

AUTOMATED ELECTROMYOGRAPHY ANALYSIS: UPDATE

Jeffrey L. Sponsler, MD MS, Charles Parker, BA
Alaska Brain Center, LLC
4552 E Bogard Rd, Wasilla, Alaska USA 99654
jsponsler@akbraincenter.com
cparker@akbraincenter.com

ABSTRACT

BACKGROUND: Analysis and presentation of electromyography test results requires in-depth knowledge and is labor-intensive. The EMG and Nerve Conduction Analysis System (ENCAS) has been developed and is operational in a neurology clinic. **METHODS:** The system was coded in Common Lisp Object System and has knowledge stored in objects, methods, and a specification base. An EMG file is parsed, test objects created, analysis performed, interpretation rules applied, and results are stored via a Lisp/MYSQL interface into the clinic electronic medical record. **RESULTS:** The system is operational and in use daily. Analysis and storage takes one second (compared to 20 minute manual analysis). **CONCLUSIONS:** Analysis of EMG data can be encoded using methods and results stored into clinic EMR for rapid access and flexible reporting. The system is successful and improves office efficiency.

KEY WORDS

LISP, ELECTROMYOGRAPHY, ARTIFICIAL INTELLIGENCE, DATABASE

1. Introduction

This report describes the evolution of an automated electromyograph/nerve conduction study system (ENCAS). The system processes nerve physiologic data from the test machine to the analytical modules and finally to the clinic electronic medical record (EMR).

2. Background

The neurologist will typically perform a test known as electromyography (EMG) [1]. The EMG test includes nerve conduction studies (NCS) and 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 90%). 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, 8]. Literature review yields no knowledge based NCS/EMG interpretation systems. We developed an expert system [9] to parse and partially analyze EMG data previously. This paper describes a system that performs heuristic analysis and interfaces with a database management system (DBMS).

The test equipment software records latencies and conduction velocities and these data are written into the test data file [9]. 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. This report includes addition of analytical heuristics and automated storage into the clinic EMR.

3. System Architecture

The modular system architecture is described in Figure 1.

The system architecture includes these modules: EMG File Parser, Test Interpretation, Command Creator, Command Execution, Display Module. The modules are described below.

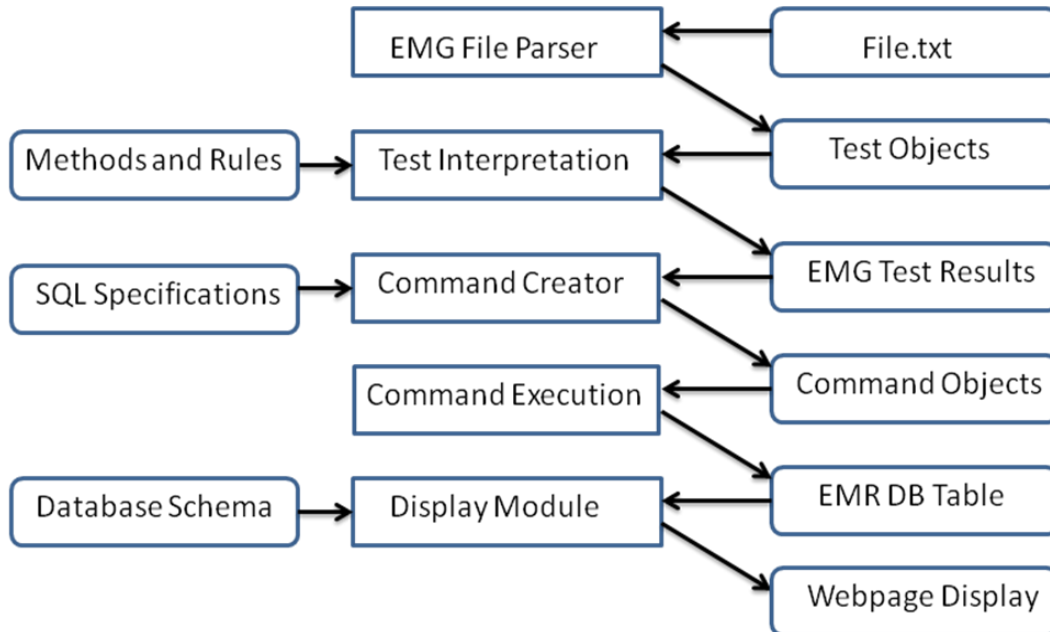


Figure 1. The modules of ENCAS are described. Data flows from a text file to the EMR and webpage display. Knowledge sources (required input to modules) are shown on the left side of the figure.

