Anticipatory Postural Adjustments and kinematic arm features when postural stability is manipulated

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Beyond the classical paradigm that presents the Anticipatory Postural Adjustments (APAs) as a manner to create forces that counteract disturbances arising from the moving segment, during a pointing task, there is a controversial discussion about the role APAs to facilitate the movement and perform a task accurately. In addition, arm kinematics features are classically used to infer the content of motor planning for the execution and the control of arm movements. The present study aimed to disentangle the conflicting role of APAs during an arm-pointing task in which the subjects reach a central diode that suddenly turns on, while their postural stability was manipulated. Three postures were applied: Standing (Up), Sit without feet support (SitUnsup) and Sit with feet support (SitSup). We found that challenging postural stability induced an increase of the reaction time and movement duration (observed for the SitUnsup compared to SitSUp and Up) as well as modified the upper-limb velocity profile. Indeed, a greater max velocity and a shorter deceleration time were observed under the highest stability (SitSup). Thus, these Kinematics features reflect less challenging task and simple motor plan when the body is stabilized. Concerning the APAs, we observed the presence of them independently of the postural stability. Such a result strongly suggests that APAs act to facilitate the limb movement and to counteract perturbation forces. In conclusion, the degree of stability seems particularly tuned to the motor planning of the upper-limb during a pointing task whereas the postural chain (sitting vs. standing) was also determinant for APAs.

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2 **postural stability is manipulated**

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24   **Abstract**

25   Beyond the classical paradigm that presents the Anticipatory Postural Adjustments (APAs)

26   as a manner to create forces that counteract disturbances arising from the moving segment, during

27   a pointing task, there is a controversial discussion about the role APAs to facilitate the movement

28   and perform a task accurately. In addition, arm kinematics features are classically used to infer

29   the content of motor planning for the execution and the control of arm movements.

30   The present study aimed to disentangle the conflicting role of APAs during an arm-pointing task

31   in which the subjects reach a central diode that suddenly turns on, while their postural stability

32   was manipulated. Three postures were applied: Standing (Up), Sit without feet support

33   (SitUnsup) and Sit with feet support (SitSup). We found that challenging postural stability

34   induced an increase of the reaction time and movement duration (observed for the SitUnsup

35   compared to SitSUp and Up) as well as modified the upper-limb velocity profile. Indeed, a

36   greater max velocity and a shorter deceleration time were observed under the highest stability

37   (SitSup). Thus, these Kinematics features reflect less challenging task and simple motor plan

38   when the body is stabilized. Concerning the APAs, we observed the presence of them

39   independently of the postural stability. Such a result strongly suggests that APAs act to facilitate

40   the limb movement and to counteract perturbation forces. In conclusion, the degree of stability

41   seems particularly tuned to the motor planning of the upper-limb during a pointing task whereas

42   the postural chain (sitting vs. standing) was also determinant for APAs.

43 **Introduction**

44   Postural perturbations induced by fast arm movements in a standing condition were

45 widely studied and generally displace the body's center of mass (COM) causing a disruption of

46 posture. Classically, it is accepted that anticipatory postural adjustments (APAs) begin before the

47 limb upward movement taking place to counteract the expected mechanical effects of the focal

48 perturbation in a feedforward way (Moore et al., 1992; Santos, Kanekar & Aruin, 2010). Authors

49 suggest that they are generated at a high level of the central nervous system (CNS) promoting

50 earlier changes in the activity of the postural muscles in order to compensate for a potential shift

51 in the COM (Sijper & Latash, 2000; Yoshida et al., 2008).

52   Beyond this classical paradigm that presents APAs as a manner to create forces that

53 counteract disturbances arising from the moving segment, there is a controversial discussion

54 about the role of present APAs. For instance, Stapley et al (1999) found that, rather than acting to

55 stabilize the COM, APAs created necessary conditions for forward COM displacement within the

56 base of support in the upright position(Stapley et al., 1999). Tijtag et al (2013) investigated APA

57 in one-handed ball catching and proposed that APAs besides a stabilization of some body part are

58 functionally link to the task specificity and ensure an active role in task goal achievement (Tijtgat

59 et al., 2013).

60   Their results challenge the classical role assigned to APAs in the literature. In this paper

61 we propose to contribute to this controversial issue by studying APA in a stable posture, where

62 equilibrium control is minimized and thus the APA may be more related to the task performance.

63   While sitting, the base of support is substantially larger and the center of mass is

64 positioned closer to the base of support than in the standing position. Thus, the task of

65 maintaining the center of mass projection within boundaries of the base of support is less

66 challenging and one may expect different patterns of APAs before arm pointing.

67   The majority of studies on the APAs have been carried out in standing adults performing

68 various types of arm movements (Cholewicki, Polzhofer & Radebold, 2000; Sijper & Latash,

69 2000; Cecchi, Došlă & Marini, 2001; Juras & Słomka, 2013) and the few existing reports while

70 sitting are somewhat incomplete and conflicting(Van Der Fits et al., 1998; Aruin & Shiratori,

71 2003a; van der Heide et al., 2003; Le Bozec & Bouisset, 2004; Cuisinier, Olivier & Nougier,

72 2007). In particular, APAs are sometime absent in individuals performing reaching tasks while

73 sitting (Moore & Brunt, 1991; Van Der Fits et al., 1998), while other studies, where seated

74 subjects exerted maximal force on a bar, showed APAs in trunk and hip muscles (Teyssedre et al.,

75 2000; Le Bozec & Bouisset, 2004). Although these studies have achieved interesting results,
76 some of them did not involve lower limb muscle investigation, which are mainly responsible for
77 ankle joint mobility (i.e., tibialis anterior and soleus). Indeed, a recent review of the literature
78 showed that the effect a manipulated initial position, as the amount of feet and/or back support, or
79 leaning toward a side, for example, was not studied (Chikh et al., 2016).

