's association with abnormality was obtained by calculating the sensitivity, specificity, positive, and negative predictive values (Sackett et al., 1985: page 77). For this analysis, several independent variables were dichotomised. To dichotomize symptom frequency, symptoms that occurred all the time, or at some point every day were considered persistent; symptoms from time to time were intermittent. To dichotomize occupation, occupations that

required hand use but were not known to be predisposing to CTS were added to the predisposing occupations.

Stepwise logistic regression analysis (Hosmer and Lemeshow, 1989) was performed to investigate the relationships between combinations of clinical predictors and the probability of electrophysiological abnormality. The dependent variable was electrophysiological abnormality, presence of abnormality (d=1), and absence of abnormality (d=0). For the initial investigation, the asymptotic covariance estimate method (ACE) was used and the analyses included all the clinical predictors, as they were deemed important for clinical reasons, to determine which were most predictive. The ACE method uses a linear approximation to the likelihood ratio test (Hosmer and Lemeshow, 1989: page 111) and is recommended for initial analyses because it is faster and less expensive than the maximum likelihood ratio method (MLR) (BMDP Manual, Volume II: page 941). The clinical predictors selected to build the prediction equation using the MLR method were those providing a significant improvement in the log-likelihood chi square at the alpha level of 0.10.

The maximum likelihood estimates of the logistic regression coefficients $\hat{B}_i$ of the logistic model

$$\ln \; p_x/q_x = B_o + B_1x_1 + \ldots + B_px_p$$

(Schlesselman, 1982:234) were generated as well as the standard errors of the estimates of $\hat{B}_i$'s. In this formula,

ln p_x/q_x indicates the log odds, or logit, of risk (probability) of abnormality. The B_i parameters are logistic regression coefficients and represent the effect of each variable, adjusted for the effect of the other variables, on the probability of abnormality. The probability of abnormality was expressed by the equation:

$$\text{Probability (abnormality)} = \frac{e^{Bo + Bi}}{1 + e^{Bo + Bi}}$$

To test the model, another prediction of the model was made using all of the experimental subjects, thus including subjects exhibiting abnormalities on some as well as all the nerve conduction tests, i.e., those subjects who fall into the grey area of diagnosis were included. Subjects with fewer abnormal tests may, in fact, have a milder problem, thus providing a wider spectrum of disease from which to predict the model.

Further predictions of the model were made using the second variables created to categorize hand numbness and hand pain (page 54) with the most conservative and definitive specification of abnormality, (i.e., subjects without abnormality on any test, and subjects with abnormalities on all tests) and the subsequent specifications of abnormality (including subjects exhibiting abnormalities on some as well as all the nerve conduction tests to provide a wider spectrum of disease).

CHAPTER IV

RESULTS

4.1 Introduction

The first results reported are related to the first sub-problem, viz.:

1. Establishment of normative range of nerve conduction values based on values obtained for control subjects. Variables found to affect the nerve conduction results are identified. Criteria for abnormality of nerve conduction values are established. To account for variables influencing the nerve conduction values, the criteria for abnormality are adjusted.

The next sections of results deal with nerve conduction in the experimental subjects. Descriptive statistics for the total group of subjects are presented. The criteria for abnormality are applied to establish the extent of nerve conduction abnormality in the experimental subjects. The extent of electrophysiological abnormality is presented and the effect of adjustment to the criteria for abnormality is demonstrated.

The next results related to the second sub-problem are presented, viz.:

2. Determination of an appropriate categorization of experimental subjects into those with

electrophysiological abnormality and those without abnormality, based on a reduced number of nerve conduction tests. Correlations among the eleven nerve conduction variables are described.

Finally, the results related to the primary purpose of the study are presented, i.e., development of a model for predicting electrophysiological abnormality from a set of clinical variables.

3. Determination of the relationship between the clinical predictors or their combinations and abnormal results of nerve conduction studies.

4.2 Establishment of Normative Values Based on Controls

Descriptive statistics about the nerve conduction variables and the variables that affect them for the total group of control subjects, and males and females separately, are presented in Table V. The results of t-tests illustrated that differences existed between males and females for the nerve conduction variables MDML and MDSL2, both of which were only slightly longer in males; MSCV4, which was slower in females; and DIFFRESP, which was greater for females. Although the sex difference for MDSL4 was not statistically significant (P = 0.06), plots of the relationships between MDSL4 and the variables distance and temperature were observed to be different in males and females. Therefore, males and females were considered separately in the multiple regression analyses which follow.

Differences between males and females were observed for several of the variables that affect nerve conduction values. The distances over which distal latencies were measured (variables MDIST, MDIST2, and MDIST4) were shorter for female subjects than for male subjects and hand temperatures (TEMP) were cooler in female subjects. These sex differences were highly significant (P = 0.000).

Table V

Descriptive Information about Nerve Conduction Variables in the Control Subjects

	TOTAL GROUP N=104		FEMALES N=54		MALES N=50	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Nerve Conduction Variables						
MDML*	3.4	0.4	3.3	0.3	3.5	0.4
MDSL2*	2.3	0.2	2.2	0.21	2.4	0.2
MDSL4	2.5	0.3	2.4	0.3	2.5	0.3
MMCV	57.7	2.7	58.1	2.7	57.2	2.7
MSCV2	61.8	5.3	61.5	5.6	62.1	4.9
MSCV4*	57.7	4.9	56.7	5.1	58.9	4.6
SCVM2U5	1.58	5.60	1.70	5.59	1.46	5.68
SCVM4U4	-2.84	4.98	-3.39	5.03	-2.24	4.90
DSLM2U5	0.30	0.20	0.28	0.19	0.31	0.20
DSLM4U4	0.16	0.23	0.18	0.24	0.14	0.22
DIFFRSP*	0.27	1.08	0.47	1.09	0.05	1.05
Variables which could affect Nerve Conduction Variables						
MDIST[1]*	6.2	0.7	6.0	0.5	6.6	0.08
SDIST2[2]*	14.1	1.1	13.4	0.6	14.8	1.0
SDIST4[3]*	14.1	1.3	13.6	1.1	14.8	16.0
DISTM2U5[4]	2.1	0.8	1.97	0.73	2.19	0.78
DISTM4U4[5]	0.16	0.23	0.18	0.24	0.14	0.22
TEMP*	32.1	2.0	31.3	0.4	33.0	1.4
HEIGHT*	168.4	11.7	160.9	9.6	176.6	7.6
AGE	38.4	12.1	36.9	12.4	39.9	11.8

* Difference between males and females $P \leq 0.05$

[1] Distance over which MDML was measured.

[2] Distance over which MDSL2 was measured.

[3] Distance over which MDSL4 was measured.

[4] Difference in distance over which MDSL2 and UDSL5 were measured.

[5] Difference in distance over which MDSL4 and UDSL4 were measured.

Multiple regression analyses using stepwise selection were conducted to determine the dependence of the nerve conduction values on the variables of temperature, age, distance, height, sex, and interaction with sex. The analyses produced the regression equations reported in Table VI. Only those regression analyses yielding multiple correlation coefficients indicating that 10% of the variance in the nerve conduction variable was accounted for by another variable ($R^2 \geq 0.10$) are reported in Table VI.

Table VI

Multiple Regression Equations
of Nerve Conduction Variables with Influencing Variables

MDML females	= 6.13 - .09 TEMP	R^2=.35
MDSL2 males	= .34 + .14 MSDIST2	R^2=.37
MDSL2 females	= 1.79 - .04 TEMP + .13 MSDIST2	R^2=.36
MDSL4 males	= -.04 + .17 MSDIST4	R^2=.56
MDSL4 females	= 2.76 - .05 TEMP + .10 MSDIST4	R^2=.42
MSCV4 females	= 20.56 + 1.16 TEMP	R^2=.24

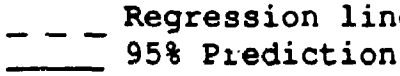
Prediction bands were placed around those multiple regression equations to adjust the upper and lower limits for the criteria for assigning abnormality for the nerve conduction variables that were found to be affected by other

variables. Thus, prediction bands were placed around the equations to set the upper limits for the variable MDML for females; for MDSL2 and MDSL4 for males and females; and the lower limit for the variable MSCV4 for females.

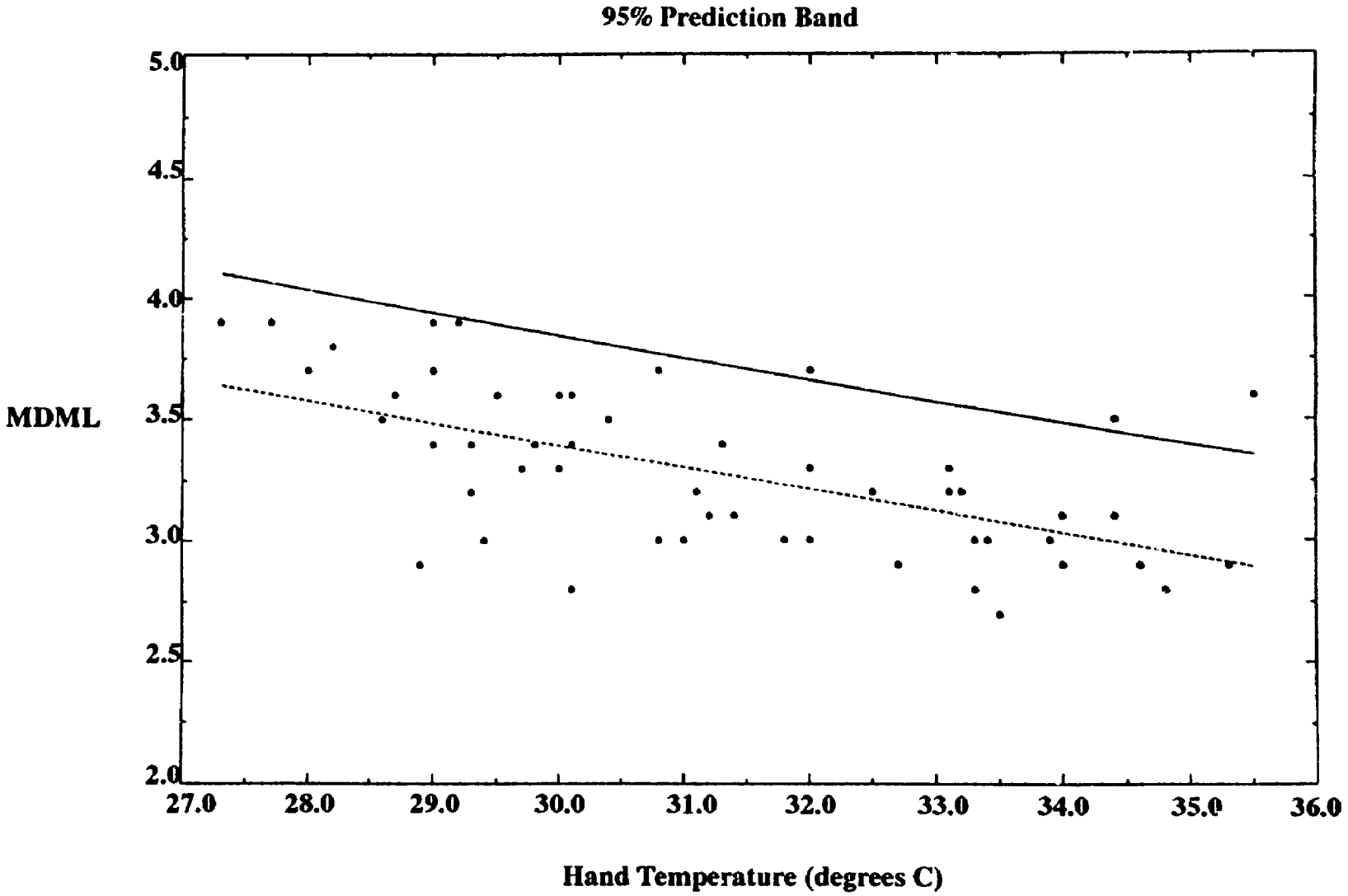
An example of a 95% prediction band is illustrated in Figure I. The example was based on the regression equation for MDML as a function of hand temperature in females. The values in the figure were those for the control group from which the regression equation was derived. When the prediction equation was applied to the experimental subjects, the values of the subjects that were above the prediction band were the values that were considered abnormal. It can be seen that the prediction band appeared to be a straight line rather than curved at the extremes. When plotted to extend beyond the values of these data, the line was curved at the extremes.

Figure I

95% Prediction Band
for MDML as a Function of Hand Temperature
in Female Control Subjects



Median Nerve DML as Function of Hand Temperature



For the nerve conduction variables that were not affected by other variables and did not require adjustment of the abnormality criteria, the 95th or 5th percentile values were used to designate abnormality. These values are presented in Table VII.

Table VII

95th and 5th Percentile Values
of Nerve Conduction Variables

		Cutoff value		
	Percentile	Total group	Males	Females
MDML	95th	-	4.2	A
MDSL2	-	-	A	A
MDSL4	-	-	A	A
MMCV	5th	53.3	-	-
MSCV2	5th	53.2	-	-
MSCV4	5th	-	50.5	A
SCVM2U5	5th	-7.7	-	-
SCVM4U4	5th	-11.2	-	-
DSLM2U5	95th	.6	-	-
DSLM4U4	95th	.6	-	-
DIFFRESP	95th	-	1.9	2.3

"A" refers to adjusted criteria.

4.3 Nerve Conduction in the Experimental Subjects

The means and standard deviations of the nerve conduction variables for the experimental subjects are presented in Table VIII. These values were calculated from the unadjusted nerve conduction data without accounting for the variables that affected them. It was to these unadjusted values that the criteria for assigning abnormality were applied.

Table VIII illustrates that, compared with the control values, the distal latencies of the total group of experimental subjects were prolonged, the conduction velocities were reduced, and there was more variability among the values. These results are not surprising since this group consists of subjects with a wide range of electrophysiological results, i.e., subjects with no abnormality and subjects with severe abnormality.

The number of observations used to calculate the means and standard deviations are indicated. There were few true missing data points. The apparent missing observations were due to inability to elicit a response, and this indicates conduction block. The absent responses, recorded as zeros, were omitted from the calculation of means and standard deviations for interpretability. Absent responses for the median nerve were included in the computation of variables for assigning abnormality in the next section. Absent responses

Table VIII

Descriptive Information about the Nerve Conduction Variables in the Experimental Subjects

	Total Group Mean	S.D.	Number of Observations*	
Nerve Conduction Variables				
MDML	4.2	1.3	285	
MDSL2	2.8	0.7	269	
MDSL4	2.9	0.6	227	(1 missing)
MMCV	55.9	4.1	285	
MSCV2	51.7	11.1	269	
MSCV4	49.6	9.8	227	(1 missing)
SCVM2U5	-6.8	10.8	264	
SCVM4U4	-10.1	10.1	221	
DSLM2U5	0.8	0.6	264	
DSLM4U4	0.6	0.6	221	
DIFFRESP	1.8	3.0	276	(2 missing)
Variables which could affect Nerve Conduction Variables				
MDIST[1]	6.1	0.7	285	
SDIST2[2]	13.7	0.9	269	
SDIST4[3]	13.8	1.2	227	(1 missing)
DISTM2U5[4]	2.2	0.7	264	
DISTM4U4[5]	0.4	1.1	221	
TEMP	32.4	1.7	285	
HEIGHT	165.8	9.4	283	(2 missing)
AGE	44.3	13.7	284	(1 missing)

* Missing observations - due to inability to elicit sensory nerve responses, except where indicated.

[1] Distance over which MDML was measured.

[2] Distance over which MDSL2 was measured.

[3] Distance over which MDSL4 was measured.

[4] Difference in distance over which MDSL2 and UDSL5 were measured.

[5] Difference in distance over which MDSL4 and UDSL4 were measured.

for the ulnar nerve were not used in the calculation of the variables assessing differences (SCVM2U5, SCVM4U4, DSLM2U5, DSLM4U4). This was because the values of the resulting variables indicated median nerve disorder when, in fact, the disorder was of the ulnar nerve. The data of subjects who had absent ulnar responses were reviewed individually to ensure that these subjects were appropriately assigned with respect to median nerve conduction abnormality.

