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A Technical Note

Design and preliminary evaluation of a portable instrument for assisting physiotherapists and occupational therapists in the rehabilitation of the hand

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Abstract—This paper describes a portable instrument designed to monitor progress accomplished by patients participating in a hand rehabilitation program. The instrument is driven by a microcontroller and features signal conditioning circuits to measure and record the strength and duration of hand contractions. An alphanumeric display provides the patient with performance indications to allow biofeedback reinforcement, and clear instructions on how to perform the prescribed exercises. Exercise data acquired by the portable instrument can be transferred to a host computer for analysis and archival storage. Results of a preliminary clinical evaluation in 14 patients are presented.

Key words: *computer analysis, hand rehabilitation, microcontroller, physical and occupational therapy, signal conditioning circuits, surface electromyogram.*

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INTRODUCTION

A deficit in hand functionality and performance due to injury is relatively frequent, and the consequences of permanent disablement are severe for the individual as well as for society. Normal medical treatment of hand injury begins with a clinical evaluation to determine the degree of injury, and the type of intervention (surgery, immobilization, mobilization, etc.) required to restore normal physiology. Afterwards, a rehabilitation program is prescribed to the patient. The first part of this program is generally aimed at controlling edema and pain, and at improving mobility of the articulation and soft tissues. The second part consists of a series of therapy sessions. Each therapy session is composed of a prescribed number of hand reinforcement exercises. Periodic evaluations are carried out to monitor the progress accomplished by the patient.

It is well-recognized that this therapeutic method plays an important role in improving hand

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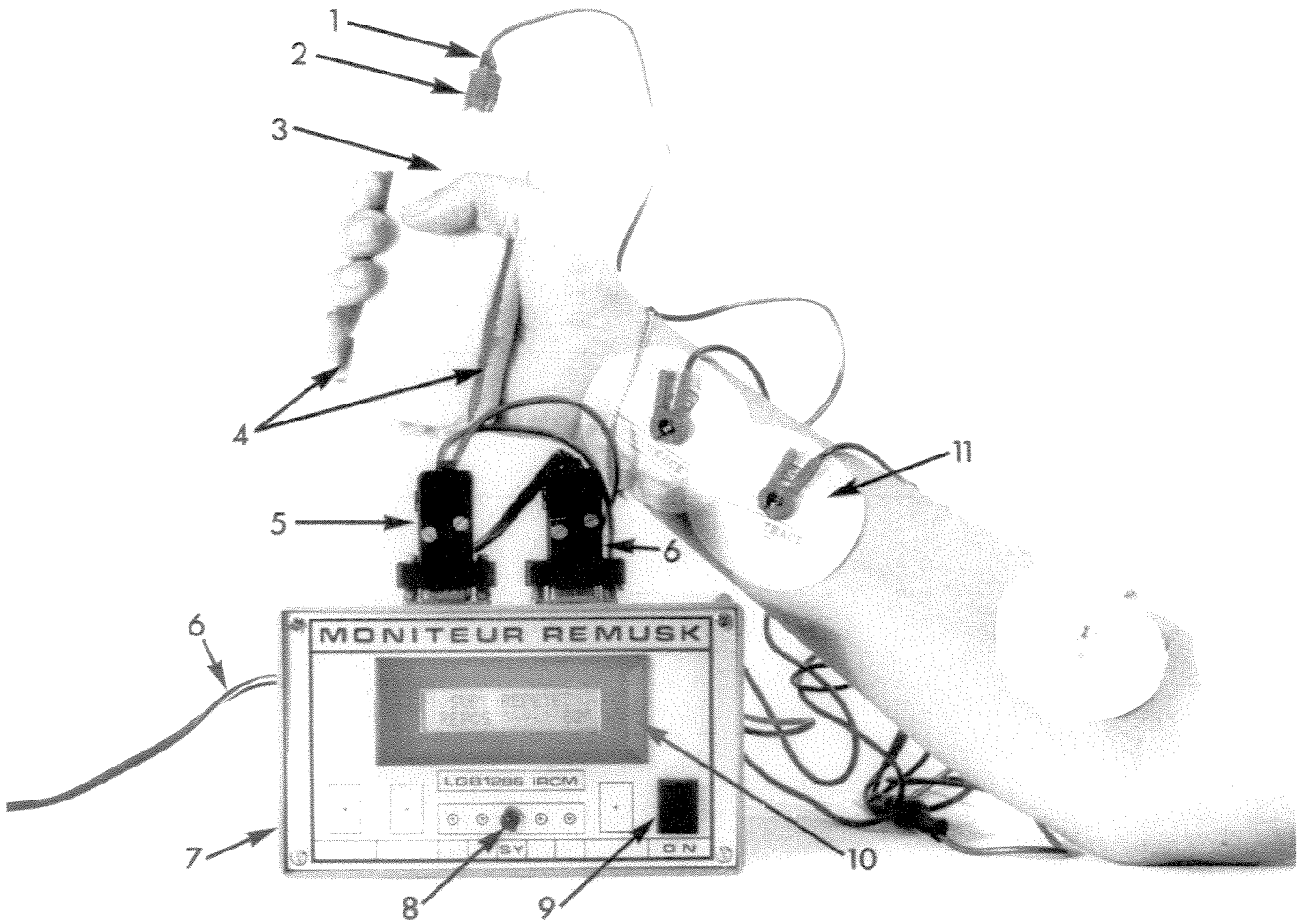