80   Aruin and Shiratori (2003) found that APAs in sitting with feet support compared to
81 standing were attenuated in the leg muscles (tibialis anterior, soleus, rectus femoris, and biceps
82 femoris) but not in trunk muscles (erector spinae and rectus abdominis)(Aruin & Shiratori,
83 2003a). However, they only compared the amount of muscle activation and not the latency within
84 a temporal window of 100 ms before the movement. Thus, they precluded conclusions on the
85 activation order within the direction specific response. In addition, they did not worry about
86 important aspects of the sitting posture, such as the amount of feet and/or back support. Indeed,
87 the quantity of reaction force exerted by the feet determines the center of pressure position along
88 the antero-posterior axis and the torque for the task.

89   Accordingly, the present study aimed to disentangle the conflicting role of APAs during an
90 upper-limb motion, using different postural stabilities (standing and sitting). For this, we used an
91 arm-pointing task in which the subjects reach a central diode that suddenly turns on, while their
92 postural stability was manipulated. In order to characterize the movement performance, we
93 measured the kinematic parameter and registered the latency of lower limb muscles. We
94 hypothesized that different arm kinematics features reflecting postural stability (i.e. arm shorter
95 reaction time(Papaxanthis, Pozzo & Schieppati, 2003; Berret et al., 2009), arm velocity
96 profile(Stapley, Pozzo & Grishin, 1998; Stapley et al., 1999) will be present during unstable
97 postures, suggesting different motor plans for the execution and the control of arm movements
98 performed in different equilibrium context. We further hypothesized that whether the main
99 concern of APA is the compensation of postural perturbations (i.e., consequences of COM
100 displacement), then the increase of body stability should induce attenuation or a modification of
101 APA patterns. On the other hand, if APA serves the preparation for forthcoming upper limb
102 movement (i.e. in order to accelerate the center of mass) to perform the task accurately, one could
103 expect the presence of similar APAs patterns independently of the equilibrium constraint.

104   **Experimental Procedures**
105 **Subjects**

106   Ten healthy men between the ages of 21 and 28 years (mean height 1.71±0.04 m, weight
107   71.8±6.2 kg), with normal or corrected to normal vision, no known neurological or muscle
108   disorders, took part in the study. All subjects were right-handed. They gave their informed
109   consent. The study was approved by the Federal University of Pará's ethics committee (Ethical
110   Application 46943215.0.0000.0018), before the beginning of the study.

Experimental set up and Protocol

112   Subjects either stood on the floor barefoot (Up) or were seated on the edge of a height-
113   adjustable chair with (Sit Sup) or without feet on a force platform (SitUnsup). In all seated
114   posture we preconized that the surface in contact with the chair was 30% of the thigh length (i.e.,
115   from the head to the femur to the intra-articular line of the knee). To ensure any contact of the
116   feet with the ground we adjusted the height of the chair, in SitUnsup posture. In SitSup posture,
117   we standardized the ground reaction force (Fz) not to exceed 5% of the total Fz during stance
118   (Fig. 1).

119   *Insert Figure 1*

120   Figure1. Experimental pointing task. View of the experimental set-up for the task showing a participant in
121   final posture and the three possible targets. The central diode of the bar between the two laterals was situated exactly
122   in front of the participants' right shoulder. Participants were asked to point their index finger at the central diode
123   which suddenly turned on. Postures: A(Up); B (SiUnsup); C (SitSup)

124   They were required to keep their eyes fixed on a horizontal bar, placed in front of them at
125   2m from the floor and 2.5m from the participants' feet, with a central diode aligned with their
126   right shoulders. Participants were asked to point with their index finger towards the central diode,
127   which was suddenly turned on. Subjects stayed with the left arm down along the body and the
128   right index finger pointing towards the ground, with an angle of between 30° and 35° between the
129   arm and trunk. In all trials, participants were told to raise their arm as fast as possible and to start
130   as quickly as possible after the appearance of the visual stimuli, remaining for a few seconds with
131   their arm in the air, and to move their index finger back towards the initial starting position.
132   Randomized blocks of ten trials in each posture were performed with a 5 minutes' rest between
133   them.

Kinematic and electromyographic recording

135   A three-dimensional motion analysis system (Simi Motion), with two cameras at a

136 sampling frequency of 120 Hz, was used in order to record the participants' movements. The

137 participant had eight infrared reflective markers placed at the main joints of right upper limb (i.e.,

138 index; wrist; elbow and shoulder).

139   Surface electromyographic (EMG) data, from the dominant-side leg and trunk muscles

140 using disposable self-adhesive electrodes (Red Dot, 3 M): tibialis anterior (TA), soleus (SOL),

141 rectus femoris (RF), semitendinosus (ST) and Deltoidis anterior, were recorded using two EMG

142 devices (Emgsys 30306®, EMG System do Brazil, Brazil), with a sampling rate of 2 KHz and a

143 frequency spectrum of 20 to 500 Hz. The EMG signals were amplified (4,000), and digitized with

144 a 16-bit resolution. The participants' skin was prepared for Ag/AgCl electrodes (Medtrace® 200

145 – Kendall, Canada) using Nuprep® (Weaver and Company – Aurora, United States) and alcohol.

146 The active electrodes were placed on the muscles at 20-mm intervals, and the reference electrode

147 was placed on the spinous process of the seventh cervical vertebra based on the orientations

148 proposed by the Surface Electromyography for Non Invasive Assessment of Muscles

149 guidelines(Hermens et al., 2000).