4.4 Abnormality within the Experimental Subjects

Abnormalities for the nerve conduction variables within the experimental subjects were determined based on the criteria for abnormality established by the prediction bands and percentile techniques. The number of subjects exhibiting abnormality for each of the nerve conduction variables is presented in Table IX. The table includes the numbers of subjects classified as normal and abnormal for the nerve conduction tests when unadjusted cutoff values were used and when adjusted criteria for assigning abnormality were used.

Table IX

Numbers of Experimental Subjects with Abnormal Nerve Conduction Results Using Unadjusted Cutoff Values and Adjusted Criteria for Assigning Abnormality

Nerve Conduction Variable	Number of Subjects Using Unadjusted Cutoff Values[1]		Using Adjusted Criteria[2]	
	Normal	Abnormal	Normal	Abnormal
MDML	141	144	137	148
MDSL2	147	138	109	176
MDSL4	119	165	105	179
MMCV	219	66	219	66
MSCV2	122	163	122	163
MSCV4	110	174	107	177
SCVM2U5	147	133	147	133
SCVM4U4	125	150	125	150
DSLM2U5	119	161	119	161
DSLM4U4	121	154	121	154
DIFFRESP	178	103	186	95

	[1]Unadjusted Cutoff Values	[2]Required Adjustments to Criteria
MDML	≥ 4.0 or = 0	males ≥ 4.2 or = 0 females adjust for temperature
MDSL2	≥ 2.8 or = 0	males adjust for distance females adjust for temperature and distance
MDSL4	≥ 2.9 or = 0	males adjust for distance females adjust for temperature and distance
MMCV	≤ 53.3	< 53.3 (no adjustment)
MSCV2	≤ 53.2	< 53.2 (no adjustment)
MSCV4	≤ 50.0	males ≤ 50.5 females adjust for temperature
SCVM2U5	≤ -7.7	≤ -7.7 (no adjustment)
SCVM4U4	≤ -11.2	≤ -11.2 (no adjustment)
DSLM2U5	≥ .6	≥ .6 (no adjustment)
DSLM4U4	≥ .6	≥ .6 (no adjustment)
DIFFRESP	≥ 2.0	males ≥ 1.9 females ≥ 2.3

Table IX demonstrates that after the adjusted criteria were applied MDSL4, followed closely by MSCV4 and MDSL2, identified the largest numbers of subjects with abnormality (179, 177, and 176 subjects respectively). MSCV2 and DSLM2U5 identified somewhat fewer subjects (163 and 161 subjects respectively). The effect of using adjusted criteria for the variables that required adjustment was to increase the proportion of abnormality for the latency and conduction velocity variables. For DIFFRESP, the proportion of abnormality was reduced by using different cutoff values for males and females.

Observation of the amount of abnormality for each variable, when the adjusted criteria were used, shows that the test results were not consistent, i.e., some nerve conduction tests identified more abnormality than others in this group of subjects. It is evident that redundant information is provided by the use of eleven tests. Therefore, inter-relationships among the nerve conduction variables were investigated with the intent to reduce the number of variables used in the classification of median nerve conduction abnormalities.

4.5 Inter-relationships among Electrophysiological Variables in Control Subjects and Experimental Subjects

The relationships among the eleven nerve conduction variables in the control subjects were examined using techniques of correlation and factor analysis. For these analyses, the data were not adjusted for the effects of sex, temperature, and distance. This lack of adjustment may have introduced error by increasing or decreasing the extent of the relationships among the variables. Pearson product moment correlation coefficients were calculated for each combination of variables and Table X shows the correlation matrix.

Table X

Correlation Matrix of Unadjusted Nerve Conduction Variables in Control Subjects

	MDML	MDSL2	MDSL4	MMCV	MSCV2	MSCV4	SCV M2U5	SCV M4U4	DSL M2U5	DSL M4U4
MDSL2	.76									
MDSL4	.58	.72								
MMCV	-.29	-.29	-.34							
MSCV2	-.61	-.71	-.56	.25						
MSCV4	-.47	-.44	-.62	.29	.70					
SCVM2U5	-.25	-.35	-.29	.05	.54	.29				
SCVM4U4	-.13	-.11	-.25	-.11	.19	.38	.46			
DSLM2U5	.22	.43	.32	-.08	-.50	-.29	-.80	-.48		
DSLM4U4	.16	.16	.35	.02	-.25	-.40	-.44	-.91	.55	
DIFFRESP	.01	-.01	-.01	.16	-.01	-.16	-.06	-.31	.15	.25

Table X illustrates the highest correlations between the latency comparison variables and their corresponding conduction velocity comparison variables, i.e., DSLM4U4 and

SCVM4U4 (r = -.91), and DSLM2U5 and SCVM2U5 (r = -.80). Correlations existed also between distal sensory latencies and their corresponding conduction velocities but the relationships were not as strong, i.e., MDSL2 and MSCV2 (r = -.71), MDSL4 and MSCV4 (r = -.62). Other highly correlated pairs were: MDML and MDSL2 (r = .76), MDSL2 and MDSL4 (r = .72), MSCV2 and MSCV4 (r = .70),

To further investigate the inter-relationships among the nerve conduction variables in the control subjects, factor analysis was performed. The results of the factor analysis, presented in Table XI, illustrate a three-factor solution with varimax rotation, which explained 71.4 percent of the variance. MMCV did not load strongly on any of the three factors while DIFFRESP loaded less than the other variables on the third variable. The communality values for MMCV and DIFFRESP, i.e., the values that describe the proportion of variance explained by the common factors, were 0.34 and 0.51 respectively. Since SCVM2U5 and DSLM2U5 (the two computed variables measuring the difference between the median nerve to the second digit and the ulnar nerve to the fifth digit) load on the second factor, and SCVM4U4 and DSLM4U4, (the two variables measuring the difference between the median nerve and ulnar nerve to the fourth digit) load on the third factor, the results suggest that they are measuring different things.

Table XI

Principal Components Analysis
of Unadjusted Nerve Conduction Variables
in Control Subjects

	Communality	Factor	Eigenvalue	Pct of Var
MDML	.68	1	4.60	41.8
MDSL2	.78	2	2.16	19.6
MMCV	.34	3	1.09	9.9
MSCV2	.75	4	.88	8.0
MSCV4	.70	5	.73	6.6
SCVM2U5	.86	6	.59	5.4
SCVM4U4	.85	7	.40	3.6
DIFFRESP	.51	8	.23	2.1
MDSL4	.72	9	.16	1.5
DSLM4U4	.82	10	.11	1.0
DSLM2U5	.85	11	.05	.4

Rotated Factor Matrix:

	FACTOR 1	FACTOR 2	FACTOR 3
MDML	.82	-.09	.03
MDSL2	.84	-.28	-.06
MMCV	-.54	-.05	.22
MSCV2	-.75	.43	-.03
MSCV4	-.72	.10	-.42
SCVM2U5	-.18	.91	-.09
SCVM4U4	-.04	.46	-.80
DIFFRESP	-.03	.12	.70
MDSL4	.81	-.15	.19
DSLM4U4	.11	-.49	.75
DSLM2U5	.20	-.88	.18

This finding suggests the retention of one of the two variables measuring each comparison, i.e., either SCVM2U5 or DSLM2U5, and either SCVM4U4 or DSLM4U4. Since each pair of

variables is so highly correlated, the use of either the conduction velocity variable or DSL for each pair is appropriate.

Since the goal was to reduce the number of variables used to detect abnormality in the experimental subjects, similar correlation analysis and factor analysis were performed using the experimental subjects. The nerve conduction variables were the values before the criteria for abnormality were applied. These data were continuous (as they were in the control subjects) but a greater range of nerve conduction values and greater variability among them was present. As in the control analyses, their precision was limited by the lack of adjustment for the effect of other variables. The correlations among the variables are presented in Appendix VI. The results of the factor analysis performed on the unadjusted variables of the experimental subjects are presented in Table XII.

The three-factor solution, which explained 78.8% of the variance, was not as readily interpretable as that for the control subjects. However, MMCV and DIFFRESP demonstrated lower communality values than the rest of the variables (0.47 and 0.20 respectively). They were the variables least correlated with the other nerve conduction variables and the variables which loaded least strongly on the factors. MSCV2 loaded most strongly on the first factor, as did MDML and

SCVM2U5. On the second factor, MDSL4 and the comparison variable DSLM4U4 loaded strongly. MDSL2 and the comparison variable DSLM2U5 loaded strongly on the third factor.

Table XII

Principal Components Analysis
of Unadjusted Nerve Conduction Variables
in Experimental Subjects

	Communality	Factor	Eigenvalue	Pct of Var
MDML	.76	1	5.20	47.3
MDSL2	.93	2	2.16	19.6
MMCV	.47	3	1.30	11.9
MSCV2	.91	4	.91	8.2
MSCV4	.93	5	.70	6.4
SCVM2U5	.81	6	.35	3.2
SCVM4U4	.87	7	.15	1.4
DIFFRESP	.20	8	.11	1.0
MDSL4	.92	9	.08	0.8
DSLM4U4	.92	10	.03	0.2
DSLM2U5	.94	11	.02	0.2

Rotated Factor Matrix:

	FACTOR 1	FACTOR 2	FACTOR 3
MDML	-.81	-.31	.06
MDSL2	-.00	.03	.96
MMCV	.66	-.12	-.15
MSCV2	.91	.28	.07
MSCV4	.70	.60	-.28
SCVM2U5	.81	.33	.18
SCVM4U4	.63	.62	-.29
DIFFRESP	-.20	-.20	.40
MDSL4	.17	.95	.04
DSLM4U4	.18	.94	.01
DSLM2U5	.06	.05	.96

Peculiar to this solution, SCVM4U4 and to a lesser extent MSCV4 loaded on both the first and second factors.

To reduce the error introduced by other variables which affected the nerve conduction variables, correlation analysis and factor analysis were performed using the data for the experimental subjects after the criteria for adjustment were applied. The data for these analyses were dichotomous variables coded 0, normal, and 1, abnormal, for each of the variables. The correlation matrix of the nerve conduction variables after adjustment, for the experimental subjects, is presented in Table XIII.

Table XIII

Correlation Matrix of Nerve Conduction Variables After Applying Adjusted Criteria of Abnormality in Experimental Group

	MDML	MDSL2	MDSL4	MMCV	MSCV2	MSCV4	SCV M2U5	SCV M4U4	DSL M2U5	DSL M4U4
MDSL2	.69									
MDSL4	.67	.81								
MMCV	.28	.33	.33							
MSCV2	.64	.87	.76	.36						
MSCV4	.69	.83	.91	.30	.78					
SCVM2U5	.60	.67	.64	.23	.68	.65				
SCVM4U4	.61	.67	.73	.27	.67	.74	.74			
DSLM2U5	.65	.74	.73	.23	.69	.77	.80	.76		
DSLM4U4	.67	.71	.77	.29	.67	.78	.71	.85	.81	
DIFFRESP	.61	.51	.54	.30	.57	.55	.64	.60	.61	.58

Inspection of Table XIII shows that, as expected, high correlations between distal sensory latencies and the associated sensory conduction velocities were found, i.e., between MDSL2 and MSCV2, r = .87; between MDSL4 and MSCV4, r = .91; between DSLM2U5 and SCVM2U5, r = .80; and between DSLM4U4 and SCVM4U4, r = .85. Other highly correlated pairs were MDSL2 and MDSL4 (r = .81), MDSL2 and MSCV4 (r = .83), and DSLM4U4 and DSLM2U5 (r = .81).

The inter-relationships among the nerve conduction variables in the experimental subjects were further investigated by principal components factor analysis. A one-factor solution to the analysis, illustrating that all the variables are interrelated, explained 67.7 percent of the variance. The value of the Kaiser-Meyer-Olkin measure of sampling adequacy, an index which compares the magnitude of the observed correlation coefficients to the magnitude of the partial correlation coefficients, was 0.92 indicating that the correlations between pairs of variables can be explained by the other variables and hence factor analysis was appropriate. The results of the factor analysis are presented in Table XIV. The factor loadings, i.e., the coefficients that relate the variables to the factor, are presented in descending order of magnitude.

Table XIV

Principal Components Analysis of Nerve Conduction Variables After Applying Adjusted Criteria of Abnormality in Experimental Subjects

	FACTOR 1				
	Factor Loadings	Communality	Factor	Eigenvalue	Pct of Var
MSCV4	.91	.82	1	7.43	67.6
MDSL4	.89	.79	2	.91	8.3
DSLM4U4	.89	.78	3	.69	6.3
DSLM2U5	.88	.78	4	.50	4.5
MDSL2	.88	.78	5	.41	3.7
MSCV2	.86	.74	6	.32	2.9
SCVM4U4	.85	.74	7	.25	2.2
SCVM2U5	.84	.69	8	.18	1.7
MDML	.80	.64	9	.12	1.1
DIFFRESP	.72	.51	10	.11	1.0
MMCV	.40	.15	11	.08	.7

Table XIV illustrates that the first nine variables loaded very strongly on the same factor and were, therefore, providing similar information. The fact that MMCV did not load strongly on this factor suggests that it was measuring something different from the first nine variables; this point was confirmed by a two-factor solution in which MMCV was the only variable of the eleven which loaded on the second factor. The eigenvalue for the second factor was 0.91, representing the total variance explained by the factor. DIFFRESP also loaded less strongly, suggesting that it was measuring something similar to the first nine variables but not the same. The results of the factor analysis suggest that the

first nine variables were inter-related and measuring the same thing and that from a statistical standpoint alone, one variable might be sufficient to illustrate abnormality of the median nerve.

Before eliminating any nerve conduction variables from those to be used in the categorization of abnormality, 2 x 2 contingency tables of each nerve conduction variable with all the other variables were created (See Appendix VII). It was found that MDSL2 was abnormal more often than MSCV2; MDSL4 was abnormal only slightly more often than MSCV4; and DSLM2U5 and DSLM4U4 were abnormal more often than SCVM2U5 and SCVM4U4 respectively. DIFFRESP and MMCV added nothing to the detection of abnormality, i.e., they did not identify abnormality that had not been identified already by the other variables. The nerve conduction findings of the subjects who were in the discordant pairs were reviewed to ensure that, if a particular variable were eliminated, the subject would be appropriately categorized.

In an effort to avoid redundancy and to reduce the number of variables considered in the detection of electro-physiological abnormality consistent with CTS, it was decided to eliminate MMCV and DIFFRESP from the list of variables being considered. This was done for the following reasons:

a) The outcome of the factor analyses on both control and experimental groups suggested that these variables are

measuring something different from all the other variables. Neither of these tests directly evaluates the function of the median nerve within the carpal tunnel.

b) The evidence in the contingency tables and subsequent review of data illustrated that MMCV and DIFFRESP did not add to the detection of abnormality, i.e., they did not detect abnormality that was not already detected by the other variables.

For the present study, it was deemed appropriate to use the distal latency variables instead of the conduction velocity variables for the following reasons:

a) There was extensive use of median nerve DSL and variables comparing median nerve and ulnar nerve DSL to diagnose CTS reported in the literature. Use of latency variables allows one comparison of the present findings with the work of others.

b) MDML was a better measure of motor conduction than MMCV for the reasons previously stated.

c) The criteria for assigning abnormality to the distal latency values were adjusted for variables that affected them.

The numbers of abnormal nerve conduction tests per subject were counted using all eleven nerve conduction variables, latencies only, and conduction velocities only. These numbers are presented in Table XV.

Table XV

Number of Subjects with Given Numbers of Abnormal Nerve Conduction Tests

Number of Abnormal Variables	Number of Subjects					
	All Variables		Latency Variables		Conduction Velocity Variables	
0	75		82		87	
1	15	101	19	101	21	
2	11		17		27	
3	4		21		27	
4	11		28		82	
5	13		118		41	
6	12					
7	12					
8	18					
9	28					
10	54	114				
11	32					

Table XV illustrates that, by comparing the number of subjects designated to have abnormal latency variables with the numbers of subjects designated abnormal using all eleven variables, the number of subjects with five abnormal latency variables was comparable to the number of subjects with nine or more combined variables. Similarly, the number of subjects with zero or one abnormal latency variables was comparable to the number of subjects with two or less combined variables.

