# ACTIVATION TIMING OF SOLEUS AND TIBIALIS ANTERIOR MUSCLES DURING SIT-TO-STAND AND STAND TO SIT IN POST-STROKE VS HEALTHY SUBJECTS

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## ABSTRACT

**Introduction**: Sit-to-stand (SitTS) and stand-to-sit (StandTS) are very important functional tasks that become compromised in stroke patients. As in other voluntary movements, they require an adequate postural control (PC) involving the generation of anticipatory postural adjustments (APAs). In order to give clues for more efficient and directed rehabilitation programs, a deeper knowledge about APAs during challenging and daily life movements is essential. **Purpose**: To analyze the activation timing of tibialis anterior (TA) and soleus (SOL) muscles during SitTS and StandTS in healthy subjects and in post-stroke patients. **Methods**: Two groups participated in this study: one composed by ten healthy subjects and the other by ten subjects with history of stroke and increased H-reflex. Electromyographic activity (EMGa) of SOL and TA was analyzed during SitTS and StandTS in the ipsilateral (IPSI) and the contralateral (CONTRA) limb to the side lesion in stroke subjects, and in one limb in the healthy subjects. A force plate was used to identify the movement onset. **Results:** In both sequences, in the stroke group SOL activation timing occurred prior to movement onset, contrary to the pattern observed in the healthy subjects. Statistical significant differences were found in SOL activation timings between each lower limbs of the stroke and healthy groups, but no significant differences were found between the IPSI and the CONTRA limb. The TA activation timing seems to be delayed in the CONTRA

limb when compared to the healthy subjects and showed also a better organization of TA timing activation in StandTS when compared to SitTS. **Conclusion:** Compared to healthy subjects, APAs seems to be altered in both limbs of the post-stroke subjects, with the SOL activation timing being anticipated in both SitTS and StandTS.

## 1. INTRODUCTION

An voluntary movement requires an adequate postural control (PC) to the desired action under a particular environment (Bigongiari et al., 2011; MacKinnon et al., 2007), being generally preceded and accompanied by postural adjustments, which have been previously described as anticipatory postural adjustments (APAs) (Aruin, 2002; Aruin & Shiratori, 2003; Ruget et al., 2008). Therefore, the muscles responsible for postural adjustments are activated before those acting as prime movers (Ruget et al., 2008). Some authors denote APAs when the activation timing occurs between the 100 ms preceding prime mover's instant of activation and lasting until 50 ms (Aruin, 2002; Aruin et al., 1998; Schumway-Cook & Woollacott, 2007), whereas other authors denote APAs when a 250 ms activation timing preceding the movement and lasting until 50 ms (Shiratori & Latash, 2001).

As previously described, some authors have focused their studies on the activation timing (onset) of muscles that represent APAs' behaviors (Dehail et al., 2007; Khemlani et al., 1999). Thus, APAs can be assessed by the amplitude of the electromyographic signal of postural muscles, as well as by their activation timing (Aruin, 2002).

There are references for the involvement of the supplementary motor area (SMA) (Jacobs et al., 2009; Yoshida et al.2008 ) and premotor cortex (PMC) (Chang et al.2010) as a potential locus of control in APAs' generation. A decreased SMA activity induced an increase in the latencies of muscle's activation (Jacobs et al., 2009), and a lesion in PMC affects the APAs of bilateral lower extremities in step initiation (Chang et al. 2010). The lesions in this cortical area, or their axons, may occur in stroke conditions, more specifically when the middle cerebral artery (MCA) is compromised, which happens in most of the cases. Therefore, the study of possible adjustments in APAs' response, as a PC indicator, is extremely important as it is a critical component to achieving independence in the activities of daily living (Lundy-Ekman, 2008).

There is some evidence that suggests that APAs are strongly dependent on the afferent input from the initial biomechanical conditions (Aruin & Shiratori, 2003). A study performed by Galli et al. (2008), which aimed to test this hypothesis, found that the APAs in the frontal plane when producing a step are under proprioception-based online control. In fact, the activation time reflects the activity of underlying pattern generators as well as both central and proprioceptive modulation (Ivanenko et al., 2006). It has been described a premature and excessive activation of the SOL muscle in stroke patients (Cheng et al., 2004). Also, an increased H-reflex response, reflecting a possible dysfunction in the modulation process, has been demonstrated (unpublished data). It remains unknown if in the presence of a dysfunction of this modulation process, due to inappropriate inputs, it is possible to observe changes in APAs' behavior in different initial conditions, like sitting and standing position. Aruin et al. (2003) reported that changes in the organization of APAs' due to differences in body positions in sitting vs standing could be expected.

