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AN INSTRUMENTED FOOTBAR FOR EVALUATING EXTERNAL FORCES IN PILATES

[1,2]Guilherme Auler Brodt, [1]Débora Cantergi, [3]Luiz Carlos Gertz and [1]Jefferson Fagundes Loss
[1]Federal University of Rio Grande do Sul, Porto Alegre, RS, Brazil
[2]University of Caxias do Sul, Caxias do Sul, RS, Brazil
[3]Lutheran University of Brazil, Porto Alegre, RS, Brazil
browtch@gmail.com

INTRODUCTION

External forces and motion coordinates are the main input data for determining joint loading using inverse dynamics analyses. The effectiveness of the models depends on data from anthropometric, kinematic and dynamometric techniques that help movement description and mathematical modeling [1].

Force plates are widely used for measurements of external forces. However it can only be used in situations involving flat surfaces. Due to this limitation, many devices have been developed or adapted to measure the external force vector acting on the human body, such as instrumented shoes [2], hand grips [3], instrumented pedals [4], among others.

During Pilates exercises the magnitude of force has been estimated either by spring length and spring constant [5, 6], or measured directly by means of load cells [7]. Nevertheless, the Reformer is an apparatus consisting of a carriage on rails with springs attached (Figure 1). The magnitude of force applied at the footbar to displace the carriage depends on a) the spring length variation; b) the spring constant; and c) the number of springs attached to the carriage. However, the force direction is unknown during the performance of the exercise.

In this context, the goal of this study was: 1) to develop and describe a device capable of measuring the direction and magnitude of the force exerted by the subject on the Reformer's footbar; and 2) to compare the force found using the device with the force estimated using the spring parameters. In order to illustrate the use of the device, a small test-experiment was performed during an exercise commonly executed on the Reformer.

METHODS

The Reformer footbar was instrumented with four tension-compression S shaped load cells (Strain Gage-based, S type - Alfa Instrumentos Eletrônicos Ltda.) rigidly fixed to the bar. The load cells were arranged two by two at each extremity of the footbar with 90° between the pairs, measuring the vertical horizontal components of the force applied on the bar (Figure 1). The adopted referential indicates α value of 0° when the resultant force is horizontal, with angles increasing in counter-clockwise (Figure 1).

The load cells were plugged into a four-channel data acquisition system (Miotec Biomedical Equipment Ltda.) sampled at 2000 Hz per channel. All signals were filtered using a low-pass second order Butterworth digital filter, with a cut-off frequency of 15 Hz.

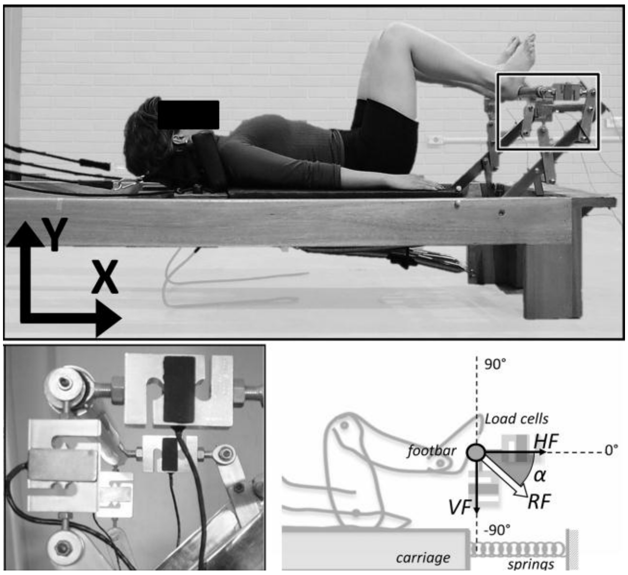

Figure 1: Subject performing the Leg Work exercise. The instrumented footbar and schematic figure that represents the main components of the reformer (carriage and springs) and the instrumented footbar.

Load cells were calibrated separately according to the manufacturer's specifications prior to their attachment to the footbar. All springs were calibrated [8] before the experiment resulting in a constant of 0.300 ± 0.007 kg/cm, and the mean coefficient was used for all the springs.