The most conservative and definitive classification of subjects into those with abnormality and those without

abnormality was as follows: those with no abnormal variables were considered normal (n=82) and those with abnormality on all five latency variables were considered abnormal (n=118). This classification was the most conservative specification of median nerve abnormality for developing the prediction model.

Two other specifications for diagnosing CTS were used to evaluate the robustness of the associations and the prediction model. For the first, normality was defined as no abnormality or only one abnormal latency value (n=101), while subjects with two to five abnormal latency values were considered abnormal (n=184). This specification is the most inclusive of the whole spectrum of abnormality. It includes subjects whose degree of abnormality is less extreme, the subjects who fall into the grey area. For the second, normality was defined as no abnormality or only one abnormal latency value (n=101), while subjects with four or five abnormal latency values were considered abnormal (n=146). This specification includes subjects whose abnormality is between the most conservative and the most inclusive.

4.6 Relationship of Clinical Features to Electrophysiological Findings

Using the most conservative specification of abnormality, i.e., no abnormal variables versus abnormality on all five latency variables (ABNLAT 0 VS. 5), the univariate association of each independent variable with the dependent variable was determined. These results are illustrated by the Chi square values in Table XVI. Nocturnal discomfort, the Flick sign, and Phalen's test were shown to be highly associated with abnormality. No other variables attained the $P \leq 0.05$ level required for statistical significance.

The capability of the independent variables to predict abnormality was further investigated by examining the sensitivity, specificity, positive and negative predictive values of each variable. These results are presented in Table XVII. The prevalence of abnormality at this specification was 59%. The raw values on which this table was based are in the Appendix VIII.

Table XVI

Chi Square Analysis of Association between Predictor Variables[1] and Abnormality (ABNLAT 0 VS. 5)

	Chi[2]	d.f.	P-value
Symptom frequency	2.04	2	0.361
Nocturnal discomfort	26.51	1	0.000*
Flick sign	25.87	1	0.000*
Clumsiness	1.30	1	0.254
Hand numbness	9.10	3	0.128
Hand pain	5.78	3	0.123
Family history	3.69	1	0.055
Job	1.30	2	0.522
Recreational activities	4.53	2	0.104
Atrophy	0.49	1	0.485
Light touch	2.50	2	0.286
Pin prick	1.51	3	0.680
Hyperaesthesia	0.58	1	0.446
Two point discrimination	1.38	3	0.710
Weakness	0.02	1	0.876
Tinel's sign	0.00	1	1.000
Phalen's test	7.31	1	0.007*
Cuff compression	0.00	1	1.000

* $P \leq 0.05$

[1] Discrete

Table XVII
Sensitivity, Specificity, and Predictive Values
of the Dichotomous Clinical Features (ABNLAT 0 VS. 5)

Independent Variables	Sensitivity	Specificity	Predictive Values Positive	Predictive Values Negative
Symptom frequency	78.8	29.3	61.6	49.0
Nocturnal discomfort	83.9	51.2	71.2	68.9
Flick sign	78.8	57.3	72.7	65.3
Clumsiness	43.2	47.6	54.3	36.8
Family history	16.1	93.9	79.2	43.8
Job	56.8	35.4	55.8	36.3
Recreation	41.5	72.0	68.1	46.1
Atrophy	8.5	95.1	71.4	41.9
Weakness	28.0	74.1	61.1	41.4
Hyperaesthesia	21.2	84.1	65.8	42.6
Tinel's sign	17.8	81.7	58.3	40.9
Phalen's test	64.3	56.1	67.3	52.9
Cuff compression test	72.3	27.5	59.3	40.4

The results presented in Table XVII indicate that nocturnal discomfort and Flick sign had higher sensitivities (83.9% and 78.8% respectively) than Phalen's test (64.3%) and were fairly good predictors of abnormality (positive predictive values of 71.2% and 72.9%). Family history had the highest positive predictive value, 79.2%, with a low sensitivity of 16.1% and high specificity of 93.9%. A similar trend was observed for atrophy.

Logistic regression analysis was performed to develop a multivariate model for predicting the electrophysiological

abnormality based on a set of clinical variables. The clinical variables used for the analysis were all of the variables indicated in Table XVI except cuff compression. Duration of symptoms was also included in the analysis. The variables that subsequently entered the equation to create the model were those providing a significant improvement in the log-likelihood chi square at the alpha level of 0.10. The results of the logistic regression analysis, including regression coefficients and standard errors of the estimates are shown in Table XVIII. In addition, the crude and adjusted odds ratios of abnormality for the clinical predictors are presented. The Table reports only those variables that had a significant improvement in the log-likelihood chi square ($P \leq 0.05$), i.e., those variables that significantly changed the prediction of abnormality. The coefficients represent the effect of each variable, adjusted for the effect of the other variables, on the probability of detecting abnormal nerve conduction studies.

Based on the results of the logistic regression shown in Table XVIII, the model for the natural log of the probability of predicting abnormal latencies from clinical predictors was:

$$\ln p_i/q_i = -1.65 + 1.38\ FS + 1.38\ ND + 0.009\ SD$$

where $\ln p_i/q_i$ is the natural log of the probability of detecting abnormality, FS refers to Flick sign, ND refers to nocturnal discomfort, and SD refers to symptom duration. The

probability value (P = 0.566) for the Hosmer Lemeshow Chi square statistic suggests that the goodness of fit for this model is adequate. With the univariate chi square analyses, reported in Table XVI, Phalen's test was observed to be

Table XVIII
Logistic Regression Analysis for Prediction Model
(ABNLAT 0 VS. 5)

	Coefficient	S.E.	P-value
Flick sign	1.377	0.341	0.000
Nocturnal discomfort	1.378	0.356	0.000
Symptom duration (mon.)	0.009	0.005	0.044
(constant)	-1.647	0.363	

Crude and Adjusted Odds Ratios of Abnormality
by the Dichotomous Clinical Predictors in the Model

	Crude Odds Ratio	Adjusted Odds Ratio	95% Confidence Limits About the Adjusted Odds Ratios
Flick sign	5.0	4.0	2.0-7.7
Nocturnal discomfort	5.5	4.0	2.0-8.0

associated with abnormality. In contrast, Table XVIII illustrates that using multivariate analysis, symptom duration contributed significantly to the explained variance whereas Phalen's test did not. (Symptom duration was not included in the chi square results as it was a continuous variable.)

Further univariate analyses and logistic regression analyses were conducted using differing designations of abnormality. For the next designation, all the 285

experimental subjects were included in the analyses for the purpose of including a wide spectrum of CTS and disorders that could be easily confused with CTS. Subjects with no abnormality or only one latency abnormality were classified as normal, and those with two or more abnormalities were classified as abnormal (ABNLAT 0,1 VS. 2-5).

The univariate associations of the independent variables with abnormality were investigated using chi square analyses.

Table XIX

Chi Square Analyses of the Association between Predictor Variables[1] and Abnormality (ABNLAT 0,1 VS. 2-5)

	Chi[2]	d.f.	P-value
Symptom frequency	2.57	2	0.276
Nocturnal discomfort	16.85	1	0.000*
Flick sign	17.49	1	0.000*
Clumsiness	1.21	1	0.271
Hand numbness	8.86	3	0.031*
Hand pain	3.21	3	0.360
Family history	7.17	1	0.007*
Job	1.67	2	0.434
Recreational activities	2.21	2	0.331
Atrophy	0.00	1	1.000
Light touch	0.70	3	0.873
Pin prick	2.11	3	0.550
Hyperaesthesia	3.02	1	0.082
Two point discrimination	0.60	3	0.900
Weakness	0.32	1	0.572
Tinel's sign	0.00	1	1.000
Phalen's test	4.16	1	0.041*
Cuff compression	0.43	1	0.511

* $P \leq 0.05$
[1] Discrete

The results of the chi square analyses presented in Table XIX indicate that nocturnal discomfort, the Flick sign, and family history were highly associated with this designation of abnormality, while hand numbness and Phalen's test were less highly associated.

The ability of the clinical variables to predict abnormality is illustrated by their predictive values. The predictive values for the clinical predictors at this

designation of CTS are presented in Table XX. The raw data on which this table is based are in Appendix IX.

Table XX
Sensitivity, Specificity, and Predictive Values
of the Dichotomous Clinical Features (ABNLAT 0,1 VS. 2-5)

Independent Variables	Sensitivity	Specificity	Predictive Values Positive	Predictive Values Negative
Symptom frequency	78.3	26.7	66.1	40.3
Nocturnal discomfort	76.1	48.5	72.9	52.7
Flick sign	72.3	53.5	73.9	51.4
Clumsiness	42.9	49.5	60.8	32.3
Family history	19.6	93.1	83.7	38.8
Job	58.2	38.6	63.3	33.6
Recreation	34.8	71.3	68.8	37.5
Atrophy	8.2	92.1	65.2	35.5
Weakness	31.0	73.0	67.9	36.5
Hyperaesthesia	25.5	84.2	74.6	38.3
Tinel's sign	17.9	82.2	64.7	35.5
Phalen's test	59.4	54.0	69.9	42.5
Cuff compression test	73.1	31.8	66.9	38.6

Using the specification ABNLAT 0,1 VS. 2-5, the prevalence of CTS was 65%. The sensitivities for nocturnal discomfort and Flick sign were less than those reported in Table XVII, i.e., the sensitivity for nocturnal discomfort was 83.9% at the specification ABNLAT 0 VS. 5, and was 76.1% at ABNLAT 0,1 VS. 2-5. The specificities of nocturnal discomfort and Flick sign were also lower. The changes in sensitivity

and specificity reflect the difference in the specification of abnormality and in disease spectrum. The effect of these changes on the predictive values was that the positive predictive values were minimally higher and the negative predictive values were considerably lower. Despite the univariate association noted for Phalen's test, the sensitivity, specificity, and associated positive and negative predictive values were low. The positive predictive value for family history was higher than that for the previous specification which reflected the slight increase in sensitivity as well as the higher pretest probability.

Multivariate logistic regression analyses were conducted to test the robustness of the previous prediction model. The results of the logistic regression analysis for this specification of abnormality, ABNLAT 0,1 VS. 2-5, are presented in Table XXI.

Table XXI
Log_stic Regression Analysis for Prediction Model
(ABNLAT 0,1 VS. 2-5)

	Coefficient	S.E.	P-value
Flick sign	0.994	0.272	0.000
Nocturnal discomfort	0.902	0.277	0.000
Family history	1.159	0.453	0.005
(constant)	-0.735	0.262	

Crude and Adjusted Odds Ratios of Abnormality
by the Clinical Predictors in the Model

	Crude Odds Ratio	Adjusted Odds Ratio	95% Confidence Limits About the Adjusted Odds Ratios
Flick sign	3.0	2.6	1.6-4.6
Nocturnal discomfort	3.0	2.6	1.4-4.6
Family history	3.3	3.1	1.3-7.7

The results shown in Table XXI indicate that the highly significant univariate associations of Flick sign, nocturnal discomfort, and family history with abnormality were preserved using multivariate techniques. However, the weaker associations of hand numbness and Phalen's test were not maintained. Symptom duration, which was present in the previous prediction model was not included in this model. The model for the natural log of the probability of predicting abnormality from the clinical predictors was:

$$\ln p_i/q_i = -0.74 + 0.99\ FS + 0.90\ ND + 1.16\ FH$$

where $\ln p_i/q_i$ is the natural log of the probability of

detecting abnormality, FS refers to Flick sign, ND refers to nocturnal discomfort, FH refers to family history. The P-value for the Hosmer Lemeshow Chi square was 0.694 indicating that the model provided an adequate fit to these data.

A third logistic regression analysis was used to further test the robustness of the emerging model. Excluded from this analysis were those subjects with an intermediate number cf latency abnormalities, i.e., subjects with no abnormality or only one latency abnormality were classified as normal, and subjects with four or five abnormalities were classified as abnormal (ABNLAT 0,1 VS. 4,5). The univariate associations of the clinical variables with CTS were evaluated by chi square analyses. The results of the chi square analyses are presented in Table XXII.

The results of the chi square analyses reported in Table XXII are very similar to those for the previous specification of CTS (ABNLAT 0,1 VS. 2-5) shown in Table IX. Nocturnal discomfort, the Flick sign, and family history were again highly associated with detection of abnormality. In contrast to the previous specification, hand numbness was highly significantly associated with detection of abnormality. Phalen's test showed a weaker but significant association.

Table XXII

Chi Square Analysis of the Association between Predictor Variables[1] and Abnormality (ABNLAT 0,1 VS. 4,5)

	Chi^2	d.f.	P-value
Symptom frequency	2.05	2	0.359
Nocturnal discomfort	23.87	1	0.000*
Flick sign	20.16	1	0.000*
Clumsiness	0.81	1	0.367
Hand numbness	11.97	3	0.008*
Hand pain	2.64	3	0.450
Family history	7.01	1	0.008*
Job	1.38	2	0.502
Recreational activities	3.41	2	0.181
Atrophy	0.00	1	1.000
Light touch	1.43	2	0.490
Pin prick	1.08	3	0.782
Hyperaesthesia	2.66	1	0.103
Two point discrimination	0.91	3	0.822
Weakness	0.15	1	0.697
Tinel's sign	0.00	1	1.000
Phalen's test	5.13	1	0.024*
Cuff compression	0.19	1	0.665

* $P \leq 0.05$
[1] Discrete

The predictive values, obtained to further examine the ability of the clinical variables to predict this specification of the electrophysiological abnormality (ABNLAT 0,1 VS. 4,5), are presented in Table XXIII. The raw data on which this table is based are in Appendix X.

Table XXIII
Sensitivity, Specificity, and Predictive Values
of the Dichotomous Clinical Features (ABNLAT 0,1 VS. 4,5)

Independent Variables	Sensitivity	Specificity	Predictive Values Positive	Predictive Values Negative
Symptom frequency	80.1	26.7	61.3	48.2
Nocturnal discomfort	81.5	48.5	69.6	64.5
Flick sign	75.3	53.5	70.1	60.0
Clumsiness	43.8	49.5	55.7	37.9
Family history	19.9	93.1	80.6	44.5
Job	56.2	38.6	56.9	37.9
Recreation	37.7	71.3	65.5	44.2
Atrophy	7.5	92.1	57.9	40.8
Weakness	30.1	73.0	62.0	41.7
Hyperaesthesia	25.3	84.2	69.8	43.8
Tinel's sign	17.1	82.2	58.1	40.7
Phalen's test	61.5	54.0	65.7	49.5
Cuff compression test	72.0	31.8	60.8	43.5

Using ABNLAT 0,1 VS. 4,5 as the specification of abnormality, the prevalence of disease was 59%, the same as it was for the primary specification. In fact, the sensitivities, specificities, and predictive values were all very similar to those observed for both previous specifications of CTS. The sensitivity values for nocturnal discomfort, Flick sign, and Phalen's test were between those of the previous two specifications. The specificities tended to be more similar to those of ABNLAT 0,1 VS. 2-5. The predictive values are also similar with the exception of the

positive predictive value for atrophy which dropped from 71.4% to 57.9%.

The multivariate associations of the clinical predictors with ABNLAT 0,1 VS. 4,5 are illustrated in Table XXIV.

