Can Simple Electronic Instrumentation Associated with Basic Training Help Users of Assistive Devices?

Presenting and Verifying the Effectiveness of a Biofeedback Module for an Instrumented Crutch

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Abstract: Crutches are prescribed towards compensating lower limb overload and adding sensory information through upper limb. However, adequate loads are required to avoid upper limb lesions and further lower limb injuries. Therefore, this work describes the development and application of a biofeedback module for a Lofstrand crutch, based on a simple electronic instrumentation. The goal is to train the user to apply proper load on the crutch. Basic training was performed by healthy subjects before and after static and dynamic activities. Results showed the feasibility of the device and the effectiveness of the training to reach the target (load on the crutch of 20% of body weight).

1 INTRODUCTION

The most active form of human mobility is gait, being characterized by the gait cycle. Gait cycle (stride) is the continuous repetitive pattern of walking or running, including stance (single and double supports) and swing phases. It starts when one foot makes contact with the floor and ends when the same foot makes contact again (Agarwal et al., 2012; Simoneau, 2011; Wall, 2001). During the stance phase, the foot is in contact with the floor; and the leg moves freely above the floor in the swing phase (Baker, 2012).

Assistive devices for mobility are prescribed to compensate orthopaedics problems such as pain, joint instability and lower limb overload (Cook and Hussey, 2002).

In addition to reducing the load on the lower limbs, the crutches are used towards increasing the support base, adding sensory information and allowing acceleration control during the gait (Saad, 2007; Delisa and Gans, 1983). Applied loads less than 20% of body weight of the user are adequate for this device (Chen et al., 2001; Melis et al., 1999).

To verify loads on the crutch, Leite and Cliquet (2002) developed a system based on the instrumented Lofstrand crutch and user friendly software to analyse and save the data. The crutch was instrumented with strain gauges, being characterized by threshold of 105N. The system was validated with force plate equipment, and simultaneous measurements using both systems present values with correlation of 0.98.

This paper describes the development and application of a biofeedback module for the instrumented Lofstrand crutch described previously. This device based on simplistic electronic instrumentation and coupled to the crutch sends an audio signal when the user exerts more than 20% of body weight on the crutch. The aim is to familiarize the user with the proper load, thus avoiding upper limb lesions and further lower limb injuries. To verify the effectiveness of the biofeedback module, healthy subjects performed rapid training and executed pilot trials based on static and dynamic activities.

2 MATERIALS AND METHODS

This work was done at the Laboratory of Biocybernetics and Rehabilitation Engineering - USP and at Laboratory of Biomechanics and

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Rehabilitation of the Locomotor System - UNICAMP. Instrumentation was designed at USP, and pilot trials performed by healthy subjects were carried out on both laboratories.

The instrumented Lofstrand crutch has four strain gauges in Wheatstone bridge configuration, compensating temperature variation. The voltage across the centre of the bridge is applied to instrumentation amplifier, assuring adequate range of signal and isolation of measurement circuit. Besides, the instrumentation amplifier presents rail-to-rail output (range of 4.8V) and makes the connection between the bridge and the biofeedback module (Leite and Cliquet, 2002).

2.1 Biofeedback Module

The main components of the biofeedback module are microcontroller, binary-coded decimal (BCD) to 7-segment decoder, 8-bit monolithic digital-to-analog converter (DAC), comparator circuit and non-retriggerable monostable multivibrator (Figure 1).

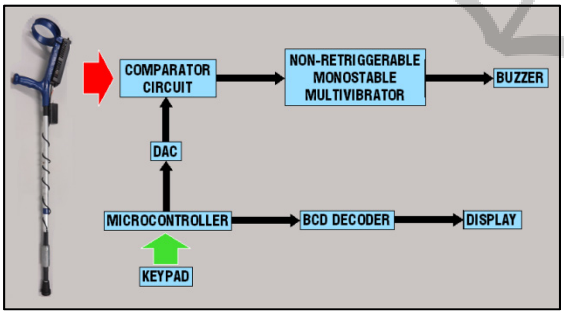

Figure 1: Block diagram of the biofeedback module, including the instrumented Lofstrand crutch.

