Balance Perturbation Leads a Stretching Reflexion on Tibialis Anterior Muscle

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Abstract: Human posture control is a sophisticated process involving the relationship among multiple joints, muscle groups and environment. The aim of this study is to show how the balance perturbation (in posterior-anterior direction) leads to a stretching reflexion on the tibialis anterior (TA) muscle. A case study that involved a male participant with 23 years old. To disturb the participant's balance, it has been employed a specially plataform designed with dimensions 1.5 m by 1.5 m with movement of 5 mm of amplitude on a total time of 3 ms along the axis coinciding with participant's anterior-posterior axis. Soleus (SO) and TA electromyography signal (EMG) has been recorded. Perturbation in the equilibrium was delivered in the posterior-anterior direction. The first event observed was the pre-activation of the TA muscle that leads a reduction in the SO muscle activation, due the stretch reflex at TA.

1 INTRODUCTION

Human posture control is a sophisticated process involving the relationship among multiple joints, muscle groups and environment (Horak, 2006). Theoretically, the passive muscle stiffness can ensure postural control in upright position under static conditions (Neves et al., 2013). However in practice, it is necessary coordinated muscle activity to ensure balance in daily activities (de Medeiros et al., 2010). The two main functional goals of postural control are: postural orientation and balance. Postural balance involves movement strategies to stabilize the center of mass within the base of support due to stability disturbances externally caused (Gage, 2004; Horak, 2006; Robinson, 2011). Static balance is guaranteed when the sum of all external forces and all external torques acting on the body equals zero, however, under the mechanical point of view, the body is never in a condition of perfect balance, as the sum of forces and torques acting on it are only momentarily zero. Thus, Duarte and Freitas (2010) propose that the human body is in constant unbalance and in an endless quest for balance.

Maintenance of body balance in the environment is determined by central systems and peripheral structures responsible for motor execution, whose functioning depends on the integration of information from the sensory structures of the proprioceptive, vestibular and visual systems. These sensory structures respond in complex and different ways for each perturbation on the body (Melzer, Benjuya and Kaplanski, 2004).

For balance control to occur in a harmonious way the sensory system is used to obtain continuous and integrated information on position and trajectory of the body, allowing the issuance of motor responses arranged to be performed by the osteomioarticular effector system (Robinson, 2011).

There are three basic strategies for correcting body balance as responses to postural perturbations: (a) the strategy of the ankle, where the body moves as a relatively rigid mass about the ankle, (b) hip strategy, used when the center of gravity (CG) moves quickly but with a relatively small displacement or when the support base is narrow or unstable and (c) a step strategy used when the GC is scrolled beyond the limits of stability (Horak et al., 1989).

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Between motor responses, are the stretch reflex and proprioceptive reflex. These reflexes are involuntary responses to external stimuli in different movements, automated or forecasting.

Corporal movements to balance recovery can trigger reactive fast motor response that leads a muscle pre-activation, sudden stretch and inhibition of antagonist muscles. One of these reactive a motor response is the reciprocal inhibition, which is an important neurophysiological phenomenon leading to better coordination of movements and efficiency (Robinovitch and Murnaghan, 2013). According to Hortobagyi et al. (2006), the reciprocal inhibition may decrease with age and contribute to poor performance of movements in older people, because it is an important tool in neurophysiological motor coordination.

Through the disturbance of equilibrium occurs subsequent order: (a) muscle pre-activation; (b) sudden muscle stretch; (c) inhibition of the antagonist muscles. The aim of this study is to show how the balance perturbation (in posterior-anterior direction) leads to a stretching reflexion on the *tibialis anterior* (TA) muscle.

2 METHOD

A case study was conducted with a 23 years old male participant, 67kg of body mass and 1.79 m tall, to show how the balance perturbation leads to a stretching reflexion on the tibialis anterior muscle. This study has been approved by Human Research Ethics Committee of Pontifícia Universidade Católica do Paraná (PUCPR) under register number 620.735.

2.1 Experimental Protocol

The experimental protocol comprises the participant's balance perturbation with concurrent record of balance maintenance muscular action. The participant has been told to stand still on orthostatic position on a movable platform keeping 17cm of feet aperture and 14° of ankle abduction, facing forward the researcher. Initially the movable platform has remained still while the participant was advised that it would start moving. After some random time, suddenly and without participant's warning the platform has performed an alternative movement of 5mm of amplitude on a total time of 3ms on the anterior-posterior direction. Along this time the (TA) and *Soleus* (SO) muscular action has been recorded through a data acquisition system fed by electromyography signal (EMG). The participant has kept his eyes open along the experiment. The platform has started moving from participant's posterior to anterior side, a perturbation similar as pulling a carpet intending to cause the participant to fall sitting. Figure 1 shows the research's participant standing still on the movable platform.