Table XXIV
Logistic Regression Analysis for Prediction Model
(ABNLAT 0,1 VS. 4,5)

	Coefficient	S.E.	P-value
Nocturnal discomfort	1.124	0.331	0.000
Flick sign	1.081	0.299	0.000
Family history	1.102	0.477	0.010
Symptom duration	0.008	0.004	0.030
(constant)	-1.392	0.314	

Crude and Adjusted Odds Ratios of Abnormality
by the Dichotomous Clinical Predictors in the Model

	Crude Odds Ratio	Adjusted Odds Ratio	95% Confidence Limits About the Adjusted Odds Ratios
Nocturnal discomfort	4.2	3.1	1.7-5.8
Flick sign	3.5	2.9	1.6-5.3
Family history	3.3	3.0	1.2-7.7

The logistic regression model based on this specification of abnormality (ABNLAT 0,1 VS. 4,5) was a combination of the two previous prediction models. The highly significant univariate associations of nocturnal discomfort, Flick sign, and family history with abnormality were preserved in the multivariate analysis. The univariate associations noted for hand numbness and Phalen's test, after adjusting for the

effect of the other variables, failed to retain statistical significance. The prediction model for the natural log of the probability of predicting CTS from clinical predictors was:

$\ln p_i/q_i = -1.39 + 1.12\ ND + 1.08\ FS + 1.10\ FH + 0.008\ SD$

where $\ln p_i/q_i$ is the natural log of the probability of detecting abnormality, ND refers to nocturnal discomfort, FS refers to Flick sign, FH refers to family history, and SD refers to symptom duration. The P-value for the Hosmer Lemeshow chi square was 0.738 indicating that the model provided a satisfactory fit to the data.

Separate analyses were performed using the same specifications of abnormality (ABNLAT 0 VS. 5; ABNLAT 0,1 VS. 2-5; and ABNLAT 0,1 VS. 4,5) but using the second variables created to describe hand numbness and hand pain as described in the methods section (page 55). The univariate associations of the variables with each specification of abnormality and the predictive capabilities of the predictor variables are not shown. The results of the logistic regression analyses for all three specifications are presented in Table XXV. The P-value for the Hosmer Lemeshow Chi Square for ABNLAT 0 VS. 5 was reduced by the addition of Tinel's sign to the model (P = 0.491). The P-values for the other two analyses indicate that the data fit the models appropriately (P = 0.961, P = 0.797 respectively).

Table XXV illustrates the selection of numbness as the

most important predictor of abnormality in the results of the analyses for all three specifications.

Table XXV
Logistic Regression Analysis for Prediction Model
Using 2nd variables for hand numbness and pain

(ABNLAT 0 VS. 5)

	Coefficient	S.E.	P-value
Numbness	2.742	0.414	0.000
Nocturnal discomfort	1.021	0.405	0.014
Tinel's sign	-0.998	0.456	0.030
(constant)	-1.903	0.393	

(ABNLAT 0,1 VS. 2-5)

	Coefficient	S.E.	P-value
Numbness	2.042	0.287	0.000
Family history	0.905	0.469	0.046
(constant)	-0.783	0.225	

(ABNLAT 0,1 VS. 4,5)

	Coefficient	S.E.	P-value
Numbness	2.304	0.341	0.000
Nocturnal discomfort	0.789	0.342	0.022
(constant)	-1.699	0.335	

4.7 Summary of Logistic Regression Modelling

The clinical variables that were consistent in the prediction model were Flick sign and nocturnal discomfort. To a lesser extent, the variables family history and symptom duration were also found to be predictive. The prediction model proved to be robust using the various definitions of abnormality which represented varying spectrums of abnormality. The robustness of the model was further illustrated by the supplementary analyses which utilized the second variables created to categorize hand numbness and hand pain. In these supplementary multivariate analyses, the variable hand numbness was the most predictive. This variable was highly associated with Flick sign which it replaced in the prediction model. As in the primary analyses, family history and nocturnal discomfort were also found to be predictive of electrophysiological abnormality.

These results indicate that the electrophysiological indicators of CTS can be predicted using clinical features. Some of the predictor variables demonstrated associations with electrophysiological abnormality using Chi square analyses. These relationships were elucidated by the multivariate logistic regression analyses, after accounting for the effect of the other predictor variables.

CHAPTER V

DISCUSSION AND CONCLUSIONS

The present study was designed to develop a clinically useful model for predicting abnormality in the nerve conduction tests conventionally used in the diagnosis of CTS. The prediction model employed a set of widely recorded clinical symptoms and signs combined in a multiple logistic regression analysis. The robustness of the prediction model was evaluated by comparing the predictions based on different specifications of abnormality.

5.1 Normative Nerve Conduction Values in the Control Group

Normative data are used to establish normal conduction limits beyond which abnormality is identified. The nerve conduction values of the control subjects were not normally distributed which made the use of the normal distribution statistics inappropriate. To diagnose nerve conduction abnormality in the present study (for the variables that did not require adjusted criteria), the percentile technique was used. The present study was the first one in this general topic area in which this technique has been employed. Had the data been normally distributed, the percentile technique would have produced the same 95% range as parametric calculations. Studies in the earlier literature reported assigning

abnormality to values exceeding the limit of normal (Thomas et al., 1967) or to values exceeding two standard deviations from the mean (Kemble, 1968; Di Benedetto et al., 1986).

The normative values of the present study are within the same range as those obtained in previous studies. The mean MDML of the control group in the present study was 3.4 ms. (SD 0.4). Mean values of normal control subjects for MDML reported previously ranged from 3.07 to 3.8 msec. as indicated in Table I. Published MDML cutoff values ranged from 4.0 to 4.7 msec. (Table II). The value 4.0 msec. is the same as the cutoff value in the present study before adjusting the criteria for abnormality. After adjusting for sex, the cutoff value for males in the present study was 4.2 msec.

In the present study the mean value for MDSL2 was 2.3 msec. (SD 0.2 msec.) The range of mean values of MDSL2 for control subjects reported in Table I was similar, from 2.06 to 2.8 msec. In a more recent study designed to provide updated normative values for sensory conduction in the median nerve, the same mean and standard deviation values were obtained for MDSL2 as in the present study. The cutoff value based on the mean plus two standard deviations was 2.7 msec. (Di Benedetto et al., 1986) which was very similar to the cutoff value obtained in the present study. Before applying the adjusted criteria for assigning abnormality, the 95th percentile cutoff for MSDL2 in the present study was 2.8 msec.

The mean value for MMCV in the control subjects in the present study was 57.7 (SD 2.7) and the 5th percentile cutoff was 53.3 m/s. Stevens (1987) reported a higher mean MMCV value and more variability in a control series, 59.1 m/s. (SD 5.1). A lower cutoff value of 49 m/s was based on two standard deviations from the mean.

The normative values for the variables DSLM2U5 and DSLM4U4 are illustrated in Table XXVI. These two variables which compare median and ulnar nerve distal sensory latencies are expected to be similar in normal individuals. The advantage of using them is the fact that, for the comparison within an individual, temperature is constant and distances are easier to standardize. Some difference between the median and ulnar nerve latencies is to be expected because the length of the nerves within the hand is not identical even when distances between the stimulating and recording electrodes are the same. For the variable DSLM2U5, a higher mean value than in the present study was obtained for fifty control subjects who were volunteers screened for diseases of the peripheral nerves (Felsenthal, 1977). DSLM2U5 was measured at room temperature (exact hand temperature unspecified) with efforts to keep distances constant (Felsenthal, 1977). The cutoff for abnormality was also higher than the cutoff of 0.6 ms. used in the present study. The values provided by the present study may be more accurate since twice as many control

subjects were evaluated.

The mean value for the variable DSLM4U4 obtained by Jackson and Clifford (1989) was slightly lower than in the present study. Their control group consisted of normal volunteers, hospital staff, and patient volunteers who were screened by history and physical examination to rule out relevant systemic conditions (Jackson and Clifford, 1989).

Table XXVI

Normative Values for the Variables DSLM2U5 and DSLM4U4 (msec.)

	Mean	S.D.	Range	N	Cutoff
DSLM2U5					
Present study	0.3	0.20	0.00 - 0.90	104	0.6[1]
Felsenthal, 1977	0.4	0.28	-	50	0.96[2]
DSLM4U4					
Present study	0.16	0.23	-0.50 - 0.80	104	0.6[1]
Jackson & Clifford, 1989	0.13	0.15	-0.08 - 0.46	38	0.43[2]

[1] 95th percentile cutoff.
[2] Mean + 2 S.D. cutoff.

No published studies were found which reported normative values with which to compare the variables MDSL4, MSCV2,

MSCV4, SCVM2U5, SCVM4U4, and DIFFRESP.

The foregoing discussion of the normative values obtained in the present study and in studies published in the literature indicates that numerous investigators have obtained mean values in the same range as those in the present study. Any differences that exist could be due to several considerations some of which have not been addressed specifically in the published accounts, e.g., sample size, the extent to which the sexes were represented, the effect of hand temperature, the effect of the distance between the stimulating and recording electrodes, other differences in electrodiagnostic techniques.

In the present study, the control group of 104 subjects was a reasonable size for determining normative values. The sex distribution of 50 males and 54 females represented both sexes adequately. The effects of sex, hand temperature, distance, age, and height were investigated and adjustments made as required.

The ideal control group for establishing normative values would consist of people with no hand symptomatology who have been selected from the general population. The control group for the present study consisted of people referred for nerve conduction testing in whom CTS and peripheral neuropathy were ruled out. The fact that the subjects were not completely healthy made it possible that the normative nerve conduction

values were biased, i.e., they could be more abnormal than in the general population. To investigate this possibility, the normative values obtained in this study were compared with those in published reports and found to be similar, as indicated above. The comparison of values obtained in different laboratories must be viewed with caution, however, due to differences in the composition of the control groups, the methods and equipment used.

If the normative values were more abnormal than in the general population, the cutoff values for abnormality used in this study would have been high and less abnormality than truly existed would have been detected. The fact that there was a high prevalence of abnormality in this study suggests that this did not occur.

5.2 Adjustment of the Criteria for Abnormality

The results for the control group in the present study indicated that adjustments to the criteria for assigning abnormality based on regression equations were necessary as follows: for females, the variables MDML and MSCV4 required adjustment for temperature; for females, the variables MDSL2 and MDSL4 required adjustment for temperature and distance; for males, the variables MDSL2 and MDSL4 required adjustment for distance.

In no other studies have adjustments been made to the

abnormality criteria for the effect of hand temperature with the rigor employed in the present study. However, the importance of hand temperature to nerve conduction has been recognised. In some studies, hands were warmed if the temperature fell below a specified value, e.g., 31° (Jackson & Clifford, 1989), 30° (Johnson et al., 1981). It has been suggested that the finger temperature be maintained at 31° to provide a reliable method of estimating true nerve conduction values (Di Benedetto et al., 1986). It has also been suggested that distal sensory latency, measured at a distance of 13 cm., changes 0.1 msec. per degree Celsius down to 30°C. and below 30.5°C., hands must be warmed (Stevens, 1987).

In a study of the temperature effects on the nerve conduction, differences in the rate of change in DML were observed in normal subjects compared with CTS subjects (Bolton et al., 1982). The fact that there are differences in the ways in which normal and compressed nerves respond to differences in temperature makes it difficult to adjust for the effect of temperature unless presence or absence of abnormality has already been established. No published studies have been found which report the effect of temperature at those values at which hands were tested in the present study, i.e., 27.2 to 36.6°C.

In the present study, adjustments were made to the criteria for abnormality for distance. In some of the

previous studies, either the distance between the stimulating and recording electrodes has not been mentioned or a mean value has been mentioned. However, the effect of differences in distance between the stimulating and recording electrodes has been recognised by some investigators. A fixed distance between stimulating and recording electrodes was chosen for all subjects in some studies. For MDML the distance has been reported to be 6 to 8 cm. (Stevens, 1987) or 8 cm. (Monga et al., 1985). The distance for MDSL has been reported to be 13 cm. (Stevens, 1987) or 14 cm. (Di Benedetto et al., 1986).

In the present study, there were differences in MDML values and the variables affecting MDML between males and females. In a recent study in which distances were standardized, MDML was observed to be correlated with height (Rivner et al., 1990). There was no discussion of differences between males and females. It is likely that the observed differences in height were also related to differences in sex and could be accounted for by separating males and females as was done in the present study.

In summary, it was clearly necessary either to standardize temperature and distance at the time of testing or to account for differences statistically. Distances were not standardized in this study because it is not the policy in the laboratory in which the data were collected. Instead, an anatomical point on the wrist at which the underlying nerve

is closest to the surface is used. This allows the stimulus to be of the lowest intensity and still give a supramaximal response. The reason for preferring to use an anatomical point rather than a standard distance is that as the stimulus intensity applied to the nerve is increased, the stimulus tends to spread distally and will produce erroneously short latencies.

It was also necessary to adjust for the effect of temperature. The range of hand temperatures in the experimental group was the same as in the control group in which it was shown that temperature had an effect on some of the nerve conduction variables. Although efforts were generally made to warm hands of subjects if their hands were cold, the hand temperature of 25 of the experimental subjects was less than 30°C. All but one of these measurements were obtained in the colder months, from November to March. There was not an excess of abnormality in this group. After application of the adjusted criteria for abnormality, the extent of abnormality was as follows:

ABNLAT value 0 = 12 subjects
1 = 2 subjects
2 = 1 subject
3 = 1 subject
5 = 9 subjects

The required adjustments for sex, temperature, and distance were made to the criteria for assigning abnormality rather than to the actual values of the variables in the

experimental subjects. As a result, the nerve conduction variables were dichotomized to normal or abnormal.

5.3 The Effect of Adjustment of the Criteria for Abnormality

The effect of adjusting the criteria for assigning abnormality to the nerve conduction values of the experimental subjects was to identify additional subjects with abnormality for four of the five variables to which adjusted criteria were applied. For each of the variables, the numbers of subjects with abnormality using unadjusted cutoff values and adjusted criteria were the following (the increase is shown in parentheses): MDML 144 to 148 (4), MDSL2 138 to 176 (38), MDSL4 165 to 179 (14), MSCV4 174 to 177 (3), and DIFFRESP 103 to 95 (-8).

The question that must be asked is: Has abnormality been over-identified using these criteria? This question cannot be answered definitively without a true gold standard for diagnosing CTS. However, several facts indicate that the adjustment was appropriate. (1) Before adjusted criteria were applied, MSCV4 identified 174 subjects with abnormality, only five fewer than the largest number identified with adjusted criteria. (2) The numbers of subjects identified by MDSL4, MSCV4, and MDSL2 were very similar after adjusted criteria were applied (179, 177, and 176 respectively). (3) In an early study, Melvin et al. (1973) showed by discriminant

function analysis that MDSL2 was the variable that was the most sensitive in detecting CTS. In the present study MDSL2 was observed to detect more abnormal subjects than most of the variables (see Table IX). The variables which detected more abnormal subjects, MDSL4 and MSCV4, were not used in conventional nerve conduction testing in 1973. (4) The electrodiagnostic techniques are becoming increasingly more sophisticated and sensitive. The literature contains numerous studies describing purportedly more sensitive techniques than the well-accepted conventional techniques that were used in the present study (Buchthal & Rosenfalck, 1971; Kimura, 1978; Jackson & Clifford, 1989). For these reasons, any concern about over-estimating abnormality in the present study is probably unfounded.

5.4 The Gold Standard for Detecting Abnormality

Nerve conduction studies, specifically abnormal latencies, were used in the present study as the gold standard for detecting the electrophysiological abnormality frequently associated with CTS. It is recognized that nerve conduction studies are not a gold standard for diagnosing CTS. However, they have frequently been used as such in the literature, as indicated in Table II. In clinical practice, electrodiagnosis is frequently used as the standard to confirm the clinical diagnosis of CTS. Hence, it is important to discuss the

diagnostic properties of electrodiagnosis as it is used to detect the electrophysiological abnormality frequently associated with CTS.

The extent of false-negative nerve conduction results was estimated in one study to be 8% of 292 subjects, as these subjects with normal nerve conduction studies improved after surgical release of the carpal tunnel (Grundberg, 1983). However, since the precise details of nerve conduction testing were not provided, it is not known whether the methods used in that study were as sensitive as those used in the present study. Conversely, as purportedly more sensitive tests such as palmar stimulation, are being evaluated, they have been found to be only minimally more sensitive than the more traditional tests used in the present study. The delicate balance that exists between finding more sensitive nerve conduction tests and obtaining positive results in normal individuals has been indicated (Redmond and Rivner, 1988).