The microcontroller used was PIC16F84 (Microchip Technology Inc., Chandler, AZ, USA) and it was programmed to determine the value corresponding to 20% of body weight (N) from body mass (kg) of the crutch user. Furthermore, through the calibration equation of the crutch, this value is converted into a digital electrical signal; and then, applied to the DAC.

The comparator circuit, which used an operational amplifier as active component, receives electrical signals from the crutch instrumentation amplifier and the DAC. It compares the desired load exerted on the crutch with the actual load and, if the load on the crutch is greater than the desired one for longer than 1s, the multivibrator is activated.

Based on the 555 monolithic timing circuit, the non-retriggerable monostable multivibrator was configured to generate an audio signal with duration of 1s.

The whole electronic circuit, including the original circuit of the crutch, is powered by two rechargeable batteries (9V, 150mAh).

2.2 Pilot Trials

Five healthy subjects were recruited to participate in this study (Table 1). Inclusion criteria were body mass above 50kg and normal gait pattern. Exclusion criteria were based on the presence of any upper extremity musculoskeletal disorders, and not being able to understand the instructions for the trials. Subject C had no experience with assistive devices for ambulation, and others had previous experience (less than 3 months of use). Informed consent and Ethical Committee approvals were obtained.

Table 1: Subjects characteristics.

Subjects	Gender	Age (year)	Body mass (kg)
A	M	23.9	80.1
B	M	22.7	76.7
C	F	22.0	68.6
D	M	23.7	73.9
E	M	26.1	82.4

For each subject, before initiating the trials, the body mass was determined using a bathroom scale equipped with high precision sensor (Accumed Produtos Médico Hospitalares Ltda., Duque de Caxias, RJ, Brazil). The crutch was fitted according to the user height, such that the handle was approximately at the level of the greater trochanter, leaving the elbow flexed about 30^o (Edelstein, 2013; Moriana et al., 2013; Laufer, 2003). Thus, the use of the crutch is not influenced by user height.

Pilot trials were based on two activities (static and dynamic) acquiring force values on the crutch, and a period of training using the biofeedback module. Each activity was repeated 3 times. Left lower limb injury was simulated by the subjects; thus, they used the crutch on the right forearm (contra lateral side) (Melis et al., 1999). For all trials, subjects were instructed to exert 20% of body weight on the crutch.

During static activity, the subjects remained standing, with the feet aligned. The tip of the crutch was 100mm lateral and 150mm anterior to the right foot (Edelstein, 2013). This activity lasted 10s, and marks were put on the floor to help the subject and standardize the trials (Figure 2).

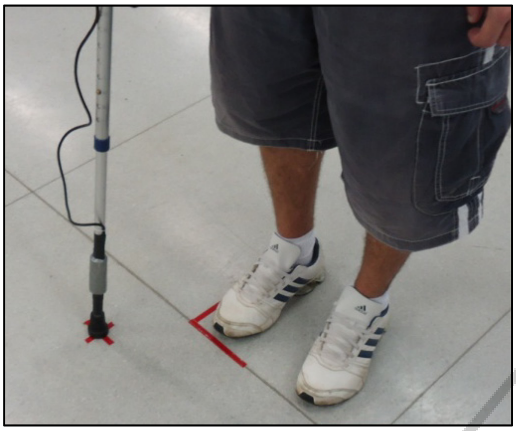

Figure 2: Subject during static activity.

The subjects performed a route of 8m in straight line aided by crutch during dynamic activity. They were instructed to advance the crutch and the pseudo injured lower limb (left) and then step forward with the healthy lower limb (right), with simultaneous contra-lateral support of heel and crutch (Saad, 2007) (Figure 3). Gait speed was a free choice, according to the natural pattern of the subjects.

