Automated Analysis of Electromyography Data

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ABSTRACT

Background: Interpretation of nerve conduction studies (NCS) and electromyography (EMG) tests are intensive time-consuming processes (30 minutes per patient study). *Goal*: To create a computer program to automate this process including report generation. *Methods*: A computer program (called EMG and Nerve Conduction Analysis System, ENCAS) using Common Lisp programming language, Common Lisp Object System, object oriented-programming, text parsing algorithm, and clinical neurophysiology domain specific knowledge was written. This program was deployed in clinical practice and evaluated for time efficiency and test precision. *Results*: ENCAS reduced the time for EMG analysis from 30 minutes to 1 second and accuracy was 95%. Independent program verification has not been performed; automation of analysis improves accuracy over human analysis.

KEY WORDS
Neurology, Expert System, Electromyography

1. Introduction

The neurologist will typically perform a test known as electromyography (EMG) [1]. The EMG test includes nerve conduction studies (NCS) and together these tests provide detailed objective information regarding the integrity of the peripheral nervous system and spinal nerve roots [2]. EMG/NCS testing is now usually conducted by a trained EMG technician under the guidance of a neurologist; digital computers are used for the testing. The software generally does not contain diagnostic interpretation and this interpretation is time-consuming. In this report, we describe the program, EMG and Nerve Conduction Analysis System (ENCAS), which automates interpretation and reduces time of interpretation from approximately 30 minutes to less than 5 minutes (a reduction of about 80%). This system was designed and implemented by the clinic neurologist (who has training in artificial intelligence). Coding was done with Common Lisp [3], and object oriented programming using Common Lisp Object System (CLOS) was the key AI technology [4]. The author has prior experience integrating neurology and AI, specifically electronic neuroanatomy [5], neurology expert systems for epilepsy [6] and stroke [7]. Literature review yields no knowledge based NCS/EMG interpretation systems.

The test equipment software computes latencies and conduction velocities and these data are written into the test data file [8]. The program ENCAS reported here is required for a second phase of computations and the expert interpretation. These steps are stereotyped and time-consuming and therefore reasonable to automate.

2. Fundamentals of EMG Data

Information collected during nerve conduction studies is numeric and includes latency (the time from stimulus to the detected physiological response, in milliseconds). The information also includes amplitude (the measure in millivolts from baseline to response peak). A calculated attribute, conduction velocity, is derived using distance from stimulus to response in relation to time to response (latency). For a complete review of these concepts see [1] and [2]. The test equipment software computes latencies and conduction velocities and these data are written into plain ASCII test data file. ENCAS is required for a second phase of computations and the expert interpretation. This process is stereotyped and time-consuming and therefore a good candidate for automation.

Sensory Nerve Data

Physiological data for sensory nerve fibers is obtained by technicians using test equipment and is stored by SYNERGY in a text file named by patient. These data include multiple tests and each test typically includes test parameters (distance from stimulator to electrode), and results (latencies and conduction velocities).

Motor Nerve Data

Physiological data for motor nerve fibers is obtained by technicians using test equipment and is stored in a text file named by patient. These data include multiple tests and each test typically includes test parameters (distance from stimulator to electrode), and results (latencies and conduction velocities).

Median Neuropathy At the Wrist

A common disorder seen in the neurology clinic is median neuropathy at the wrist (carpal tunnel syndrome). There are multiple tests for median neuropathy that can be performed by the neurologist. These include sensory and motor latencies, lumbrical/interosseus comparison, digit III wrist/palm comparison, median/radial thumb test, median/ulnar digit IV test; there are many others [1][2].

Parsing EMG Data and Storage

EMG data is initially in a text file generated by the EMG test program. The principle data is organized by ordering of data and by specific key strings that the parser identifies. NCAS software parses this file using a pattern keyword matching algorithm. For example, the keyword matcher will recognize "L Median - Dig III" as the Digit III Wrist/Palm test and will scan for ordered data elements and populate an object with these data. An CLOS object (for Median Digit III) will include identifier, stimulation point, recording point, response latency (in milliseconds), response amplitude (in millivolts), response flag (Yes or No), and optionally computed conduction velocity (CV).

