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Validation of an integrated experimental setup for kinetic and kinematics 3D analyses in a training environment.

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Abstract

Biomechanical analyse using incorporated and synchronised tools (EMG, motion capture, force sensors, force platform, and digital camera) are classically performed in a laboratory environment which may influence the performance. We present a system for studying the running sprint start that synchronizes motion capture, EMG, and ground reaction force data. To maximise motion capture (Vicon 612 with 6 cameras), a special dim environment was created in the stadium.

"Classical" tools were combined with "design" tools intended to analyse the different aspects of movement. For example, a synchronisation system was built to create a common base time for all data recordings and an EMG portable system was synchronised by a cable which was disconnected by the athlete's movement. This

disconnection represented an independent event recorded by different tools. A "gap" was measured for some sprint start events between kinetics and motion capture data. Calibration results, measurements of time "gap", and duration of the independent event are used to validate the accuracy of motion capture and the synchronisation. The results validate the entire experimental setup and suggest adjustment values for motion capture data. This environment can be used to study other movements and can easily be applied to several sports.

Key Word: Running, motion capture, synchronisation, starting-blocks, sensors, integrated setup.

Introduction

Classically, biomechanical studies propose substitution equipment, such as treadmills and ergocycles, to collect kinematics and kinetic data for human movement analyses (Schache et al., 2001a). However, Schache et al. (2001b) noted that ground reaction forces could not be measured for the treadmill running trials, which meant that the required inverse dynamics could not be performed to calculate relevant kinetic data. In addition, the authors demonstrated significant differences between overground and treadmill running for all the time-distance parameters (e.g. stride rate and length, duration of stance and swing phases). These results also confirm previous studies which show that movement performance may be modified by an experimental setup (Wank et al., 1998). This suggests that sporting performances must be studied in natural training conditions. The key difficulty when completing biomechanical studies is to obtain the same common base time in order to analyse each parameters. The synchronisation of tools creates this common base time for recording the different events of movement data (Rome, 1995).

The aim of this technical note is to propose the development and validation of a system of synchronized motion capture, EMG and ground reaction force data collection useful for studying sport movements in an indoor realistic environment. In addition to standard force platform recordings, we also recorded and synchronized the horizontal forces applied to the starting blocks and the instant when the hands are of lifting from the starting position. More specifically, we arranged "classical" tools (optoelectronic system, force platform, and EMG system) alongside "design" tools (starting-blocks, chronometer, and hand sensors) (Nouillot and Natta, 2004 ; Natta and Brénière, 1997).

Method

Subjects

A sample of 5 male high level sprinters was studied (age: 21.5 years (SD 1.0), height: 181.0 cm (SD 7.6) and body mass 75.25 kg (SD 3.8)). Twenty-seven skin-markers were located on the athlete's body, corresponding to anatomical landmarks (fig. 1).

Experimental protocol

Each trial consisted of a 20 m sprint (time of all the trials: 3.348 s, SD 0.097) and the sprinter performed four trials with complete recovery between each running sequence. The distance covered by the athletes was around 50 m to a completed deceleration without risk of injury. Data were collected between the start signal and the end of the first step.

"Classical" tools.

Optoelectronic motion capture system. A Vicon system 612 consisting of six Vcam cameras was used (200 Hz, 300,000 pixels). In our experimental conditions, the accuracy of the calibration test was 2.872 mm (SD 0.529).

EMG portable system. Pre-amplified surface electrodes (gain: 1000) recorded the activity of seven muscles (*trapezius, right pectoralis superior, left pectoralis*

superior, erector spinae, gluteus maximus, rectus femoris and gastrocnemius). Electrodes were placed on the muscles bellies. The EMG of the *trapezius, erector spinae* and leg muscles was recorded from the side of the body corresponding to the leg that the sprinter preferred to place in the rear starting block. The leg EMG data of *gluteus maximus* and *gastrocnemius* served as an indicator of the muscular synergies during the extension and a comparator point with the literature (Mero and Komi 1990, Guissard and Duchateau, 1990). The EMG portable system (Datalog, Biometrics, France) was fixed on the waist of the athletes. It provides eight analogue channels and one numerical channel. For the study, seven analogue channels served for the muscle recording, the other one for the reference placed on the wrist. The numerical channel served for the EMG synchronisation cable (ESC). Data were collected with a frequency of 1 KHz on a SD card (128 Mb).