Use of the results of nerve conduction studies as the gold standard for diagnosing CTS is supported by intra-operative investigation of the median nerve (Brown et al., 1976). There was observed to be good correspondence between the abnormal appearing segments of the median nerve and the major conduction abnormalities. Despite the on-going debate about using nerve conduction studies as the standard for diagnosing CTS, in fact, they are the best standard available

at this stage of the disease process, i.e., prior to surgical treatment.

Two gold standards related to surgery have been suggested. One is to actually observe the compressed nerve. In instances where compression is obvious, this may be a good standard, but it seems likely that there will be many cases in which compression is not obvious. In addition, since the trend is toward performing smaller incisions, it is unlikely that a good view of the nerve will be obtained.

The other suggested surgical gold standard is to diagnose CTS on the basis of surgery after which relief of symptoms is observed. Even this standard is not perfect since (i) some people benefit from placebo therapy, even surgical, and would be misdiagnosed as having CTS; (ii) some people who have CTS will not experience relief of symptoms because the surgery was improperly performed technically, or because the severity of CTS precluded an effective outcome; and (iii) not all people with symptoms undergo surgery. It is hard to imagine that there is a real gold standard for diagnosing CTS. The results of surgery may be the best standard available.

There is definitely a relationship between median nerve conduction abnormality at the wrist and CTS. However, in the present study, as there is no gold standard for assessing this relationship, caution must be exercised in interpreting the prediction model. The model was developed to predict the

abnormality usually associated with CTS, not to predict the diagnosis of CTS.

Another issue related to the use of electrodiagnosis to detect abnormality is the fact that there is no consensus either in the literature or clinically about how many or which of the electrophysiological criteria must be abnormal for a subject to be considered to have abnormality. Some authors have used one abnormal variable (Gelmers, 1979; Bowles et al., 1983; Heller et al., 1986), others have used both abnormal sensory and motor criteria (Pryse-Phillips, 1986; Seror, 1988).

At the beginning of the study, eleven variables were identified as being relevant to the detection of abnormality. All of these were adjusted for the effects of influencing variables. There was no obvious division of experimental subjects into those with abnormality and those without abnormality based on the eleven variables. Therefore, with the goal of reducing the number of variables used in detecting abnormality, the inter-relationships among the nerve conduction variables were investigated. Only one published study was found in which inter-relationships among the variables were investigated (Melvin et al., 1973). The relationship between MDML and MDSL2, which was observed in the control subjects and also in the experimental subjects to whom the adjusted criteria for assigning abnormality had been

applied, was confirmed.

The relationship between distal latencies and the associated conduction velocities is readily apparent (since the conduction velocity is computed from the latency, i.e., conduction velocity = distance/latency). Similarly, it is apparent that relationships exist between median nerve DSL variables and the variables that compare median and ulnar nerve DSL. The correlations and factor analyses confirmed the extent of the inter-relationships.

Differences in the correlations in the experimental group before the adjusted criteria were applied compared with the control group and the experimental group after the adjusted criteria were applied were due to more variability among the nerve conduction values. A larger spectrum of nerve conduction values was represented, i.e., normal range plus the full range of abnormality. After applying the adjusted criteria for assigning abnormality to the group of experimental subjects, the effects of sex, distance, and temperature were ameliorated. In addition, the amount of variability among the actual nerve conduction values was reduced by using 0, 1 values. In this group, the most highly correlated variables were also the variables observed to identify the largest numbers of subjects with abnormality after the adjusted criteria for abnormality were applied.

In the effort to represent the nerve conduction variables

parsimoniously, information was obtained from the published literature, from clinical practice, and from statistical findings and a balance was sought. Because of the extensive use of latencies in the literature, and because adjustments could be made to account for the effects of the influencing variables on the latency variables, and because it seemed redundant to use both latencies and conduction velocities, the decision was made to use the five latency variables to determine abnormality in the experimental subjects. This decision was made prior to, and completely independently of, any consideration of the symptoms. Therefore, there is no reason to think that the method of reducing the number of electrophysiological variables used to assign abnormality altered the results of the study.

In summary, although nerve conduction studies are not a perfect gold standard, it was appropriate to use them to detect electrophysiological abnormality in the present study. The question of how many of the tests must be abnormal for subjects to have abnormality was not definitively specified either in the literature or in clinical practice despite the routine use of electrodiagnosis to confirm the diagnosis of CTS. In the present study, it was shown that there is considerable inter-relationship among the nerve conduction variables. Therefore, distal latency variables were used to detect abnormality rather than conduction velocity variables.

The elimination of two tests which did not directly evaluate conduction within the carpal tunnel was done for the purpose of classifying abnormality within this study. It is not to be implied that these tests should be eliminated from consideration of the differential diagnosis of CTS.

5.5 Univariate Relationships between Clinical Predictors and Nerve Conduction Abnormality

In interpreting the relationships between the clinical predictors and abnormality, potential sources of bias must be considered. One potential source of bias concerned the people who declined participation. The number of refusals was small, less than 10%. Unfortunately, since no information was obtained from those who refused participation, it was not possible to determine the extent to which their lack of participation may have biased the group. However, the reasons for refusing to participate were related to external considerations, time constraints or living out of town. Refusals to participate would have altered the results only if the refusals were linked to both the symptoms and the electrophysiological results, e.g., if people with mild symptoms and normal nerve conduction studies refused. It is unlikely that this occurred since the patients would not have known the results of their nerve conduction tests. Although the technicians had knowledge of the results of the tests, they were neither trained to interpret them, nor given the

authority to reveal the results to the patients.

Another potential source of bias relates to the methods of data collection. All data were collected by the same person to eliminate the problem of inter-rater reliability. Intra-rater reliability was not evaluated but the procedures were discussed and reviewed by the Neurologist involved with the study. It is obvious that the quality of the clinical information is dependent upon the skill and care of the assessor. Efforts were made to perform all testing in an accurate and standardized manner and to consider each variable independently of the others. All assessments were made without knowledge of the results of nerve conduction testing.

The results of the Chi square analyses at the three specifications of abnormality demonstrated that nocturnal discomfort, Flick sign, symptom duration, and family history were associated with abnormality. The predictive capability of the clinical variables is assessed by the level to which the positive predictive value increases the probability of abnormality and the level to which the negative predictive value reduces the probability of abnormality.

Since the clinical variables behaved similarly at the three specifications of abnormality in the present study, discussion of the results will be generalized and the primary specification will be used for illustrative purposes. Nocturnal discomfort and the Flick sign did not discriminate

to a significant degree to rule in abnormality based on a univariate prediction. When the specification of abnormality resulted in a prevalence of 59%, the variable nocturnal discomfort had a positive predictive value of 71.2% and a negative predictive value of 68.9%. Positive and negative predictive values for Flick sign were 72.7% and 65.3% respectively. In contrast, family history discriminated to a greater extent. The positive and negative predictive values were 79.2% and 43.8% respectively.

Few evaluations of the clinical predictors used in the present study have been published. Investigations have been conducted to evaluate the individual association of one or several provocative tests with nerve conduction abnormality. Previous studies investigating Tinel's sign and Phalen's test reported widely ranging sensitivities and specificities (Table III). Because most of these studies had design problems, their results are not included in the discussion of the results of the present study. The problems have been reviewed and considered in the design of the present study.

In the present study, the sensitivities and specificities for Tinel's sign remained the same at the three specifications of CTS, i.e., approximately 18% and 82% respectively. Only one earlier report (see Table III) had a reasonable sample size, used an appropriate control group consisting of disorders easily confused with CTS, used electrodiagnosis to

classify presence or absence of CTS, and separated left and right hands in the analyses to achieve independent measurements for analysis (Woodbury et al., 1984). The specificity was the same as in the present study while the sensitivity was only slightly higher (25%) than the present study (Woodbury et al., 1984).

Within the present study, the sensitivities of Phalen's test were slightly more variable depending upon the specification of CTS, ranging from 59% to 64%. The specificities were less variable, 54% to 56%. The sensitivities and specificities observed in a previous study, 29% and 78% respectively, were different from those found in the present study (Woodbury et al., 1984) (see Table IV). The probable reason for the difference in sensitivity and specificity between the studies is the fact that, in the present study, only the symptomatic hand or the more symptomatic hand was used. In the previous study, all right hands were analyzed together and all left hands were analyzed together. This could have affected the spectrum of disease and hence the sensitivity and specificity. It is also possible that the assessment of whether or not the test was positive was different.

In a recent study, the relationship of twelve provocative tests with CTS was evaluated (deKrom et al., 1990). None of the tests were observed to change the prior probability of

CTS to a clinically significant posterior probability. The findings of this reported study concur with those of the present study for some of the tests that were common to both studies, i.e., tests for thenar atrophy, weakness of abductor pollicis brevis, Phalen's test, and the tourniquet test.

The predictive value of diagnostic tests is affected by the prevalence of abnormality, which in the present study was quite high. The prevalence of electrophysiologically confirmed CTS in general practice has not been reported in the literature. The closest estimate available is based on the sample that was drawn from the general population which demonstrated that 28 of 500 people, 6%, had CTS that was confirmed by nerve conduction studies (deKrom et al., 1990). Clinicians wishing to use the sensitivities and specificities of an individual diagnostic test to determine predictive values and thereby to predict the likelihood that an individual patient has electrophysiological abnormality, would need to have an estimate of the prevalence of electrophysiologically confirmed CTS in their practices.

Katz et al. (1990) tried to provide this information by projecting their results to a hypothetical sample with 15% prevalence. This illustrated the effect of a lower prevalence, i.e., lowering the positive predictive value and raising the negative predictive value.

The associations of the clinical variables with

electrophysiological abnormality have been assessed in the present study by Chi square analyses and strong associations were found for the variables Flick sign, nocturnal discomfort, Phalen's test, family history, and hand numbness. Despite these associations, none of the individual clinical variables improved the prediction of abnormality to a clinically useful level.

5.6 The Prediction Model

Multiple logistic regression analysis was performed to develop a model for predicting electrophysiological abnormality from a set of clinical variables. For the most conservative and definitive specification of abnormality (ABNLAT 0 VS. 5), the variables that were selected in the logistic regression prediction model were Flick sign, nocturnal discomfort, and symptom duration.

The prediction model proved to be robust when the definition of CTS was expanded to include the differing spectrums of electrophysiological abnormality. This was illustrated by the analyses of the two subsequent specifications of abnormality. For the specification ABNLAT 0,1 VS. 2-5 which contained the whole spectrum of electrophysiological abnormality, the prediction model included the same first two variables as the primary model, and family history rather than symptom duration. For the

specification ABNLAT 0,1 VS. 4,5 which contained a spectrum of electrophysiological abnormality between that of the most conservative specification and the complete spectrum, the prediction model also included the same variables, but nocturnal discomfort and Flick sign changed positions in the model, and family history was the third variable. These findings demonstrate that nocturnal discomfort and Flick sign are the two variables most predictive of electrophysiological abnormality. Duration of symptoms, and family history were also shown to be important predictors; family history was more predictive than symptom duration when a wider spectrum of electrophysiological abnormality was being predicted.

The supplementary analyses which utilized the second variables created to categorize hand numbness and hand pain further exemplified the robustness of the model for predicting electrophysiological CTS from clinical variables. These numbness and pain variables were more global and took into account the reported history of numbness and pain. As a result, these variables may be more representative of clinical judgement. In the three multivariate analyses incorporating these variables, numbness, nocturnal discomfort and family history were the most predictive variables. Flick sign did not attain significance at the 0.05 level as it was highly associated with hand numbness.

Katz et al. (1990) had similar results for hand numbness.

A self-administered hand pain diagram was found to be associated with CTS. The hand pain diagram may have been measuring something similar to the variable used to measure history of hand numbness in the present study and similar associations with the nerve conduction abnormality were noted. In contrast to the findings of the present study that nocturnal discomfort was highly predictive of abnormality, Katz et al. (1990) observed that nocturnal discomfort was not associated with CTS.

A curious result in the supplementary analyses of the present study was that Tinel's sign was observed to be somewhat predictive of electrophysiological abnormality. The results of previous studies of Tinel's sign have been variable as indicated in Table III. In the present study, Tinel's sign was found to be positive less often than in other studies (51/285 subjects). The test is performed by "tapping gently" and perhaps the assessor tapped too gently. Care must be taken, however, because even in people with no symptomatology, tapping over the median nerve can elicit tingling in the median nerve distribution in the hand. This is similar to the effect of pressure over the ulnar nerve at the elbow eliciting tingling in the ulnar nerve distribution of the arm (striking your "funny bone"). Conversely, it is also possible that Tinel's sign is not useful in the diagnosis of CTS. Gelmers (1979) suggested that it was never intended to be used in the

diagnosis of CTS when he wrote the following:

> "Jules Tinel (1915), after studying a large number of peripheral nerve injuries, noted that gentle tapping of the proximal stump of an injured nerve some time after injury produced a tingling sensation of so-called "fourmillement". This tingling sensation was different from the pain that may result from pressure applied to an injured nerve. ...Tinel stated that this sign indicates young axis cylinders in the process of regeneration, but he did not mention its presence in an entrapment neuropathy. Nevertheless, since the work of Phalen (1966), Tinel's sign has become popular in the diagnosis of carpal tunnel syndrome." (Gelmers, 1979: page 255).

In the earlier studies of the relationship of clinical tests and signs with CTS, the analyses consisted of univariate predictions of disease. In only a few studies were the results of two tests combined in an effort to improve the prediction. The present study has used the advantage of multivariate analyses to gain insight into the combined effects of several variables on the prediction of electrophysiological abnormality.

The results of the present study indicate that the electrophysiological indicators of CTS can be satisfactorily modelled (predicted) using clinical features, i.e., nocturnal discomfort, Flick sign, duration of symptoms, and family history. Although the associations of the predictor variables were evident in the univariate Chi square analyses, the multivariate logistic regression analyses helped to clarify which of the weaker associations observed in univariate

analyses were more predictive, after accounting for the effect of the other predictor variables. Many combinations of clinical variables could be used to predict abnormality but this particular combination yielded the best prediction.

5.7 Generalizability

The prevalence of abnormal electrophysiological results in this study was 59 to 65%. The results of this study must be viewed with the prevalence in mind. Use of the prediction model in general practice should be with caution as its use in situations of lower prevalence remains to be determined. However, within a higher prevalence environment, such as a factory where repetitive movements of the wrist are performed, the model could prove quite useful.