150 **Data analysis parameters and Statistics**

151 **Kinematic data**

152 The kinematic parameters of each marker (trajectory and tangential velocity profile) were

153 analyzed using Matlab. The data on x, y and z axis were filtered with a 10-Hz low-pass, second

154 order Butterworth filter. We defined the total movement duration (MD) as the time interval of the

155 index tangential velocity profile that exceeded five percent of its maximum value. Moreover, we

156 calculated the movement velocity (MV) and the reaction time (RT). Finally, we also examined

157 the differences of index tangential velocity profile in function of participant postures. For this, we

158 calculated the ratio of acceleration time to total movement duration (i.e., time to peak velocity).

159 **EMG data**

160 The data were synchronized and analyzed off-line with MatLab programs. All signals were

161 filtered with a 100-Hz low-pass, second-order Butterworth filter, and EMG signals were rectified.

162 Individual trials were viewed off-line on a monitor screen.

163   After additional visual inspection of the data, Tzero moment, as defined by the marker on

164 the finger, was considered as the instant when the tangential velocity of the marker reached 5% of

165 PV during that particular trial (Bertucco & Cesari, 2010). After alignment, trials within each

166 series were averaged for each subject. To quantify the anticipatory changes in the muscle activity

167 prior to movement, EMG signals were integrated from -150 with respect to Tzero (∫EMG150).

168 This was further corrected for background activity, defined as the integral from -500 to 450 ms

169 with respect to Tzero (∫EMG50) as follows:

170 $$\int EMG = \int EMG\ 150- 3*\int EMG\ 50$$

171 The muscle latency was detected in a time window from -450 ms to +200 ms in relation to

172 Tzero by a combination of computer algorithm and visual inspection of the averaged trials. The

173 latency for a specific muscle was defined as the instant lasting for at least 50 ms when its EMG

174 amplitude was greater (activation) or smaller (deactivation) than the mean of its baseline value,

175 measured from-500 to -450 ms, plus 2 SD (Aruin & Shiratori, 2003b).

176 **Statistics**

177 Statistical procedures were performed in RSudio (R version 3.3.2 and RStudio 1.0.136)

178 and included repeated-measures ANOVA with Body posture (sitting whit support, sitting without

179 support and standing) as factor. Post-hoc analyses were done with Tukey HSD tests when

180 necessary. For all these statistical treatments, the significance level was set at $p < 0.05$.

181 **Results**

182 **Kinematic characteristics**

183 Kinematic' characteristics are summarized in Table 1. Finger displacement showed that a similar

184 trajectory length was performed in the three posture [$F_{(2, 28.9)}$,p= 0.77)]. RT presented a main

185 posture effect between the three postures [$F_{(2, 6.41)}$, p = 0.005]). Post-hoc test revealed that RT

186 was higher in SitUnsup posture compared to standing and Sit Sup posture ($p < 0.001$). MD also

187 showed a main posture effect [$F_{(2, 3.56)} = 0.0042$] and the post-hoc test showed the highest MD

188 in the SitUnsup posture, compared to the others ($p < 0.001$). No statistical differences were

189 observed for MV of the index movement between the three postures [$F_{(2, 2.46)} = 0.104$]). The

190 results also revealed a postural effect onto index tangential velocity profile [$F_{(2, 10.86)} =$

191 0.0003]. In Sitsup posture subjects had higher ratio of acceleration time to total movement

192 duration comparing to Up and SitUnSup postures.

193   This indicates that the temporal parameters of the upper-limb movements were affected by

194   the postural conditions whereas their spatial features remained similar.

195   Table 1. Comparison between Kinematic parameters.

196   Mean values kinematic parameters. Values are given as mean (SD). * p <0.005difference between
197   Sit Unsup and the two other postures. ** p <0.005difference between Sit Sup and the two other
198   postures.

199   Insert Table 1

200   **Muscle Activation Timing between postures**

201   Figure 2 shows the rectified EMG data obtained for one trial for a typical subject

202   comparing the tree postures.

203   *Insert Figure 2*

204   Figure 2:Raw muscle activity of a typical subject recorded during one single trial. Plotted signals were just
205   rectified and normalized with respect to their maximum values recorded over all trials. The vertical dashed
206   line mark finger movement onset (**tzero**). The time interval between 300 ms before movement onset was
207   considered.Up: Upright posture;   SitSup: Sit posture with contact feet support; SitUnsup: Sit unsupported
208   posture; Muscles: DEL: Deltoideous; ST: Semitendinosus; RF: Rectus Femoris; SOLSoleous; TA: Tibialis
209   Anterior.

210   Figure 3 shows the scatter of the overall dataset of the timing of muscle activations (all

211   the trials of all participants in the three protocols).

212   In the Upright posture, muscles participated in the APAs in the following order: the

213   proximal lower limb muscles (ST: 110ms±10 and RF 80ms±20) followed by the distal lower limb

214   muscles (SOL: 80ms±10 and TA: 70ms±30). While seated this order were reverse: TA and SOL

215   had earlier onset [SitSup (TA: 90ms±20 and SOL: 80ms±20) and SitUnsup (TA: 90ms±10 and

216   SOL: 100ms±10], followed by ST and RF [SitSup (ST: 90ms±20   and RF: 80ms±10) and

217   SitUnsup (ST: 90ms±10 and RF: 80ms±10)].

218   Comparing the timing of muscle activation between the postures, the ANOVA showed a

219   main posture effect for TA [$F_{(2, 591)}$ = 18.18, p<0,000001] and ST   [$F_{(2, 591)}$ = 18.18,

220 p<0,000001]. The post-hoc analysis revealed earlier activations of the ST in Upright posture (p <

221 0.001) compared to both seated posture and earlier onset of TA in seated posture (p < 0.001)

222 compared to Up.

