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Abstract Maintaining a stable upright position and body orientation are fundamental tasks to perform everyday activities and ensure the quality of life. The ability to maintain these can be damaged by various pathologies/disfunctions, such as stroke and aging. Therefore, it is important to quantify how the postural control reacts to different situation and how is affected by different pathologies, which could bring a big contribution in a clinical context, by helping to diagnose pathologies that can bring postural impairments. An experimental protocol was developed that combines both electromyography and posturography. To help validate this protocol, 53 patients (43 healthy and 10 stroke patients) performed it twice within a two-week period. By comparing the results from the two runs, it was possible to assess that these were not statistical different, and thus prove that the protocol is viable tool to build a normative database.

Keywords: Signal Processing, Electromyography, Postural Control, Balance

1 Introduction

Maintaining the upright standing position does not require much effort, however it is a task that involves the coordination of a few different systems. Out of all, the three most important systems for this task are the motor system, sensor system and the central nervous system [7,30]. A correct posture is defined by the condition of balance between bones and muscles, and the relative alignments of the body elements, which enables the accomplishment of any action or just the sustenance of the body and it is a very important body ability [5,15]. Maintaining a stable standing position and body orientation are fundamental tasks to perform daily activities and ensure the quality of life [5,31].

The combination of these systems has two important goals: ensuring that equilibrium is maintained, even if there is an outside stimulus destabilizing it, and help the body keep a relative position to the environment surrounding it [3,15]. There are many factors that may cause problems in these systems, therefore it is important to study and comprehend its behavior [9,23]. This can be achieved by simultaneously recording muscle activity (EMG) and the body center of pressure, while varying the posture of a person. With these recordings, a normative database can be built in order to study and compare the differences between healthy and patients suffering with different pathologies.

In this study, a protocol combining both EMG and posturography was developed and applied in two groups: individuals without pathology and stroke patients. In order to check the validity, the protocol was applied twice in a two-week period and the results have been compared to asses if the experimental conditions effected the results.

2 Contribution to Life Improvement

By defining a normative database, researchers and physicians/therapists are able to compare the results of different pathologies and postural influencing factors to what a normal muscle and center of pressure should be. The results from these studies can help physicians to make earlier diagnostics and objectively track the progression of diseases, such as in ankylosing spondylitis, a chronic inflammatory disease, very difficult to be diagnosed in its early stages [26], or the tracking the progress of patients that suffered a stroke. Furthermore, decrease postural stability is also a factor associated with new and recurrent lower extremity injuries in an active population [24,25].

3 State of the Art

As previously mentioned, maintaining a stable standing position and body orientation are fundamental tasks to perform daily activities and ensure the quality of life [5,31]. Therefore, it is important to study the subtle changes in center of pressure and muscle activity to achieve a good postural control.

A force platform can be used to provide an indirect and non-invasive measure about the body center of pressure (COP) [21], this technique being called posturography. By analyzing the COP trajectory in the platform, person's posture control can be studied [9,29]. This technique is widely used, although there is a lack of standardization in experimental protocols. This lack leads to different tasks being performed, with different number of repetitions and different time acquisition periods, which contributes to a big variety of COP signal parameters, inducing the misinterpretation of the results [5,16,29,32]. The first studies conducted can be traced to 1968, where tests were performed to assess the ability to maintain balance [18]. Benvenuti [1] created a protocol that uses the static upright standing position to quantify the nature and severity of the postural instability of each individual, but due to the lack of difficulty of the proposed approach, Nashner [6] developed the Sensory Organization Test (SOT), which is composed of six sensory conditions that evaluate the individual's balance.

The postural control system is highly controlled by the motor system and it is important to assess the muscle response when evaluating the postural control and equilibrium of a subject [12]. Trunk muscles have an important role in the preservation and stabilization of the upright standing position. Therefore, electromyography (EMG) analysis in these muscles can provide a more comprehensive evaluation of the muscular activity during balance perturbations [10,14,20,28].