3.1 Software Modules

In this section we describe major software modules. For clarity, we trace a single test ("median ulnar sensory orthodromic") of the median nerve through processing. This test involves gathering physiological data of the median nerve and the ulnar nerve at the wrist. Interpretation includes comparing data to reference values and also comparing the median nerve and ulnar results. This is a standard test for carpal tunnel syndrome [2].

3.2 Module: EMG File Parser

This module is describe in a previous paper [9]. Briefly, the Parser reads the file, and generates a list of strings that are delimited by the space character.

Test Identification. Test Identification involves checking a string to see if the string is found in the list of key strings (e.g., "median" "ulnar" "orthodromic") and if a match is made a new test object is defined and input strings are stored into the new object. For our example, the new class would be *Sensory-Median-Ulnar*. The strings consumed are removed from the input list and the process iterates until all strings are consumed. This is an algorithmic parser.

3.3 Module: Test Interpretation

Test Interpretation is an algorithmic knowledge module encoded in methods. The methods are specific to the test class (i.e., Sensory-Median-Ulnar) and results are stored in the test object. Each test object is stored on a master test object. Interpretation is standard for neurology EMG labs and is discussed at length in Preston [2].

Diagnostic Analysis. The Diagnostic Analysis Module uses heuristics that are stored as methods. We define *N-Score* as a normalized score with range from zero to 100. An N-Score less than 60 is severely abnormal and an N-Score greater than 95 is normal). The normalized scores (N-Scores) are interpreted based on expert knowledge. For example, if there are three moderately abnormal median nerve scores then the heuristically derived score is severe. If there are 2 or fewer moderately abnormal scores, the final score is moderately abnormal. The heuristics are based on the manner in which the clinician would process the individual test scores. An average function was used initially but was replaced by expert knowledge and results were better. A table lookup converts N-Score (e.g., 60) to a text grade ("severely abnormal").

TEST SCORE	HEURISTIC SCORE	INTERPRETATION
90 + 90 + 90	90	Mildly Abnormal
90 + 90 + 80	90	Moderately Abnormal
80 + 80 + 80	75	Severely Abnormal
80 + 80 + 60	70	Severely Abnormal

Figure 2. Heuristic scoring of test results. Three or more abnormal results will tend to result in a more severe grade. The heuristic is based on the clinical impression that multiple abnormal test results have more weight and suggest a more severely abnormal overall score.

3.4 EMG Test Results.

Each EMG test object is stored on a master test object of class EMG-Test-Results. The storage step is included as the final step of Test Interpretation. Part of this object is displayed below.

```
#<EMG-TEST-RESULTS>
HEADER-DATA: #<HEADER-DATA>
MEDIAN-NERVE-RT-RESULTS: #<MEDIAN-
NERVE-RT-TEST-RESULTS>
ULNAR-NERVE-RT-RESULTS: #<ULNAR-NERVE-
RT-TEST-RESULTS>
RADIAL-NERVE-RT-RESULTS: #<RADIAL-
NERVE-RT-TEST-RESULTS>
NEEDLE-EMG-UE-RT-RESULTS: #<NEEDLE-EMG-
UE-RT-TEST-RESULTS>
```