223 *Insert Figure 3*

224 Figure 3 : Latency (activation/deactivation before tzero) for lower limb muscles. Up: Upright posture;
225 SitSup: Sit posture with contact feet support; SitUnsup: Sit unsupported posture; Muscles: DEL:
226 Deltoideous; ST: Semitendinosus; RF: Rectus Femoris; SOLSoleous; TA: Tibialis Anterior.*p<0,05 two
227 way anova and post hoc test (differences between SIT SUP x UP and SIT UNSUP x UP)

228 **Muscle Activation Rates and Magnitude between Postures**

229 To demonstrate the consistence of the results, we calculated the activation rate for each

230 muscle in each posture, which corresponded to the percentage of trials showing significant

231 muscle activation (burst). This corresponded to a minimal of 60% of trials with burst.

232 The normalized integrated electromyographic activity (EMGi) are summarized in Table 2.

233 SOL and ST showed a similar behavior and presented a main posture effect between the three

234 postures [F(2, 6.31), p = 0.003]). Post-hoc test revealed that both SOL and ST had higher APA

235 integral in Up posture

236 compared to SitUnsup and SitSup (p < 0.001). RF also showed a main posture effect [F(2, 4.56)

237 = 0.002] and the post-hoc test showed the lowest APA integral in the SitUnsup posture,

238 compared to the others (p < 0.001). The results also revealed a postural effect onto TA APA

239 integral [F(2, 9.84) = 0.0003]. In Sitsup posture subjects had higher values comparing to both Up

240 and SitUnsup postures

241 *Insert Table 2*

242 **Temporal organization of finger and knee displacements**

243 After processing the EMG data and observing the movement execution we decided to

244 repeat the experiment with four additional subjects. Indeed, the visual observation of the pointing

245 task performed with a SitUnsup posture showed a clear posterior displacement of the ankle joint

246 (i.e knee flexion). To quantify such displacement and its relation with the upper-limb motion we

247   recorded the kinematic of three additional markers placed on the right lower limb (i.e.,

248   5[th]metatarsal; ankle; knee and hip).

249   Pointing task movements demonstrated linear displacement of the ankle dependent of the

250   adopted posture. Figure 4 illustrates the forward/backward trajectory this joint related to the

251   upward finger displacement. We observed that while seated without feet support, subjects

252   adopted a synchronous flexion of the knee (i.e. backward displacement of the ankle) with the

253   finger displacement. Indeed, a backward displacement of the ankle began 30 ms ±1.0 before the

254   finger upward displacement. This pattern did not happen in the other two postures and suggests a

255   synergic pattern of lower-upper limbs, accompanying arm movement.

256   *Insert Figure 4*

257   Figure 4: Kinematic synergy a typical subject recorded during one single trial. Plotted signals were
258   normalized with respect to their total movement duration.Up: Upright posture;   SitSup: Sit posture with contact feet
259   support; SitUnsup: Sit unsupported posture. A(Finger Velocity); B (Ankle displacement); C (Finger displacement).

260   **Discussion**

261   The present study aimed to verify whether and how APAs patterns and kinematic features

262   changes while the subject postural stability was manipulated. Indeed, two seated postures (with

263   and without feet support) and a standing posture were adopted while subjects performed an arm

264   pointing task. These different postures permit to modify the degrees of postural stability.

265   Accordingly, three postures were used, from high (i.e., sitting with feet support) to low stability

266   (i.e., standing), as well as an intermediate position with a larger base of support but without feet

267   contact that generated a higher instability than in sitting with support. The main results revealed

268   that kinematic parameters and APAs latencies are dependent of the postural chains/configuration

269   as well as the degree of stability that these last ones promote.

270   *Kinematic features*

271   Different kinematic patterns were expected due to the postural stability manipulation since

272   the base of support was limited to the feet in Up posture and defined by the buttocks in SitUnsup

273   or both buttocks and feet in SitSup posture. As previously predicted, challenging postural stability

274   induced different planning evidenced by an increase of the RT and MD for the seated condition

275   without support compared to seated with support or standing. This suggests that arm motor plan

276 becomes more challenging in the SitUnsup posture as indicated by the greater RT that is
277 classically interpreted as an index of task difficulty (Cuisinier, Olivier & Nougier, 2007). One
278 possibility would be that sitting without support does not give efficient mechanical mean (i.e.
279 buttock) to accurately control posture and movement, thus challenging the motor planning. This
280 is partially verified when considering the arm velocity profile which was significantly affected by
281 postural stability. In agreement with our initial prediction we found greater max velocity and
282 shorter deceleration duration of the arm pointing movement in the most stable position. Indeed,
283 the velocity profile (or ACC/MD ratio) is classically described as reflecting the content of motor
284 planning (Morasso 1982, Papaxanthis et al., 2003b). More specifically, it is known that
285 movements performed in the vertical plane used similar motor planning independently of the
286 effector, and are directly dependent of the mechanical effect of gravity force field that change
287 during upward and downward movement (Papaxanthis, Dubost & Pozzo, 2003). Herein, our
288 result suggests that the equilibrium constraints rather than postural configuration were taken into
289 account to plan an upper arm movement. This confirms the greater difficulty to plan the task (i.e.
290 smaller pic of velocity) when a subtask (equilibrium) is added to the pointing one. Another point
291 is that, although the APA was similar between the two-seated posture (see APA features bellow),
292 the acceleration time and movement duration ratio (ACC/MD) was higher in the Sitsup posture.
293 If the role of APA was only to counteract the perturbation, we would expect to find a different
294 behavior of temporal activation between theses postures. Our results also extent a recent research
295 form Stamenkovic &, Stapley (2016) which demonstrated that the muscle spatial recruitment was
296 in favour of assisting initiation of movement in reaching during stance(Stamenkovic & Stapley,
297 2016).