Figure 1.
Photograph of the portable monitor, as used by the patients: 1. pressure sensor; 2. water-filled rubber cylinder; 3. conventional hand exerciser; 4. rigid semilunar plexiglass bars; 5. EMG and pressure transducer cables and connector; 6. power supply cable and connector; 7. compact plastic instrument box; 8. processor-activated red light-emitting diode (LED); 9. power switch; 10. liquid crystal display; 11. disposable EMG electrode.

functionality and performance. One of the most important obstacles, however, is a loss of interest by the patient due to the slow recovery process and the routine aspects of the reinforcement program. Periodic interventions of physiotherapists or the occupational therapists are thus required to stimulate and motivate the patients. Work done by Brown *et al.* from 1976 to 1979 has clearly demonstrated that biofeedback can strongly motivate the patient engaged in a hand rehabilitation program (1,2,4).

A review of instrument literature shows a lack of portable instruments with biofeedback capabilities for stimulating patients during hand reinforcement exercises. The present paper describes a small portable instrument designed specifically for this purpose, as well as to help physiotherapists in evaluating the progress accomplished by patients.

INSTRUMENT DESCRIPTION AND OPERATION

A. Hardware description

A photograph of the portable monitor is shown in **Figure 1**. The instrument comprises the following modules: 1) A microcomputer board based on a 16-bit microcontroller (Intel 8097) featuring an analog multiplexer and a 10-bit analog-to-digital (A/D) converter. This board has 16 Kbytes of static nonvolatile memory, 16 Kbytes of programmable read-only memory, a RS-232-C serial interface, and circuits for setting amplifier gain and generating acoustic and visual cues. An alphanumeric liquid crystal display of two lines of 16 characters each provides clear instructions to the user and display

results; and, 2) A two-channel analog board containing circuits for acquiring a surface electromyogram (EMG) and the signal from a force transducer.

As shown in **Figure 1**, the force transducer is a conventional hand exerciser which has been modified to include, in its central portion, a water-filled rubber cylinder containing a SENSYM pressure sensor. Two rigid semilunar plexiglass bars are attached to each side of the exerciser to ensure uniform distribution of the force developed by contractions of the hand. This transducer is calibrated with a series of weights (0, 6, 12,....,42, and 48 KGF) according to the method described by Ionescu *et al.* (3).

Operation of these monitors requires an IBM-PC (or compatible) personal computer. The computer acts as the host system to program the portable monitors, read data acquired during each session of hand reinforcement, generate graphics of extracted parameters, manage the patient database, and perform statistical analyses. For programming, or reading the recorded data, the monitors are momentarily linked to the host computer via an RS-232-C port. No physical connection to the host is required for data recording, and the monitors can be used for hand reinforcement exercises at home, on vacation, while traveling, and at work. The sale price of each monitor is estimated to be about $1,200.00 (US), including the connecting cable and the host software.

B. Software description

Software for the hand reinforcement evaluation system consists of two sections: 1) programs executed by the host computer; and, 2) the monitor-resident control programs.

The host computer software is menu-driven and relatively easy to use. It comprises a set of programs to perform the following operations: 1) Set up the operational mode of the monitor (calibration or data acquisition); 2) Store in the nonvolatile memory of the monitor the patient's identification data and a set of parameters determining the patient's protocol (duration of contraction, pause intervals, rest periods, number of contractions per session, number of sessions, etc.); 3) Transmit the data acquired by the monitor to the corresponding patient data file on the host computer; and, 4) Store the calibration table of the force transducer in the nonvolatile memory of the monitor.

