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A home-care system for the telemonitoring and telerehabilitation of the hand incorporating interactive biofeedback

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Summary

We have designed and constructed force measurement equipment to assess hand–finger function in pressing tasks. The equipment was used for monitoring the follow-up of five hand-transplanted subjects. Interactive software was integrated into the instrument to monitor the functionality of the hand and fingers during exercises in realtime. The interactive software included biofeedback to provide realtime quantitative responses for the patient and the therapist. Acceptance of the system was investigated with patients and therapists: the system was found to be user-friendly and effective; it was practical both for patients and therapists. The system could be used in a telerehabilitation centre or in a patient's home.

Introduction

Severe neuropathies, arthrosis, tendon inflammations, poor working practices, repeated use of working devices and elderly pathologies can lead to severe damage to the functionality of the hand. Most industrial devices are designed to evaluate the overall hand force, without investigating the force of the individual fingers involved in motor tasks.[1–3] Ideally, functionality in daily motor tasks (such as pushing buttons, pulling levers and grasping objects) should be evaluated by quantifying the individual finger force expressed in the tasks. Different approaches have been reported in the literature, investigating both the delivered force of individual fingers and the finger force coordination, and the grasping force.[4–6] Other studies have described home-care systems for hand rehabilitation.[7,8]

We have designed and constructed force measurement equipment to assess the hand–finger functionality in pressing tasks. The equipment was designed and constructed as part of an Italian project 'Instrumentation and methods for hand functional assessment in the transplant of organs taken by cadaver (2001–2002)' funded by the Italian Ministry of Health.[9] The aim of the present study was to monitor the follow-up of five hand-transplanted subjects. Interactive software was integrated into the instrument to monitor the functionality of the hand and fingers during exercises in realtime. The interactive software included biofeedback to provide realtime quantitative responses for the patient and the therapist.

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Rehabilitation system

The Hand Monitoring/TeleRehabilitation System consisted of three main parts:

(1) a set of devices equipped with sensors for measuring the force exerted by the fingers;
(2) software for the biofeedback (located in the patient's home PC) and software for data management, e.g. storage, transfer and analysis (located in the home PC and in a computer at the remote centre);
(3) communication equipment for the patient–therapist interaction (videoconference) and data transfer.

A schematic representation of the system is shown in Figure 1.

Measurement devices

Two types of sensor-based measurement devices were constructed, one for measuring the finger force in two different hand postures. The first type was named the keyboard and consisted of a flat box containing five sensor-equipped keys for measuring the force of all fingers. The second type was named the mouse and consisted of a mouse-like shaped backing containing a single sensor-equipped key for measuring the force of the thumb

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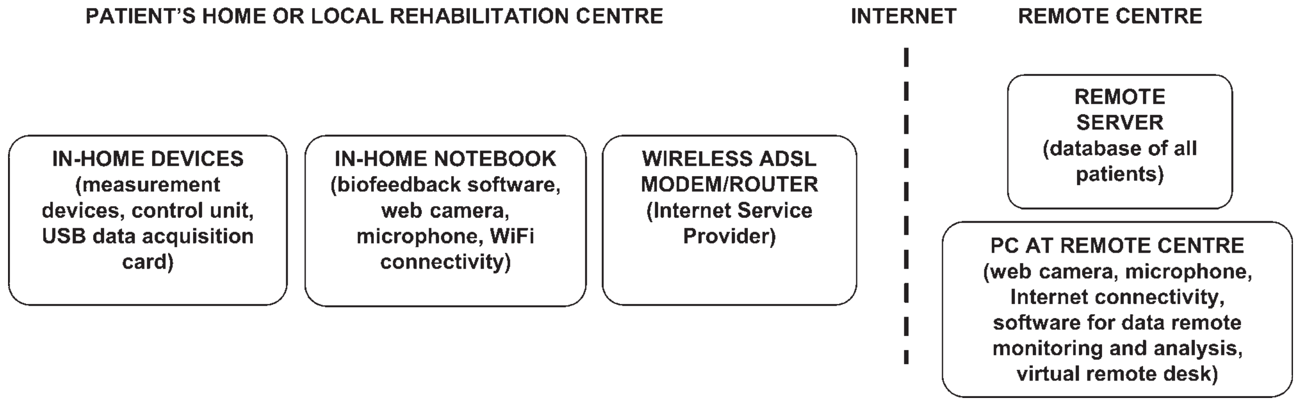

Figure 1 Schematic representation of the hand monitoring/telerehabilitation system

or of the little finger. We designed and constructed four devices, one keyboard and one mouse for each hand.