2.2 Movable Platform

In order to disturb participant's balance it has been employed a specially designed 1.5m by 1.5 m platform which is allowed to move up to 0.9 m along both horizontal orthogonal axes. In this particular protocol, the platform has been driven by a linear pneumatic actuator performing an alternative movement of 5 mm of amplitude on a total time of 3 ms along the axis coinciding with participant's anterior-posterior axis. Displacement has been measured with a potentiometric linear transducer.

2.3 Electromyography

Muscular activation has been measured employing a four channel surface electromyography system. Site's skin preparation and placement of electrodes have been in agreement with that stated by SENIAM project (SENIAM, 2014). Electrodes's site preparation comprised body hair shaving followed by skin abrasion employing cotton and alcohol 70°. It has been employed self-adhesive surface electrodes in a bipolar configuration (Ag/AgCl ∅2,2cm) positioned at 1/3 on the line between the tip of the fibula and the tip of the medial malleolus in the direction of the line between the tip of the fibula and the tip of the medial malleolus for TA and at 2/3 of the line between the medial condyles of the femur to the medial malleolus in the direction of the line between the medial condyles to the medial malleolus for SO. Reference's electrode was placed around the ankle at the anterior face of Tibia.

2.4 Data Acquisition and Processing

Data acquisition has been performed employing a National Instruments board, model NI-USB-6009, and a specially designed software developed on LabView with a sampling rate of 2KHz with input analog channels on a differential configuration resulting in a 14 bits resolution.

Data processing has been performed on Matlab, comprising the following steps:

i) EMG RMS envelop determination;
ii) Muscular recruitment threshold determination;

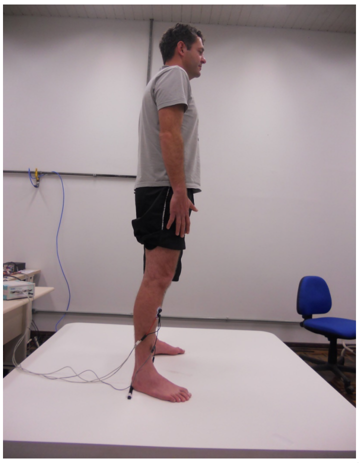

Figure 1: Research's participant standing still on the movable platform with EMG electrodes on TA and SO muscles.

iii) Start of muscular recruitment determination;
iv) Time delay between start of balance's perturbation and start of muscular recruitment determination;
v) EMG RMS envelop normalization;

Items (*i*) to (*v*) have been performed independently and sequentially from TA to SO muscles.

EMG RMS envelop determination has been performed employing function "filtfilt" of Matlab. This function's input arguments where numerator and denominator of a 5th order Butter-Worth low-pass filter with a 20Hz cut-off frequency and 2 kHz sample frequency obtained by function "butter" of Matlab. The third input argument of function "filtfilt" was the absolute value of corresponding EMG.

A 1s lasting window of the EMG RMS envelop preceding perturbation's start has been selected on a monitor's computer plot by visual inspection. The mean value and the standard deviation of EMG RMS envelop into this window have been obtained. Muscular recruitment threshold has been obtained by the sum of 100% of mean value and 150% of standard deviation.

Based on visual inspection of a plot, the researcher has been allowed to select the instant of time that the value of EMG RMS envelop has become greater than the muscular recruitment threshold. This has been considered the start of muscular recruitment. Time of start of balance's perturbation was obtained based on displacement's transducer signal. Subtracting these two time values has resulted on the time delay between start of balance's perturbation and start of muscular recruitment.

EMG RMS envelop normalization has been performed by subtracting the muscular recruitment threshold from corresponding EMG RMS envelop value. Doing so, one may consider that both muscles have a null normalized muscular recruitment threshold.