The monitor-resident software provides step-by-step instructions to the patient for performing his reinforcement exercises and acquires data related to the strength and duration of hand contractions. In the present version of this program, messages are shown on the liquid crystal display to report results of previous tests and to describe the next action to be performed. An audible signal prompts the user to begin a contraction and a small red light indicates how long the contraction must be sustained. The force developed during each contraction is displayed as a percentage of the maximal force developed during a reference contraction done at the beginning of a session and this indication provides a form of biofeedback.

At any time during a patient reinforcement program, the physiotherapist can connect the monitor to the host computer in order to transfer the acquired data to the corresponding patient's file. Evolution profiles of acquired parameters can then be displayed graphically as a function of time or submitted to statistical analysis. The seven parameters presently extracted and stored at each contraction are:

1. The maximal force developed (Kgf)
2. The mean force developed (Kgf)
3. The velocity of contraction (Kgf/sec)
4. The contraction energy (milli-Joules-sec)
5. The duration of the contraction (sec)
6. The patient's reaction delay (sec)
7. The peak value of the EMG (micro-Volts).

This particular set of parameters was chosen to provide the physiotherapists or the occupational therapists with complete and quantitative parametric information on the contractions done by the patients. For research purposes, the approximate shape of the force signal for each contraction can be reconstructed if necessary.

PRELIMINARY CLINICAL TESTS

A. Method

The objective of this study was to evaluate the benefits offered by a portable instrument capable of providing biofeedback, as compared to the traditional approach to hand rehabilitation. Fourteen patients were recruited from the Departments of Physiotherapy of the Hôtel-Dieu and Notre-Dame Hospitals in Montreal over a period of eight

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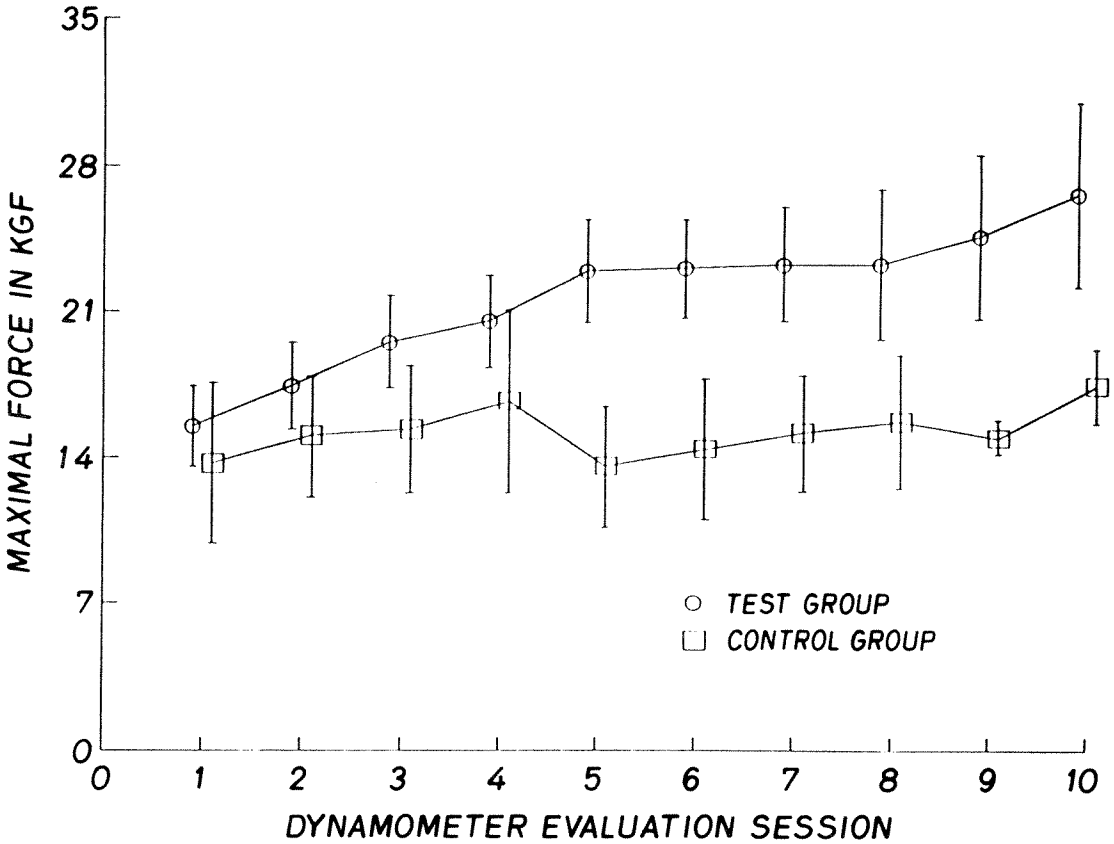