298   Since subjects were free to modulate the kinematic features of the movement, one could
299 expect that the CNS would only use APA to minimize the perturbing effect of the dynamics of the
300 movement, as described in the classical paradigm. But, we did not observed differences in the
301 velocity of the movement between the positions in opposite of previous papers. This mean that
302 the perturbation was equal, although APA magnitude, as it will be described in the next topic,
303 were different in the upright position, compared to the other two. Previously, it was described that
304 APA magnitude is scaled with movement velocity (Bertucco & Cesari, 2010), which was not the
305 case in our paper. This strongly suggests that APA has an additional contribution than the
306 classical paradigm.

307   *APAs features*

308   Concerning the EMG latencies of the lower limb muscles (ST, RF, SOL and TA), we
309   observed the presence of APAs independently of the posture, confirming our prediction. Stable
310   postures may not require APAs stabilizer, but the presence of APAs regardless the stability
311   suggests an additional role of APA beyond the feedforward control of the other body parts (i.e as
312   accelerators, or to facilitate the pointing movement). Indeed, for all postures, the activity of these
313   muscles anticipated the arm pointing movement replicating the classical deactivation of anterior
314   muscles (RF and TA) and activation of posterior muscles (SOL and ST) (Teyssedre et al., 2000;
315   Chiovetto et al., 2010). By showing the presence of APA whatever the stability condition, our
316   results demonstrated that adults performing arm movements while seated also present direction-
317   specific activity preceding the focal muscle. This supports the idea that APAs may be used either
318   to facilitate the task and/or to control the postural instability by activation of the same trunk
319   muscles in different feedforward patterns (Aruin & Shiratori, 2003a) according to the postural
320   configuration (i.e. sitting vs. standing posture).

321   Another point is that, although the APA was similar between the two seated posture, the
322   acceleration time and movement duration ratio (ACC/MD) was higher in the Sitsup posture,
323   which indicates a greater facility to plan the movement in this situation. If the role of APA was
324   only counteract the perturbation, we would expect to find a different behavior of temporal
325   activation between theses postures.

326   However, even if we observed APAs for all postures, the temporal pattern of these APAs
327   differed and was dependent of the postural chains/configuration. While the thigh muscles (ST
328   and RF) were activated earlier than the lower leg muscles (SOL and TA) in Up posture, the order
329   was inverted when seated (both, with or without support). Therefore, our results demonstrated
330   that sitting posture, regardless the stability, was associated with APAs in a different pattern
331   compared to standing.

332   In standing posture the earlier events are located on the proximal muscle RF and ST while
333   in sitting this is the distal one (TA). Anticipation of ST in the Up posture, appears to be related to
334   its role in the hip extension in order to counteract the forces on the pelvis produced by the
335   reaching task and producing a trunk forward tilting movement (Hodges, Cresswell &
336   Thorstensson, 1999; Pozzo, Ouamer & Gentil, 2001). Indeed, the seated subjects had the pelvis
337   stabilized by the natural postural chain (Forssberg & Hirschfeld, 1994; Van Der Fits et al., 1998;
338   Le Bozec & Bouisset, 2004; Cuisinier, Olivier & Nougier, 2007; Vette et al., 2010) and ST acted
339   as knee flexor instead of hip flexor and also activated after the lower leg muscles. This is

340   supported by our kinematic data about the SitUnsup posture that highlighted a simultaneous
341   upward finger (arm) and backward ankle displacement. We propose that this kinematic profile
342   reflects a strategy dedicated to facilitating the upper-limb movement in this posture. Two
343   assumptions may be related to that. First, the initial muscle tone is different from standing to
344   sitting postures (i.e. different joint positions, muscle length) and thus the following activity of
345   these muscles change with respect to the resting state of the muscles. Second, the upward
346   acceleration of the arm produces a forward trunk tilting that can be counteracted when sitting
347   with support but is more difficult when no support is added on the feet. So, APAs not only serves
348   the whole-body equilibrium to the movement initiation, but are also concerned to provide the
349   correct postural set to obtain the correct movement(Cavallari et al., 2016).

350   The APA magnitude of SOL and ST are in line with the literature that states that more
351   APA is necessary to counterbalance the disturbances under more challenge stability situations.
352   For RF muscle, Sit Unsup posture showed even lower magnitude compared to the other postures,
353   and this may be related to the ankle displacement observed in this position (i.e.activation of the
354   antagonist , ST). Surprisingly, TA did not show this behavior, and had higher magnitude in SitSup
355   position. This refute the reasonable that APA magnitude is strictly related to the mechanical
356   perturbation. Although we did not record the center of pressure (COP) data, maybe this muscle
357   had some participation in COP displacement, accompanying the movement, in forward direction.
358   This may not have happened in Sit Unsup due to kinematic pattern imposed by lack of feet
359   contact and the ankle backward displacement.

360   Contrarily to SitUnsup posture, the SitSup did not present knee displacement due to the
361   constraint of feet contact with the floor. However, the EMG pattern between both sitting posture
362   was the same, since the postural chain was not modified. We also found that the TA activity
363   appeared earlier for the seated postures compared to standing posture, acting as an ankle
364   dorsiflexor(Erim et al., 1996; Aruin & Shiratori, 2003a; van der Heide et al., 2003). This early
365   activity of TA in standing posture did not happen since the mechanical load in this joint is totally
366   different and the body weight is completely loaded over it, delaying its participation. The fact that
367   we observed different APA patterns between the sitting postures and the standing condition and
368   not between the stability levels confirm our predictions (see supplementary table). Thus, our
369   results strongly suggest that APA acts to facilitate the limb movement and to counteract
370   perturbation forces. Kinematics features, on the other hand, seem to reflect less challenging task
371   and simple motor plan when the body is stabilized.