The devices measured the force exerted by each finger while pressing against the keys. The keyboard device was a flat box of size 210 mm in width, 300 mm in length and 20 mm in height. Five keys were equipped with metallic strain-gauge sensors (Figure 2a). The mouse device was about 60 mm in width, 150 mm in length and 30 mm in height. It contained a single key, mounted on a lateral part of the device (Figure 2b). The mouse was placed on a flat box, of the same size of those of the keyboard.

The keys were aluminium cantilever beams, 63.5 mm long, equipped with two 90° rosette strain gauges (EA-13-062TT-350 Vishay Micro-Measurements, Luchsinger srl, Italy), each pasted on an area near to the fixed terminal side of the key (Figure 2c). The keyboard was suitable for hands of different sizes. The mouse device was used for measuring the force exerted by the thumb. This device could also measure the force exerted by the little finger during an adduction movement, with the hand positioned beside the mouse. The mouse size allowed a comfortable grasp for hands of different sizes.

During the execution of pressing task exercises (Figures 3a and 3b), the measurement device (keyboard or mouse) was inserted in a flat support and the arm of the subject was rested on this support. Signals coming from sensors were conditioned by means of small printed circuit boards, located in each measurement device. A separate control unit was used to manage the signal acquisition and to connect the measurement devices and the USB data acquisition card. The measurement system, including the four sensor-equipped devices and the control unit, is shown in Figure 4.

Software

The system provided visual biofeedback used in the rehabilitation exercises. The acquired data were transferred via the Internet to the server at the remote rehabilitation centre, where the patient's database tables were located. Software was developed for the analysis of the data by therapists and clinicians.

The system allowed different rehabilitation programmes to be delivered. The software selected the order of the exercises to be executed and the visual biofeedback type to be displayed on the monitor during exercises. The different rehabilitation schemes could be modified according to the patient's progress. During exercises, a window was shown on the monitor, containing a box for the user's commands to manage the data acquisition (the 'Command Window'). Some charts displayed the acquired force data or a force profile to be replicated by the patient. The charts provided visual biofeedback for the patients and allowed them to modulate their performance.

Two main types of exercises could be executed: the maximal voluntary contraction (MVC) exercises and the force regulation exercises. The MVC exercises could be executed with a single hand (unilateral task) or both hands (bilateral task): the subject pressed against the keys, using