Figure 2.
Graphical comparison of the evolution of the mean isometric force developed by the test and control groups (vertical bars represent the error of the mean).

months. Eight patients were issued portable monitors, while six patients used conventional hand exercisers. Comparisons were made between the mean isometric force developed by each group as a function of time.

Each patient participating in this study underwent a clinical evaluation session during which the force exerted in three strong isometric contractions was measured with a calibrated dynamometer. The mean isometric contraction force was used to classify the patient. To obtain homogeneous groups for statistical comparisons, the patients were selected two at a time and classified according to a prestratification scheme. For instance, the first two patients were classified randomly: one in the test group, the other in the control group. The second and following duos were classified so as to minimize the differences in mean isometric force developed by each group. That is, the patient with the lowest isometric force was classified in the stronger group and vice-versa. This procedure provided patient groups which displayed similar mean isometric force at the onset of the reinforcement protocol.

The reinforcement program of each patient lasted 10 weeks and was the same for the two groups. The subjects were asked to perform 30 hand reinforcement sessions at a rate of three sessions per week. Each session consisted of three series of ten contractions. A contraction had a duration of five seconds, followed by a pause of ten seconds. After performing ten consecutive contractions, a rest period of two minutes was allowed. At the beginning of each week, the patients underwent a clinical evaluation where the isometric force was measured with a standard dynamometer, and the results saved to disk for further analysis. At the end of the clinical evaluation period, the mean isometric force developed by each group was computed as a function of the dynamometer session number (i.e., approximate weeks). A two-parameter (group, time) variance analysis was then used to determine if there were any significant differences in: 1) the evolution