4 Research Contribution and Innovation

4.1 Developed Protocol

The protocol developed by this work combines both EMG and posturography data to provide a deeper and richer insight about the body postural control systems. As previously mentioned, this is very useful to clinicians in helping them to diagnose pathologies that can bring postural impairments at earlier stages.

The multichannel EMG recording were performed in four different muscles groups. These muscles and electrode placement are as follows: *rectus abdominis* (around 3 cm lateral to the midline above the umbilicus), *external obliques* (around 10 cm lateral to the midline above umbilicus and aligned with muscle fibers), *iliocostalis* (around 6 cm lateral to the midline at the L3[1]) and *multifidus* (around 2 cm lateral to the midline at the L5[1])[18]. Fig. 1 represents the placement of the electrodes during the realization of the protocol.

A) B)

Fig. 1 Illustration of the placement of the electrodes. A) placement of the electrodes in the abdominal wall and B) placement of the electrodes in the lower back.

The first step of the protocol is the recording of the basal muscle activity. To record that, subjects lay down on a marquise for 15 seconds in a supine position

[1] L3 and L5 – Third and Fifth Lumbar spine vertebra

Afterwards, the maximum voluntary contractions (MVC) for each muscle needs to be determined. There are three different tasks to obtain the MVC for each muscle.

For the *rectus abdominis*, the examiner asks the test subject to raise from a supine position using only the trunk, while at the same time counteracting the subject's efforts by placing his hand on the subject's chest [11]. For the *external obliques*, the examiner asks the subject to rotate one side of its body from a supine position, while at the sometime counteracting the subject's efforts by placing his hand on the shoulder being raised. This is done for both sides [11]. Finally, for the lower back muscles, the subject adopts a prone position and lifts their upper body, while the examiner places his hand between the subject's shoulders and counteracts this force [11]. Each of these MVCs procedures were repeated 3 times.

After obtaining the MVC for each muscle, the subjects were asked to perform nine different tasks, with duration of 30 seconds each (or as long as it could be managed), on top the force platform. The tasks were:

- Subjects stood on the force platform in a standing position, with, SEO, and without visual feedback, SEC [17,19,21,27,33].
- The subjects stood with only the right foot on the platform, with, REO, and without visual feedback, REC. These tasks were then repeated with the left foot (LEO and LEC) [19,33].
- Finally, on top of a table an object is placed on the left side of the subject, at a distance of 15 cm from the extended left arm. The subject is then asked to pick up the object with their right hand, RR. This test is then performed on the right side of the subject, by placing the object on the right side asking the subjects to pick up the object with their left hand, RL. Finally, and according to the dominant hand of the subject, an object is placed in front of it at the previously mentioned distance. Then it was asked to the subjects to pick the object with their dominant hand, RC [2,8,13].

This protocol was performed twice within two weeks to ensure that the experimental conditions do not influence the results from the protocol. During the trails, it was observed that unipedal tasks caused great discomfort for the stroke patients, and thus the protocol applied to this group was reduced to remove the REO, REC, LEO, and LEC tasks.

4.2 Subjects

This study was conducted both at Faculdade de Ciências e Tecnologias da Universidade Nova de Lisboa and the Medical Center for Rehabilitation of Alcoitão (CMRA). The experimental protocol was approved by the CMRA ethical committee and all participants gave their written informed consent. The subject are divided into two different populations, one comprised of individuals without pathology and patients that suffered a stroke. Additionally, to be included in this study, the stroke patients had to meet two selection criteria: be able to maintain an upright standing position, and have cognitive ability with no total aphasia.

For the no pathologic group, a total of 43 individuals were recruited. There were 24 females and 19 males, with ages comprised from 18 to 55 years, heights from 150 to 190 cm, and weights from 47.5 to 110,0 Kg. For the stroke patient group, 10 patients attending the CMRA were recruited, with ages comprised from 43 to 77, heights from 160 to 188 cm, and weights from 57.0 to 103.0 Kg.

