Monitoring changes of the tibialis anterior during dorsiflexion with electromyography, sonomyography, dynamometry and kinematic signals

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Abstract— **Dorsiflexion (DF) of the foot plays an essential role in both controlling balance and human gait. Electromyography (EMG) and Sonomyography (SMG) can provide information on several aspects of muscle function. The aim was to describe a new method for real-time monitoring of muscular activity, as measured using EMG, muscular architecture, as measured using SMG, force, as measured using dynamometry, and kinematic parameters, as measured using inertial sensors (IS) during isometric and isotonic contractions of the foot DF. The present methodology may be clinically relevant because it involves a reproducible procedure which allows the function and structure of the foot DF to be monitored.**

Keywords— **electromyography, sonomyography, dynamometry, kinematic, tibialis anterior, dorsal flexion.**

I. INTRODUCTION

By parameterising foot DF during isometric and isotonic contractions and synchronising EMG, SMG, dynamometry and IS, new variables can be studied to facilitate the monitoring of key aspects of this foot gesture and therefore gait.

The main aim of this study was to describe a new method for real-time monitoring of muscular activity, as measured using EMG, muscular architecture, as measured using SMG, force, as measured using dynamometry, and kinematic parameters, as measured using IS during isometric and isotonic contractions of the foot DF. The second aim was to establish a descriptive analysis of each of the variables of interest.

II. METHODS

A. Participants

6 healthy young adults (3 men and 3 women) aged 28.17 ± 6.55 years, 1.68 ± 0.11 metres tall and 68.5 ± 10.85 kg in weight were brought in for this study. Each of the participants gave informed consent in writing prior to the study. Ethical approval for the study was granted by the Ethics Committee of the Faculty of Health Sciences at the University of Malaga.

B. Experimental procedure

The subjects sat in a chair which had been specially adapted in line with their size. The hip and knee were positioned at 90°. Attached to the chair was a spe-

cially designed height-adjustable device comprising two platforms, one vertical and one horizontal, which the load cell was connected to. The platforms formed an angle of 90°, therefore allowing maximum DF whilst preventing plantar flexion of the foot (Figure 1 and 2). The sole of the right foot was placed on the horizontal platform, whilst the posterior lower half of the leg was in contact with the vertical platform, forming a maximum angle of 90° between foot and leg. The foot and the lower half of the leg were attached to the device with Velcro straps in order to prevent any changes of position during the test. The bisection of the knee joint and the centre of the rotation axis of the load cell had an angle of 0° in the frontal plane and in the sagittal plane measured with a dual-axis goniometer.

The electrodes were positioned and the skin prepared in accordance with European Recommendations for Surface Electromyography (sEMG) [1].

A free area was left in the tibialis anterior (TA) muscle belly in order to position the ultrasound (US) probe without affecting the position and connection of the electrodes. The probe stayed fixed in the chosen position thanks to a mechanical articulated arm system in which the probe head was placed, thus allowing its height and angle to be adjusted.

The load cell was positioned between the ground and the horizontal platform, and secured to both using ring clamps. A series of non-extendable links allowed the distance to the ground to be adjusted in accordance with the subject's leg length (Figure 1).

The inertial sensor was placed and fixed on the distal end of the horizontal platform so as not to disturb foot placement or the development of the test (Figure 2).

After several contractions for the purpose of familiarisation, each subject was asked to use the right foot and the tests described below were carried out in the same order:

Maximal Voluntary Contraction (MVC). The maximal isometric DF of the foot or the maximal voluntary contraction (MVC) used for normalisation of the study variables was recorded for each subject. Three maximal isometric DFs of the right foot were carried out for 5 seconds, with a 90-second rest between each one. An artificial horn was sounded to mark the start of each contraction. All subjects received the same initial instructions with regards to the gesture and the same verbal stimuli were given as feedback during each contraction. US signals, electromyography signals and the force generated by the resistance offered by the load cell secured to the ground and to the horizontal platform were collected during this test.

MVC submaximal contractions. Subjects performed 75%, 50% and 25% of their MVC. These values were calculated from the maximum peak recorded during the MVC. The selected protocol (Trainer Dyn. MEGA) showed feedback (vertical bar) of electrical activity of the TA muscle on the computer screen. A visual reference was placed on the computer screen for the subject to know how far to lift in each contraction. The rest of the test development was the same as the MVC.

Isotonic DF. Isotonic foot DF without any resistance consisted of a dynamic test in which the foot started from a position of 90° with respect to the leg, with the participating subject having to reach the maximal foot DF range as quickly as possible. This test also included three consecutive contractions with a 90-second rest between each one. The rest of the test development was the same as the MVC. Electromyographic, kinematic and US records were taken during the test.

Before the test protocol, each subject performed as many repetitions of the gesture as deemed necessary in order to become familiar with it.