Several studies about APAs' patterns have been performed in relation to arm or leg movements (Maeda & Fujiwara, 2007; Slijper et al., 2002; Yoshida et al., 2008). However, there is a huge lack of knowledge in more challenging actions like sit-to-stand (SitTS) and stand-to-sit (StandTS), which are very important functional tasks that become compromised in stroke patients (Bishop et al., 2005; Camargos et al., 2009; Cheng et al., 2004). During SitTS and StandTS sequences, tibialis anterior (TA) muscle seems to be the most representative muscle for APAs (Goulart & Valls-Solé, 2001) in order to stabilize the foot before forward movement of the body (Dehail et al., 2007; Khemlani et al., 1999). According to the reciprocal activation pattern, an opposite behavior of the SOL muscle should then be expected (Bishop et al., 2005; Knikou & Rymer, 2002). Therefore, the earlier activation of TA, which is important for the foot stability (Cheng et al., 2004; Khemlani et al., 1999), can be influenced by the level of activity of the soleus (SOL) muscle.

The neuronal pattern evoked during a task is always targeted to maintain the body centre of mass over the base of support (Dietz, 1996) and sensory inputs can have global influences in selecting motor patterns (see, for example, the review in (Rossignol et al., 2006)). Despite the influence of SMA area over APAs generation, the finding that loading the ankle plantar flexors influence the behavior of SOL muscle (Mazzaro et al.,

2007) may justify the hypothesis that the activation timing of TA and SOL might be different due to differences in loading like it occurs during sitting vs standing position.

The purpose of this study was to analyse the activation time of TA and SOL during SitTS and StandTS in the ipsilateral (IPSI) and contralateral (CONTRA) limb of stroke patients with an increased H-Reflex in the CONTRA limb, and compare it with healthy subjects.

## 2. METHODS

### 2.1 Sample

This study included two groups with age raging from 30 to 65 years: the "healthy group" and the "stroke subjects" group. Ten voluntary individuals (three female and seven male), with a first isquemic stroke and an associated higher H-Reflex response in CONTRA limb, in relation to healthy subjects, participated in this study. The inclusion criteria were: lesion at the territory of middle cerebral artery (MCA), in a sub-cortical level, confirmed by computerized axial tomography of the brain; a score superior to 34 on the Fugl-Meyer Assessment of Sensorimotor Recovery After Stroke scale (Lamontagne et al., 2002); able to perform SitTS and StandTS sequence independently (Camargos et al., 2009; Cheng et al., 2004). For both groups, subjects that were under medication that could affect motor performance and without cognitive function to understand orders (assessment using the Mini-Mental State Examination) were excluded. All subjects with previous history of neurologic disease, such as Parkinson disease, pontine and/or cerebellar lesions, sensory impairment, diabetes, thrombophlebitis, history of lower limb surgery or any orthopedic or rheumatoid conditions interfering with SitTS and StandTS sequences were also excluded. The healthy group consisted of 10 individuals (six female and four male) that were considered sedentary, according to the Centre for Disease Control for the American College of Sports Medicine (Thompson, 2001). The same exclusion criteria were applied for this group.

This study was approved by the Ethics Committee of Escola Superior de Tecnologia da Saúde do Porto, in Portugal. All subjects gave their informed consent according to the Declaration of Helsinki.

The "healthy subjects" and "stroke subjects" groups were characterized in relation to age, weight and height in order to assess their variability. Moreover, the stroke subjects

group showed a time evolution superior to two years and seven of those individuals had the lesion on the left side and the other three on the right side (Table 1).

## 2.2 Instruments

For the lower limb evaluation, the corresponding part of the adapted version to the Portuguese population of the Fugl-Meyer Assessment of Sensorimotor Recovery After Stroke was used.