For testing the device, one female Pilates trained volunteer (54.6 kg; 1.63 m) performed the leg extension exercise (Figure 1). To track the position of the carriage during the experimental trial and estimate the variation in the length of the springs, one video camera (JVC GR-DVL 9800) sampled at 50 fields/s recorded the movement during the experimental procedure. Reflective markers were positioned on the carriage and the hip, knee and ankle of the subject. The speed of execution was defined using a metronome. The volunteer performed 5 repetitions of the legwork exercise in different speeds (0.5 and 1.0 m/s).

RESULTS AND DISCUSSION

The R^2 of all calibration procedures was higher than 0.99. At the slow speed the mean curve of the measured force appears to be very similar to the estimated force curve, presenting only a time difference, with the peak of the measured force happening at 36% of the exercise cycle, while the measured force happens exactly at 50%. At the fast speed, no resemblance between the shapes was found, suggesting that the shape of force curve is highly dependent on the execution speed (Figure 2).

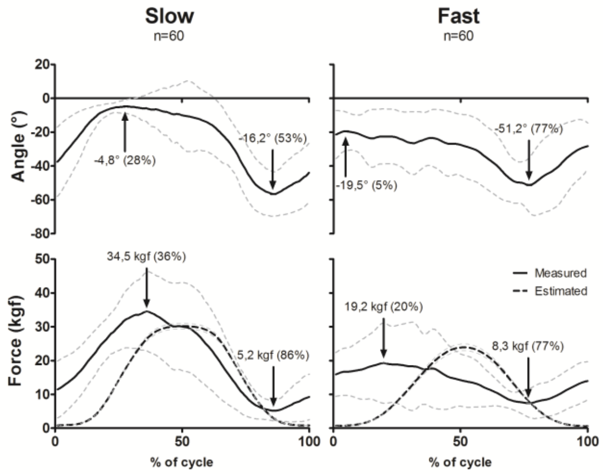

Figure 2: Measured angle and estimated and measured force magnitude in different speeds of execution.

By adapting commercial load cells to the apparatus a high correlation coefficient was achieved in the calibration curves. In addition, using commercially available loads cell facilitates replication of this methodology. Moreover, with the suggested arrangement, it is possible to evaluate the direction of the resultant force applied to the footbar, which is fundamental for obtaining a broader assessment of the demand made by the exercise on the individual.

The magnitude of external force in the Pilates environment has been assessed in other situations. Self et al. [7] used load cells to measure the force of the springs, and thus infer the force being applied to the individual in a situation similar to that used in the present study. This methodology is comparable to the estimation of spring force using spring length variation and spring constant. The forces normalized by body weight found in the present study (0.18 to 0.62 %BW) are very similar to those found by Self et al [7]. (0.20 to 0.65 %BW). Despite these similarities, this methodology applied to the reformer apparatus is susceptible to errors. When forces are measured in the spring, the inertial forces that may be generated by the movement of the carriage are not considered. By attaching the load cells directly to the footbar, allowing direct measurement of the force exerted by the subject, the inertial component resulting from the acceleration of both the subject's and the carriage's mass are being measured together with the force from the springs.

Due to the inertial component, in the present study, when the force was estimated using spring length and spring coefficient, the shape of the force data was very different when compared to the force measured with load cells. When the force of the springs is directly applied to the moving human segment [5,6] the estimation of this force obtained from spring parameters appears to be adequate. However, when the springs are not directly attached to the human segment, as is the case of the Reformer, the estimation of this force does not appear to match the force measured on the footbar. Having the vertical and horizontal components of the forte, it is possible to infer how different people will perform the same exercise, and later how the external forces will determine the joint forces when inverse dynamics analysis is used, for example.

CONCLUSIONS

The instrumented footbar was efficient to measure the magnitude of the force and its direction without changing the original characteristics of the Reformer and without impairing or constraining the performance of the exercise. Using this device it is possible to observe how the force applied to the footbar behaves during different Pilates exercises, and how different populations (e.g, beginners vs. advanced, young vs. elderly and injured vs. healthy) perform the same movement. Furthermore, force data can be used as input for inverse dynamics analysis.

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