3.5 Test Results for Median Nerve

In this paper, we trace a single test (median ulnar sensory orthodromic) of the median nerve through processing. The object is partially displayed here. Other tests for this nerve include digit II sensory, digit III sensory, APB motor, and others.

```
#<MEDIAN-NERVE-RT-TEST-RESULTS>:
MEDIAN-DIGIT-II-SENSORY-RIGHT
#<SENSORY-RT-MEDIAN-DIGIT2>
MEDIAN-DIGIT-III-SENSORY-RIGHT
#<SENSORY-RT-MEDIAN-DIGIT3>
MEDIAN-ULNAR-PALMAR-SENSORY-RIGHT
#<SENSORY-RT-MEDIAN-ULNAR>
MEDIAN-RADIAL-DIGIT-I-SENSORY-RIGHT
#<SENSORY-RT-MEDIAN-RADIAL>
MEDIAN-APB-MOTOR-RIGHT #<RT-MEDIAN-
MOTOR-APB>
N-SCORE 60
ALL-SCORES-WRIST (64.8074f0 60 50.0f0
50.0f0)
INTERPRET-WRIST "Severely abnormal"
```

3.6 Median Ulnar Palmer Sensory Orthodromic Test

The median ulnar palmar sensory orthodromic test (MUPS) results object is displayed here. The key datum here is the median-ulnar-ratio (1.74); based on published standards [2] this is an abnormal result.

```
#<SENSORY-RT-MEDIAN-ULNAR>:
SOURCE-STRING "R Median Ulnar -
Transcarpal comparison"
COMPUTED-SCORE 50
DISTANCE 14
STIMULATION "Palm"
RECORDING "Wrist"
MEDIAN-LATENCY 3.18
ULNAR-LATENCY 1.82
MEDIAN-ULNAR-RATIO 1.74
MEDIAN-GRADE "severe"
MEDIAN-LATENCY-NORMALIZED 50
MEDIAN-LATENCY-INTERPRETATION
"demyelinating process"
STUDY "Right Median Ulnar Sensory
Orthodromic Comparison"
```

3.7 Module: Command Creator

The Command Creator module is described here. Module inputs include SQL Specifications and EMG Test Results. The output is a set of Command objects wherein each object stores a mysql insert command.

3.8 Database Storage Setup

The knowledge required to move EMG test data from Common Lisp to the EMR is stored in specifications. There are 12 test classes and 12 corresponding specifications. Several specifications (and the resulting data structures) are shown below.

3.9 SQL Specification for Class

SQL specifications are of class *SQL-Spec-For-Class* and *SQL-Specification*. Generator functions include *sql-spec-for-class* (creates a SQL-Spec-For-Class object), *sql-specifications* (creates multiple SQL-Specification objects), and *sql-specification* (creates one SQL-Specification object). Each SQL-Spec-For-Class specification maps from an EMG test class to a mysql table. The global current SQL-Spec-For-Class object is set. Each SQL-Specification is defined and for the current SQL-Spec-For-Class defines a mapping from slotname to SQL attribute. Each SQL-Specification definition must include the "sql-table" (where the data is to be stored). If the slot name and attribute are the same only the slotname is required.

In the example below, the SQL-Specification function includes an output-processor function (sql-boolean-convertor) that converts List symbol T into "yes".

```
(sql-spec-for-class
: class-name 'SENSORY-MEDIAN-ULNAR
: sql-table 'EMG_RESULTS
: sql-test-name 'sensory_median_ulnar)

(sql-specifications
'(distance stimulation recording
median-latency ulnar-latency median-
ulnar-latency-ratio median-latency-
interpretation median-ulnar-latency-
grade median-ulnar-latency-
interpretation median-grade)

(sql-specification
: slotname 'median-response
: sql-attribute 'median_response
: output-processor #'sql-boolean-
convertor)
```

3.10 Knowledge Base of SQL Specifications

Below is an example SQL-Spec-For-Class object. Components include the *class-name* (EMG test class), the *SQL-Table*, the *SQL-test-name* (test identifier in the database) and *class-slots* (list of slot/attribute mappings). Each SQL-Spec-For-Class object (see "SENSORY-MEDIAN-ULNAR") contains a list of class slot specifications. Here is listed a few of the slot SQL specifications.

```
<SQL-SPEC-FOR-CLASS SENSORY-MEDIAN-
ULNAR>:
CLASS-NAME: SENSORY-MEDIAN-ULNAR
SQL-TEST-NAME: SENSORY_MEDIAN_ULNAR
SQL-TABLE: EMG_RESULTS
CLASS-SLOTS: (<SQL-SPEC EMG_RESULTS
DISTANCE>
<SQL-SPEC EMG_RESULTS STIMULATION>
<SQL-SPEC RECORDING EMG_RESULTS
RECORDING>
<SQL-SPEC EMG_RESULTS MEDIAN_RESPONSE>
<SQL-SPEC EMG_RESULTS ULNAR_RESPONSE>
<SQL-SPEC EMG_RESULTS MEDIAN_LATENCY>
<SQL-SPEC EMG_RESULTS ULNAR_LATENCY>
<SQL-SPEC EMG-RESULTS MEDIAN_GRADE>
<SQL-SPEC MEDIAN-LATENCY-INTERPRETATION
EMG_RESULTS>
<SQL-SPEC STUDY EMG_RESULTS STUDY>)
```