The EMG signal was acquired and processed using the Bioplux_research system (Plux, Portugal), and the Acqknowledge software (Biopac Systems, Inc. USA). A force plate, FP4060-10 model from Bertec Corporation (U.S.A), connected to a Bertec AM 6300 amplified, and to the Biopac MP150 Workstation, was used. For the H-Reflex measurement, the electrically induced EMG activity of soleus muscle was obtained using a Biopac MP150 Workstation (Biopac Systems Inc., Santa Barbara, CA, USA) with appropriate software for the data acquisition and analysis (Acqknowledge, version 3.9). The EMG signals were acquired using pre-amplified active electrodes (TSD150B, Biopac Systems Inc., Santa Barbara, CA). The electromyographic and force plate data were collected at 1000 Hz.

## 2.3 Procedures

### 2.3.1 Preparation

Immediately before the electrode placement, the skin was prepared to reduce the impedance to a level equal or inferior to 5 KΩ (Camargos et al., 2009; Cheng et al., 2004; Correia et al., 1993).

For TA EMGa data collection, the electrodes were placed on the 1/3 of the line that goes from the superior extremity of the fibula to the inferior extremity of the medial malleolus (Cheng et al., 2004). For the SOL muscle, the electrodes were placed 2 cm below medial gastrocnemius muscle and 2 cm medially to the midline of the leg (Palmieri et al., 2002).

For H-reflex data, the stimulation electrodes were located in transversal configuration, with the cathode over the tibial nerve in the popliteal fossa, and the anode placed proximal to the patella on the lower anterior aspect of the thigh, in order to selectively activate Ia afferents at lower thresholds and to reduce the stimulus artifact (Chen & Zhou, 2011; Higashi et al., 2001; Palmieri et al., 2004; Tokuno et al., 2008).

*2.3.2 Data Collection*

*a) Timing activation*

After an explanation about the procedures, all individuals performed the task with shorts and with standard shoes with soles of 1 cm high (Kim et al., 2011). It was also established a minimum interval of 5 minutes between the electrode placement and the EMG data acquisition. The task initiated from sitting position, with arms parallel to the body and 2/3 of the femur supported on the seat. A plinth was placed in height adjusted to 100% of the lower leg length (from the knee joint to the ground), as a reference for the subjects to assume the sitting position. Before the verbal command "You may stand up and remain still" and "you may sit down", the individuals were instructed to perform the task at a normal speed without using the upper limbs or moving their feet (Dubost et al., 2005), while maintaining a visual reference placed 2 meters away. One minute rest between each trial was provided, and the necessary repetitions were performed in order to obtain three valid trials. On the stroke subjects group, both members were analyzed simultaneously, while on the healthy group each member was randomly selected.

*b) H-Reflex*

Tests were performed with the subjects in supine laying position, with feet being supported in a slightly flexed position, with a knees angle of approximately 20º.

Subjects were familiarized with sub-maximal electrical stimuli over a period of 10 minutes before the beginning of the testing session while confirmed the place of the cathode (Scaglioni et al., 2003). This placement was considered adequate when the stimulus threshold for eliciting the H-reflex was less than the required to induce a M-wave in the soleus muscle and the value M-max and its stabilization was obtained (Palmieri et al., 2004; Tucker et al., 2005).

The soleus muscles were stimulated by delivering percutaneous electric stimulation in the tibial nerve (Chen & Zhou, 2011; Higashi et al., 2001; Palmieri et al., 2004). Each stimulus, delivered from a constant-current stimulator, was inferior to 0.5 ms in order to avoid unpleasant sensations from the stimulation of skin nociceptors (Chen & Zhou, 2011; Palmieri et al., 2004; Tucker et al., 2005). The pulse intensity was increased gradually from below the threshold of the H-reflex to supra-maximal for M response with increments of 10% of the individual maximal M-wave. Three pulses were delivered sequentially at each stimulus intensity (Palmieri et al., 2004; Tucker et al.,

2005). To minimize the effect of post-activation depression the inter-stimulus duration was no less than 10 s (Chen & Zhou, 2011; Palmieri et al., 2004).

### 2.3.3 Data Processing

#### a) Timing activation

The raw EMG signal and the force plate data were processed using the Acqknowledge software. The raw EMG signal was filtered with a band-pass filter of 20 and 500 Hz and the values of root mean square were calculated (Billot et al., 2010; Lamontagne et al., 2002; Lamontagne et al., 2000). The signal from the force plate was also filtered, using a low pass filter of 10 Hz.

