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A personal computer based system used in electromyography for interpretation and reporting

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Programs for rule based electromyography (EMG) interpretation and reporting are described. A number of parameters are obtained during an EMG investigation. The combination of these data leads to a neurophysiological conclusion. Knowledge from the literature, research and experience is the basis for rule development. Rules have been developed for 14 of the most commonly used classifications of an EMG. The syntax is relatively easy and the user may change the rules, add rules or apply the system for other types of data. The results are displayed in a new graphical way. The system presented here is part of an integrated EMG laboratory with administrative routines, distributed databases for storage of results and routines for automatic report generation.

Expert system; Electromyography; Medical reasoning; Neurophysiology; Report generator; Integrated electromyography laboratory

1. Introduction

Patients with symptoms from muscles or nerves such as weakness, atrophy, numbness, tingling and pain are often referred for neurophysiological investigation. Such procedures may include electromyography (EMG), nerve conduction studies, evoked potentials, repetitive nerve stimulation, quantitative sensory testing, autonomic tests and electroencephalography (EEG).

The findings from most of these investigations are presented as numerical values which represent various parameters characterising a physiological signal from muscle, nerve or brain. The results are usually relatively easy to present in tables and graphs. One of the techniques, EMG, used in clinical routine for diagnosis and monitoring of neuromuscular disorders, differs from the others

in this respect. More parameters are analyzed, and interpretation and reporting are more complex. Within the field of medicine, the area of EMG has been chosen as a test bench for the development of expert systems since numerical data are available, general rules to classify findings are defined and the final interpretation is sufficiently complex to offer a challenge to artificial intelligence (AI) systems [1–7]. Our initial aim was to develop a personal computer (PC) based system to produce standardized and practical reports of EMG findings. During the developmental process, we found a need for more consistent interpretation of EMG findings and for a better defined nomenclature. This led to a rule based system that gives guidance in interpretation and serves as a report generator. In addition the system turned out to be useful in a teaching situation. It does not aim to be a complex AI system for EMG but a practical and useful tool for the above-mentioned tasks. Further development will add other features. The system will also be applicable for other neurophysiological tests.

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This system is now a module in an integrated EMG laboratory.

2. Problem

During routine EMG examination, a number of parameters are obtained describing the electrical activity of muscle. Recordings are performed with the muscle at rest, at slight activation and at strong contraction. The interpretation is based on the combination of these data. Deviations from the normal pattern may indicate a muscle or nerve disease.

The EMG report to the referring doctor includes:

- description of findings in each muscle (raw data);
- interpretation of findings in each muscle;
- overall interpretation of the EMG findings; and
- a general conclusion based on results from all neurophysiological tests performed in that patient.

In most neurophysiological departments the EMG parameters are still assessed in a semi-quantitative way although computer based systems are available for nearly all of the tests that are performed [8]. There is an international consensus about the principal cause of changes in the EMG parameters [9] but often the results from only one or even a few parameters are insufficient to describe more specifically the status of nerve or muscle. Only the combination of a number of parameters will lead to correct interpretation. To take an example where the interpretation is based on combination of findings: it is agreed that if an average value of 20 recordings shows high amplitude, long duration motor unit potentials (MUPs), the pattern is compatible with reinnervation. The concurrent finding of abundant fibrillation potentials indicates that a number of muscle fibres are probably still denervated, i.e. the denervation/reinnervation process is still ongoing, and the finding is classified as 'subacute neurogenic' condition. At this stage the individual MUPs usually show a very unstable shape at consecutive discharges, which is used to confirm the classification. If, on the other hand, the amount of fibrillations is less pronounced and the MUPs are rela-

tively stable but the other MUP parameters are the same, the findings are classified as 'chronic neurogenic'. Thus, the combination of findings gives a more detailed picture of the dynamics of the process and adds another dimension to the final conclusion.

The *nomenclature and scoring of degree of abnormality* varies between different laboratories, even within the same country. Attempts to standardize these on the basis of current knowledge and routines have been part of the challenge in the development of the system under discussion. It has been necessary to define various types of findings (myopathy, inactive, subacute and acute neurogenic, and so on) and degree of abnormalities in terms of slight, moderate and pronounced. Rules characterizing the combination of findings for each of these have therefore been constructed.