372   More studies in the field are required to add new perspective to the field of rehabilitation,
373   for assessment and treatment.

Conclusion

375   The present study showed that the APAs seem to be related to the stability conditions
376   since we observed differences of EMG features for the two seated postures whereas the
377   equilibrium constraints differed. Conversely, the degree of stability seems particularly involved in
378   the motor planning of the upper-limb during a pointing task whereas the muscle postural chain
379   (sitting vs. standing) was also determinant for APAs.

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Figure 1

Experimental pointing task.

View of the experimental set-up for the task showing a participant in final posture and the three possible targets. The central diode of the bar between the two laterals was situated exactly in front of the participants' right shoulder. Participants were asked to point their index finger at the central diode which suddenly turned on. Postures: A(Up); B (SiUnsup); C (SitSup).

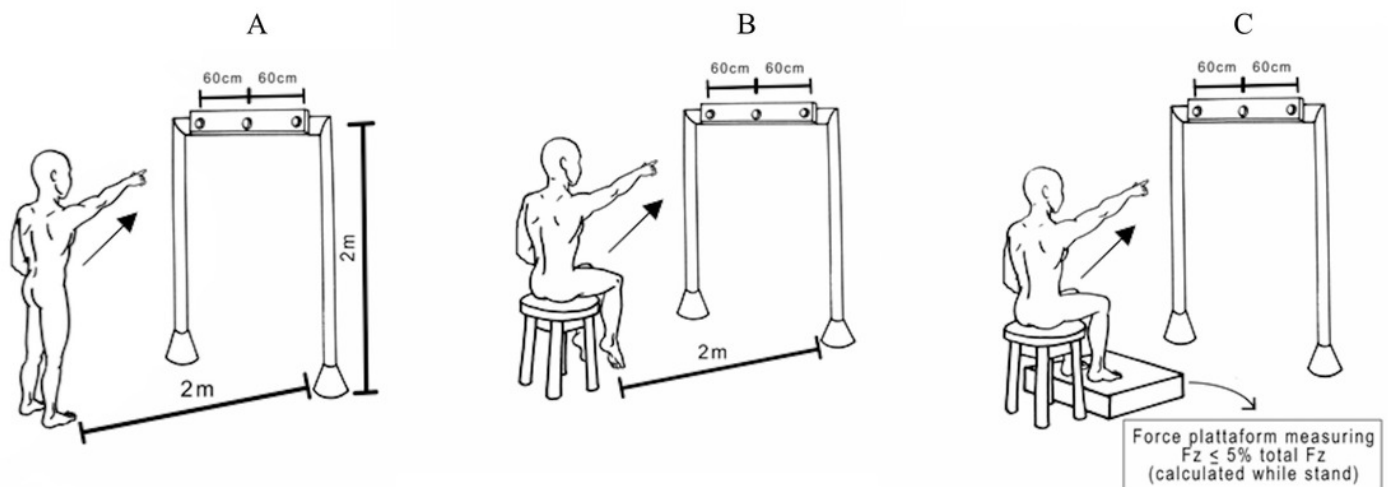



Figure 2

Raw muscle activity of a typical subject recorded during one single trial.

Plotted signals were just rectified and normalized with respect to their maximum values recorded over all trials. The vertical dashed line mark finger movement onset (**tzero**). The time interval between 300 ms before movement onset was considered.Up: Upright posture; SitSup: Sit posture with contact feet support; SitUnsup: Sit unsupported posture; Muscles: DEL: Deltoideous; ST: Semitendinosus; RF: Rectus Femoris; SOLSoleous; TA: Tibialis Anterior.

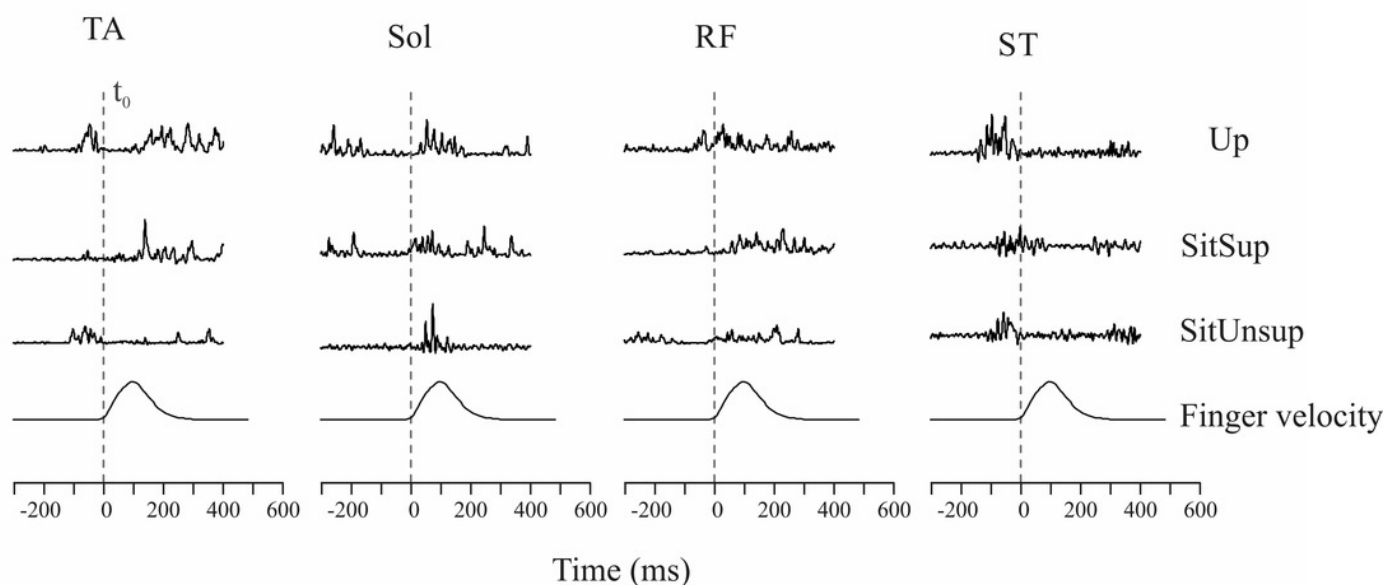



Figure 3

Latency (activation/deactivation before tzero) for lower limb muscles.