SitTS events were identified by Bishop *et al.* (2005), through antero-posterior ground reaction force ($F_{AP}$), where the peak of this force represents the transition between the flexion-momentum and momentum-transfer stages of SitTS. The study of APAs in SitTS can be done through observation of the variation in the $F_{AP}$ vector in the onset movement of SitTS (Bishop et al., 2005; Galli et al., 2008). In the present study, the moment onset was defined as time zero (T0) and was identified through $F_{AP}$. T0 was defined as the instant lasting at least 50 ms when $F_{AP}$ value was greater or smaller than the mean of its baseline value plus 2 standard deviation (SD). The onset of TA and SOL relatively to T0, was identified by electromyography, and a rest interval was selected from -500 to -450 ms, being analyzed the average (M) and SD values. The beginning of the muscular activity was defined by the interval of time when the electromyographic signal exceeds the mean of its baseline value plus 2 SD during a time interval equal or superior to 50 ms. The mean time of TA and SOL onset was adopted for each subject.

All procedures were performed for each trial, having the arithmetic mean of the values obtained for each variable in 3 satisfactory trials. The data acquisition was always performed by the same investigator to ensure the reproducibility of the technique and reduce subjectivity.

#### b)H.-Reflex

All EMG signals were filtered (10-1000 Hz) and the peak-to-peak amplitudes of the H-reflexes and M-waves were recorded for all the test stimulations in order to calculate the value of Mmax/Hmax ratio.

### 2.4 Statistics

The statistical analysis was performed using the Statistical Package for Social Sciences (SPSS, IBM, USA) version 18.0.0 for Microsoft Windows 7. Using

descriptive statistics, the measures of central tendency (M) and dispersion (SD) for the timing of SOL and TA EMG activity were calculated.

The Wilcoxon Signed Rank Test (Z) and Mann-Whitney Test (U) were applied to compare the activation timing between the IPSI and CONTRA limb of the individuals from the stroke group, and also between the stroke and the healthy group, respectively (Marôco, 2010). The Mann-Whitney Test was also used to compare the Mmax/Hmax values between CONTRA limb and a limb of healthy subjects. The Paired-Sample T Test and Independent-Sample T-Test were used to analyze the differences in the execution task time between SitTS and StandTS and between stroke and healthy subjects, respectively. Differences with a $p < 0.05$ were considered statistically significant.

## 3. RESULTS

The time of execution of SitTS and StandTS were compared, and no differences were obtained in stroke (p=0.349) and healthy (0.081) subjects. Also, no differences were observed between both groups in relation to time of execution of SitTS (p=0.605) and StandTS (p=0.191).

*SitTS and StandTS of healthy subjects requires TA preactivation followed by SOL activation after the beginning of the movement*

Analyzing TA and SOL onsets in healthy subjects during SitTS, it is observed that TA is activated prior the movement ($-156.7 \pm 98.2$ ms), contrary to SOL, which starts to be active afterwards ($170.6 \pm 80.5$ ms) (Fig.1A). Similarly, during StandTS, the TA activation timing occurs before the movement ($-228.9 \pm 185.1$ ms), unlike what is observed in SOL ($207.9 \pm 402.2$ ms) (Fig. 1A).

*SOL activation timing seems to be anticipated in both SitTS and StandTS in the IPSI and the CONTRA limbs of stroke subjects*

In the IPSI limb of stroke patients, in both SitTS and StandTS, TA seems to have an activation timing ($-224.9 \pm 103$ ms and $-188.4 \pm 139.4$ ms, respectively) that is not significantly different from what was observed in the healthy group (p=0.257 and p= 0.643, respectively), occurring prior to the movement as well (Fig. 1B). In opposite, SOL onset appears before the beginning of the movement ($-122.6 \pm 150.9$ ms for SitTS and $-209.1 \pm 160$ ms for StandTS, respectively), being close to the activation timing of

TA of the same limb (Fig. 1B). Moreover, SOL activation timing of the IPSI limb of stroke patients is significantly different from the SOL activation timing of healthy subjects (SitTS, $p<0.0001$; StandTS, $p= 0.018$). Similarly, the activation timing of SOL in the CONTRA limb (-222.7 ± 140.9 ms for SitTS and -152.0 ± 56.2 ms for StandTS) occurs before the movement, and no significant differences were found when the IPSI and CONTRA limbs were compared ($p=0.086$, $p=0.753$).