A single SQL-Spec object is shown here. This specification states the destination table, the attribute, the ENCAS class name and the ENCAS slotname. When processed the data in the slot "slotname" is moved into the table attribute "SQL-Attribute."

```
<SQL-SPEC MEDIAN-LATENCY EMG_RESULTS
MEDIAN_LATENCY>:
```

```
CLASS-NAME: SENSORY-MEDIAN-ULNAR
SLOTNAME: MEDIAN-LATENCY
SQL-TABLE: EMG_RESULTS
SQL-ATTRIBUTE: MEDIAN_LATENCY
```

Two other specifications are shown here:

```
CLASS-NAME: SENSORY-MEDIAN-ULNAR
SLOTNAME: DISTANCE
<SQL-SPEC DISTANCE EMG_RESULTS
DISTANCE>:
SQL-TABLE: EMG_RESULTS
SQL-ATTRIBUTE: DISTANCE
```

```
<SQL-SPEC ULNAR-RESPONSE EMG_RESULTS
ULNAR_RESPONSE>:
CLASS-NAME: SENSORY-MEDIAN-ULNAR
SLOTNAME: ULNAR-RESPONSE
SQL-TABLE: EMG_RESULTS
SQL-ATTRIBUTE: ULNAR_RESPONSE
INPUT-PROCESSOR: #<Function IDENTITY>
OUTPUT-PROCESSOR: #<Function SQL-
BOOLEAN-CONVERTOR>
```

3.11 Insert Patient Name to Get ID

The next phase of processing involves using data in the Patient Identification Header data (last name, first name, date of birth) to generate an insert command. The header data is parsed from the input file. The patient ID insert command is processed by (mysql "INSERT INTO `emg_tests` (patient_id, test_date) VALUES ...") function. A mysql query (mysql-insert-id) for unique ID is performed and the ID is stored. This ID is used in the next step of command building.

3.12 Module: Command Generator

The next step involves looping over each SQL-Spec-For-Class and its class-slots (list of SQL-Specs). New objects of class *SQL-EMG-Command* and class *Command-String-Data* are generated. One SQL-Spec-For-Class maps to a single SQL-EMG-Command. Each SQL-Spec (linking slot to SQL attribute) is used to generate a command string. All command strings are concatenated into a complete SQL Insert statement. The unique test ID obtained in the previous step (e.g., "26") is included in each complete command string. An example is below.

```
<SQL-EMG-COMMAND 26
SENSORY_MEDIAN_ULNAR right EMG_RESULTS
12 command strings>:
```