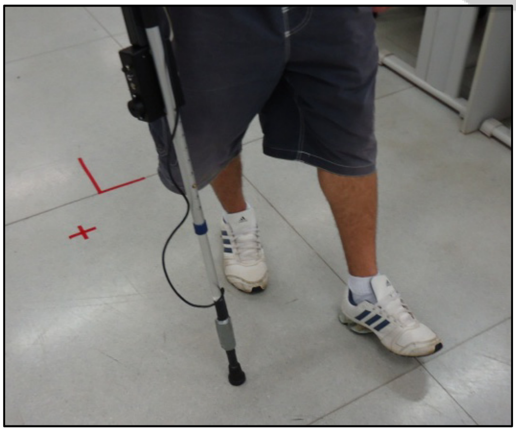

Figure 3: Subject during dynamic activity.

The period of training was based on the use of the biofeedback module, in order to familiarize the subject towards applying 20% of body weight on the crutch. Thus, the body mass data was entered in the module, and every time the load exceeded the value of 20% of body weight, the audible signal was emitted. The subjects were free to use any training strategy for as long as they felt like, not exceeding 5 minutes for each subject.

After the period of training, static and dynamic activities were repeated to verify the training effectiveness.

2.3 Data Processing and Analysis

All acquired data were low pass filtered at 10Hz (finite impulse response) to smooth the signal.

For static activity, mean and standard deviation (SD) were calculated for the force values above 105N, and maximum (max) and minimum (min) forces were determined in relation to 30s of activity duration. Mean and SD values are related to accuracy and precision, respectively, i.e., the user's ability to apply appropriate loads repetitively on the crutch.

In relation to dynamic activity, the number of gait cycles (strides) was counted during the whole route (3x8m). Therefore, the number of gait cycles corresponds to the number of contacts of the crutch on the floor. The peak value of forces was determined for each contact of the crutch and mean and SD, maximum and minimum of values of peak above 105N were calculated.

3 RESULTS

Figure 4 shows the biofeedback module and the final version of the instrumented Lofstrand crutch, whose mass is 1.1kg.

Figure 4: Biofeedback module and the final version of instrumented Lofstrand crutch.

On the front panel, the module has a 10-digit keypad in which the value of body mass of the crutch user is entered. The module accepts values at range of 12.0 to 99.9kg. Thus, this value must be typed with 3 digits, in other words, with a resolution of 0.1kg. Each digit is shown on the 7-segment display sequentially.

Table 2: Target forces and forces applied on the crutch during static activity.

Subjects	Before the training			Target [N]	After the training		
	Min [N]	Mean(SD) [N]	Max [N]		Min [N]	Mean(SD) [N]	Max [N]
A	▲	▲	▲	157.0	106.4	121.2(7.6)	139.9
B	▲	▲	▲	150.3	107.3	125.9(9.8)	146.0
C	▲	▲	▲	134.5	▲	122.4(13.5)	156.3
D	▲	117.4(6.5)	135.3	144.8	114.9	132.1(8.3)	153.1
E	▲	115.4(8.1)	139.8	161.5	▲	127.1(19.9)	188.6

The lateral side presents a pushbutton to reset the microcontroller (if necessary), the buzzer which receives the output of the non-retriggerable monostable multivibrator, and a toggle switch to set one of two functions of the final version of instrumented Lofstrand crutch: acquiring signals corresponding to forces applied to the crutch or training the user with biofeedback. The second function is independent of the computer, allowing the user to train anywhere (outside clinical environment).

In relation to the static and dynamic activities, the target forces applied on the crutch for subjects A, B, C, D and E were 157.0N, 150.3N, 134.5N, 144.8N and 161.5N, respectively.

Before the training, during static activity, two subjects applied forces above 105N, and even then, the minimum force was not detected. After the training, all subjects applied forces that were detected by the crutch. Table 2 presents the force values for each subject.

For dynamic activity, table 3 presents the number of gait cycles and the number of detected contacts of the crutch on the floor.

Table 3: Gait cycles and Subjects characteristics.

Subjects	Before the training		After the training	
	Gait cycles	Detected contacts	Gait cycles	Detected contacts
A	21	21	21	19
B	21	15	19	17
C	24	4	24	24
D	22	22	21	21
E	21	21	21	16

Figure 5 shows peak value of forces for each subject during the dynamic activity, before and after the training with biofeedback module.