Force platform. An AMTI force platform (121.92 cm x 60.96 cm) was embedded in the track and covered with the same synthetic flooring as the track. Ground reaction force (GRF) components were studied at the first step of the sprint start (sampling rate: 1 KHz).

"Design" tools

Starting blocks (SBs). Commercial SBs based were equipped with horizontal force sensors on each block (rear and front) and prolonged by a metallic plate which ensures that the athlete did not put any part of their feet on the track. Thus, sensors captured the whole horizontal forces produced by the athlete during the sprint start. Sensors were connected to an amplifier (gain: 500).

Hand contactors (HCs). The HCs were constructed with a deformed aluminium circle plate. Each HC produced an electric signal when the hand was no longer in contact with the ground. Thus, it was possible to record separately and precisely the moment when each hand (right and left) was raised. HCs were connected to the same amplifier as the SBs.

Chronometer. The digital chronometer (1/1000 s) was started by an electric impulse and was stopped by the breaking of a light beam emitted by a flashlight and captured by a photocell.

Experimental set-up

Analogue Data: Two amplifiers were connected to SBs, HCs and force platform. A box of analogue channels (BAC) was constructed to supply the 6 channels from the force platform, the 4 channels from the SB and HC and the synchronisation channel via the amplifiers. All channels were transferred to the workstation through the "Vicon's patch panel" (fig. 2).

Synchronisation system (SS). With the SS, the start signal (5 volt square wave pulse) was activated when the experimenter depressed a foot pedal switch and was simultaneously distributed to five components: chronometer, LED Box, loudspeakers, EMG system and BAC. A light signal emitted by the LED Box was recorded by a digital video camera to control the scene. The electric impulse also triggered the chronometer as well as the loudspeakers emitting the start signal to the

athlete. The 5V square wave was sent from the SS to the BAC and EMG system (fig. 2). Thus, the EMG portable system was linked with the SS by the EMG synchronisation cable (ESC). The ESC was disconnected when it was tightened with the forward movement of the athlete during the start. This allowed us to avoid background noise often present in radio transmission data acquisition.

Capture environment. The dimensions of the capture environment were 6 m x 1.5 m x 2 m. The capture environment was equipped with curtains and panels to shield against daylight. This ensured optimal light exposure for the kinematic data acquisition (fig. 3). The extreme conditions of capture require a larger diameter of skin markers (25 mm).

Data processing

Changes in muscles activities of *gluteus maximus* and *gastrocnemius* was analysed from the start signal to the end of the first step. This analyse was realise to compare data with kinetics and literature.

The accuracy of the measurement could be estimate by calculated value of the centre of masse (CoM). With this end, a comparison between the horizontal velocity variation of the CoM, on the first step, by the integration of the acceleration calculated from the force platform signals and the derivation of the CoM displacement from the movement modelling was realised in the antero-posterior axe. The modelling of the CoM was obtained by the application of the Zatsorsky's model (1990) on the skin markers coordinates (fig. 1).

In order to verify the accuracy of acquisitions, we analysed the following variables:

1) the time interval between the synchronisation signal and the disconnection of the

ESC (an independent event of sprint parameters); 2) the stride length from the take-off on the rear block to the first foot contact; 3) the four time-events, in chronological order, which were namely the end of the push-off on the rear block (t_{RBE}), the end of the push-off on the front block (t_{FBE}), the first step landing (t_{L1}) and the toe-off (t_{T1}) and 4) a "gap". This "gap" represented a time interval between measurements of the same events collected by the different tools (Vicon, SB and force platform). For example, the beginning of a step was located on a force platform by a rise of the force curve and was located on the Vicon system by the lower point of the fifth metatarsal marker. Yet, this marker was not necessarily the first point which entered in contact with the ground. This induced a gap. A paired *t*-test was performed to compare duration and time-events.