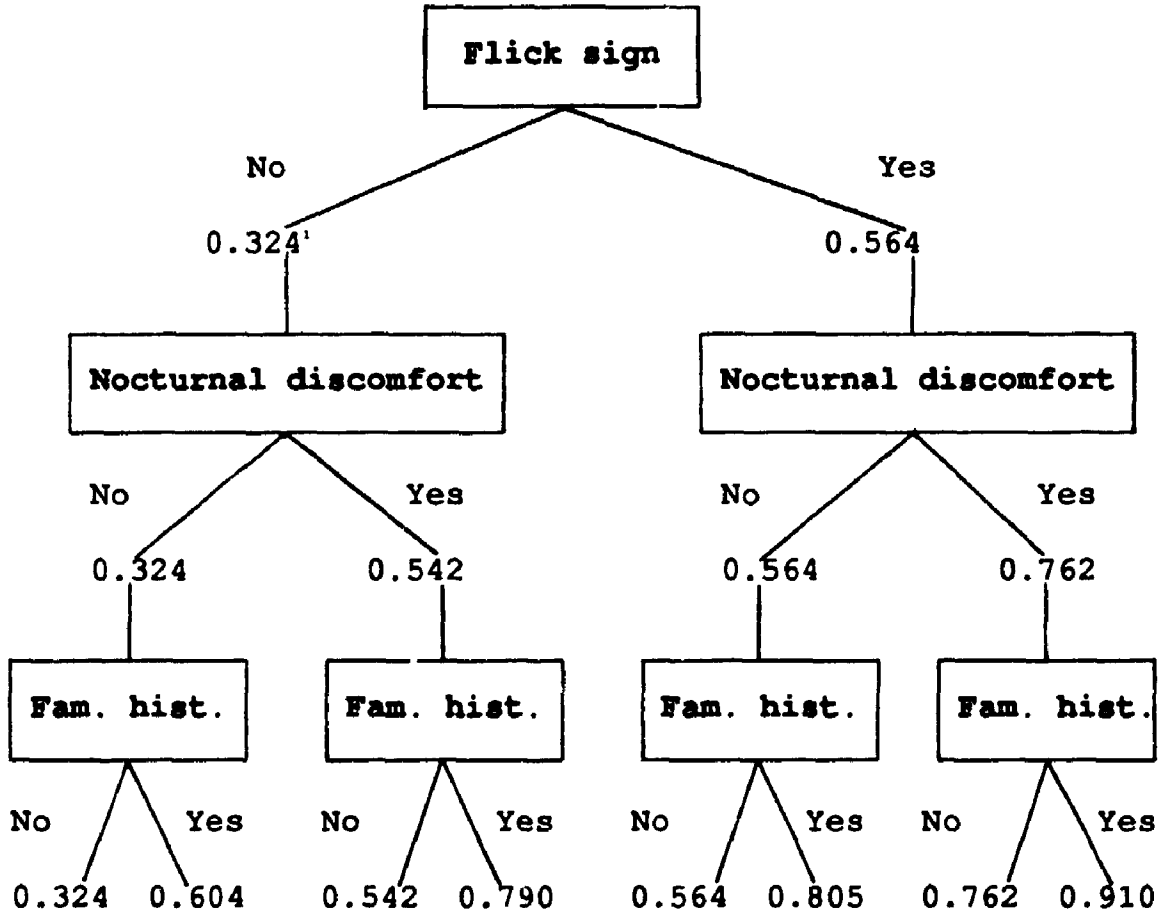
5.8 Clinical Implications

The results indicate that clinical features can be used to predict the electrophysiological abnormality. Schematic representation of the way in which the prediction can be used is illustrated in Figure II. The prediction model used for this figure was based on the first set of analyses using ABNLAT 0,1 VS. 2-5 as this model is most applicable to the clinical situation in which the whole spectrum of disease is likely to exist.

When a clinician encounters a patient whose history raises the possibility of CTS, figure II illustrates that,

Figure II

Probability of Nerve Conduction Abnormality
based on Prediction Model
ABNLAT 0,1 VS. 2-5



[1] Probability of abnormality accounts for all the variables in the model.

given the presence of the variables in the prediction model, the patient's probability of abnormal electrophysiological results is P = 0.910.

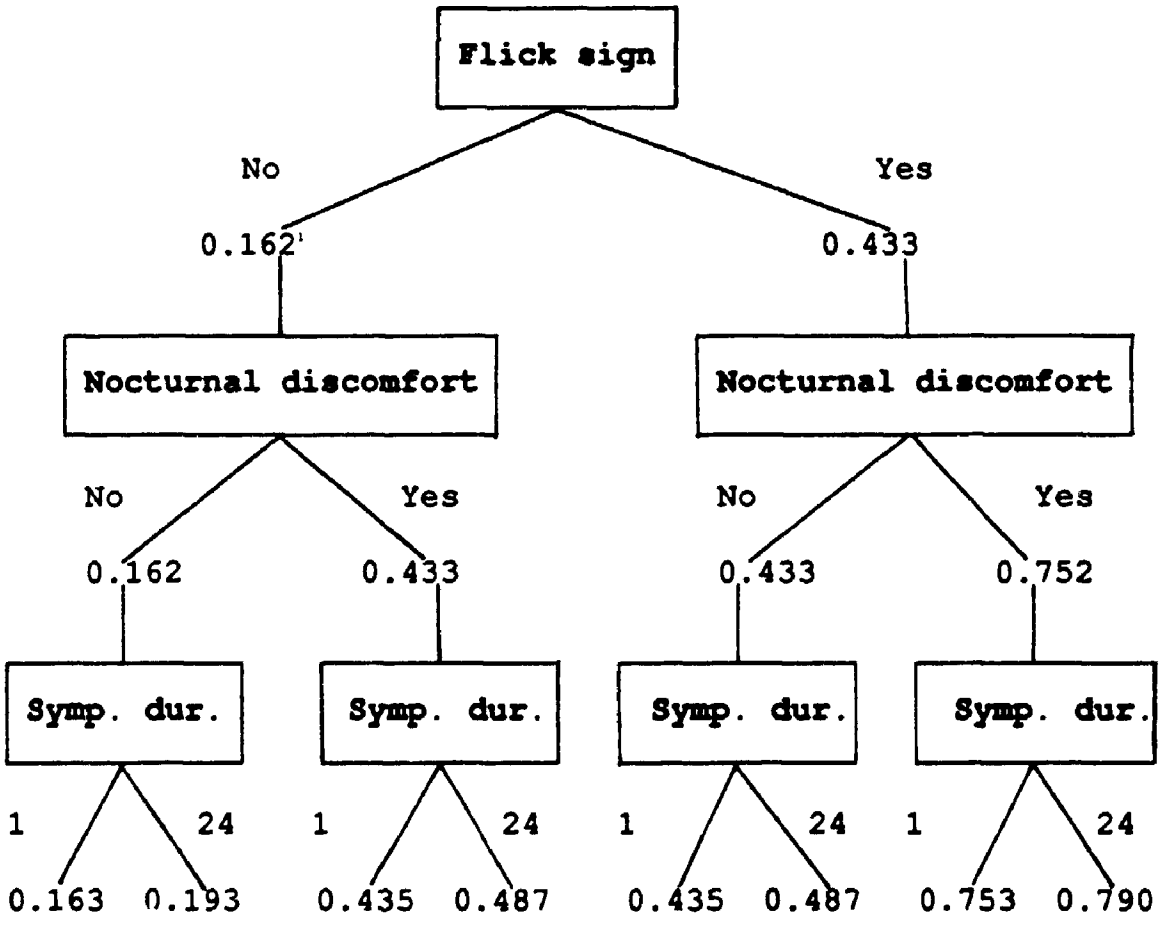
Figure III and Figure IV illustrate the schematic representation of the prediction model for ABNLAT 0 VS. 5 and ABNLAT 0,1 VS. 4-5 respectively.

Figures V, VI, and VII demonstrate the prediction at each abnormality specification for the second variable for hand numbness.

The prediction model could be of benefit to clinicians who do not have easy access to nerve conduction testing either because of long waiting lists or because they live in a remote area, e.g., Northern Ontario or a small rural community. Nerve conduction studies are used for different reasons, usually to establish a differential diagnosis, to confirm a reasonably certain diagnosis, or to act as a baseline prior to surgery in instances where the diagnosis is definite. Knowledge of the likelihood of electrophysiological abnormality may provide some clinicians sufficient predictability to proceed with conservative treatment without the need for nerve conduction testing.

Figure III

Probability of Nerve Conduction Abnormality
based on Prediction Model
ABNLAT 0 VS. 5

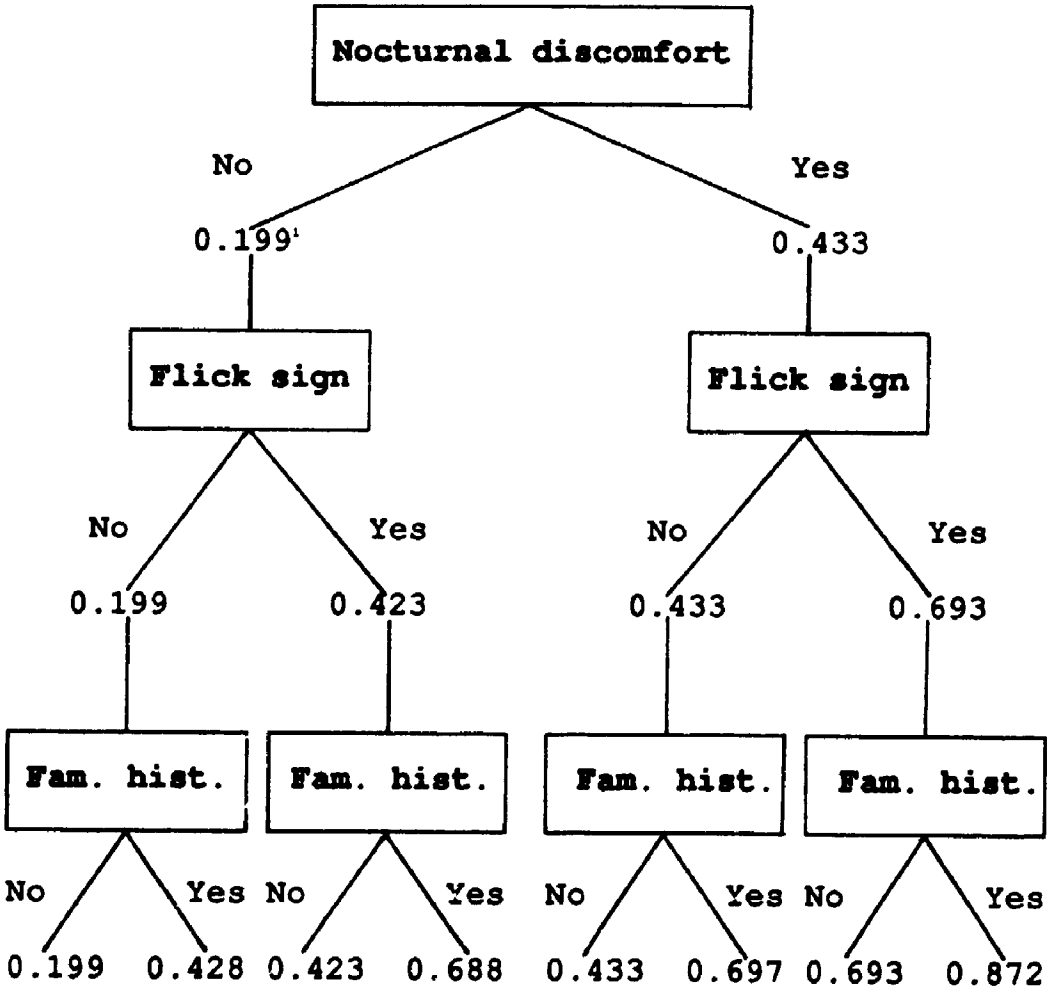


[1] Probability of abnormality accounts for all the variables in the model.

Symptom duration is a continuous variable; the logistic regression coefficient is multiplied by the patient's duration to calculate the probability of abnormality. To illustrate, one month and 24 months were used.

Figure IV

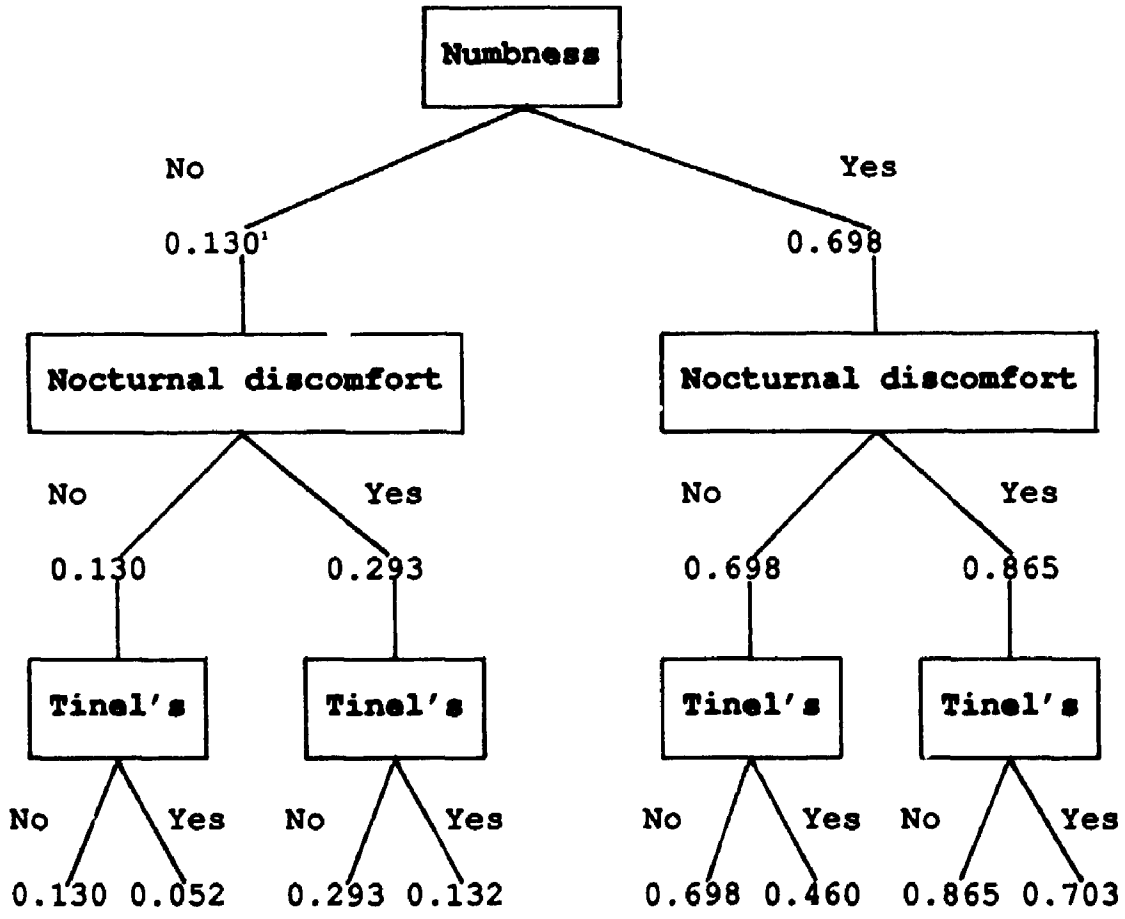
Probability of Nerve Conduction Abnormality
based on Prediction Model
ABNLAT 0,1 VS. 4,5



[1] Probability of abnormality accounts for all the variables in the model including symptom duration. Symptom duration (coefficient .008), the final variable, is not in the figure.

Figure V

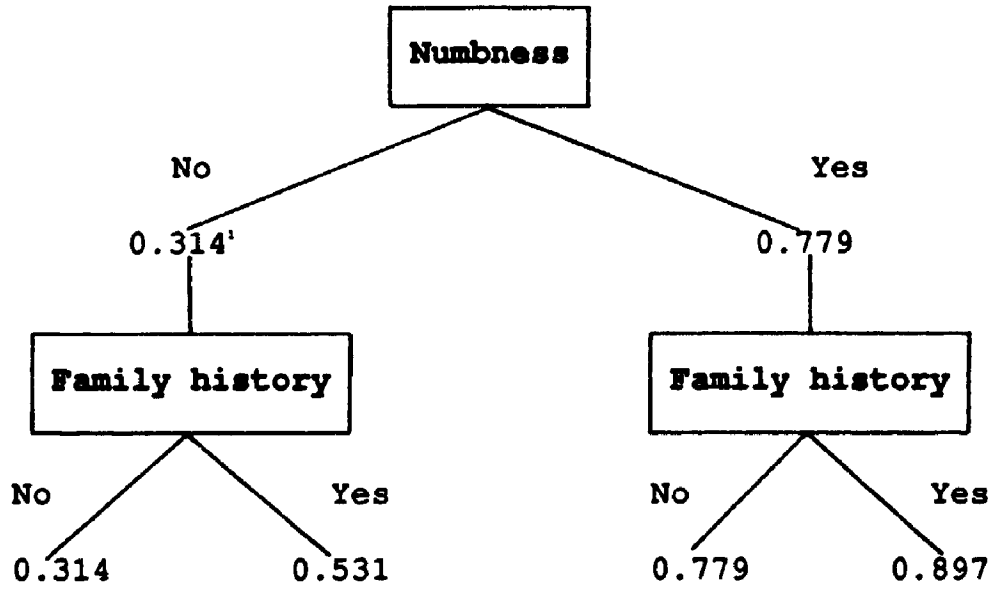
Probability of Nerve Conduction Abnormality
based on Prediction Model
ABNLAT 0 VS. 5
Using 2nd Variable for Hand Numbness



[1] Probability of abnormality accounts for all the variables in the model.