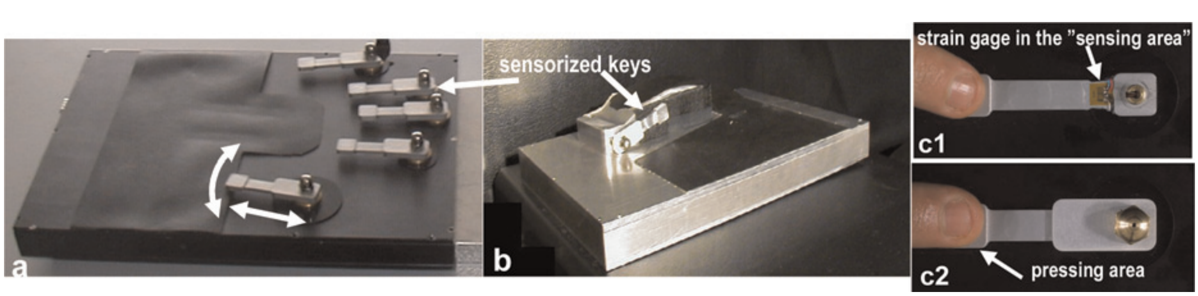

Figure 2 Sensor-based devices: (a) keyboard; (b) mouse; (c1 and c2) keys

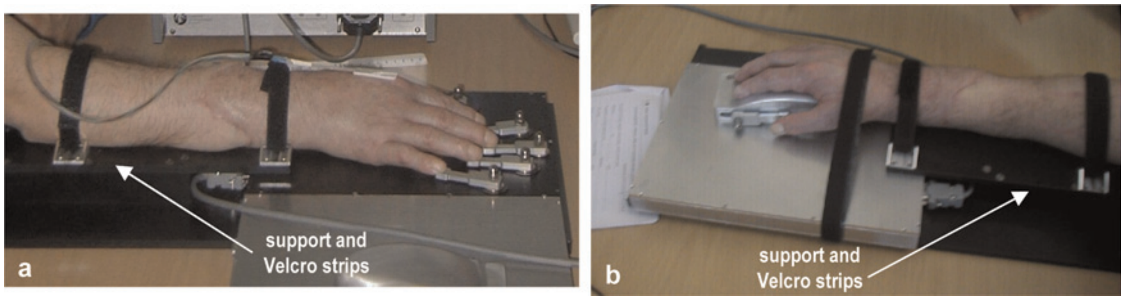

Figure 3 Force measurement: (a) a hand-transplanted patient executing exercises with the keyboard; (b) a hand-transplanted patient executing exercises with the mouse

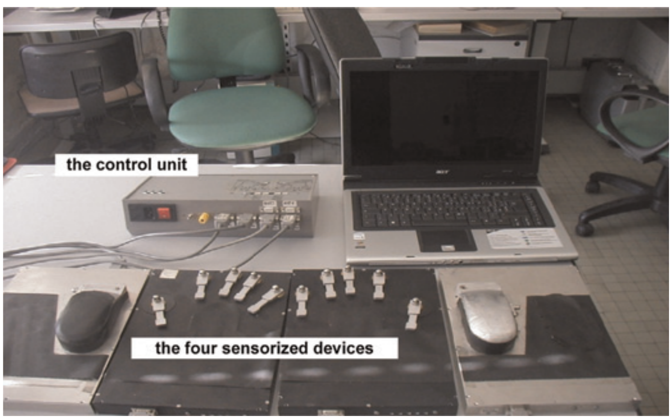

Figure 4 A view of the entire measurement system, including the measurement devices (2 keyboards and 2 mice) and the control unit

a single finger (single-finger exercises) or all fingers simultaneously (multifinger exercises), with his or her maximum force. During exercises, the force exerted by each finger was displayed on the corresponding chart (Figure 5). In the force regulation exercises, the patient was asked to match a force profile or a force level. In the force-matching tasks different patterns of force profile were employed: constant pattern, step, ramp or trapezoidal. During exercises, a red line was presented to the patient representing the force profile to be matched and a blue line represented the actual force exerted. The patients were then able to check how good their performance was and to adjust their force accordingly. In the force-reaching tasks a vertical blue bar was presented to the patient, representing the force level to be reached and a red bar represented the force exerted. Figure 6 shows the visual biofeedback in the force-matching tasks (Figure 6a) and force-reaching tasks (Figure 6b).

Communications equipment

The patient's PC contained a web camera, a microphone and a wireless network card. A wireless ADSL modem/router allowed wireless Internet communication. The web camera and the microphone were used to interact with the therapist by videoconference. During videoconferencing, the therapist could display on his or her PC the desktop of the patient's PC, by means of remote virtual desktop software. In addition, the hand monitoring/telerehabilitation system allowed any patient–therapist videoconference to be recorded.