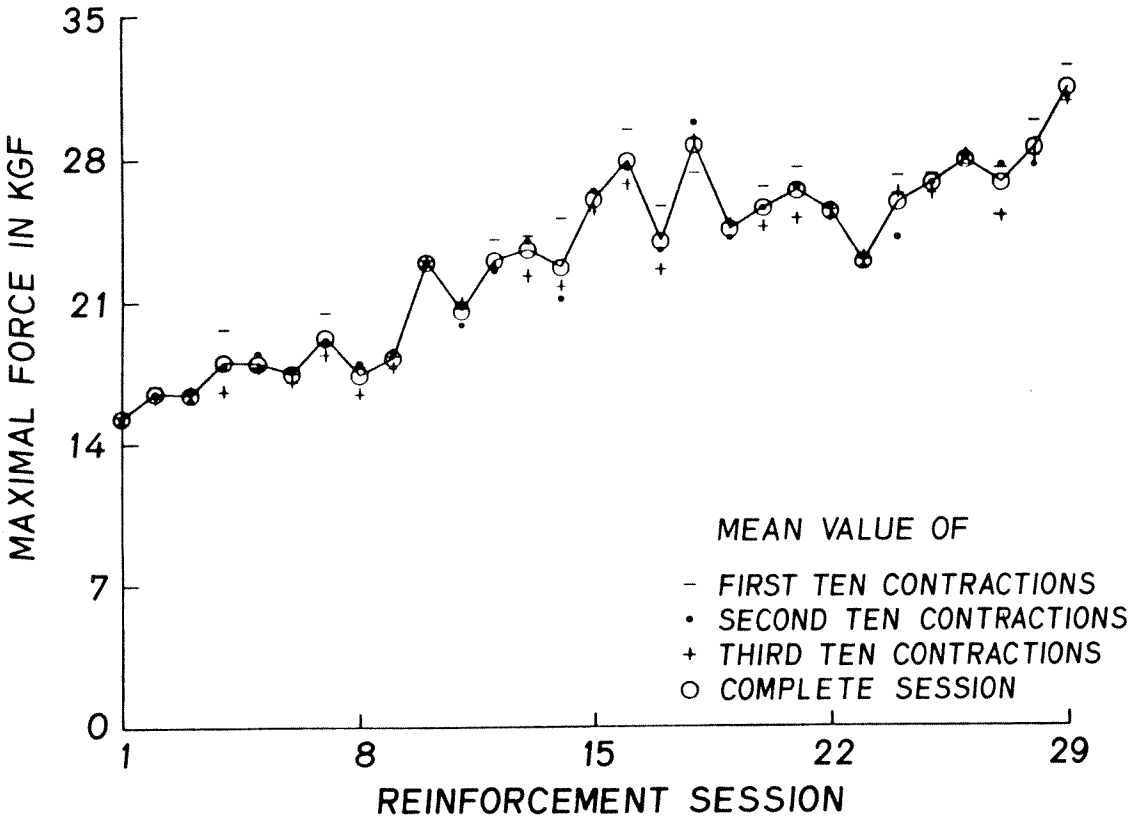

Figure 3.
Graphical representation of the maximal force developed by a patient as a function of the reinforcement sessions.

of each group with time; and, 2) the evolution of the two groups.

B. Results

The evolution of the mean isometric force developed by each group is shown in **Figure 2**. The statistical analysis showed that both groups improved their mean isometric force as a function of time ($p \leq 0.0001$). However, the rate of increase of the test group is higher than that of the control group. The difference can be seen starting at the sixth dynamometer session ($p = 0.91$) and becomes significant ($p \leq 0.05$) at the tenth session ($p = 0.045$).

One important advantage of the portable monitors is that they provide quantitative data for each reinforcement session. Trend graphs of various parameters can be constructed and used by the physiotherapist or the occupational therapist to monitor the patient's progress and modify the exercise protocol if necessary.

Examples of three trend graphs for a patient are shown in **Figures 3, 4,** and **5**. The symbols (–, 0 and +) represent, respectively, the mean value measured for each parameter during the first, second and third series of ten consecutive contractions. The symbol (0), connected by line segments represents the mean value of the measured parameter for the complete session (30 contractions).

Figure 3 shows the trend of the maximal force developed by the patient. It is clear that this patient has continuously improved his initial force during the first 16 reinforcement sessions. At the beginning (reinforcement sessions 1 to 9) improvement was slow. It increased more rapidly between the 10th and the 18th sessions. A plateau was attained between the 18th and the 27th sessions. Finally, the two last exercises indicate that another improvement phase was starting at the end of the prescribed program.

Figure 4 shows the trend of the contraction energy as a function of session number. This parameter seems to be a sensitive indicator of

