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Dependence of anticipatory postural adjustments for step initiation on task movement features: a study based on dynamometric and accelerometric data

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Abstract — **The present study investigates the dependence of anticipatory postural adjustments (APA) for step initiation on velocity and length of the first step, by means of both dynamometric data, acquired by a force platform, and accelerometric data, achieved by means of sensor nodes positioned on the lower legs and on the trunk. Results focus on antero-posterior center of pressure (CoP) displacement and antero-posterior accelerations. Peak of backward CoP excursion during APA, considered as magnitude of APA, was found to depend mostly on step velocity, and, in less amount, to step length. Accelerometers detected a reliable accelerometric pattern during APA, and stance leg backward acceleration before stepping presents a peak with a behavior very similar to peak of CoP in terms of dependence on velocity and step. The results allow deduction on the role of APA to control step initiation, and suggest possible promising applications of portable and low-cost accelerometric sensors, to monitor motor performance in several fields as rehabilitation, clinics and closed loop applications.**

I. Introduction

Voluntary movements are associated with postural phenomena that precede the onset of the movements and that are referred to as anticipatory postural adjustments (APA). Such postural preparations occur in the opposite direction of the task voluntary movement, usually following a diagonal pattern [1;2]. APA have been largely considered on the basis of global biomechanics variables, such as resultant forces, centre of mass (CoM) kinematics, centre of pressure displacement [3-5], or considering muscle activations with surface EMG [6], and, in less amount, considering single segments involvement in the APA [2].

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The present study focuses on APA for step initiation. Such preparatory phase implies the center of pressure (CoP, i.e. the application point of the resultant ground-reaction force) to move backward and laterally toward the swing limb to move the body CoM forward and over the stance limb, in preparation for single-limb support [1;4;7]. The movement phase begins when the swing limb start to move, i.e. at heel-off of the stepping foot [5].

Postural preparations change according to the characteristics of the corresponding task movement. For example, APA prior to step initiation were found to be sensitive to a reduction of postural basis or to constraint imposed to CoM displacement. Previous studies suggested that APA duration might be related to forward displacement of the CoM, or to CoM velocity at the end of the first step for gait initiation [3;8].

However which is the primary role of APA in function of characteristic of the task movement has not been widely exploited. In particular, it is not well known which kinematic variable APA control mostly, in terms of velocity or length of the step. This information may be relevant in rehabilitation programs, in clinics to monitor possible step and gait impairments because of a specific disease (such as Parkinson's disease) or because of chronic deterioration of the movement system as in the elderly [4;9].

Since APA were found to be impaired in several disease and to need to be appropriately scaled in function of both the task movement and the initial support conditions [3;10;11], they result as key variables that might be monitored to evaluate ability of movement preparation in different diseases or after rehabilitative or pharmacological therapies. The recent advances in miniaturized sensors, such as accelerometers, allowed the use of such sensors for a variety of biomedical applications, as human movement analysis, because of their characteristic of low-cost, portability and the useful kinematic information they provide [12]. In addition, accelerometers allow measurements that are not directly attainable by classical movement analysis systems, as dynamometric platform and optical movement analysis systems for kinematic acquisition, since they can directly provide acceleration of a single body segment.

In the present study we investigated the possible detection of APA by accelerometric sensors, the dependence of APA, measured by CoP displacement (global biomechanics), on step features, and the possible relation between APA accelerometric variables and APA CoP variables in terms of dependence on step features.

II. METHODS

A. *Participants and Protocol*

Five male volunteers (age 25±2.8 years, height 1.72±0.07 m) participated in the study. All subjects were right-handed and did not report any history of neuromuscular or central nervous system disorders. At the beginning of each experimental trial, subjects stood barefoot and motionless on a dynamometric platform, with arms at their side. Heels location was fixed on the platform, to ensure accurate execution of the entire experiment. The subjects were asked to voluntarily take two steps starting with the right foot. Length of the first step was imposed in each trial by a target line on the ground, which subjects had to hit with the heel. Three different step lengths were considered (Figure 1): 1) Short step (SS), defined by a 35 cm heel-heel distance; 2) Normal step (NS), defined by a 65 cm heel-heel distance 3) Long step (LS), defined by a 95 cm heel-heel distance. Subjects performed 3 trials for each step length at their natural velocity, without receiving any specific instruction, and 3 trials for each step length at their maximal velocity.