*The TA and SOL activation timing pattern during SitTS and StandTS may be inverted in the CONTRA limb of stroke patients*

Although TA appears to be activated prior the movement in the CONTRA limb of stroke patients in both SitTS (-15.3 ± 52.4 ms) and StandTS (-79.0 ± 86.4 ms), data suggests that SOL activation timing occurs before TA (-222.7 ± 140.9 ms and -152.0 ± 56.2 ms, respectively), which is against what should be expected (Fig. 1C).

## 4. DISCUSSION

Muscle activation timing represents only one of the several components of the motor control system (Cowan et al., 2001). Thus, it is important to be aware that for an efficient voluntary movement to happen, it must be preceded and accompanied by postural adjustments, the APAs, whose responsible muscles need to activate prior the prime muscle movers (Ruget et al., 2008). In SitTS and StandTS, the forward movement of the trunk over the lower limbs justifies the need of TA activation timing prior to the movement. This is based on the fact that the central nervous system can previously adjust anticipatory activity of muscles in response to perturbations/changes in the direction of the movement (Aruin & Shiratori, 2003).

In the healthy subjects, we observed that, for both SitTS and StandTS, TA seems to play an important role for APAs since it is active prior to the beginning of the movement, with activation timing between the -250 ms APAs interval period referred by Shiratori et al. (2001). Following what was previously described, this finding was already expected and in agreement with other studies, which showed that TA seems to be the most representative muscle for APAs in order to stabilize the foot during SitTS and StandTS (Goulart & Valls-Solé, 2001; Khemlani et al., 1999).

Moreover, based on the study of Kim et al. (2011) which showed that high-heeled shoes interfere with the amplitude and the timing characteristics of the EMG activities in SitTS, we hypothesized that a lower loading in sitting position, when compared to standing, would decrease the firing of the muscle afferents from the ankle extensors and thereby reduce the EMG background, allowing for a different TA activation timing between both sequences. Although no statistical significance was found, TA preactivation seems to occur earlier in StandTS than in SitTS. Nevertheless, in order to achieve evident conclusions, further research is required.

Regarding the stroke subjects, we observed in both the IPSI and the CONTRA limbs that SOL activation timing seems to be anticipated, whether it is SitTS or StandTS, which is in line to what was found by Cheng *et al*. (2004). Taking into account that: 1) APAs result from an activation that occurs prior to the movement in order to set an adequate postural control to allow the movement to happen without perturbations, and that (2) the activation time of SOL muscle in the CONTRA and IPSI limb was lower than the -250 ms (APAs activation time defined by Shiratori & Latash (2001), we hypothesis that SOL might contribute to APAs in both limbs of the stroke subjects. It should be noted that no differences were observed in SOL activation timing between the IPSI and the CONTRA limbs. These results reinforce the idea of a dysfunction in both limbs of the stroke subjects, suggesting the existence of lesion or possible dysfunction of the ipsilateral networks involved in APAs generation. The cortico-reticular system, which involves inputs from SMA and PMC, may explain this fact. However, this finding can also be justified based on the asymmetrical posture that is commonly assumed by stroke patients, leading to different patterns of APAs as an anticipatory co-activation of agonist-antagonist muscles to deal of the instability of the task (Aruin, 2006). It was interesting to note that the IPSI and CONTRA seem to present different behavior concerning magnitude and phasic activation (Fig. 1). Consequently, it would be important in future studies to analyze these parameters, to better understand the nature of IPSI behavior. All subjects performed the movement sequences at their self-selected velocity in order to get more homogeneous levels of effort between both groups. However, it would be important in future studies to analyze the effect of speed in APAs during the movement sequences analyzed as speed has been demonstrated to exert influence on APAs generation (Yoshida e tal.2008). But, the absent of significant differences for time execution tasks between healthy and stroke subjects and between

tasks, in addition to the fact that no differences were observed in subjects' height, suggests that the velocity did not upset our results.