Results

In the start (push-off duration in blocks), times of the horizontal force production on the rear block were 139 ms (SD 37) for the beginning and 316 ms (SD 34) for the end (t_{br}). The EMG earlier activity (before the force production) was measured in the *gluteus maximus* muscle (99 ms (SD 28)). For the *gastrocnemius* the activity began with the force production in the rear block (138 ms (SD 23)). For both muscles, the end of the activity was measured before the end of the force production in the rear block (227 ms (SD 34) for the *gluteus maximus* and 274 ms (SD 30) for the *gastrocnemius*). The force platform data show a first step which began at 545 ms (SD 48) and finished at 744 ms (SD 39). The second EMG activities were measured for the *gluteus maximus* at 434 ms (SD) and for the *gastrocnemius* at 500 ms (SD 66). The end of these activities was 647 ms (SD 72) for the *gluteus maximus* and 720 ms (SD 61) for the *gastrocnemius* (fig. 4).

On the first step, the mean horizontal velocity variation was $1.178 \text{ m}\cdot\text{s}^{-1}$ (SD 0.105) with the force platform data and $1.238 \text{ m}\cdot\text{s}^{-1}$ (SD 0.160) with the Vicon system data and after modelling. The statistic analysis (paired t -test) for the kinematics of the CoM did not present any significant difference between the two methodologies ($t=0.590$, $p=0.558$). During the first sprint step, the mean of the velocity variation of the CoM in the antero-posterior axe presented similar values.

Disconnection of the ESC produced by the forward movement of the athlete after the start signal generated a negative square wave pulse in the EMG and analogue data (force platform, SB, HC, Vicon system) (fig. 2). The time interval between signal synchronisation and this negative square wave pulse provided an indicator for controlling the accuracy of the synchronisation on all the tools. The time interval obtained from several trials revealed a significant linear relationship between analogue and EMG data ($y=1.005 x + 0.003$, $R^2=0.9986$). Moreover, the mean difference of this time interval was 0.002 s and a paired t -test demonstrated that the differences were not significant ($t=1.84$, $p=0.072$).

In order to evaluate whether the optoelectronic data was accurate enough, taking into consideration the scale measurements for the sprint, we calculated the stride length from the take-off on the rear block to the foot contact (1.33 m, SD 0.12). As the results, measurement error was estimated at 0.2%.

To check the accuracy of time variables, we measured the "gap" between data collected on systems (force platform, SB and Vicon). With kinetics systems (force platform and SB), the mean values of the four specific time-events of the sprint start were presented in table 1. Results show that the four time-events of both systems (kinetics and kinematics) were significantly correlated ($p<0.05$). The Pearson coefficients of correlation were $r=0.968$ for t_{RBE} , $r=0.967$ for t_{FBE} , $r=0.998$ for t_{L1} and

$r=0.994$ for t_{T1} . However, the paired t -test showed a significant difference. Thus, a "gap" existed in measurements supplied by the two methods when reporting identical events. This "gap" should be born in mind during experiments using only one method. The mean values of this "gap" were presented in table 1.

Lastly, the mean standard deviation of the mean "gap" (13 ms, SD 9) was of the same order of magnitude as the measurement error (2 ms) between signal synchronisation (start signal) and the negative square wave pulse (disconnected ESC).

Discussion and implications

In this study, the timing of the leg muscles (fig. 4) corresponded with the literature (Mero and Komi, 1990; Guissard and Duchateau, 1990). These results showed the accuracy of the synchronisation signal between EMG and kinetics data. The kinematics data of the CoM also provide statistical identical results and show the measure precision. These both elements allowed us to validate the use of your experimental setup. The synchronisation of further tools on a cyclic movement allowed to measured the "gap" between two different indicators which related the same event. Results could be used to further specify the datation of the same event during the following cycle when other tools could not be used. For example, the measure of the beginning of the first step was more accurate with the force platform than with the movement of the fifth metatarsal marker. Nevertheless, few coaches could have at their disposal embedded force platform and even less a succession of force platform. In return, optoelectronic system could transportable and could cover a higher shield of measures. Results validated the whole experimental setup and could

be used to study motor behavior. This approach could be applied in a lot of different sport activities and could be combined with other tools.

Because of the cables which constrained the movement or of the background noise with telemetric system, the use of EMG systems is often difficult to measure large displacement on training stadium. The system validated in this study makes up for both inconveniences: it allowed to carry an acquisition box which could receive an external signal before the beginning of the movement without restraining the displacement of the athlete. Many sports activities begin by an initial position before movement and could therefore find this system useful. All results could be integrated by coaches and athletes as feedback. At last, the whole information gathered could have a direct impact on training and performance.