There is also a great diversity in *reporting* the results. This is partly due to locally specific situations such as knowledge in EMG of the referring doctor, the EMGer's involvement in the further management of the patient, secretarial help, usage of computers in the laboratory and so on.

The expert system presented here makes rule based conclusions about type of change in the muscle and produces an EMG report in a standardized and modular way. It is flexible and may be considered as a shell since all parameters and rules can be modified by the user. It is introduced as a part of the integrated EMG laboratory.

3. Description of the system

The individual modules of the system will be described in some detail and exemplified by their use in our department of clinical neurophysiology.

3.1. Anatomical database

Different muscles may show various types of change and must therefore be reported separately. The distribution of abnormal findings among muscles carries important diagnostic information. For each complete EMG investigation a number of muscles are therefore studied.

Muscle name is chosen from an *anatomical knowledge base* containing all muscles usually used

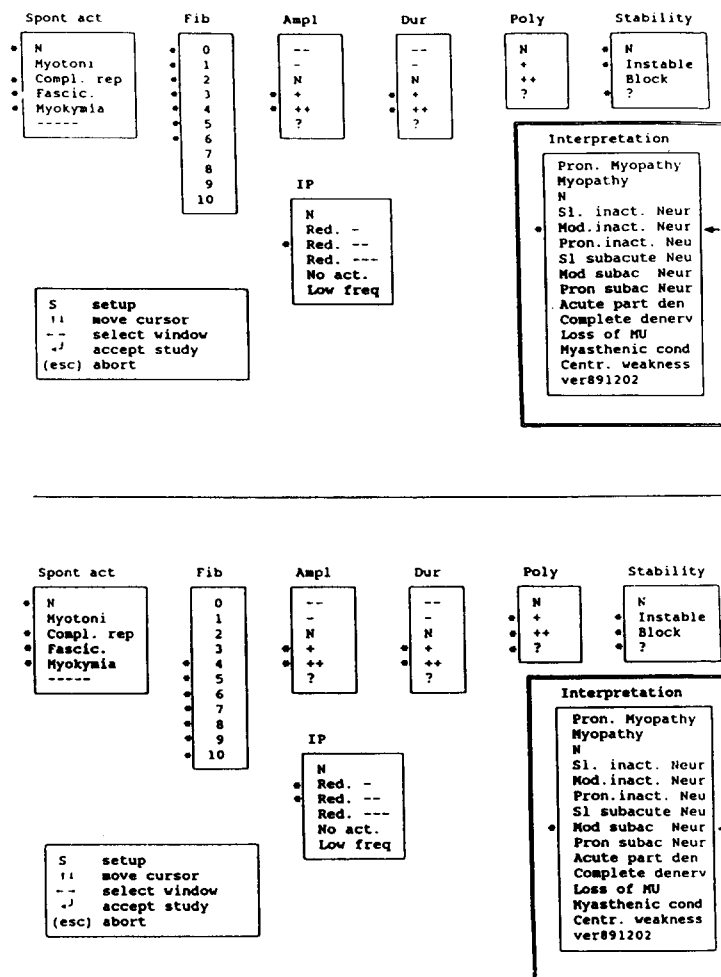


Fig. 1. Rules for defining 'moderate inactive neurogenic lesion' (upper panel) and 'moderate subacute neurogenic lesion' (lower panel) here displayed on a screen frame normally seen during the investigation. The criteria for the interpretation are indicated by asterisks (normally not seen) in the 'parameter windows'. An arrow in the 'interpretation window' indicates the conclusion.

in EMG investigations. Name of muscle, its peripheral nerve and root level(s) are stored. A scrolling function is used to display muscles from a table organized e.g. in an anatomic order from head to foot. In addition a SEARCH function is available to search for a specified nerve or root. All muscles fulfilling the search criterion are highlighted in the muscle table.