In stroke subjects the tendency to have a decreased of excessive activation timing of SOL during StandTS (-152.0 ms), in relation to SitTS (-222.7 ms), can lead some clues about the possibility of having some modulation process also in CONTRA limb despite the higher H-Reflex. Considering this, it is possible to state, as in Aruin et al. (2003), that APAs were redistributed between muscles depending on the availability of the mechanical contact with the environment. In spite of we had not included the role of gravity and of the body alignment in our study, they can be hypothesized as possible contributors to these differences. Despite the inhibition mechanisms were mostly study in relation to magnitude of EMGa, a possible influence of these mechanisms in onset of muscle behavior can be hypothesized as there is some evidence for task dependency of reciprocal inhibition mechanisms (Kido et al., 2004).

Notwithstanding the absence of statistical significance, the TA activation in the CONTRA limb seems to be delayed in both SitTS (-15.3 ms) and StandTS tasks (-79.0 ms). This result is in agreement with the findings in (Chang et al., 2010), which include a delay in the activation timing of the primary postural muscles during stepping in post stroke individuals. In addition, it also seems that the activation timing pattern is inverted in the CONTRA limb, since SOL fires before TA. A previous study by Slijper *et al.* (2002) demonstrated that stroke subjects had asymmetrical APAs between both sides of the body. Moreover, it is important to note that no differences were found in TA and SOL between the CONTRA and the IPSI limbs during StandTS in stroke subjects, and differences were observed in TA during SitTS in the same subjects. This finding suggests that there is a neural connection in standing position, in spite of the higher H-Reflex in CONTRA limb of the stroke group. This interpretation is supported by the evidence demonstrating that sensory information can be used to modify online the feedforward command of the APAs (Ruget et al., 2008)**.** In fact, TA seems to have a better capacity of anticipatory postural behavior in StandTS when more loading is imposed over plantarflexors muscles. Moreover, the results of this study concerning the differences in timing activation response between SitTS and StandTS conditions can be supported by the fact that loading variation would be accompanied by an increased or decreased, in the baseline lower limb muscle activity (Marsden et al., 2003). Also, this

finding suggests that it would be possible to organize APAs response in subjects with higher H-Reflex.

The results obtained in the present study can be important to define better rehabilitation strategies for stroke subjects since the improvement of PC is a critical component to achieve independence in the activities of daily living (Lundy-Ekman 2008). The therapeutic decisions must then consider whether there is a need to modify proprioceptive feedback from the muscles and joints to modulate SOL activity in order to allow a more previous TA activation timing. These issues reinforce the need to discuss the neural and the biomechanical aspects of SOL muscle activation in stroke subjects and the possible dysfunction of proprioceptive acuity. The results of this study support the importance of considering the IPSI limb in rehabilitation and in the biomechanical characterization of this group as this limb presents dysfunctional characteristics that have already been found in other studies (Silva et al., 2012a; Silva et al., 2012b).

## 5. CONCLUSION

In post-stroke subjects, APAs seem to be altered in both limbs, showing an anticipated activation timing of SOL in both IPSI and CONTRA limbs, and a delayed onset of TA in the CONTRA limb.

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**Table 1** – Mean (M) and standard deviation (SD) values of age, height, weight and H-reflex of healthy and stroke groups. Also, values of time evolution and side lesion are presented.

|  | Stroke group | Healthy group | p-value |
|---|---|---|---|
| **Age (years)** | 55.3 (8.3) | 50.4 (10.8) | 0.280 |
| **Height (cm)** | 164.7 (10.1) | 167.8 (9.3) | 0.971 |
| **Weight (Kg)** | 76.5 (8.4) | 67.6 (6.7) | 0.052 |
| **H-reflex** | 82.2 (22.9) | 45.6 (27.6) | 0.007 |
| **Time evolution (months)** | 26.5 (10.2) | --- | --- |
| **Lesion side, number of subjects** | Right, n=3 Left, n=7 | --- | --- |
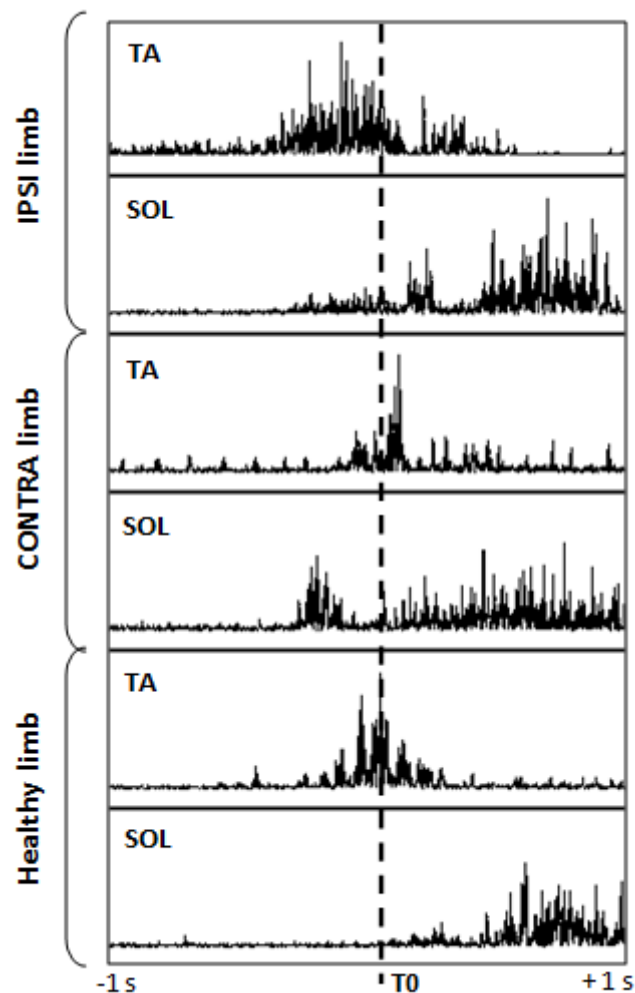