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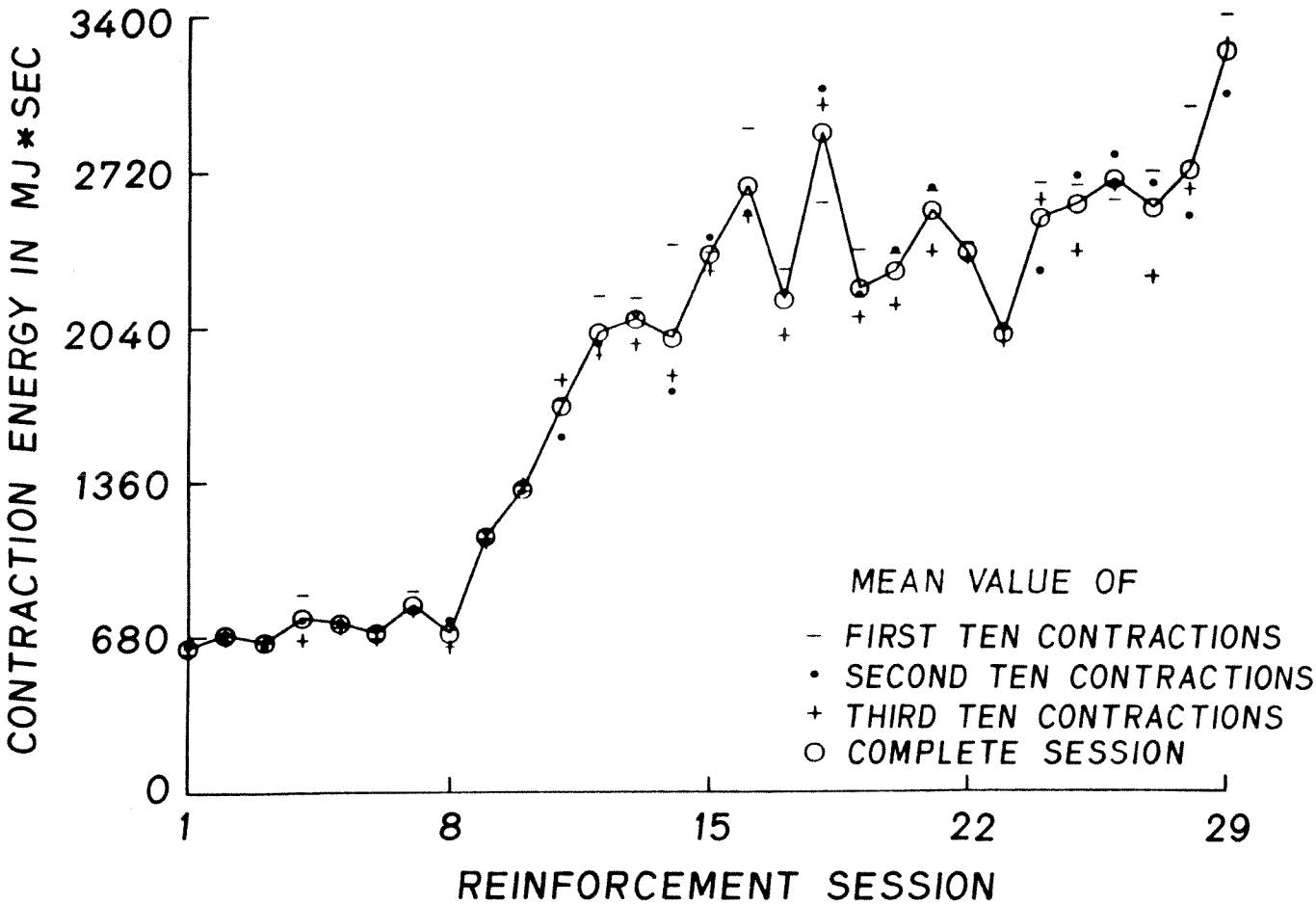

Figure 4.
Graphical representation of an analog of the average energy spent by a patient at each contraction as a function of the reinforcement sessions.

patient improvement. For instance, the mean contraction energy spent during the first eight sessions increased very slowly. During the following eight sessions, it increased considerably. As in **Figure 3**, a plateau was reached between the 18th and 27th sessions and a second improvement phase appears in the last two sessions. The trend of this parameter suggests that the maximal rate of improvement was attained between the 8th and 18th sessions.

Figure 5 shows the mean duration of the contractions performed by the patient; this parameter is nearly constant except for small variations between the 11th and the 24th reinforcement sessions.

DISCUSSION AND CONCLUSION

Although the number of patients included in this preliminary study was small, it is possible to conclude that the portable monitors had a positive impact on hand rehabilitation as compared to the traditional method of periodic evaluation with a dynamometer. This is thought to be due in part to the biofeedback provided by the instrument. For instance, the display of the force developed during each contraction stimulates and motivates the patients in pursuing their reinforcement program. In fact, it was observed that fewer patients in the test group abandoned their reinforcement program.