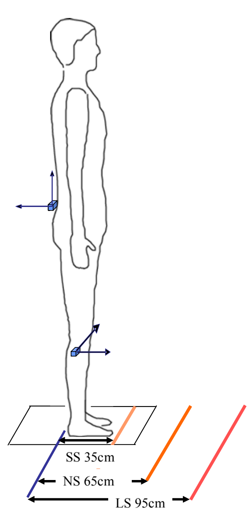

Fig. 1 Experimental set up: target step length and accelerometers positioning (leg accelerometers were positioned symmetrically)

B. *Data acquisition*

The ground reaction forces and CoP displacement were obtained by a BERTEC 4060-08 dynamometric platform.

Accelerometric data were obtained by means of 3 sensor nodes, each of them based on a dual-axes accelerometer (ADXL202, sensitivity 312 mV/g). The sensor nodes were mounted on the subjects, by means of Velcro belts, as follows (Figure 1): - one node on the posterior trunk, about at the level of the total body CoM with the sensing axes oriented approximately along the body antero-posterior and vertical directions; - two nodes on the lower limbs, laterally just below the knee of the right and left leg respectively, with the sensing axes oriented approximately along the body antero-posterior and medio-lateral directions.

The experimental set-up also included kinematic data that were acquired by means of a 6-infrared cameras motion analysis system (BTS SMART), and 18 reflective markers placed on anatomical landmarks [13]. However, in the present study, only the kinematic of the stepping foot was considered, to identify the initiation of the stepping phase, by means of the markers placed on the malleolus and metatarsus.

All signals were acquired at 60 Hz.

C. *Anticipatory postural adjustments variables*

The onset of the anticipatory phase for stepping was identified by the first measurable change on CoP excursion, toward the backward direction and, laterally, toward the swing limb [4]. The end of the APA was identified by the time of heel-off, detected by the reflective marker on the malleolus of the stepping foot.

The APA magnitude was measured by the peak of antero-posterior CoP (CoP-AP) excursion in the backward direction during APA. The antero-posterior accelerations measured by the sensor nodes were primarily considered in the present study, to investigate the presence of a reliable acceleration pattern during APA. In Figure 2 timing and excursion of principal acquired signals are shown, for a representative subject during a natural velocity SS. Antero-posterior acceleration of the stance leg (Acc-AP) was then mainly considered for analysis and results.

Dependence of APA measures on velocity and length of the step was evaluated by means of a 2 factors repeated measures ANOVA, followed by Tukey-Kramer multi-comparison tests [14].

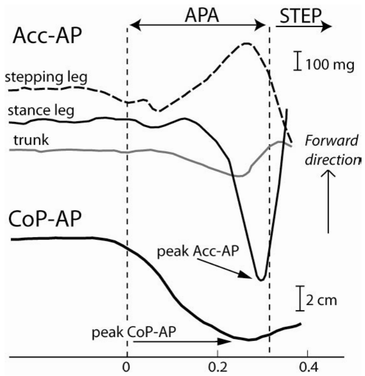

Fig. 2 Accelerometric and CoP signals during APA for a representative trial

III. Results

A. Accelerometric data

Figure 2 already suggested the presence of a consistent pattern in accelerometric data during APA, that was particularly reliable for stance leg Acc-AP. Such pattern was characterized by a backward acceleration peak that followed peak of CoP-AP and preceded heel-off. In each trial, the postural preparation was associated with a peak of backward acceleration of the stance leg and such measure was then considered as the index of APA performance as detected by accelerometric data.

As represented in Figure 2, antero-posterior acceleration of the stepping leg was generally in phase with that of the stance leg, for the first phase of APA, and in opposition of phase during the second phase. This behaviour was present for the majority of cases, but with several exceptions mainly concentrated on one of the subjects.