Object Oriented Storage of EMG Data

A standard object oriented hierarchy of CLOS classes has been defined for all tests. These classes include median sensory, median motor, ulnar sensory, ulnar motor, and so on. Specialized methods are written for classes when processing differs from the basic inherited methods. Important methods include *analyze test* and *report results*. Classes that describe all muscles and nerves involved in these tests are available in the Neuro-Anatomic Atlas [5]. The Atlas provides knowledge regarding the nerve roots innervating each muscle, nerve root components of each nerve. For example, the biceps muscle is innervated by roots cervical 5 (C-5) and cervical 6 (C-6) and by the musculocutaneous nerve.

Analysis of Latency Data

The median sensory test involves obtaining latency and amplitude for the nerve segment. The latency data is compared with reference data and percentage (measure/reference x 100%) is computed. A function grades the percentage into three discrete classes: normal (< 100%), mild (101-110%), moderate (110-130%), and severely abnormal. A prolongation of latency of 130% or more is considered severely abnormal [2]. Abnormal latency correlates physiologically with the level of demyelination; if a nerve fiber has lost myelin (due to diabetes or other disease) the stimulation response latency value will be prolonged (representing decrease of action potential velocity).

Analysis of Amplitude Data

Amplitude data is compared with reference values in the same way with percentage computation. A function grades the percentage into three discrete classes: normal (> 100%), mild (90-100%), moderate (75-90%), and severely abnormal. A relative amplitude of 75% or less is considered severely abnormal [2]. Amplitude is known to correlate with total number of axons in the peripheral nerve and so a drop in amplitude represents a loss in total functioning axons (and this is termed conduction failure or conduction block) [1] [2].

Class: Sensory Study Median Digit III

The median sensory test involves obtaining latency and amplitude for the nerve segment. The latency data is compared with reference data and percentage (measure/reference x 100%) is computed. The *function latency-interpretation* grades and interprets the latency value and function *amplitude-interpretation* does the same for amplitude. These values are stored in the class instantiation for the patient. A report is generated and this includes a text description of analysis and interpretation. The *wrist/palm velocity ratio* is also computed and if the ratio is less than 75% this is severely abnormal and represents focal neuropathy at the wrist.

An example of ENCAS output illustrates:

ANALYSIS of Left Median Sensory Antidromic Study (Stimulus Wrist and Palm Recording Digit III):
RESPONSE WRIST Yes RESPONSE PALM Yes
LATENCY 3.2 (REF < 3.5) PERCNT 91.43 GRADE normal (normal)
AMPLITUDE 34.7 (REF > 20.0) PERCNT 173.50 GRADE normal (normal)
WRIST VELOCITY 52.0 PALM VELOCITY 59.1 COMPUTED VEL 44.90
WRIST/PALM VELOCITY RATIO 76.0% GRADE moderate (demyelinating process)

Class: Motor Study Median APB

For analysis of median nerve at the wrist, conduction velocities are determined first from wrist to abductor police brevis (APB) muscle and then from elbow to APB. An example of ENCAS output illustrates:

ANALYSIS of Right Median Motor APB Study (Stimulus Wrist, Recording APB):
SITE1: MEDIAN APB RESPONSE WRIST Yes
WRIST LATENCY 4.35 (REF < 3.9) 111.54% LATENCY GRADE moderate (demyelinating process)
WRIST AMPLITUDE 6.1 (REF > 6.0) AMPLITUDE 101.67% AMPLITUDE GRADE normal (normal)

SITE2: MEDIAN APB RESPONSE ELBOW Yes ELBOW LATENCY 11.55
ELBOW AMPLITUDE 4.5 (REF > 6.0) AMPLITUDE 75.00% AMPLITUDE GRADE moderate (axon loss)
VELOCITY 37.5 (REF > 50) 75.00% GRADE moderate (demyelinating process)

Class: Motor Study Median Ulnar Lumbrical Interosseus

The median ulnar lumbrical interosseus comparison study is performed as follows. The ratio of median latency to ulnar latency is computed and if the ratio is greater than 130% this is considered severely abnormal and represents median neuropathy at the wrist. An example of ENCAS illustrates:

ANALYSIS of Right Median Ulnar Sensory Orthodromic Comparison (Stimulus Palm, Recording Wrist):
ULNAR RESPONSE Yes ULNAR LATENCY 2.25
MEDIAN RESPONSE Yes MEDIAN LATENCY 2.75
MEDIAN ULNAR RATIO 122.2% GRADE moderate (demyelinating process)

Class: Motor Study Median Ulnar Lumbrical Interosseus

This test compares the peak latency of the median/lumbrical system against the ulnar/interosseus system. Typically, the median latencies are shorter. In median neuropathy, the median latencies are relatively longer.

An example of ENCAS output shows an abnormal test result.

ANALYSIS of Right Median Ulnar Lumbrical Interosseus (Stimulus Wrist, Recording Palm):
LUMBRICAL RESPONSE Yes INTEROSSEUS RESPONSE Yes
MEDIAN LATENCY 4.95 (ULNAR LATENCY 3.85) PERCENT 128.57
GRADE moderate (demyelinating process)

Median Nerve Overall Interpretation

An object, *median test results*, is populated during this analysis. Each test result is added to this object and then final overall statistics are reported. These statistics are total counts of severe, non-severe abnormal, and normal results. These are printed into the report. The final step is storage of the text report into the patient's electronic medical record. An example of ENCAS output illustrates:

Right Median Nerve: Count of normal results = 1.
Right Median Nerve: Count of mildly abnormal results = 0.
Right Median Nerve: Count of moderately abnormal results = 3.
Right Median Nerve: Count of severely abnormal results = 2.
Diagnosis: RIGHT MEDIAN NEUROPATHY AT THE WRIST

Suite of Nerve Conduction Tests

The entire set of programmed tests includes median nerve, ulnar nerve, radial nerve, musculocutaneous nerve, medial antebrachial nerve, lateral antebrachial nerve, sural nerve, superficial peroneal nerve, peroneal nerve, tibial nerve, and H-reflex. The nerve comparison studies the median/ulnar orthodromic sensory test and lumbrical/interosseus study.

Interpretation of EMG Data

The second major part of the peripheral nerve test is the *needle electromyography* (EMG) test. Needle study involves placement of a small bipolar needle into a muscle; physiologic data is viewed on monitor (digital oscilloscope) and the neurologist enters the interpretation via a menu interface. A class *muscle-emg* was designed and contains basic slots including insertional activity, spontaneous activity (fibrillations), positive sharp waves, fasciculations, high frequency discharges, amplitude grade, MUAP duration, polyphasia, recruitment. See [1] and [2] for definitions of these key EMG elements.

These data are written into the text file. . The key string "Needle EMG" alerts the parser new needle study information follows in the file. The data of the needle EMG study is parsed from the text file. Key strings (such as "L Biceps") alert the parser that a new needle study is being listed and a new EMG object is instantiated (in this example, a *biceps-emg* class).

Detailed report text

The NCAS software interprets each text string conventionally. The user entered grades are converted into English equivalents (e.g., acute radiculopathy). Each muscle object definition (in the knowledge base), contains innervating nerve root (root-c8.right) notes. Reporting includes nerve root information (see example below). Reporting software will alert the reader about radiculopathy, fasciculations, polyphasia, MUAP duration, and recruitment/activation.

NEEDLE EMG RESULTS FOR Left Extensor digitorum:
Chronic radiculopathy in ROOT LEFT C7
Chronic radiculopathy in ROOT LEFT C8
NEEDLE EMG RESULTS FOR Left Biceps:
Chronic radiculopathy in ROOT LEFT C5
Chronic radiculopathy in ROOT LEFT C6