3.2. Parameters

A number of parameters are measured to characterise the EMG. We have chosen seven main

groups as being the most important (Fig. 1). Some of them are obtained at each investigation in all EMG laboratories, others only in a smaller number of laboratories. Most commonly the quantitation is made by visual analysis although a number of computerized systems have now been developed for automatic analysis [8]. They will eventually be introduced more widely. In the example shown in Fig. 1 the data from an investigation is imported by manual insertion. (If data from automatic analysis methods are available they are often expressed as number of standard deviations (SD) from mean values in a reference sample. This is a

useful way of normalizing individual results. These data can be imported automatically.) Before any data is inserted, all parameter values are set to **NORMAL** as default (other alternatives can be chosen in a setup function).

3.3. Assessment of individual parameters

3.3.1. Spontaneous activity (except fibrillation potentials)

This is a pure descriptive parameter (type **YES / NO**), indicating whether or not a specific type of spontaneous activity is ever seen in that muscle. Certain types of spontaneous activity may exceptionally be seen in normal muscle, another type is typical for myopathies, another for conditions characterized by denervation.

3.3.2. Fibrillations and positive waves

This is quantified as number of recording sites out of ten in which fibrillation potentials or positive waves are seen.

3.3.3. Amplitude duration

These parameters can be quantified by means of analytic systems (an external PC or integrated in the EMG equipment). In the majority of laboratories, visual semiquantitative analysis is still made from signals stored on the display screen. If exact data is lacking, manual scoring may be used as input as shown below.

N = normal (± 2 SD);

- or + = 2–3 SD outside normal limits ('slight – moderate abnormality');

-- or ++ = deviation by more than 3 SD ('pronounced abnormality')

No information = data could not be obtained, e.g. in cases where no EMG activity is elicited.

3.3.4. Polyphasic

This parameter may be quantified as well, but often visual scoring is used.

N = normal;

+ = slightly increased (2–3 SD);

++ = pronounced polyphasicity (more than 3 SD);

? = not assessed.

3.3.5. Stability (jitter in the MUP)

Algorithms to assess this parameter are still under

development, thus stability is therefore assessed semiquantitatively.

N = normal;

Jitter = many MUPs show instability;

Block = many MUPs show blocking components;

? = not assessed.

3.3.6. (IP (interference pattern))

N = normal or full. Early recruitment is included here as also is the disproportionate density of the interference pattern (fullness) at reduced force in myopathies. **NORMAL** only refers to density, not shape or spectral content.

Red. - = slightly reduced density;

Red. -- = moderately reduced density;

Red. --- = pronounced reduction in density, single oscillations;

No act. = no voluntary activity obtained;

Low freq. = reduced firing rates of individual motor units.

4. Interpretation of findings in each muscle

4.1. Principal bases for development of interpretation rules

The main principles that should be covered by the rules of interpretation are summarized in the following knowledge base:

Myopathies. Low (or normal) amplitudes, short duration increased number of polyphasic MUPs and normal or slightly decreased density of interference pattern. Pronounced myopathy is flagged when MUP parameters are excessively abnormal or when duration is very short and there is a reduction of the interference pattern.

Inactive neurogenic. This has sometimes been called chronic neurogenic, a term that less distinctly reflects the basic interpretation of the EMG findings. An inactive neurogenic condition is characterized by signs of *earlier reinnervation* that is completed. The process is completed in most recordings although some degree of ongoing reinnervation may be seen. The EMG shows little or moderate amount of fibrillation potentials, increased MUP amplitude and duration, and relatively stable MUPs. The preceding denervation

was either a single event in the past (traumatic nerve lesion, poliomyelitis) or a slowly progressive disorder (hereditary neuropathy, spinal muscular atrophy). In a minority of the recordings evidence of ongoing denervation/reinnervation is seen particularly in the last group. In other laboratories the term *chronic partial denervation* is used as interpretation of the EMG findings in this subgroup.