Conclusions

When analysing a complex movement, it is often necessary to combine different types of data. Thus, it is essential to synchronise all the systems used for the experimental device. This flexible setup should be developed according to the objectives of the study. Such an environment is particularly suitable for studying indoor sports. Finally, the interest generated by results obtained in real training conditions points to the need for a permanent experimental setup.

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Fig. 1

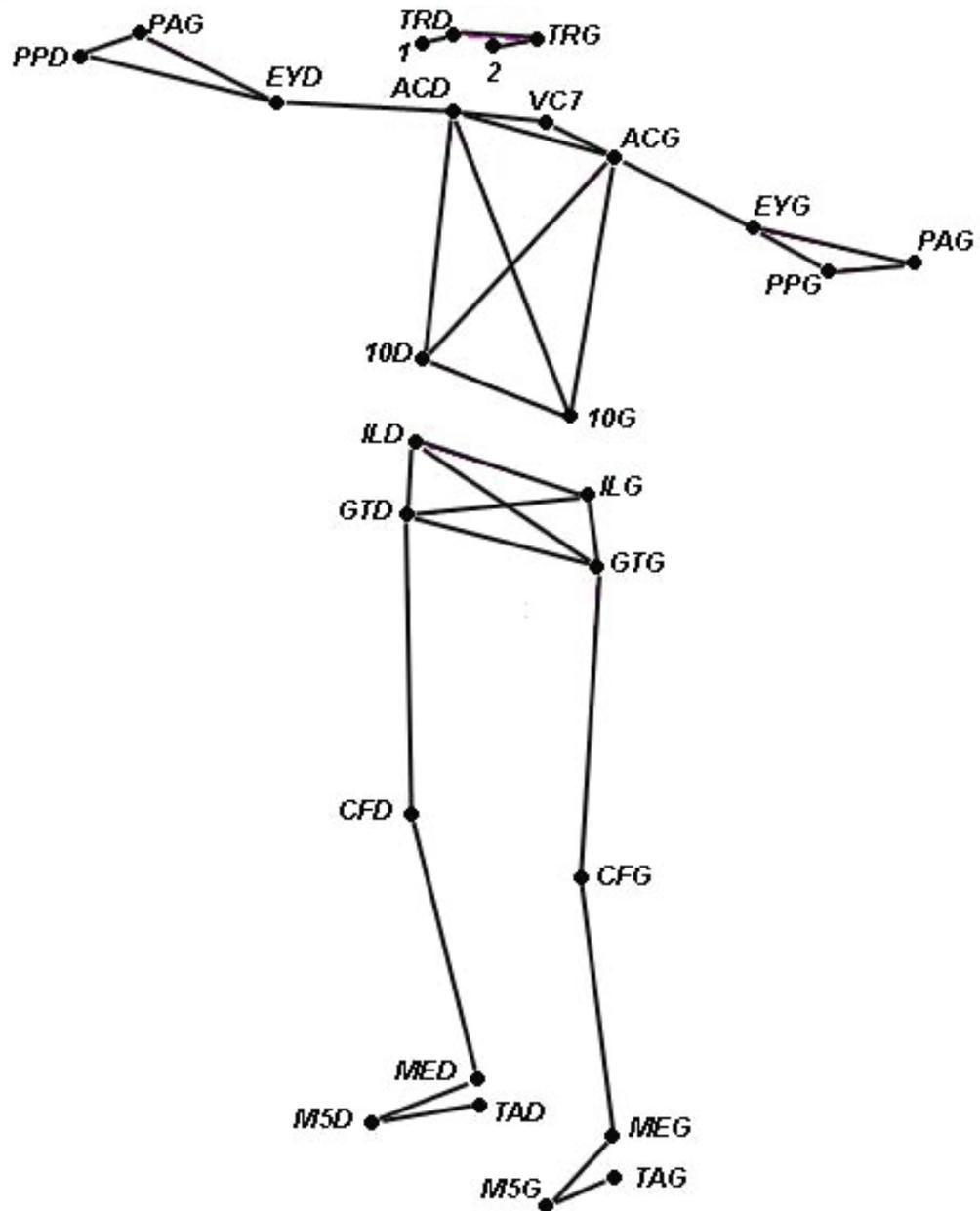


Figure 1: body marker placement

M5G and M5D (fifth metatarsophalangeal joints), TAG and TAD (heels), MEG and MED (lateral malleolus), CFG and CFD (femoral condyles), GTG and GTD (greater trochanters), ILG and ILD (anteroposterior iliac), 10G and 10D (tenth lateral ribs), ACG and ACD ("acromion"-collarbones), VC7 (seventh cerebral vertebra), EYG and EYD (femoral epicondyls), PPG,PAG, PPD and PAD (wrists), TRG and TRD (ears), 1 and 2 (eyes).