3. Results

Software was designed and written in approximately 40 hours by the author (a neurologist and computer scientist). The development time does not include previous work on the Neuro-Anatomic Atlas. The software engineer is also the neurologist and this is not a blinded study and therefore may have reviewer bias. Results from median neuropathy (carpal tunnel syndrome) cases are displayed in Table 1. The software had an accuracy rate of 95% for detecting severe carpal tunnel syndrome. The one case wherein ENCAS was "wrong" involved the neurologist relaxing the rules based on severe patient symptoms and giving moderate test abnormalities higher priority. The effort has been very successful. Time from test to completed EMG report is reduced from 30 to 60 minutes to about 5 minutes (mostly word processor file editing for aesthetics). NCAS data analysis/interpretation is instantaneous. The NCAS program has been incorporated into the larger systems, Neuroanatomic Atlas and SYNAPS. This incorporation was made because NCAS contains anatomy and physiology knowledge that may be used in other parts of SYNAPS. In the past two years, the ENCAS system has been in use in the clinic 2 cases per day 4 days per week on average. The estimate of manual EMG data interpretation is 30 minutes per case. Since ENCAS is essentially instantaneous is producing results, the total estimated time savings is 24,000 minutes or 400 hours (based on this formula: 2 years x 50 weeks x 8 cases/week x 30 minutes).

Literature reviewed finds no systems similar to ENCAS. Mishra [9] reports on a Prolog knowledge based system for interpretation of EMG data; this system was focused on needle EMG motor unit action potential analysis. In contrast ENCAS analyzes nerve conduction study data and uses object oriented knowledge (classes and methods).

4. Future Work

The plans for the ENCAS system include the following: (1) Develop code to transfer EMG data and ENCAS computations and conclusions into the clinic electronic medical record. (2) Develop heuristic computations to include moderately abnormal test results in final diagnosis; currently results that are not severe are ignored which is not completely correct.

5. Summary

The Electromyography Nerve Conduction Analysis System (ENCAS) has been developed using object oriented programming techniques for knowledge encoding. The program is utilized in production mode in the Alaska Brain Center, LLC neurology clinic. The application has 95% diagnostic accuracy for carpal tunnel syndrome, improves data analysis time efficiency (compared to manual interpretation), improves report precision, and is beneficial for the clinic.

Case	**Test Side**	**ENCAS CTS Ratio**	**ENCAS CTS Severity %**	**ENCAS Diagnosis**	**Neurologist Diagnosis**	**Comments**
1 (CG)	Right	1/5	20%	Normal	Normal	Below threshold.
2 CG	Left	1/5	20%	Normal	Normal	Below threshold.
3 (JW)	Right	3/5	50%	CTS	CTS	Above threshold.
4 (JW)	Left	2/5	40%	CTS	CTS	Above threshold.
5 (LC)	Right	3/7	43%	CTS	CTS	Above threshold.
6 (LC)	Left	2/5	40%	CTS	CTS	Above threshold.
7 VL	Right	0/5	0%	Normal	Normal	Below threshold.
8 VL	Left	1/5	20%	Normal	Normal	Below threshold.
9 DT	Right	0/7	0%	Normal	Normal	Below threshold.
10 DT	Left	0/5	0%	Normal	Normal	Below threshold.
11 TS	Right	0/5	0%	Normal	Normal	Below threshold.
12 TS	Left	2/6	33%	CTS	CTS	Above threshold.
13 CN	Left	0/6	0%	Normal	Normal	Below threshold.
14 MZ	Right	0/5	0%	Normal	Normal	Below threshold.
15 LB	Right	2/5	40%	CTS	CTS	Above threshold.
16 LB	Left	1/5	20%	Normal	CTS	Severe symptoms and two tests were moderately abnormal.
17 HB	Right	0/4	0%	Normal	Normal	Below threshold.
18 RB	Right	0/7	0%	Normal	Normal	Below threshold.
19 JM	Right	2/6	33%	CTS	Subclinical CTS	Above threshold; patient denies symptoms; subclinical CTS.
20 JM	Left	0/5	0%	Normal	Normal	Below threshold.

Table 1. Carpal Tunnel Syndrome Diagnosis by ENCAS. The column CTS RATIO is number of severely abnormal test results over total tests done. The column SEVERITY % is that ratio as a percentage. A severity percentage greater than 20% reaches threshold for the CTS diagnosis. The Neurologist Diagnosis is made by the physician reviewing all raw and computed data manually. The cases reported in this table were the last 20 CTS tests done in the clinic in October through November 2011.

6. References

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