Subacute neurogenic. This term is used in conditions characterized by *ongoing reinnervation*, either after a single lesion (traumatic nerve lesion) or due to ongoing denervation (motor neurone disease). The EMG contains fibrillation potentials as signs of denervation, and large MUPs which show shape instability in increased proportions of the recordings as signs of recent innervation. Some denervation is present either since the reinnervation is not yet completed in all fibres, e.g. 1–3 months after a nerve lesion or since the denervation process continues as in amyotrophic lateral sclerosis (ALS) or axonal neuropathies.

Acute partial denervation. A situation present 2–4 weeks after denervation, before the process of reinnervation has started. Signs of denervation (fibrillation potentials and positive waves) are present but no signs of reinnervation are seen yet.

Complete denervation. No activity can be elicited voluntarily or with electrical nerve stimulation. This condition can only be differentiated from neurapraxia with certainty after some time (7–10 days depending on site of lesion). Abundant fibrillation activity confirms denervation.

Motor unit (MU) loss. Loss of motor units either due to recent denervation, within 10 days, not yet causing fibrillation potentials, or due to neurapraxia. Here the MUP parameters are normal but the interference pattern is reduced (high firing rate but decreased number of active motor units).

Central weakness. Normal findings in MUP parameters but the interference pattern is reduced due to low and irregular firing rates. This may be due to upper motor neurone lesion, lack of cooperation from the patient or lack of afferent impulses (tendon rupture, dorsal root involvement).

Myasthenic condition. Unstable MUPs without concomitant findings of ongoing reinnervation that could explain the instability.

4.2. Inference machine

The inference machine is based on a set of rules. Rules for the 14 most commonly used interpretations have been developed. The rules are based on literature information, our own experience and on re-analysis of some hundred earlier EMG protocols containing raw data and interpretation. After this phase, the system was tuned dynamically to increase the congruency with conventional EMG analysis.

Conditional algorithms describe, as uniquely as possible, a given situation. The same interpretation may be reached by various combinations of input data, defined in these rules.

In a few situations a combination of findings may fulfill criteria of two rules, which is also indicated by the system. This is used in the present version of rule bases to offer some degree of flexibility, which is necessary in some situations, because of relatively crude data from visual scoring. In other situations the combination of findings is unexpected by the rule system and 'confused' is flagged. Usually however (90% of the time), the combination of findings leads to a suggestion from the system. The suggested interpretation may be confirmed or overruled by the EMGer. A separate interpretation is given for each muscle that is investigated.

The result of the inference is indicated by an arrow in the **INTERPRETATION** window (Fig. 1). The system starts with the diagnosis of **NORMAL**. Each time additional information is introduced, the system continuously produces an updated interpretation based on information available so far.

The *rules* are technically easy to change using a special syntax. When the user has defined the rules in his system they should however be changed reluctantly, otherwise the idea of standardization over time is lost.

5. Report

The final report is an essential output from an expert system. It is often difficult to produce a user-friendly display of results and this is certainly true in EMG. There is no generally accepted

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Muscles	Innervation	Spont act	Fib	Ampl	Dur	Poly	Stability	IP	Interpretation
frontalis Sin	facialis	No(ox.fib)	0	M	M	M	M	N	M
Pectoralis major Sin	C5(C6) pec lat	No(ox.fib)	9	**	**	-	Instable	Red. ...	Pron subac Neur
Triceps brachii Sin	C7(C6,C8) rad	No(ox.fib)	7	-	-	-	M	Red. ...	S1 subacute Neu
Triceps brachii Dx	C7(C6,C8) rad	No(ox.fib)	9	-	**	-	Instable	Red. ...	Pron subac Neur
Quadriceps rectus fem Dx	L2(L3) fem	No(ox.fib)	9	-	**	-	Instable	Red. ...	Pron subac Neur
Tibialis anterior Sin	L5(L4) per prof	No(ox.fib)	10	?	?	?	?	No act.	Complete denerv
Tibialis anterior Dx	L5(L4) per prof	No(ox.fib)	10	-	**	-	Instable	Red. ...	Mod subac Neur

SUMMARY

Neurography: see enclosed figure - normal findings

EMG: see enclosed figure - pronounced neurogenic changes in many segments.