4.3 Data Recording and Analysis

COP displacements were recorded using a force platform provided by Plux[1]. This equipment is characterized by 4 steel load cells able to record a maximum force of 8000N (2000N per cell). The data is streamed over Bluetooth, being sampled with a sampling frequency up to 1000Hz and a resolution of 16 bits.

For recording the EMG signals, a biosignalPlux[1] acquisition module and 8 EMG sensors were used. The biosignalPlux[1] is capable of recording 8 biosignals simultaneously with a resolution of 16 bits and sampling frequencies up to 1000Hz. This bandwidth was chosen since EMG activity can go up to 500Hz [4]. As with the force platform, the data is streamed via Bluetooth. The EMG sensors used were emgPLUX[1] an EMG sensor from Plux[1]. To connect the sensors to the patient, 2 Ag/AgCL with solid adhesive pre gelled electrodes were used per sensor (TIGA-MED Gold 01-7500, TIGA-MED GMBH, Germany).

For recording the data streamed from the platform and the biosignalsPlux[1], the software used was OpenSignals[1].

EMG signals were averaged out and the signal envelope was extracted using the root mean square (RMS) algorithm, with a window of 100 samples. Each muscle RMS signal was then normalized using the maximum value of the respective MVC.

Platform signals underwent a pre-processing phase where the raw signal was converted to a COP displacement in the antero-posterior (AP) direction (Y direction) and medio-lateral (ML) direction (X direction). Then, and for each direction, the signal was averaged out. The velocity, standard deviation, and amplitude of the signal of each direction were calculated. The total area of COP displacement was also calculated, using the convex hull algorithm and the Green's theorem.

4.4 Statistical Analysis

To compare the two moments where the protocol was executed, the paired samples t-Test was used. This parametric test allows us to compare two means from two different and related conditions, by comparing the mean differences between the paired samples and if these significantly differ from zero [22]. The null hypothesis is then:

H0: $\mu1 - \mu2 = 0$, where $\mu1$ and $\mu2$ is the population mean of variable 1 and of the variable 2, respectively.

For this work, p-values bigger than 0.05 indicate than the null hypotheses cannot be rejected and the mean difference of the paired samples is 0.

5 Results

For the EMG data, the mean and median normalized activity (a percentage of the maximum voluntary contraction value) of each muscle for a certain task was compared with the corresponding value for the rerun, using the paired t-Test with the significance level set at $p > 0.05$. For all tasks, no significant differences were found between the trial and re-trial for both the mean and median values. As an example, the lowest p-value obtain when comparing the mean value for all task for all the muscles in the study was 0.07 for Right *Rectus Abdominis* muscle for reaching an object for an object on the right side of the body task.

For the COP data, the amplitude and standard deviations (in each frontal-distal and antero-lateral) were compared, as well as the velocity and total area. As with the EMG data, the paired t-Test p-values were all above the significance level, indicating no significant difference between both runs.

Finally, the same assessment was applied to the test subjects that suffered a stroke, and no significant differences were found between runs for the EMG and COP features, confirming the results found in the previous comparison. The protocol for these patients had to be simplified since only the first five tasks could be easily (without pain or too much effort from the patients) performed by the subjects.

6 Conclusion

The objective of this work was to assess the development and validation of an experimental protocol to evaluate posture control. In order to fulfill this objective, the developed protocol was applied twice within a two-week period to ensure that the results obtained were not affected by the experimental conditions or by any other external factor. This protocol was developed in order to build a normative database of both posturography and electromyographic features that can be useful in future studies to evaluate posture control.

Two different population were recruited for this study, one healthy and one composed of stroke patients, for a total of 53 test subjects (43 individuals without pathology and 10 stroke patients). The developed protocol was applied to this two groups and some features extracted from the raw data in order to compare the results of the two different moments when the protocol was applied.

To compare this two moments, the paired sample t-Test was used, and the result of this test revealed that for all the analyzed features, no statistical difference was detected.

Based on the results obtained, the proposed protocol can be considered as a viable tool to build a normative database, by providing a systematic and standard reference when developing further posturographic and electromyographic studies.

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