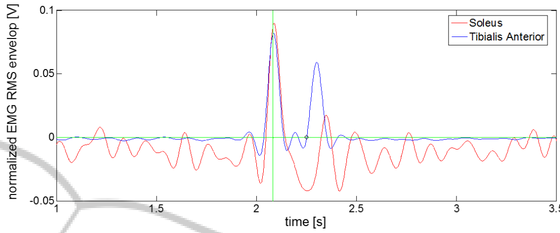

Figure 2: Normalized EMG RMS envelop of TA (blue) and SO (red); selected start of TA muscular recruitment (small blue circle); normalized muscular recruitment threshold (green horizontal line); start of balance's perturbation (green vertical line).

3 RESULTS

Through the identification of contraction thresholds of TA and SO muscles and using the normalized EMG RMS envelop it has been possible to determine temporal behavior of muscle contraction (Figure 2). This behavior corresponds to the situation in which the participant was with eyes open and with early motion of the platform on the posterior-anterior direction. The time delay between start of balance's perturbation and start of muscular recruitment contraction (muscle contraction delay) of TA and SO muscles are presented at Table 1.

Table 1: Muscle contraction delay time for TA and SO muscles.

	TA (ms)	SO (ms)
Muscle contraction delay	0.0164	0.0462

As the values shown at Table 1, the TA and SO muscles contracted at different times. This was expected due to their antagonistic action. Whereas the balance disorder had higher-anterior direction and the first muscle to contract was the TA (Table 1 and Figure 2), we believe that the ankle joint, initially held a plantar flexion. In this movement, the TA muscle due to its dorsi-flexor action is stretched and rapidly contracts to maintain the balance.

As the SO muscle performs plantar flexion, and joint action of the ankle resulting from the balance disturbance is the same, it was activated later (Table

1) to the action of the TA muscle for adjusting joint position after dorsiflexion trend held by TA.

4 DISCUSSION

Despite that the research's participant didn´t know the exact time of the perturbation, he knew that the disturbance would happen at any time. In this situation, Stokes et al. (2000) suggest that pre-activation occurs in the muscles of the participant who is subjected to a disturbance of equilibrium, which is also associated with an increased sensitivity of the muscle spindle, causing changes in length and increasing the probability of responding to a sudden muscle disorder.

Cort et al. (2013) analyzed the contributions of the muscles of the spine due to balance's disorders, they concluded that the participants also performed muscle contractions prior to perturbation. This enhances the performance of the neuromuscular system to responses to sudden balance's disorders, increasing the sensitivity of the receptors responsible for detecting motion (Cort et al., 2013).

Figure 2 shows that there is an increase in SO muscle tone prior to perturbation. However, after the disturbance, the EMG RMS envelop signal undergoes a sudden attenuation compared to the pre-perturbation. We believe that this reduction is associated with transmission's inhibition of the action potential to the muscle.

Crone et al. (1994), for example, conducted physical training aimed at increasing the response of reciprocal inhibition in healthy individuals and in individuals with musculoskeletal disorders (Geertsen et al., 2008).

This phenomenon can be explained by the occurrence of the stretch reflex in the TA muscle that has the effect of reciprocal inhibition of the antagonist muscle group to its action.

In a study by Robinovitch and Murnaghan (2013), using a linear motor connected to a mobile platform to promote a controlled perturbation, 14 young women were evaluated in three conditions (forward swing, back swing and static). The results suggest that the amount of latency (defined as the time between the onset of the disturbance and the onset of muscle contraction) in all seven analyzed muscles (Erector Right Column, Rectus Abdominis, Soleus, Gastrocnemius, Tibialis Anterior, Rectus Femoris and Biceps Femoris) seemed to occur earlier when participants performed a static position. The authors also concluded that the action of the use muscles for recovery of the balance are adapted depending on the nature of the disturbance and the requested task.

Regarding aging, the work of Piirainen et al. (2013) monitored EMG signal of muscles SO, TA and Gastrocnemius of 9 young adults and 10 older adults in the recovery of postural equilibrium after a disturbance in the anterior-posterior and posterior-anterior directions. The authors noted that, due to aging a decrease in postural control occurs. The action of SO and TA muscles may not be functional for maintaining equilibrium in the face of perturbations in different directions of evaluated perturbations, indicating a distinct global motor strategy to balance recovery, and yet, with activation of antagonistic muscle groups for different directions of perturbations.

5 CONCLUSIONS

It can be concluded that in the situation of balance perturbation in posterior-anterior direction, the TA muscle contracts before the SO, and the SO has pre-activation, which is inhibited due to the stretch reflex that occurs in the TA muscle.

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