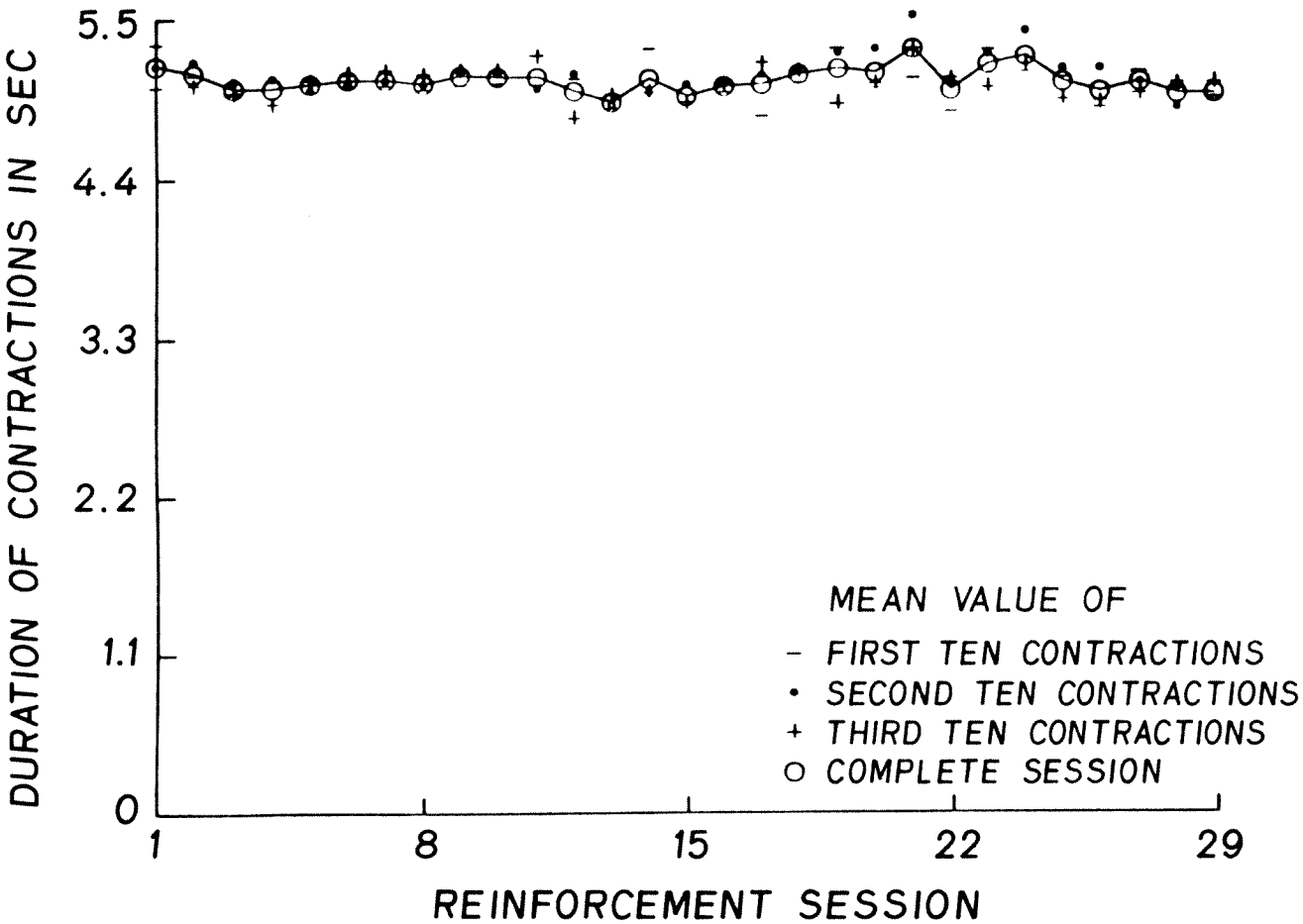

Figure 5.
Graphical representation of the duration of contractions done by a patient as a function of the reinforcement sessions.

Since the monitors are portable, they can be used at home and are convenient for patients living far from rehabilitation centers.

The main difficulty encountered during this evaluation concerned the application of EMG electrodes to the same locations in order to ensure good reproducibility of the EMG signal. It is well-known that the amplitude of the EMG signal is influenced by both the location and the preparation of the recording areas on the forehand, as well as by the type of electrodes used.

In summary, the results obtained so far are encouraging and demonstrate that the instrument can be useful to both the patient and the physiotherapist. The motivation of the patient is enhanced by biofeedback of the force developed and the physiotherapist obtains reliable data with which to assess performance of the reinforcement sessions. The instrument is highly versatile and easy to modify. For instance, by developing appropriate transducers, the system can be easily adapted for monitoring the reinforcement of other muscular structures.

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REFERENCES

1. **Brown DM, DeBacher GA, Basmajian JV:** Feedback goniometers for hand rehabilitation. *Am J Occup Ther* 33(7):458-463, 1979.
2. **Brown DM, Nahai F:** Biofeedback strategies of the occupational therapist in total hand rehabilitation. In *Biofeedback: Principles and Practice for Clinicians,* 2nd Edition, 90-106. Baltimore: Williams & Wilkins, 1975.
3. **Ionescu GD, Blanchard M, Durand J, Lavoisier P, Guardo R, Durand LG:** Design of a new instrument for assisting the physiotherapist in the rehabilitation of the hand. *Proceedings of the IEEE Montech '87 Conference on Biomedical Technologies,* 158-161, 1987.
4. **Morris AF, Brown DM:** Electronic training devices for hand rehabilitation. *Am J Occup Ther* 30(6):376-379, 1976.