4 DISCUSSION

In relation to the biofeedback module instrumentation, the use of a microcontroller with an analog-to-digital converter (ADC) and perform a comparison with the firmware is a feasible alternative. However, solid state DAC enables better adjustment of the parameters coming from the microcontroller, in this case, the percentage of body weight of the user. This adjustment, which was done once, allows to set load limit (based on body weight) on the crutch through hardware.

The patients that have gone through orthopaedics surgical procedures are not allowed to put any load on the operated limb during the first weeks after surgery, and in the following months they are required to exert around 20% of body weight on the operated limb towards bone remodelling due to piezoelectric effect. Therefore, the use of assistive devices such as crutches, canes and walkers are recommended.

Loads from 15% to 50% of body weight can be applied on crutches (Melis et al., 1999). However, in relation to dynamic activities, the crutch becomes unstable when more than 20% of body weight is applied on the device (considering only one crutch) (Chen et al., 2001; Melis et al., 1999). Proper loads avoid upper limbs lesion such as carpal tunnel syndrome and, at the same time, relief loads on the hip and on the injured lower limb (Waring and Werner, 1989; Blount, 1956). Besides, it is important in the case of lower limb implant of plates and screws to stabilize bone fracture site during osteosynthesis in order to avoid the risk of bone refractures and consequent loosing of the implant.

According to the results, load on the crutch substantially changed after the training performed using the biofeedback module. In relation to the static activity, the load on the crutch increases, becoming closer to the target; thus, the pseudo injured limb was preserved without compromising the upper limb.

Biofeedback training did show improvement on both accuracy (subjects A, B and E) and precision (subject E) related to the awareness of the actual upper limb load.

Pilot trials demonstrated the effectiveness of training with instrumented Lofstrand crutch and

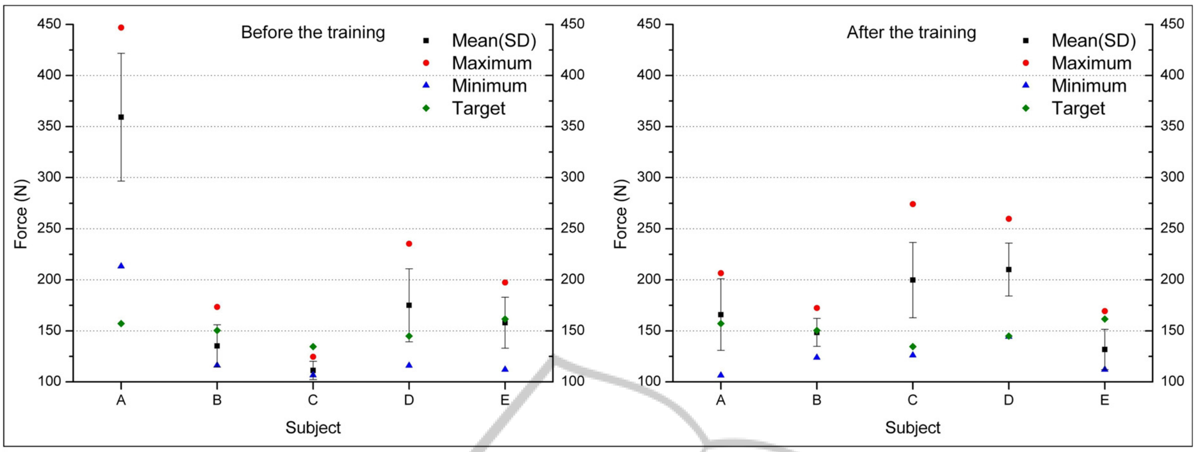

Figure 5: Peak value of forces for the dynamic activity.

biofeedback module for healthy subjects simulating left lower limb injury. Thus, the application of training with instrumented crutch becomes feasible for orthopaedics patients.

5 CONCLUSIONS

Based on simple construction, the biofeedback module can help subjects to apply more adequate loads on the crutch through basic training. Such innovation is a feasible alternative for patients of outpatient clinic that have gone through orthopaedics surgical procedures such as implants towards osteosynthesis.

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