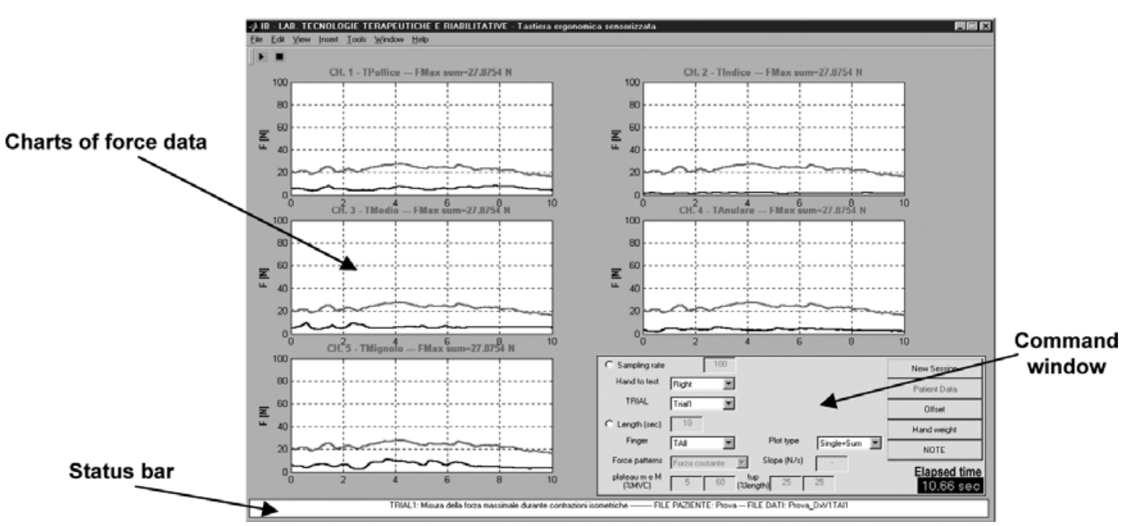

Figure 5 A screenshot of the full-screen window, during a multifinger exercise of unilateral task. Each chart shows the force exerted by each finger (black line) and the total force (broken line)

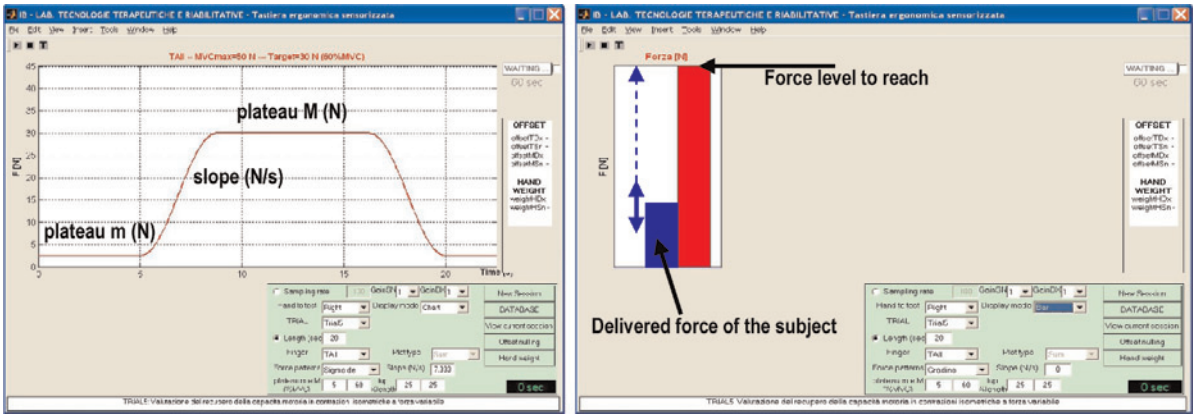

Figure 6 Example of the biofeedback software in the force regulation exercises: (a) a trapezoidal profile pattern used in the force-matching task; (b) the interface used in the force-reaching task

Methods

The system was used for the follow-up of five hand-transplanted patients. Patients were asked to execute pressing-task exercises according to clinical protocols designed by clinicians and therapists. A therapist assisted the patients in placing their hands on the devices and setting up the interactive software for the selected exercises. The rehabilitation programme consisted of different pressing tasks of maximal voluntary contraction, in order to evaluate the functionality of the patients. In addition, the maximum value exerted in these tasks was used to calculate the maximum value of the force profile in the force regulation exercises. Acceptance of the system was investigated with patients and therapists. Ethics permission was obtained from the appropriate committee.

Results

An example of the results obtained by a patient in a multifinger regulation force exercise with a trapezoidal force profile, on the keyboard with the transplanted hand, is shown in Figure 7. Figure 7a shows the visual feedback presented to the patient during exercises: the patient could modulate the force pressing all fingers simultaneously, without monitoring the individual force exerted by each finger. Figure 7b shows the contribution of each finger separately. Both patients and therapists could monitor the rehabilitation results, in order to measure progress.