Fig. 2

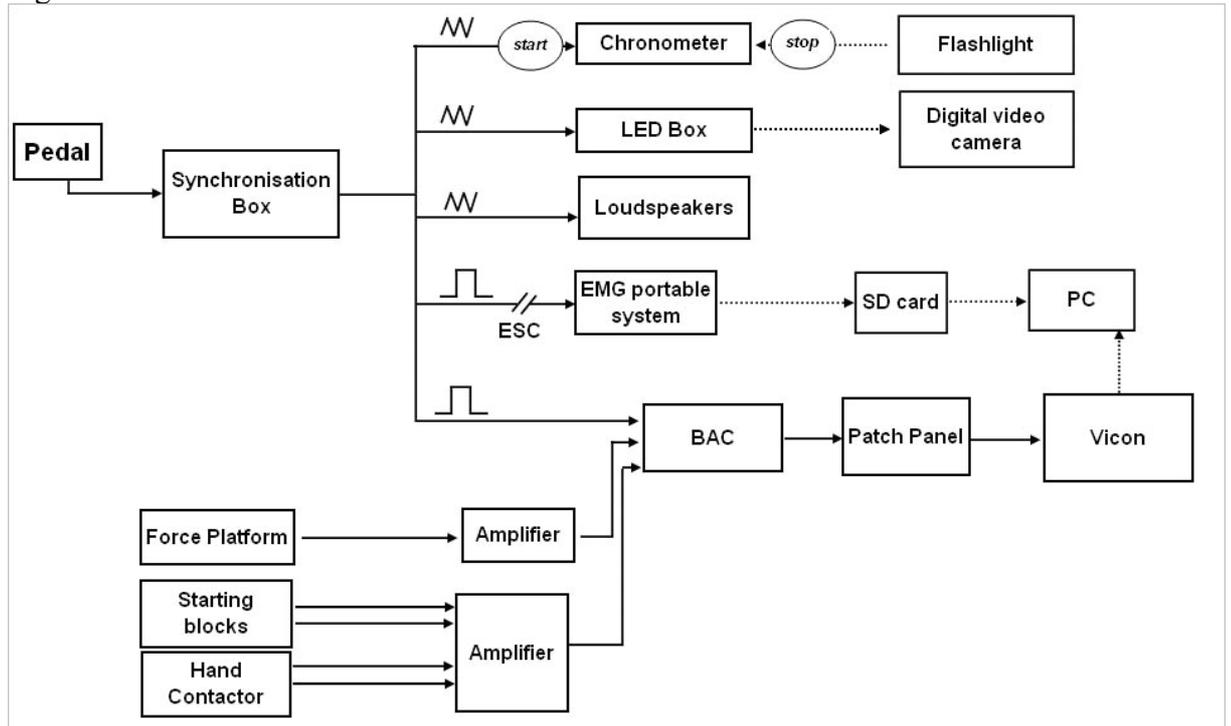


Fig. 2. Schematic tool connections. "Design" tools: the synchronisation box triggered the pedal emitted the start signal through five elements: a electric impulse (\sim) activated the chronometer, the LED box and the loudspeakers; the positive front (\square) marked the EMG and the analogue recording, respectively via the EMG synchronisation cable (ESC) and the BAC (box of analogue channel). ESC was disconnected at the sprinter's movement. The starting blocks and the hand contactor, among other, recorded the dynamics of the sprint start. They were connected via an amplifier to the BAC. "Classical" tools: the digital video camera controlled the scene. The EMG system was carried by the athlete and recorded the muscular activity of seven muscles. The force platform was place at the first step of the sprint and recorded the ground reaction forces. At last, the Vicon system recorded the first three steps of the sprint.