Figure VI

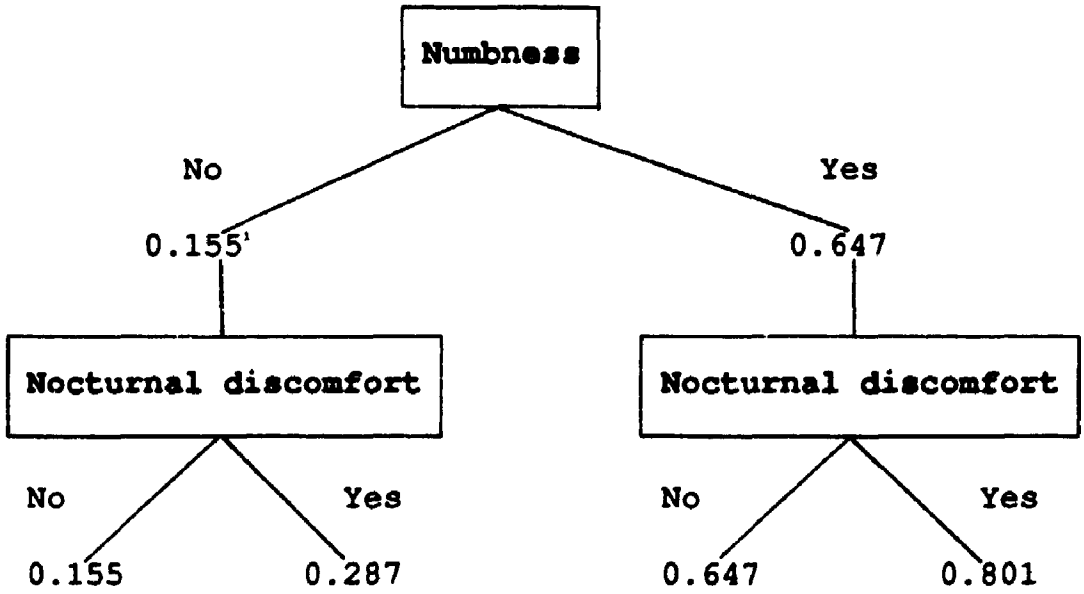
Probability of Nerve Conduction Abnormality
based on Prediction Model
ABNLAT 0,1 VS. 2-5
Using 2nd Variable for Hand Numbness



[1] Probability of abnormality accounts for all the variables in the model.

Figure VII

Probability of Nerve Conduction Abnormality
based on Prediction Model
ABNLAT 0,1 VS. 4,5
Using 2nd Variable for Hand Numbness



[1] Probability of abnormality accounts for all the variables in the model.

5.9 Recommendations for Further Study

It is known that the model will be most predictive in the group of subjects on whom it was developed. Therefore, it is recommended that the prediction model be validated on a new sample of subjects to see how well it will predict abnormal electrophysiological findings.

In the present study, the number of electrodiagnostic tests showing abnormal results was used to define the presence of abnormality frequently associated with CTS. It is recommended that the extent of electrophysiological abnormality be investigated as the definition of abnormality associated with CTS. The symptomatology in people who have severe electrophysiological abnormality may be different from the symptomatology in people with minimal abnormality.

The development of the second variable for numbness in the present study was an effort to categorize history of numbness symptoms according to whether the it appeared to be CTS or not. Katz et al. (1990), in developing a hand pain diagram, seemed to be trying to get a global measure of patients' symptoms also. Further efforts to standardize a global measure are recommended.

The results related to nerve conduction studies in the present study contribute to the understanding of the influences on nerve conduction variables and the inter-relationships among them. In patients who have equivocal

symptoms, nerve conduction tests are necessary to identify a diagnosis. Further clarification of testing procedures with the goal of standardizing test performance among labs and reaching a consensus regarding the most appropriate tests is recommended.

5.10 Conclusions

Despite the limitations of the study, the principal result provided clinically important information. The prediction of the electrophysiological abnormality frequently associated with CTS from clinical features has been elucidated. Nocturnal discomfort and Flick sign were aspects of the history that were most highly correlated with abnormality. Clinical judgement based on the history of symptoms of numbness was also highly correlated with abnormality. The provocative signs and tests which are so often touted as diagnostic aids were not clinically useful predictors of abnormality when considered individually or in combination.

Secondarily, useful information was obtained about the nerve conduction studies. Several variables, i.e., sex, distance, and temperature, were found to influence the nerve conduction variables. These were satisfactorily accounted for by adjustment of the criteria for abnormality used in this study. Clarification of the factors influencing nerve

conduction values is vital to correctly identifying abnormality.

Many of the nerve conduction variables used to confirm the diagnosis of CTS were inter-related. The number of abnormal tests required to confirm the diagnosis is debatable but the issue may be clarified by comparison with a gold standard such as surgical results.

APPENDICES

APPENDIX I

Electrodiagnosis: Definition of terms

Latency refers to the time taken for the stimulus impulse to travel from the point of stimulation on the nerve to the onset of the evoked response (measured in milliseconds). Distal motor latency (DML) refers to the time between the point of stimulation on the median nerve at the wrist and the evoked response at the muscle. MDML is often prolonged in patients who have CTS. Distal sensory latency (DSL) is measured using an antidromic technique or an orthodromic technique. Using an antidromic technique the nerve trunk is stimulated and evoked activity recorded distally from a finger. Using an orthodromic technique, sensory nerves are stimulated distally and the response is is recorded proximally from the nerve trunk (Eisen, 1973). MDSL2 and MDSL4 are often prolonged in patients who have CTS.

Conduction velocity is the distance an impulse travels along a nerve per unit of time. The nerve is supramaximally stimulated at two points. The conduction velocity (v) in meters per second (m/s) can be calculated for the fastest fibres using the following formula: $v = d / t$ where d is the distance between the two stimulation points and t is the difference in latencies for the two points.(Ludin, 1980:31). MMCV, MSCV2, and MSCV4 may be reduced in patients with CTS.

Action potential is a brief electrical phenomenon resulting from a stimulus applied to an axon that lowers the membrane potential to a critical level, i.e., a threshold level (30 to 50 mV) (Smorto and Basmajian, 1977: 31).

Amplitude of the action potential describes the distance between the upward and downward peaks of the evoked response. The amplitude provides an approximate measurement of the number of muscle fibres or sensory endings which have been excited (Ludin, 1980:33).

F response is the latency or time taken for the stimulus impulse to travel (antidromically) from the point of stimulation of the motor nerve (at the wrist) to the spinal cord and back to the abductor pollicis brevis muscle. It is a measure of motor nerve conduction useful in assessing the location of proximal or distal conduction disturbances. (Ludin, 1980: page 34).

APPENDIX I

Letter of Explanation

Letter of Explanation

The purpose of this research project is to obtain information that will improve the diagnosis and treatment of carpal tunnel syndrome and other conditions affecting the hands. Patients who have been referred for nerve conduction studies of the nerves supplying the hands are being asked to participate. If you participate in the study, Gail Woodbury will ask you some questions and perform a brief examination of the hands. The questions and the examination will take less than 30 minutes. The nerve conduction studies will be done by _____ who will explain the tests. The results will be made available to the staff of this research project.

If you participate, you will be asked to return in three months to find out your progress and to have the nerve conduction studies repeated. In addition, you may be approached for follow-up in the future.

If you participate, you will be asked to sign a form granting permission to examine your clinical chart to record your treatment.

All information will be completely confidential. Information obtained from you will be identified by a number. The list of names and numbers will be kept locked up so that anonymity will be maintained.

You are free to refuse to participate in this study, and if you agree to participate, you may refuse to answer any questions or may withdraw from the study at any time without jeopardy to your future care.

Your participation in this study may help physicians diagnose and treat future patients more effectively.

If you have any questions about this project, please call Gail Woodbury 667-6522 (EMG Department at Victoria Hospital).

APPENDIX III

Consent to Act as Research Subject

Consent to Act as Research Subject

I.D. Number _____

The nature of the study of people who may have carpal tunnel syndrome has been explained to me and I have read and understand the letter of explanation. I hereby agree to participate in this study. I understand that my participation involves answering some questions and having an examination of my hands. I am willing to return for follow-up in three months. I am willing to be called if a later follow-up is carried out, but this consent does not constitute consent to participate in future follow-up. I hereby grant permission for the project staff to have access to the results of my nerve conduction studies and information in my clinical chart about my treatment and progress.

Signature _____

FOR OFFICE USE ONLY

Name:

Address:

Telephone Number:

Date:

APPENDIX IV

Data Collection

Data Collection

ID Number_____

Follow-up Appointment Date_____

Referring Physician_____

Address_____

Telephone Number_____

SECTION A

Gender male___female___

Date of birth_____

Marital status_____
(1 married, 2 separated/divorced, 3 single)

Height (cm) _____ Weight (kg) _____

Are you right handed___ left handed___
(IF AMBIDEXTROUS, WHICH HAND IS USED MORE FREQUENTLY?)

1. What is the highest level of schooling you have completed?

less than 8 years	___	
8 years	___	GO TO QUESTION 2
9,10,or 11 years	___	
12 or 13 years	___	GO TO (a)

(a) Have you had further education? yes___ no___ N/A___

2. What is your current employment status?

employed full-time	___	GO TO (a)
employed part-time	___	
housewife	___	
unemployed	___	
retired	___	GO TO (b)
student	___	
other	_____	

(a) What is your current occupation? _____

(b) If you were employed before, what was your last job?

_____

SECTION B

3. What is your main trouble today? Symptoms, history

_____

_____

Symptomatic hand ____ (1 right, 2 left, 3 R>L, 4 L>R)

Duration of symptoms _____ months.

4. How often do you have symptoms? _____
(1 all the time - persistent,
2 at some point every day moderately - persistent,
3 from time to time - intermittent)

5. What activities make your symptoms worse?

_____

_____

6. Do you have discomfort that wakens you at night?

Symptomatic hand No ___ Yes ___

7. Have you noticed that you drop things more often than you used to?

Symptomatic hand No ___ Yes ___

8. What do you do with your hand(s) when your symptoms are at their worst?

(Flick sign? No___ Yes ___)

9. Is there anything you are unable to do because of your symptoms?_____

10. Have you increased the frequency of any activity requiring hand use? no___ yes, specify_____

11. What recreational activities or hobbies do you do outside work?_____

12. Have you any of the following?
Pregnant ___
Diabetes ___
RA ___
Hypothyroidism ___
Wrist fracture ___
Other ___

Does anyone in your family have diabetes ___
Thyroid trouble ___
other _____

13. Has anyone in your family ever had a problem like the one you are having? no ___ yes, SPECIFY _____

SECTION C Symptoms: (yes (1), no (0))

(a) Have you pain? right___ left___

Tell me exactly where your pain is located.
digit 1 __ digit 2 __ digit 3 __ digit 4 __
digit 5 __ palm __ wrist __ forearm __
elb. __ upper arm __ shld. __ neck __

(b) Have you pins and needles? right___ left___

(c) Have you numbness? right___ left___

Tell me exactly where are the pins and needles or numbness are located?
digit 1 __ digit 2 __ digit 3 __ digit 4 __
digit 5 __ palm __ wrist __ forearm __
upper arm __

SECTION D Signs and tests: (present (1) absent (0))

Atrophy of thenar eminence right ___ left ___

Hypoesthesia

light touch sensation impaired right ___ left ___
Symptomatic hand location
thenar eminence __ , hypothenar __ ,
digit 1 __ , 2 __ , 3 __ , 4 __ , 5 __ .

pin prick sensation impaired right ___ left ___
Symptomatic hand location
digit 1 dp __ pp __ thenar __ ,
2 dp __ mp __ pp __ palm __ ,
3 dp __ mp __ pp __ palm __ ,
4 dp __ mp __ pp __ palm __ ,
5 dp __ mp __ pp __ palm __ .

Hyperesthesia right ___ left ___

Two point discrimination impaired right ___ left ___
Symptomatic hand location
digit 1 dp __ pp __ ,
2 dp __ mp __ pp __ ,
3 dp __ mp __ pp __ ,
4 dp __ mp __ pp __ ,
5 dp __ mp __ pp __ .

Weakness of abductor pollicis brevis

(abduct thumb at 90° to plane of palm) right ___ left ___

Tinel's sign right ___ left ___

Phalen's test right ___ left ___

Cuff compression right ___ left ___

Wrist circumference (cm) right ___ left ___

SECTION E Nerve Conduction Studies ID Number ___

Hand temperature _____

	Distance (cm)	Action Potential	Conduction Velocity (M/sec)	Distal Latencies (msec)
Median nerve				
Motor				
wrist-thenar				
elbow-thenar				
Sensory				
wrist-index				
wrist-4th				
F response				
Ulnar nerve				
Motor				
wrist-hypothenar				
elbow-hypothenar				
Sensory				
wrist-4th				
wrist-5th				
F response				

APPENDIX V

Rationale for Using Conduction Velocities rather than Distal Latencies

Rationale for using Conduction Velocities rather than Distal Latencies

The original intention was to use the following eight variables in the electrodiagnosis of CTS, as they are the ones found to be most helpful clinically by the neurologist involved with the study.

1. Median nerve distal motor latency (MDML)
2. Median nerve distal sensory latency to index (MDSL2)
3. Median nerve motor conduction velocity (MMCV)
4. Median nerve sensory conduction velocity to index (MSCV2)
5. Median nerve sensory conduction velocity to fourth (MSCV4)
6. Difference between median nerve sensory CV to index, and ulnar nerve sensory CV to fifth digit (SCVM2U5).
7. Difference between median nerve sensory CV to fourth digit, and ulnar nerve sensory CV to fourth (SCVM4U4).
8. Difference between median nerve F response, and ulnar nerve F response (DIFFRESP).

In other words, both the distal latency and conduction velocity were to be used to assess the motor component, and the sensory component to the index finger, but only the conduction velocity to assess the fourth digit. In addition, the sensory conduction velocity comparisons, SCVM2U5 and SCVM4U4, were to be used rather than the corresponding distal sensory latencies.

The rationale for using conduction velocities to detect

abnormality rather than distal latencies was the fact that latency is affected by the distance between the stimulating and recording electrodes which some investigators control by setting a standard distance for all hands in the study. The problem of using a standard distance is that, in a small person, the point of stimulation will be more proximal on the wrist where the nerve is deeper requiring a stronger stimulus which may affect the latency and conduction velocity values. Therefore, for this study, it was thought preferable to stimulate each subject at a definite anatomical point at the wrist and record at a particular place on the digit or hand. The result was that distances were not constant; i.e., the distances varied between subjects and the distal latencies were affected by the varying distances. Since conduction velocity is calculated by dividing the distance by the latency, the conduction velocity value takes distance into account.

Based on a) the extensive use of median nerve DSL and the comparison of median nerve DSL with corresponding ulnar nerve DSL reported in the literature to be useful in diagnosing CTS, and b) because adjustments of the abnormality criteria for distal latencies could be made to account for the confounding variables mentioned above, it was decided to include the three distal latency variables, MDSL4, DSLM2U5, and DSLM4U4 in the evaluation of the communality, or interrelationships, with the

other indices of conduction abnormality prior to establishing criteria for assigning values as abnormal.