An example of the results of one hand-transplanted patient obtained in three consecutive rehabilitation sessions is shown in Figure 8. The system was found to be user-friendly and effective; it was practical both for patients and therapists.

Discussion

The present study suggests that the system for monitoring and telerehabilitation of the damaged hand could be used in a telerehabilitation centre or in a patient's home. The flexibility of the software allowed the delivery of different telerehabilitation programmes. The system was portable and could be mounted on a desk, in a standard and thus replicable position. The videoconference communication allowed

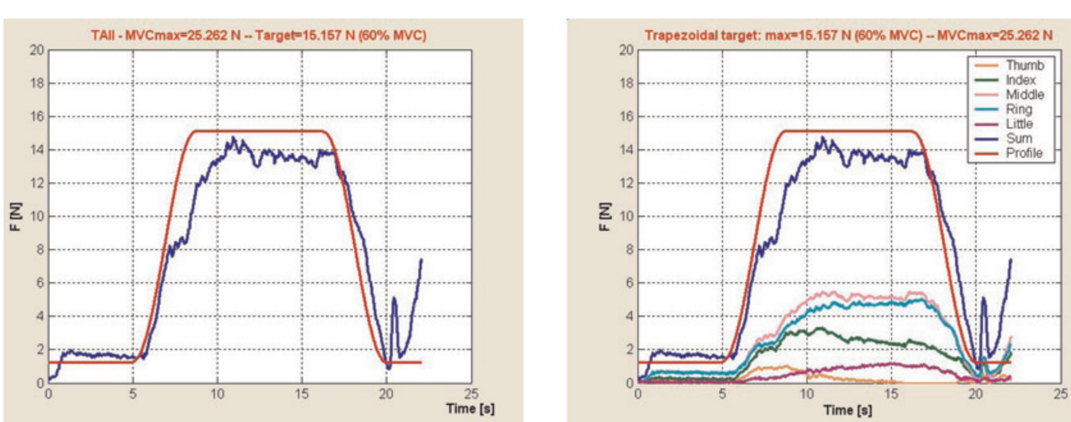

Figure 7 Example of force data of a hand-transplanted patient: (a) the on-line data during a multifinger exercise of force regulation; (b) the off-line analysis, showing the individual contribute of each finger

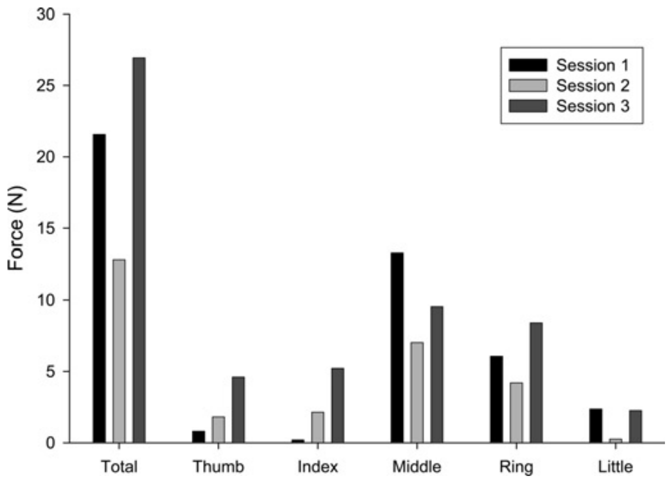

Figure 8 Example of the rehabilitation results obtained by monitoring three consecutive sessions: the patient undertook a unilateral task MVC multifinger exercise with the transplanted hand

interaction between patient and therapist. In particular, the remote virtual desktop software allowed the therapist to evaluate in realtime the patient's performance in certain tasks. Patients could execute the assigned rehabilitation programme by themselves or with a personal assistant, depending on the degree of disability.

The realtime observation of the patient's functionality avoided the need for patients to travel to the rehabilitation centre. Furthermore it gave an immediate response to the rehabilitation programme and allowed the planning of any visits required by the therapist to the patient's home. The system might be useful for a wide range of telerehabilitation programmes, i.e. for patients with hand injuries or for patients in post-stroke rehabilitation, as a part of a multifactorial rehabilitation intervention.

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