Fig. 3

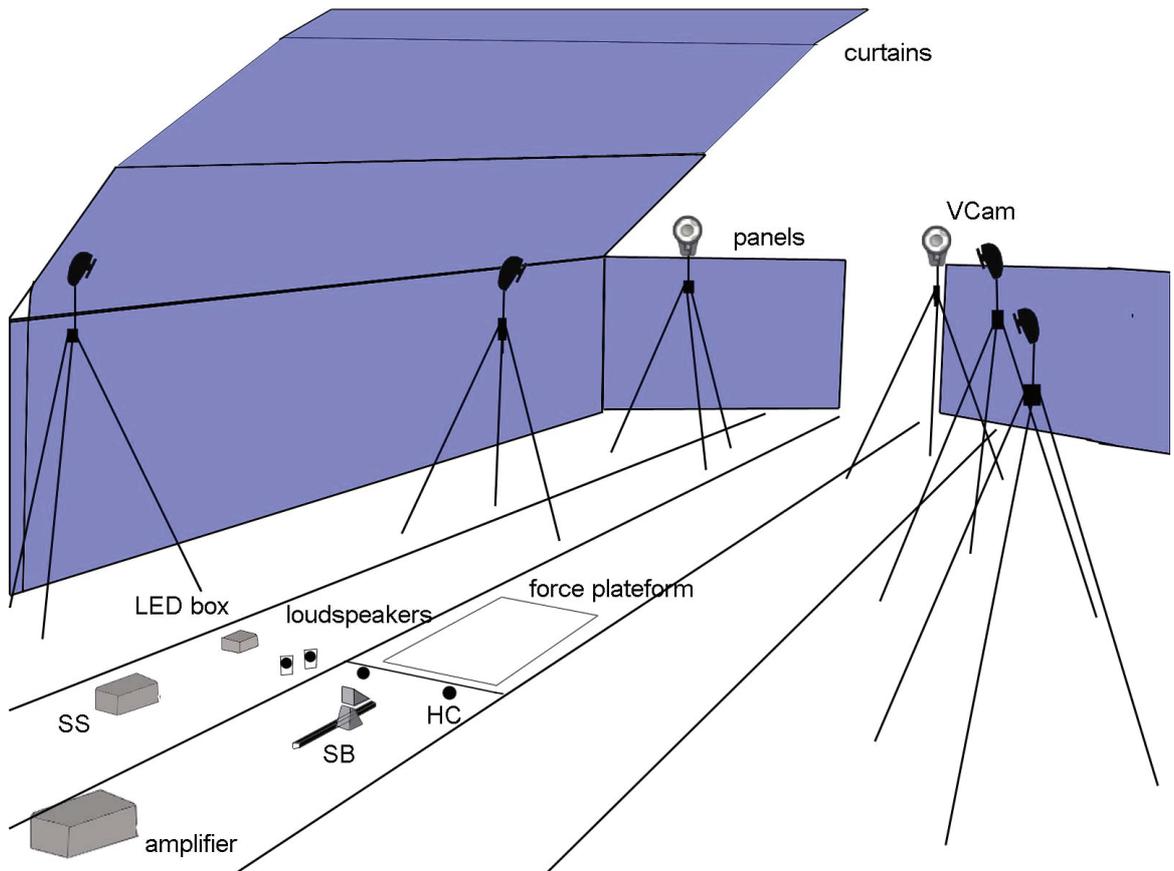


Fig. 3. Motion capture environment. HC: hand contactors; SB: starting blocks; SS: synchronisation system. Note that curtains and panels allowed the creation of the dim environment necessary for the motion capture. The distance between VCam was 4 to 4.5 m in the length and between 7 and 2 m in width, the VCams were arranged three meters off the ground and oriented downwards around the space capture, the space capture obtained was 6 m x 1.5 m x 2 m