APPENDIX VI

Correlation Matrix of Unadjusted Nerve Conduction Variables in Experimental Subjects

	MDML	MDSL2	MDSL4	MMCV	MSCV2	MSCV4	SCV M2U5	SCV M4U4	DSL M2U5	DSL M4U4
MDSL2	.05									
MDSL4	-.42	.08								
MMCV	-.39	-.13	.12							
MSCV2	-.83	.07	.42	.46						
MSCV4	-.75	-.26	.67	.39	.82					
SCVM2U5	-.68	.15	.42	.32	.84	.71				
SCVM4U4	-.65	-.25	.63	.32	.69	.90	.75			
DSLM2U5	-.02	.92	.07	-.08	.10	-.23	.22	-.21		
DSLM4U4	-.44	.02	.94	.15	.40	.66	.41	.65	.10	
DIFFRESP	.32	.20	-.12	-.09	-.16	-.23	-.15	-.34	.18	-.21

APPENDIX VII

Contingency Tables for Each Nerve Conduction Variable
by all Other Nerve Conduction Variables
Experimental Subjects

Contingency Tables for Each Nerve Conduction Variable
by all Other Nerve Conduction Variables
Experimental Subjects

MDML	MDSL2 Normal	MDSL2 Abnormal	
Normal	100	36	136
Abnormal	9	140	149
Total	109	176	285

MDML	MDSL4 Normal	MDSL4 Abnormal	
Normal	96	39	135
Abnormal	9	140	149
Total	105	179	284

MDML	MMCV Normal	MMCV Abnormal	
Normal	121	15	136
Abnormal	97	52	149
Total	218	67	285

MDML	MSCV2 Normal	MSCV2 Abnormal	
Normal	104	32	136
Abnormal	18	131	149
Total	122	163	285

		MSCV4 Normal	MSCV4 Abnormal	
MDML				
	Normal	99	36	135
	Abnormal	8	141	149
	Total	107	177	284

		SCVM2U5 Normal	SCVM2U5 Abnormal	
MDML				
	Normal	112	22	134
	Abnormal	34	112	146
	Total	146	134	280

		SCVM4U4 Normal	SCVM4U4 Abnormal	
MDML				
	Normal	103	30	133
	Abnormal	23	118	141
	Total	126	148	274

		DSLM2U5 Normal	DSLM2U5 Abnormal	
MDML				
	Normal	102	32	134
	Abnormal	17	129	146
	Total	119	161	280

		DSLM4U4 Normal	DSLM4U4 Abnormal	
MDML				
	Normal	105	28	133
	Abnormal	16	125	141
	Total	121	153	274

MDML	DIFFRESP Normal	Abnormal	
Normal	130	6	136
Abnormal	55	90	145
Total	185	96	281

MDSL2	MDSL4 Normal	Abnormal	
Normal	94	14	108
Abnormal	11	165	176
Total	105	179	284

MDSL2	MMCV Normal	Abnormal	
Normal	103	6	109
Abnormal	115	61	176
Total	218	67	285

MDSL2	MSCV2 Normal	Abnormal	
Normal	106	3	109
Abnormal	16	160	176
Total	122	163	285

MDSL2	MSCV4 Normal	Abnormal	
Normal	96	12	108
Abnormal	11	165	176
Total	107	177	284

	SCVM2U5 Normal	SCVM2U5 Abnormal	
MDSL2			
Normal	102	5	107
Abnormal	44	129	173
Total	146	134	280

	SCVM4U4 Normal	SCVM4U4 Abnormal	
MDSL2			
Normal	92	13	105
Abnormal	34	135	169
Total	126	148	274

	DSLM2U5 Normal	DSLM2U5 Abnormal	
MDSL2			
Normal	95	12	107
Abnormal	24	149	173
Total	119	161	280

	DSLM4U4 Normal	DSLM4U4 Abnormal	
MDSL2			
Normal	93	12	105
Abnormal	28	141	169
Total	121	153	274

	DIFFRESP Normal	DIFFRESP Abnormal	
MDSL2			
Normal	105	4	109
Abnormal	80	92	172
Total	185	96	281

MDSL4	MMCV Normal	MMCV Abnormal	
Normal	100	5	105
Abnormal	118	61	179
Total	218	66	284

MDSL4	MSCV2 Normal	MSCV2 Abnormal	
Normal	96	9	105
Abnormal	25	154	163
Total	121	163	284

MDSL4	MSCV4 Normal	MSCV4 Abnormal	
Normal	100	5	105
Abnormal	7	172	179
Total	107	177	284

MDSL4	SCVM2U5 Normal	SCVM2U5 Abnormal	
Normal	98	6	104
Abnormal	48	128	176
Total	146	134	280

MDSL4	SCVM4U4 Normal	SCVM4U4 Abnormal	
Normal	94	7	101
Abnormal	32	141	173
Total	126	148	274

MDSL4	DSLM2U5 Normal	DSLM2U5 Abnormal	
Normal	93	11	104
Abnormal	26	150	176
Total	119	161	280

MDSL4	DSLM4U4 Normal	DSLM4U4 Abnormal	
Normal	95	6	101
Abnormal	26	147	173
Total	121	153	274

MDSL4	DIFFRESP Normal	DIFFRESP Abnormal	
Normal	104	1	105
Abnormal	80	95	175
Total	184	96	280

MMCV	MSCV2 Normal	MSCV2 Abnormal	
Normal	115	103	218
Abnormal	7	60	67
Total	122	163	285

MMCV	MSCV4 Normal	MSCV4 Abnormal	
Normal	100	118	218
Abnormal	7	59	66
Total	107	177	284

SCVM2U5

MMCV	Normal	Abnormal	
Normal	126	89	215
Abnormal	20	45	65
Total	146	134	280

SCVM4U4

MMCV	Normal	Abnormal	
Normal	112	99	211
Abnormal	14	49	63
Total	126	148	274

DSLM2U5

MMCV	Normal	Abnormal	
Normal	105	110	215
Abnormal	14	51	65
Total	119	161	280

DSLM4U4

MMCV	Normal	Abnormal	
Normal	110	101	211
Abnormal	11	52	63
Total	121	153	274

DIFFRESP

MMCV	Normal	Abnormal	
Normal	158	56	214
Abnormal	27	40	67
Total	185	96	281

MSCV2	MSCV4 Normal	MSCV4 Abnormal	
Normal	99	22	121
Abnormal	8	155	163
Total	107	177	284

MSCV2	SCVM2U5 Normal	SCVM2U5 Abnormal	
Normal	110	10	120
Abnormal	36	124	160
Total	146	134	280

MSCV2	SCVM4U4 Normal	SCVM4U4 Abnormal	
Normal	99	19	118
Abnormal	27	129	156
Total	126	148	274

MSCV2	DSLM2U5 Normal	DSLM2U5 Abnormal	
Normal	98	22	120
Abnormal	21	139	160
Total	119	161	280

MSCV2	DSLM4U4 Normal	DSLM4U4 Abnormal	
Normal	97	21	118
Abnormal	24	132	156
Total	121	153	274

MSCV2	DIFFRESP Normal	Abnormal	
Normal	118	4	122
Abnormal	67	92	159
Total	185	96	281

MSCV4	SCVM2U5 Normal	Abnormal	
Normal	100	6	106
Abnormal	46	128	174
Total	146	134	280

MSCV4	SCVM4U4 Normal	Abnormal	
Normal	96	7	103
Abnormal	30	141	171
Total	126	148	274

MSCV4	DSLM2U5 Normal	Abnormal	
Normal	97	9	106
Abnormal	22	152	174
Total	119	161	280

MSCV4	DSLM4U4 Normal	Abnormal	
Normal	97	6	103
Abnormal	24	147	171
Total	121	153	274

MSCV4	DIFFRESP Normal	DIFFRESP Abnormal	
Normal	106	1	107
Abnormal	78	95	173
Total	184	96	280

SCVM2U5	SCVM4U4 Normal	SCVM4U4 Abnormal	
Normal	116	27	143
Abnormal	10	120	130
Total	126	147	273

SCVM2U5	DSLM2U5 Normal	DSLM2U5 Abnormal	
Normal	118	28	146
Abnormal	1	133	134
Total	119	161	280

SCVM2U5	DSLM4U4 Normal	DSLM4U4 Abnormal	
Normal	112	31	143
Abnormal	9	121	130
Total	121	152	273

SCVM2U5	DIFFRESP Normal	DIFFRESP Abnormal	
Normal	138	8	146
Abnormal	43	87	130
Total	181	95	276

SCVM4U4	DSLM2U5 Normal	DSLM2U5 Abnormal	
Normal	104	22	126
Abnormal	12	135	147
Total	116	157	273

SCVM4U4	DSLM4U4 Normal	DSLM4U4 Abnormal	
Normal	113	13	126
Abnormal	8	140	148
Total	121	153	274

SCVM4U4	DIFFRESP Normal	DIFFRESP Abnormal	
Normal	121	5	126
Abnormal	57	87	144
Total	178	92	270

DSLM2U5	DSLM4U4 Normal	DSLM4U4 Abnormal	
Normal	106	10	116
Abnormal	15	142	157
Total	121	152	273

DSLM2U5	DIFFRESP Normal	DIFFRESP Abnormal	
Normal	118	1	119
Abnormal	63	94	157
Total	181	95	276

DSLM4U4	DIFFRESP Normal	Abnormal	
Normal	116	4	120
Abnormal	62	88	150
Total	178	92	270

4.5 Inter-relationships among Electrophysiological Variables in Control Subjects and Experimental Subjects

The relationships among the eleven nerve conduction variables in the control subjects were examined using techniques of correlation and factor analysis. For these analyses, the data were not adjusted for the effects of sex, temperature, and distance. This lack of adjustment may have introduced error by increasing or decreasing the extent of the relationships among the variables. Pearson product moment correlation coefficients were calculated for each combination of variables and Table X shows the correlation matrix.

Table X

Correlation Matrix of Unadjusted Nerve Conduction Variables in Control Subjects

	MDML	MDSL2	MDSL4	MMCV	MSCV2	MSCV4	SCV M2U5	SCV M4U4	DSL M2U5	DSL M4U4
MDSL2	.76									
MDSL4	.58	.72								
MMCV	-.29	-.29	-.34							
MSCV2	-.61	-.71	-.56	.25						
MSCV4	-.47	-.44	-.62	.29	.70					
SCVM2U5	-.25	-.35	-.29	.05	.54	.29				
SCVM4U4	-.13	-.11	-.25	-.11	.19	.38	.46			
DSLM2U5	.22	.43	.32	-.08	-.50	-.29	-.80	-.48		
DSLM4U4	.16	.16	.35	.02	-.25	-.40	-.44	-.91	.55	
DIFFRESP	.01	-.01	-.01	.16	-.01	-.16	-.06	-.31	.15	.25

Table X illustrates the highest correlations between the latency comparison variables and their corresponding conduction velocity comparison variables, i.e., DSLM4U4 and

APPENDIX VIII

Raw Data for Tables on Sensitivity, Specificity, and Predictive Values ABNLAT 0 VS. 5

Raw Data for Tables on Sensitivity, Specificity, and Predictive Values ABNLAT 0 VS. 5

Frequency of symptoms	Normal	Abnormal	
Intermittent	24	25	49
Persistent	58	93	151
Total	82	118	200

Nocturnal Discomfort	Normal	Abnormal	
Absent	42	19	61
Present	40	99	139
Total	82	118	200

Flick sign	Normal	Abnormal	
Absent	47	25	72
Present	35	93	128
Total	82	118	200

Clumsiness	Normal	Abnormal	
Absent	39	67	106
Present	43	51	94
Total	82	118	200

Family history	Normal	Abnormal	
Absent	77	99	176
Present	5	19	24
Total	82	118	200

Job	Normal	Abnormal	
Not predictive	29	51	80
Predictive	53	67	120
Total	82	118	200

Recreation	Normal	Abnormal	
Not predictive	59	69	128
Predictive	23	49	72
Total	82	118	200

Atrophy	Normal	Abnormal	
Absent	78	108	186
Present	4	10	14
Total	82	118	200

Weakness	Normal	Abnormal	
Absent	60	85	145
Present	21	33	54
Total	81	118	199

Hyperaesthesia	Normal	Abnormal	
Normal	69	93	162
Abnormal	13	25	38
Total	82	118	200

Tinel's sign	Normal	Abnormal	
Absent	67	97	164
Present	15	21	36
Total	82	118	200

Phalen's test	Normal	Abnormal	
Absent	46	41	87
Present	36	74	110
Total	82	115	197

Cuff compression test	Normal	Abnormal	
Absent	19	28	47
Present	50	73	123
Total	69	101	170

APPENDIX IX

Raw Data for Tables on Sensitivity, Specificity, and Predictive Values ABNLAT 0,1 VS. 2-5

Raw Data for Tables on Sensitivity, Specificity, and Predictive Values ABNLAT 0,1 VS. 2-5

Frequency of symptoms	Normal	Abnormal	
Intermittent	27	40	67
Persistent	74	144	218
Total	101	184	285

Nocturnal Discomfort	Normal	Abnormal	
Absent	49	44	93
Present	52	140	192
Total	101	184	285

Flick sign	Normal	Abnormal	
Absent	54	51	105
Present	47	133	180
Total	101	184	285

Clumsiness	Normal	Abnormal	
Absent	50	105	155
Present	51	79	130
Total	101	184	285

Family history	Normal	Abnormal	
Absent	94	148	242
Present	7	36	43
Total	101	184	285

Job	Normal	Abnormal	
Not predictive	39	77	116
Predictive	62	107	169
Total	101	184	285

Recreation	Normal	Abnormal	
Not predictive	72	120	192
Predictive	29	64	93
Total	101	184	285

Atrophy	Normal	Abnormal	
Absent	93	169	262
Present	8	15	23
Total	101	184	285

Weakness	Normal	Abnormal	
Absent	73	127	200
Present	27	57	84
Total	100	184	284

Hyperæsthesia	Normal	Abnormal	
Normal	85	137	222
Abnormal	16	47	63
Total	101	184	285

Tinel's sign	Normal	Abnormal	
Absent	83	151	234
Present	18	33	51
Total	101	184	285

Phalen's test	Normal	Abnormal	
Absent	54	73	127
Present	46	107	153
Total	100	180	280

Cuff compression test	Normal	Abnormal	
Absent	27	43	70
Present	58	117	175
Total	85	160	245

APPENDIX X

Raw Data for Tables on Sensitivity, Specificity, and Predictive Values ABNLAT 0,1 VS. 4,5

Raw Data for Tables on Sensitivity, Specificity, and Predictive Values ABNLAT 0,1 VS. 4,5

Frequency of symptoms	Normal	Abnormal	
Intermittent	27	29	56
Persistent	74	117	191
Total	101	146	247

Nocturnal Discomfort	Normal	Abnormal	
Absent	49	27	76
Presemt	52	119	171
Total	101	146	247

Flick sign	Normal	Abnormal	
Absent	54	36	90
Present	47	110	157
Total	101	146	247

Clumsiness	Normal	Abnormal	
Absent	50	82	132
Present	51	64	115
Total	101	146	247

Family history	Normal	Abnormal	
Absent	94	117	211
Present	7	29	36
Total	101	146	247

Job	Normal	Abnormal	
Not predictive	39	64	103
Predictive	62	82	144
Total	101	146	247

Recreation	Normal	Abnormal	
Not predictive	72	91	163
Predictive	29	55	84
Total	101	146	247

Atrophy	Normal	Abnormal	
Absent	93	135	228
Present	8	11	19
Total	101	146	247

Weakness	Normal	Abnormal	
Absent	73	102	175
Present	27	44	71
Total	100	146	246

Hyperaesthesia	Normal	Abnormal	
Normal	85	109	194
Abnormal	16	37	53
Total	101	146	247

Tinel's sign	Normal	Abnormal	
Absent	83	121	204
Present	18	25	43
Total	101	146	247

Phalen's test	Normal	Abnormal	
Absent	54	55	109
Present	46	88	134
Total	100	143	243

Cuff compression test	Normal	Abnormal	
Absent	27	35	62
Present	58	90	148
Total	85	125	210

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Job	Normal	Abnormal	
Not predictive	29	51	80
Predictive	53	67	120
Total	82	118	200

Recreation	Normal	Abnormal	
Not predictive	59	69	128
Predictive	23	49	72
Total	82	118	200

Atrophy	Normal	Abnormal	
Absent	78	108	186
Present	4	10	14
Total	82	118	200

Weakness	Normal	Abnormal	
Absent	60	85	145
Present	21	33	54
Total	81	118	199

Hyperaesthesia	Normal	Abnormal	
Normal	69	93	162
Abnormal	13	25	38
Total	82	118	200