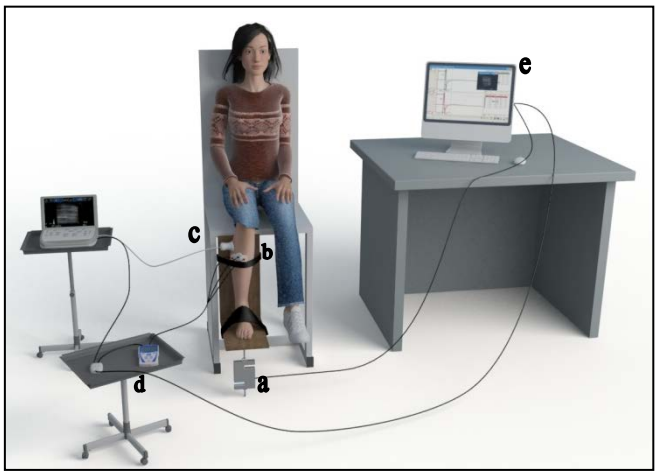

Fig. 1 Experiment Setup (Isometric test); a) load cell, (b) electrodes, (c) US probe, (d) Biomonitor ME6000, electromiograph and DV Trigger, (e) computer screen.

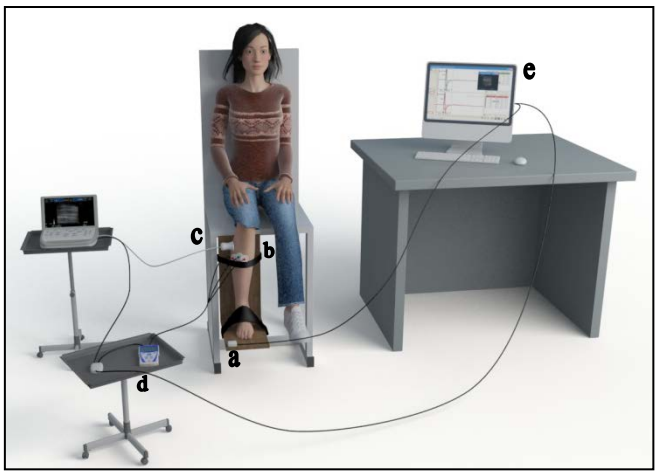

Fig. 2 Experiment Setup (Isotonic test); (a) inertial sensor, (b) electrodes, (c) US probe, (d) Biomonitor ME6000, electromiograph and DV Trigger, (e) computer screen.

C. Data acquisition

All data were recorded continuously and synchronously during each test using the Biomonitor ME6000 [2] console with Megawin 3.0.1 software (Mega Electronics Ltd, Kuopio, Finland), which each of the devices were connected to. Image acquisition was carried out using a duly adapted image capture device and a software add-on (Video EMG Option). This allowed offline searching for the US image and the electromyographic data for the selected instant. For this study, the maximum muscular activation peak was located and a snapshot was taken in order to subsequently measure the muscular architecture variables (thickness and pennation angle) of the TA.

The start and end of the synchronising of all systems during each test were marked by an activation device or trigger (DV Trigger Mega Electronics Ltd). The recording started before the first contraction with the foot in the starting po-

sition and stopped when the subject had finished the last contraction and returned to the starting position.

Electromyographic acquisition. The electrical activation of the TA muscle was measured using the Biomonitor ME6000 electromyography with a sampling frequency of 1000 Hz. Raw data were recorded and processed by MegaWin 3.0.1 software and filtered using a bidirectional fourth-order, 20 Hz low pass Butterworth filter to remove high-frequency noise from the sample.

Ultrasound acquisition. US images were obtained using the Esaote MyLab25 Gold scanner with a model LA523 probe [3].

Dynamometric acquisition. Force parameters were obtained using the load cell from ME6000 additional accessories [2].

Kinematic acquisition. Inertial sensor InertiaCube3™ [4] was used to obtain kinematic data.

D. Data Analysis

EMG Data Analysis. The electromyography variables, maximum peak and area under the curve (AUC) were extracted from the basic results for the selected area of interest for all subjects. This area includes the maximum activation peak of the electromyographic register of the TA and the two seconds around it (one second before and one second after).

SMG Data Analysis. The muscular architecture variables muscle thickness and pennation angle from the US images were taken following the procedure described by Hodges, 2003 [5]. All muscular architecture variables were obtained from the photo extracted from the video captured during synchronous

measurement. F.205.0.0 AutoCAD 2012-English SP2 software was used to extract these parameters.

Dynamometric Data Analysis. Torque of the foot DF variable was obtained from the difference between maximum and minimum peak torque recorded during each contraction intensity.

Kinematic Data Analysis. Kinematic data used as study variables were the maximum peaks of angular velocity and acceleration.