Up: Upright posture; SitSup: Sit posture with contact feet support; SitUnsup: Sit unsupported posture; Muscles: DEL: Deltoideous; ST: Semitendinosus; RF: Rectus Femoris; SOLSoleous; TA: Tibialis Anterior.*p<0,05 two way anova and post hoc test (differences between SIT SUP x UP and SIT UNSUP x UP).

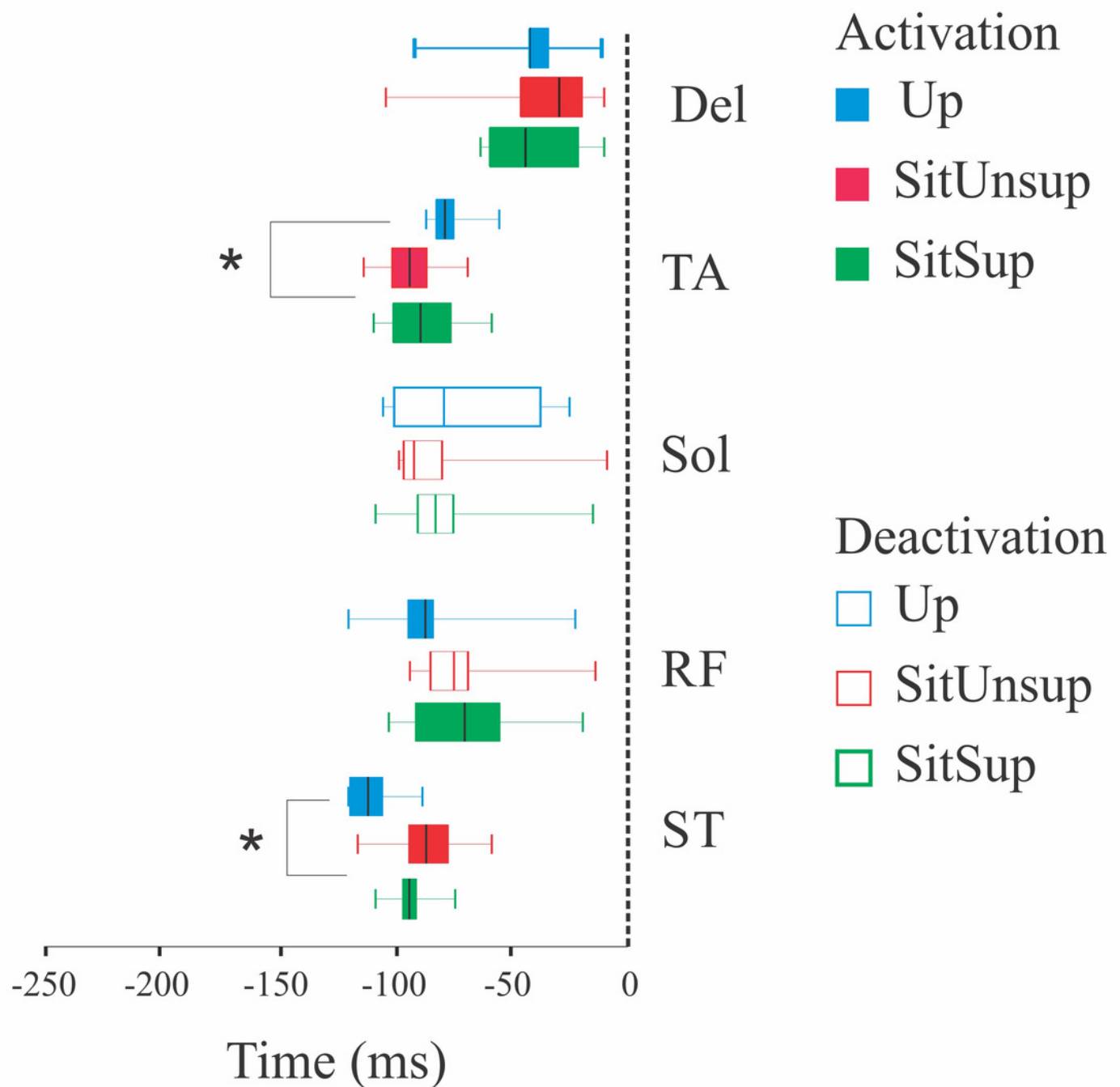
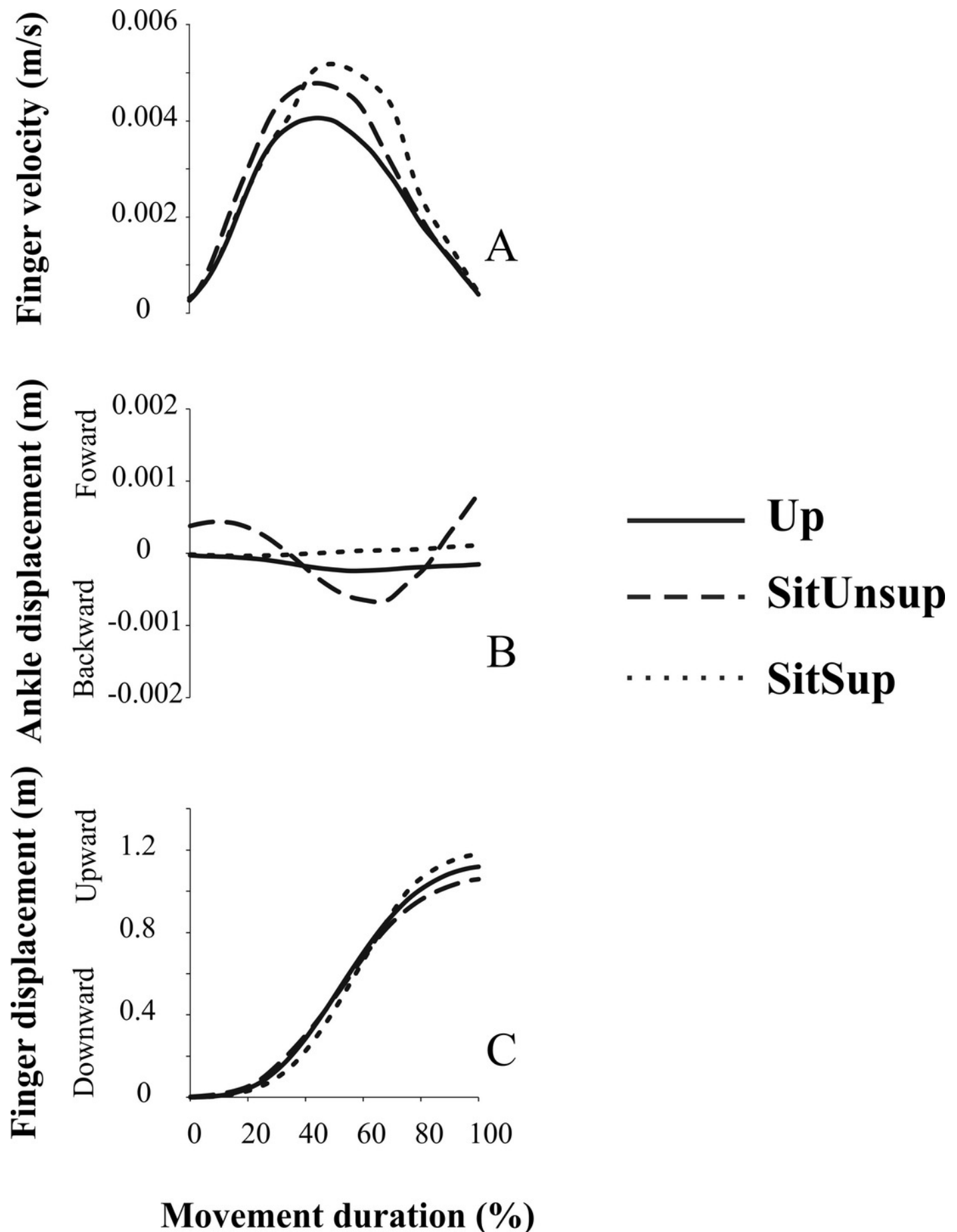