CONCLUSION:

Findings compatible with motor neuron disease

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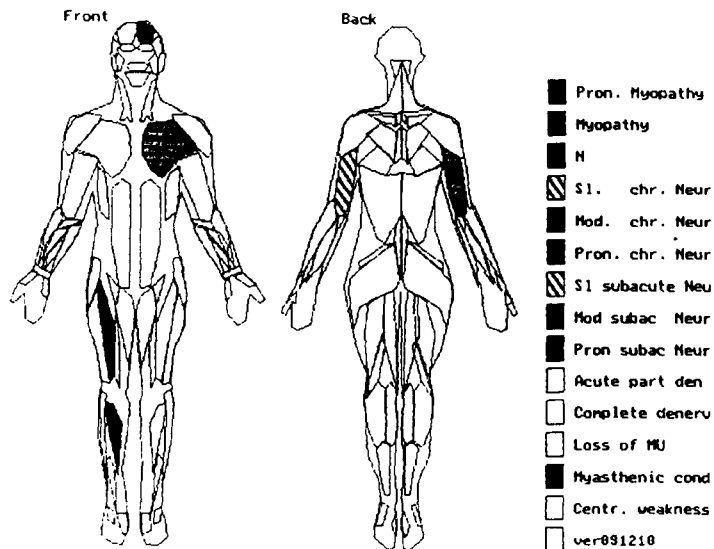


Fig. 2. Final printout showing a table of investigated muscles, raw data and interpretation (upper part), a free text summary (middle part) and the muscle man (lower part) with pattern-coded results corresponding to the information in the table.

standard way of reporting. In this system we have introduced a new type of display that hopefully conveys a large amount of important information to the reader in a fast and comprehensive way.

5.1. The 'muscle man'

A template of a schematic representation of muscles in anatomical position is stored. It con-

sists of a digitized drawing with the most commonly used muscles in EMG work. For each investigation, the interpretation of findings in each muscle is coded in colours or in black and white patterns (Fig. 2) and displayed as a 'muscle man' on the screen after a PLOT command. This display gives an overview of findings so far. One can immediately see which muscles have been investigated and the principal findings. The investigator

may judge the study incomplete at this stage and decide to continue or may confirm that the study is completed. This graph may be plotted on a colour plotter or obtained on a laser printer.

A similar plot may be used for the display of nerve conduction data.

5.2. Conclusion

The EMGer's conclusion from the entire investigation is given as free text.

5.3. Final printout

The printout thus contains three parts (Fig. 2):

- (1) a table of raw data and interpretation of the findings in each muscle;
- (2) graphic display, the 'muscle man';
- (3) concluding remarks.

6. The integrated EMG laboratory

By means of a local network (Lantastic) various types of information are available (Fig. 3). The secretary books patients some weeks before the examination (PROMAN). On the day of investiga-

tion, the name of the patient, type of investigation and name of doctor and technician are automatically fed into the analyzing equipment. Data from the examination is stored in the local PC as well as the results from the above described EMG interpretation. The doctor may insert a summarizing text in his own computer (DOC) or choose to dictate to his secretary (SECR). The secretary now commands the computer to compile an EMG or other report. Depending on the type of report, the computer makes a search of data in various stations including previous data from that patient. For EMG it usually collects data from nerve conduction studies, EMG data and interpretation including the muscle man, decrement and single fibre EMG studies and finally the free text summary. The final report is then edited according to an optional setup that may easily be modified. The report is printed on a laser printer but is also stored in the computer. Raw data is stored in the peripheral PCs as distributed databases.

The system automatically gives administrative information about production, waiting list and so on.

7. Discussion

In the process of interpreting the EMG findings, a number of more or less well defined rules are used, based on personal experience and literature. The practice varies between laboratories and even within one laboratory the same findings may be judged differently. Even the same EMGer's opinion when confronted with the same set of data may vary from time to time. Therefore there is a *need for consensus about interpretation* of EMG findings.

The generation of rules has meant extensive research within the laboratory and in the literature concerning definitions of various conditions. A general agreement has been reached locally but a wider exposure to the system will probably lead to new ideas about standardization and interpretation. This will probably be of value as a teaching tool and promote further understanding of EMG.