The values extracted from the electromyographic records and the muscular architecture obtained in the submaximal contractions and isotonic DF were normalised for each subject with regards to the maximum values obtained in the MVC.

E. Statistical Analysis

Descriptive statistical analysis was carried out with mean and standard deviation. Statistical analysis was carried out with SPSS 15.0 statistical package for Windows. The confidence level was established with a statistically significant *p*-value of less than 0.05.

Table 1 Descriptive data from Isometric test

Isometric	100%	75%	50%	25%
	Mean (Minimum - Maximum)			
Thickness TA (mm)	23.41 (19.03-30.62)	21.1 (18.13-22.68)	20.16 (17.31-21.58)	18.17 (14.31-20.27)
Pennation Angle TA (º)	11.40 (6-17)	10.8 (7-15)	8.60 (4-13)	5.60 (2-8)
Maximum Peak EMG TA (uV)	598.2 (403-873)	506.8 (302-722)	360.60 (213-602)	174. 6 (106-233)

Area EMG TA (uV)	813.6 (559-1113)	658. 6 (397-1085)	488.40 (347-635)	262 (159-381)
Torque DF Ankle (N/m)	146.98 (47.4-259.1)	116.57 (33.4-212.6)	85.2 (22.1-141.7)	33.66 (5.6-95.1)

III. RESULTS

Descriptive data included Mean and Standard Deviation (SD) from EMG, US images and Torque to Isometric test (submaximal contractions and MVC) and, on the other hand, EMG, US and kinematic parameters to Isotonic test as shown in Table 1 and 2, respectively.

Table 2 Descriptive data from Isotonic test

Isotonic	Minimum	Maximum	Mean (SD)
Thickness TA (mm)	17.73	24.43	20.12 (24.46)
Pennation angle TA (º)	8	12	9.67 (1.36)
Maximum Peak EMG TA (uV)	177	663	441 (119.94)
Area EMG TA (uV)	130	711	283.17 (218.78)
Maximum Peak Angular Velocity (º/s)	18.29	272.4	120.82 (88.49)
Maximum Peak Acceleration (m/s^2)	49.26	175.00	115.62 (53.88.85)

IV. DISSCUSION

Comparative study of muscular architecture with EMG is becoming ever more widespread since it could provide a safe, non-invasive way of determining the muscular function of the superficial muscles (5,6). This paper aims to contribute

to this methodology by offering the analysis of quantitative values which can provide changes during disease or treatment processes.

Some authors have focused their studies on the trunk, whilst others have specified abdominal musculature (5,7,8) or back musculature (9–13). Other authors have focused on the role of ADL in the upper limb (5,14,15). The lower limb is also widely studied, mainly due to its relevance in human gait (16,17). Research has been carried out into the TA muscle during isometric contractions at different intensities using EMG and SNM (5,16). Hodges et al. (5) studied the right TA muscle with an ankle initial position of 90° and the knee and hip flexed in a comfortable position for the participant (60 – 80º). The main methodological difference with the present study was the hip and knee position, both joints were fixed at 90º flexion degree. In the first study (5), “contractions increased in increments of 1% from 1% to 5% of the force recorded during a maximal effort (i.e., MVC) and in 10% increments from 10% to 100% MVC”. In the present study, the test performed were MVC, MVC submaximal contractions (75%, 50% and 25%) and an isotonic test at maximum speed. For the execution of submaximal contractions, the present study followed the procedure developed by Manal et al. (16) although they measured the left and right foot with an plantar flexion initial position of 30º and the knee fully extended.

The method used may be of interest to monitor neuromuscular activity measured using sEMG, muscular architecture measured using SMG, force measured using dynamometry and kinematic parameters measured using IS during isometric and isotonic contractions of the foot DF.

Although they present some methodological differences, there are other studies based on the synchronisation of instruments, mainly sEMG and SMG, focused on the TA during foot dorsiflexion in healthy subjects. Descriptive data shown by these authors are consistent with those obtained in this study. Hodges and collaborators [5] found an increase in thickness and pennation angle of the TA muscle during isometric contractions. Manal and collaborators (16) also found an increase in pennation angle from rest to MVC in both males and females. Maganaris and Baltzopoulos (18) obtained a decrease in pennation angle in a foot plantarflexion test; however, no significant changes were shown in TA thickness, which may be because, unlike other studies and as previously mentioned, the test was carried out from -15° of ankle dorsiflexion (rest or initial condition) to +30° of plantar flexion (MVC or final condition). Ilse M.P. Arts and collaborators recruited 95 healthy volunteers and provided normative muscle ultrasonography data for muscle thickness which are consistent with our results (19).

V. CONCLUSIONS

The present methodology may be clinically relevant because it involves a reproducible procedure which allows the function and structure of the foot DF to be monitored. The use of this synchronised recording method may be extended to diagnosis and to evaluation of therapies (7,20–23).

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