Figure 4

Kinematic synergy a typical subject recorded during one single trial.

Plotted signals were normalized with respect to their total movement duration. Up: Upright posture; SitSup: Sit posture with contact feet support; SitUnsup: Sit unsupported posture. A(Finger Velocity); B (Ankle displacement); C (Finger displacement).

Movement duration (%)

Comparison between kinematic parameters.

Mean values kinematic parameters. Values are given as mean (SD). * p <0.005difference between Sit Unsup and the two other postures. ** p <0.005difference between Sit Sup and the two other postures.

Table 1. Comparison between Kinematic parameters.

	Finger displacement (cm)	Reaction Time (ms)	Movement duration (ms)	Velocity (m/s)	Acceleration time/ Movement duration
Sit Sup	118.74(6.13)	407.31(21.03)	408.12(68.72)	0.48 (0.03)	0.46(0.06) **
Sit Unsup	116.90(8.22)	433.71(13.07)*	529.06(127.71)*	0.46 (0.03)	0.38(0.04)
Up	116.48(7.83)	411.01(18.50)	444.56(106.64)	0.45 (0.02)	0.37(0.03)

Mean values kinematic parameters. Values are given as mean (SD). * p <0.005 difference between Sit Unsup and the two other postures. ** p <0.005 difference between Sit Sup and the two other postures.

Comparison between normalized integrated electromyographic activity (EMGi).

Normalized integrated electromyographic activity (EMGi) of muscles Mean values integral parameters (%). Values are given as mean (SD). * p <0.005 difference between Up and the two other postures; ** p <0.005difference between Sit Sup and the two other postures; # p <0.005 difference between Sit Unsup and the two other postures.

Table 2. Comparison between normalized integrated electromyographic activity (EMGi).

	TA(%)	SOL(%)	RF(%)	ST(%)
Sit Sup	67.39(27.30) **	52.11(28.12)	45.07(20.85)	40.08(28.21)
Sit Unsup	45.37(35.02)	50.87(30.63)	24.40(20.20)#	40.43(28.63)
Up	49.52(32.04)	75.59(15.26) *	57.27(27.73)	55.84(23.92) *

Normalized integrated electromyographic activity (EMGi) of muscles Mean values integral parameters (%). Values are given as mean (SD). * $p < 0.005$ difference between Up and the two other postures; ** $p < 0.005$ difference between Sit Sup and the two other postures; # $p < 0.005$ difference between Sit Unsup and the two other postures.