The trunk accelerometer, that approximated CoM acceleration, detected a backward, followed by a forward acceleration pattern during APA. Similarly to stepping leg acceleration signals, such pattern, even if present in the majority of cases, was not largely consistent for the entire population and experimental conditions.

B. Dependence of APA on step features

Magnitude of APA as measured by peak of CoP-AP was found to be sensitive both to step length ($p<0.05$) and to step velocity ($p<0.01$). No factors (velocity and length) interaction was detected. In particular (multi-comparison tests), at natural velocity, APA magnitude for SS was significantly smaller than for LS. On the contrary, at maximal velocity, there were no APA magnitude differences due to length of the task step. Strong dependence of peak CoP-AP on velocity was present for each step length, where APA magnitude for maximal velocity steps was significantly larger than for natural velocity steps. Mean values and SD of peak of CoP-AP for each experimental condition are represented in Figure 3A.

Interestingly, a very similar behaviour was present in peak of Acc-AP of the stance leg. Such variables was also sensitive to step length ($p<0.05$) and velocity ($p<0.01$). Multi-comparison tests on Acc-AP did not detect any differences for step length pairwises, mostly because of variability higher for accelerometric than CoP data. However differences between peak of Acc-AP were always significant when comparing natural and maximal velocity, with peak Acc-AP higher at maximal than natural velocity for each step length condition. Mean values and SD of peak of stance leg Acc-AP are represented in Figure 3B.

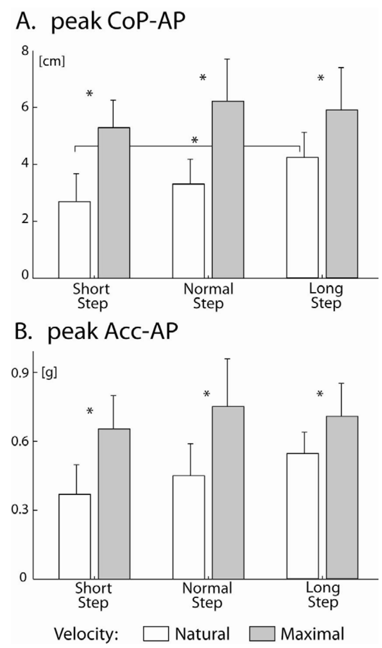

Fig. 3 Mean values and SD of peak during APA in the 3 step length and 2 step velocity conditions. A. peak of CoP-AP; B. peak of Acc-AP

We did not find any differences due to length or velocity of the step in the APA timing, both in terms of APA duration, peak of CoP-AP or peak of Acc-AP timings.

IV. Discussion

In the present study we primarily considered signals in the antero-posterior direction since characteristics of the step were in this direction. Indeed such variables resulted the most significant and sensitive to step velocity and length.

Results, even if preliminary, suggest that antero-posterior magnitude of APA is functional to step velocity more than to step length, even if, at natural velocity, magnitude of APA is sensitive to step length, in particular to differences between short and long step.

Accelerometric signal detects reliably characteristics of APA for step initiation, in particular the backward peak of Acc-AP may be considered as an index of APA functions, since it occurs at the end of APA, and it has the same behaviour of peak of CoP-AP as regard dependence on velocity and step length. Peak of backward Acc-AP just prior step initiation might be due to an action necessary to balance the following propulsive push of the stepping foot, or, on the contrary it might be necessary to cause the following propulsive motion of the stepping foot. Supplementary developments of the study will be necessary to further exploit the topic, considering also body segments kinematics during APA. The reliable pattern of peak of Acc-AP suggests possible promising applications. In fact, peak of Acc-AP is a sort of trigger of movement execution and a signal very easy to be acquired, hence it might be used to monitor step onset, appropriateness of APA, with relevance in rehabilitation programs, clinics and research on motor control, for example programming exercises or experiments to perturb the step just before it happens, or in designing closed loop applications for step and gait initiation.

Further investigations will be also necessary to evaluate inter-correlation of accelerometric pattern of the single segments under investigation. In addition, to complete the use of inertial sensors in monitoring step and gait, it will be interesting to study the accelerometric segmental patterns during gait and to identify optimal signal processing to separate dynamic from static accelerations and provide information about position and movement accelerations.

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