An EMG is in fact an electrophysiological consultation, not a laboratory test. After clinical as-

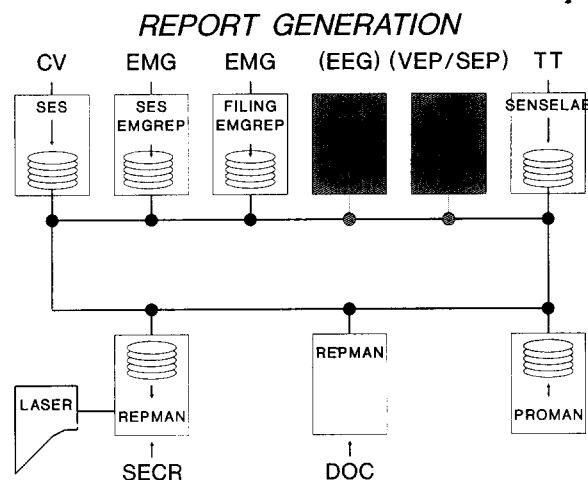


Fig. 3. Local network setup for the integrated EMG laboratory. PROMAN = the booking system containing patient information; CV = nerve conduction equipment with PC; EMG = the EMG equipment and interpreter; REPMAN = report manager used to produce the final report; DOC = doctor; SECR = secretary.

assessment and neurophysiological investigation, a summary should be compiled, useful to the referring doctor to guide him/her in managing the patient. Many times the EMG report contains noncomprehensive nomenclature, superfluous data and the main message may be diluted by redundant information. This will lower the credit of a useful and important investigation. Therefore it is important to find a way to present pertinent information in a balanced way. The report should be sufficiently detailed, give evidence on which the interpretation is based and be complete enough to be used for later comparisons. It should not be overloaded with data that should be kept in other laboratory files.

In our department, the investigation results are produced in different EMG rooms. By means of a local network, the secretary or doctor will finalize the report by adding conclusions as free text and produce an edited report. The reports may be stored in the system for easy retrieval at any time. This feature is particularly useful when the PCs are interconnected via a network, allowing database browsing from any station.

The knowledge base supported EMG interpreting and reporting is an example of an expert system that has been implemented as a practical and useful tool in the daily routine in clinical neurophysiology. It helps to standardize interpretation and reporting and is useful as a teaching instrument, computer assisted instruction.

8. Program features

8.1 General

The system runs on IBM PCs with EGA graphics, 512 kbytes memory and a hard disk. The program is written in Clipper (a dBASE compiler) and the graphical routines in Turbo Pascal.

8.2 Databases

Rules, headlines, texts and window contents are stored in dBASE files which may be edited by the user from within the main program. All parameter values are shown on the screen in windows. The

user may select any window and change the parameter value at any time using the keyboard arrows or a mouse.

8.3 Rules

One rule is connected to each row in the interpretation window. It is constructed as a logical expression where the operands are the row settings in the parameter windows. All logical operators and parentheses may be used in any combination. For example, the rule

```
Interpretation(3) = window(1) > 3 .and. (
window(4) = 2 .or. window(4) = 5 )
```

means: to fulfill interpretation number 3, a larger value (row) than 3 must be present in window 1 and value 2 or 5 must be present in window 4. Note that the text content in each window is not used by the program, only the position within the window. It only operates with windows and rows to give full flexibility, but has the disadvantage that some rules may have to be modified in case of window reorganization.

The default setting for each parameter window is user selectable. In our system this is **NORMAL** but may alternatively be set to **NO INFORMATION AVAILABLE**.

All rules are continuously scanned to give the current suggestion for interpretation which is indicated by a small flashing arrow just beside the selected interpretation. If all rules were found logical false, no arrow will be set and the text 'Confused' appears on the screen. The processing time is less than 1 s.

8.4 Results

Upon exiting from the program, all parameters for each investigated muscle are stored in a dBASE file and may be retrieved later. The program currently supports printouts on IBM Pro-Printer/Epson printers, HP7470/HP7475 pen plotters and HP LaserJet laser printers.

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