COMMAND-STRINGS

```
(<COMMAND-STRING-INSERT INSERT INTO
`emg_results` (`test_id`,`nerve_name`,
`side`,`result_name`,`result_value`)>
<COMMAND-STRING-VALUES VALUES>
<COMMAND-STRING-DATA ('26',
'sensory_median_ulnar', 'right',
'distance', '14'),>
```

```

<COMMAND-STRING-DATA ('26', ('26', 'sensory_median_ulnar', 'right',
'sensory_median_ulnar', 'right', 'median_latency_interpretation',
'stimulation', 'palm'),> ('26', 'sensory_median_ulnar', 'right',
'sensory_median_ulnar', 'right', 'study', 'right median ulnar sensory
'recording', 'wrist'),> orthodromic comparison');"
... TEST-ID 26
<COMMAND-STRING-DATA ('26', TEST-NAME SENSORY_MEDIAN_ULNAR
'sensory_median_ulnar', 'right',
'study', 'right median ulnar sensory
orthodromic comparison');>
SQL-COMMAND-STRING
"INSERT INTO `emg_results`
(`test_id`,`nerve_name`,`side`,
`result_name`,`result_value`)
VALUES
('26', 'sensory_median_ulnar', 'right',
'distance', '14'),
('26', 'sensory_median_ulnar', 'right',
'stimulation', 'palm'),
('26', 'sensory_median_ulnar', 'right',
'recording', 'wrist'),
('26', 'sensory_median_ulnar', 'right',
'median_response', 't'),
('26', 'sensory_median_ulnar', 'right',
'ulnar_response', 'yes'),
('26', 'sensory_median_ulnar', 'right',
'median_latency', '3.18'),
('26', 'sensory_median_ulnar', 'right',
'ulnar_latency', '1.82'),
('26', 'sensory_median_ulnar', 'right',
'median_grade', 'severe'),

```

3.13 Module: Command Execution

The next step involves looping over all SQL-Command-Objects. Each iteration involves running the (mysql <args>) function with the *sql-command-string* argument. The command string is passed to mysql and data is inserted into the "emg_results" table. Functions used for the interface include *connect*, *sql*, and *disconnect*. Details regarding Allegro Common Lisp mysql functions are found in the online manual [14].

3.14 Module: Webpage Display

This module (a component of the EMR) displays the ENCAS data stored in the prior step. Inputs include the database schema and the "emg_results" table and the module is coded in PHP [15]. The module generates a presentation of the EMG data organized by patient and secondarily by EMG Test.

Distance	14
Median Grade	Severe
Median Latency	3.18
Median Latency Interpretation	Demyelinating Process
Median Response	T
Recording	Wrist
Stimulation	Palm
Study	Right Median Ulnar Sensory Orthodromic Comparison
Ulnar Latency	1.82
Ulnar Response	Yes

Figure 2. The EMG data for one test ("sensory median ulnar orthodromic") are presented to users of the EMR in tabular format.

4. System Is Operational

A mature prototype has been integrated into the EMR of the Alaska Brain Center neurology clinic and is used on a daily basis. An EMG test data file is processed by ENCAS and stored into the EMR as discussed above. With this new software, the data is instantaneously available and access is nearly

instantaneous. The data can be arranged into patient reports and arrangement is easily coded using PHP code. Time to process one text file, analyze the data, and store the data into the EMR is approximately one second. The clinic performs from on to four EMG studies per day. Use of ENCAS reduces EMG analysis time from 20 minutes (for 1 study) to 3

seconds. For 4 studies, the time is reduced from 80 minutes to less than 10 seconds.

5. Areas for Future Development

Database storage of the EMG information will allow development of new system modules. These are listed here:

Correlation of nerve data and coexisting disease states. For example, a search for B12 deficiency and median nerve conduction velocities can be performed.

A search for median nerve amplitudes and glucose levels may yield important correlations between hyperglycemia and median neuropathy. Diabetes is a risk factor for neuropathy [2].

If a patient has multiple EMG studies, comparison from one study to the next can be done and results stored and presented in new EMR tables.

Presentation of EMG data in line graphs or other formats is planned.

Analysis of nerve latencies by age can yield useful statistics about natural history of nerve function.

Correlation of nerve data and medications used can be performed. For example, there are medications (such as paclitaxel) that are reported to lead to neuropathy [16]. An EMR search for radial sensory neuropathy via the EMG tables and paclitaxel use (from the medication tables) may yield important statistics (although this would be non-controlled retrospective data).

6. Conclusions

The following conclusions based on this prototype are made from this research effort:

1. We find very few automated EMG systems. Chatzikosma [17] reports on an automated sural nerve conduction analysis system that achieved 90.48% sensitivity, 86.11% specificity for detecting diabetic peripheral neuropathy. Another system was engineered by Mishra [18].
2. Automated EMG data analysis is feasible as demonstrated by this mature prototype.
3. Data transfer from Common Lisp to MYSQL data tables is mature technology.
4. Presentation of EMG data via PHP may increase clinical efficiency based on the fast access.