**Fig 1.** Activation timing of TA and SOL muscles in the IPSI, CONTRA in the stroke and the healthy groups. This is representative of the behavior in both sequences.
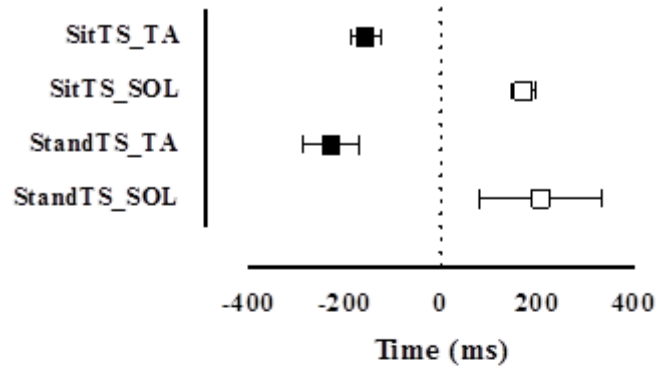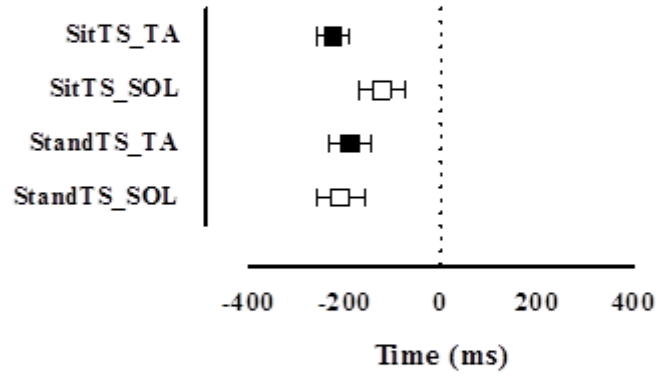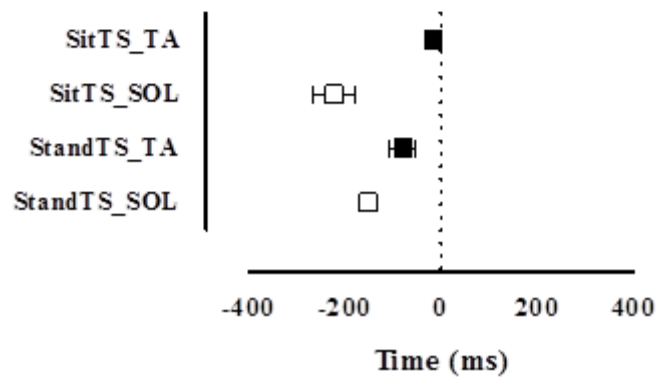
**Fig 2.** Activation timing of TA (black symbol) and SOL (white symbol) during SitTS and StandTS in healthy subjects (A), in the IPSI (B) and in the CONTRA limb (C) of stroke patients. (The data is expressed as mean ± SD.)