Fig. 4

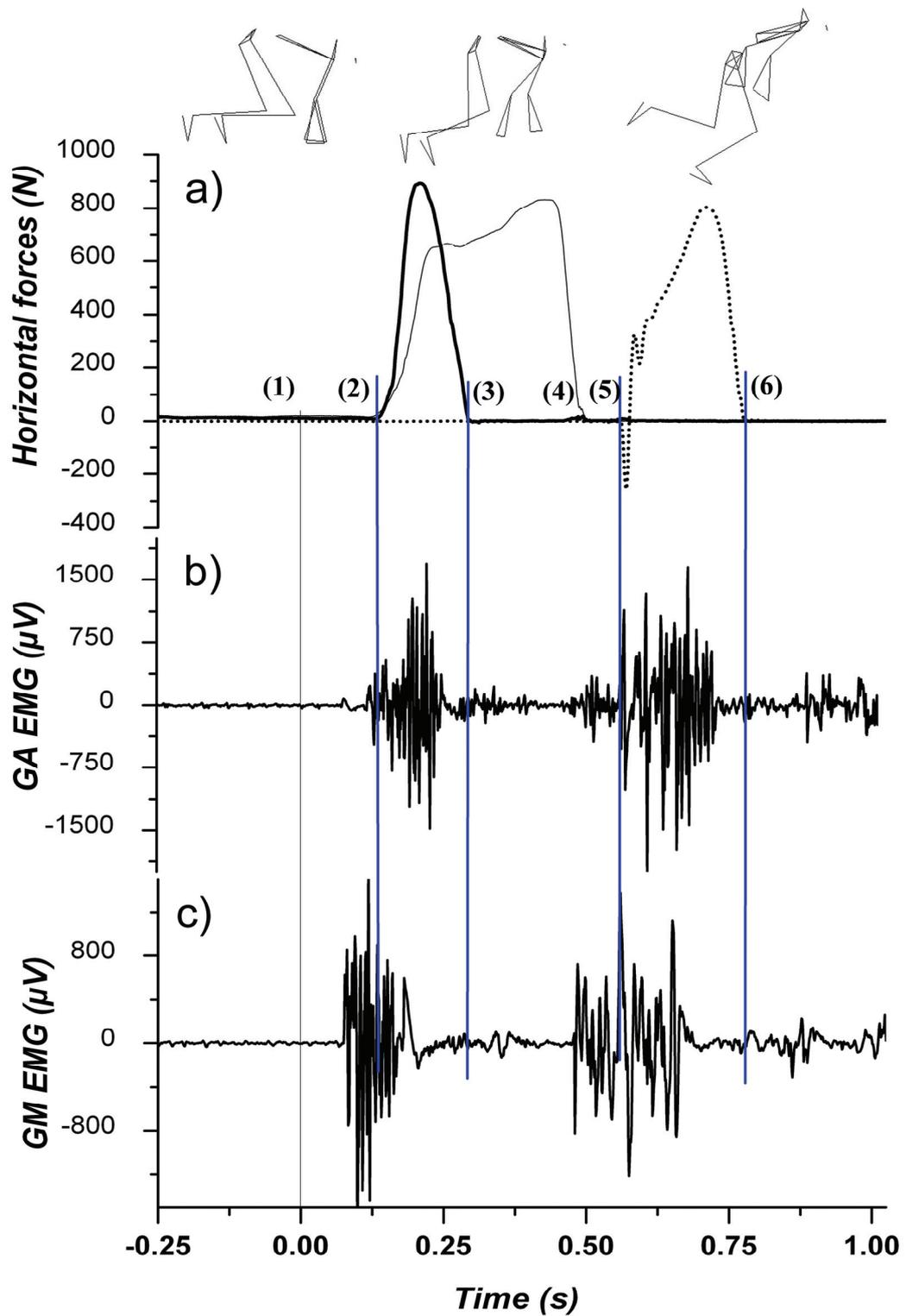


Fig. 4. Synchronisation of dynamics and EMG data

a) Horizontal force curves: the force of the foot (solid curve) recorded by the sensors of both blocks and the force on the first step of the same foot (dotted curve) recording by the force

platform, b) EMG data of the *gastrocnemius* (GA) and c) EMG data of the *gluteus maximus* (GM), (1) start signal, (2) push-off beginning on rear block, (3) push-off end on rear block (t_{RBE}), (4) first step landing (t_{L1}), (5) push-off end on front block; (6) toe-off (t_{T1}) The EMG data were recorded on the ipsilateral leg.

table 1: time-event measure with kinetics systems (SB, HC, force platform) and "gap" measure between kinetics systems and Vicon system

Parameter	<i>Variables</i>							
	t_{RBE}		t_{FBE}		t_{L1}		t_{T1}	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Time-event (s)	0.316	0.034	0.494	0.046	0.545	0.048	0.744	0.039
"Gap" (s)	0.017	0.009	0.019	0.009	0.006	0.004	0.011	0.005
Paired <i>t</i> -test		*		*		*		*

*: signifiant $p < .05$