This program augments our suite of AI/Neurology systems that have been described in previous publications [5, 6, 7, 8, 9, 10, 11, 12].

5. Further research correlating neuropathic features and disease states may result from database storage of the clinical data as described in this report.
6. The ENCAS system tightly integrates fourth and fifth generation technologies to enhance an EMR.

References

- [1] Kimura J. 2001. *Electrodiagnosis in diseases of nerve and muscle: Principle and Practice* (3d ed.).Oxford University Press, Philadelphia, pp 719-721.
- [2] Preston, D and B Shapiro, 1998. *Electromyography and Neuromuscular Disorders*, Butterworth and Heinemann, pp. 100-120.
- [3] G. Steele, *Common Lisp the Language, 2nd Edition*, Digital Press, 1990.
- [4] S. Keene, 1989. *Object-Oriented Programming in Common Lisp: A Programmer's Guide to CLOS*, Addison Wesley, 1989, ISBN: 0201175894.
- [5] J. Sponsler, F. VanScoy, J. Culberson, The System for Neurological Analysis of Patient Symptoms: An Integrated Artificial Intelligence Prototype. *Proceedings of the IASTED International Conference on Modelling, Simulation and Optimization (MSO2004)*, August 17 -19, 2004, in Kauai, Hawaii.
- [6] J. Sponsler, M. Werz, M. Kahrman, 2004. Video EEG Expert System: Software to compute seizure focus lateralization and localization prior to epilepsy surgery. *Proceedings of the IASTED International Conference on Modelling, Simulation and Optimization (MSO2004)*, August 17 -19, 2004, in Kauai, Hawaii.
- [7] J Sponsler, MD. StrokeDX: A logic programming system to diagnose stroke. *Proceedings of the IASTED Conference for Telehealth*, Innsbruck Austria, February 2012.
- [8] J Sponsler, MD, M Senta, A Kendrick-Adey. Stroke expert system extended to diagnosis CADASIL. *Proceedings of the IASTED Conference for Telehealth*, Innsbruck Austria, February 2012.
- [9] Sponsler, JL. 2012. Automated Analysis of Electromyography Data. *Proceedings of the IASTED Conference for Telehealth*, Innsbruck Austria, February 2012.
- [10] Sponsler J. 2013. NEUROBRIDGE: An AI development environment for neurology. *Proceedings of the 24th IASTED Conference on Modeling and Simulation*, Banff, Canada, July 17-19, 2013.

[11] Sponsler J. 2013. PLEXBASE: A digital model of the brachial plexus. *Proceedings of the 24th IASTED Conference on Modeling and Simulation*, Banff, Canada, July 17-19, 2013.

[12] Sponsler J, HPARSER: Extracting formal patient data from free text history and physical reports using natural language processing software. *Proceedings of the American Medical Informatics Association Annual Symposium*, Washington DC, Nov 3-11, 2001.

[12] J. Sponsler, F. Pan, 2011. An electronic medical record for neurology. *Proceedings of IASTED Conference on Telehealth*, Feb 2012.

[14] ACL MySQL Manual, <https://franz.com/support/documentation/current/doc/mysql.htm>.

[15] PHP Manual, <http://php.net/manual/en/index.php>.

[16] Duggett NA1, Griffiths LA, Flatters SJL. Paclitaxel-induced painful neuropathy is associated with changes in mitochondrial bioenergetics, glycolysis, and an energy deficit in dorsal root ganglia neurons. *Pain*. 2017 Jun 15.

[17] Chatzikosma G1, Pafili K1, Demetriou M1, Vadikolias K1, Maltezos E1, Papanas N1. Arch Med Sci. 2016 Apr 1;12(2):390-3. doi: 10.5114/aoms.2016.59265. Epub 2016 Apr 12. Evaluation of sural nerve automated nerve conduction study in the diagnosis of peripheral neuropathy in patients with type 2 diabetes mellitus.

[18] Mishra R, S Dandapt, 1993. A knowledge based interpretation system for EMG abnormalities. *Int J Clin Monit Comput* 1993 May; 10(2):131-42.