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Mobile motion capturing in sport session based on Inertial Measurement Units

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Abstract: Experimental methods in Biomechanics have been adopted for analyzing sports performance, although a systematic use has been not widely diffused. An important factor for this limitation lies in the difficulty of extending results obtained inside a laboratory, to a real sport performance. Recent technological developments in Micro Electro-Mechanical Systems raise the possibility to overcome such a limitation. This work represents a feasibility study to evaluate kinematics and muscle activation during a typical elite soccer team coaching session. One professional soccer player under the S.S. Lazio was equipped with wireless Inertial Measurement Units and wireless electromyography modules. Data were acquired in real-time during running, sprinting, and jumping trials, performed on the regular team coaching field, with the aim of exploring biomechanical variables. Results showed a symmetric kinematic behavior of the lower limbs during the three activities. Conversely, electromyography highlighted an asymmetric activation of the correspondent muscles of the two sides. This study opens the way for a novel method for sport training, leveraging findings made available via micro-technology to permit a more focused training. These findings call for a more extended experimental session, enrolling more subjects, both healthy and injured, to further explore the possibility of novel approaches to athlete-specific rehabilitation.

Keywords: soccer; IMU; sports biomechanics; EMG; lower limb kinematics.

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1. Introduction

Experimental methods in Biomechanics have been adopted for analyzing specific sport skills, although a systematic use to test global players' performance on the playing field has been not widely diffused [1]. An important factor for this limitation lies in the inefficiency of actual measurement instruments for such aim: the gold standard for motion capture, optoelectronic systems, have a limited indoor measurement volume. For such a reason, it is difficult to extendmeasurement results obtained inside a laboratory, to the real sport performance. A particularly telling example can be found in soccer, the most popular sport in the world, better known as football outside USA. While particular skills that can be performed in place, such as kicking [2] and goalkeeping [1,3] have been investigated, only a few studies, to the best of our knowledge, analyzed global soccer player performances on the regular soccer surface and limited to the study of the interaction between the feet and the ground [4,5].

During the past ten years, coaches working with elite professional soccer teams and sport scientists have been tackling the problem of measuring and analyzing not just a specific fundamental gesture, but overall players' performance during the game [6]. Recent technological developments in Micro Electro-Mechanical Systems raised the possibility to overcome previous limitations caused by the inadequacy of measurement techniques, allowing scientists to conduct real-time studies with low-intrusive sensors in any playing environment. In that vein we decided to perform a feasibility study using wireless miniaturized sensors to acquire real time data from a professional elite soccer player during a real team coaching session.

2. Methods

2.1. Participant, Experimental setup and Data manipulation

One male professional soccer player under the S.S. Lazio (age: 18 y; body mass: 77 kg; height: 181 cm) was enrolled in this preliminary study. Subject's lower limbs data were acquired during a team coaching session using a completely wireless setup composed of: (a) Force Resistive Sensors (FSRs), (b) Inertial Measurement Units (IMUs) and (c) surface electromyography (EMG). Four FSRs (Wave, Cometa, Italy) were located under each foot at heel, 1st and 5th metatarsal and toe, in order to partition the gait cycles by detecting the heel-strike and the toe-off phases. On each leg, two IMUs (Wireless Motion Tracker, Xsens Technologies, The Netherlands) were placed on the thigh and the shank to determine knee angles. Finally, 8 EMG channels (Wave, Cometa, Italy) detected the activation of the following muscles: right and left tibialis anterior (R.TIB, L.TIB); right and left lateral gastrocnemius (R.GAST, L.GAST); right and left rectus femoris (R.RFEM, L.RFEM); right and left biceps femoris (R.BFEM, L.BFEM). For each EMG signal, the activation time T, expressed in percent of the gait cycle, and the averaged rectified value ARV [7] were computed. The three measurement systems were synchronized.

2.2. *Experimental protocol*

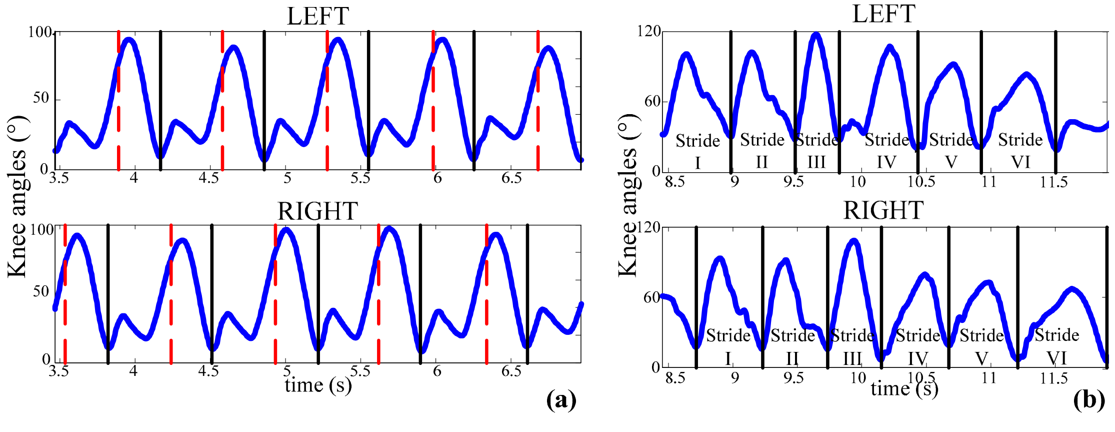
The entire experimental procedure was conducted in real-time on a regular team coaching field, performing typical training exercises. Right after the subject sensorization, a preliminary, functional body-to-sensor calibration procedure was performed using the experimental procedure described by Palermo et al. [8]. Following this brief phase, the subject started his coaching session with the rest of the team. We decided to analyze data from three typical movements of soccer training, widely used during soccer matches: (1) normal running; (2) sprinting, and (3) jumping with legs together.

3. Results and discussion

3.1. *Running trial*

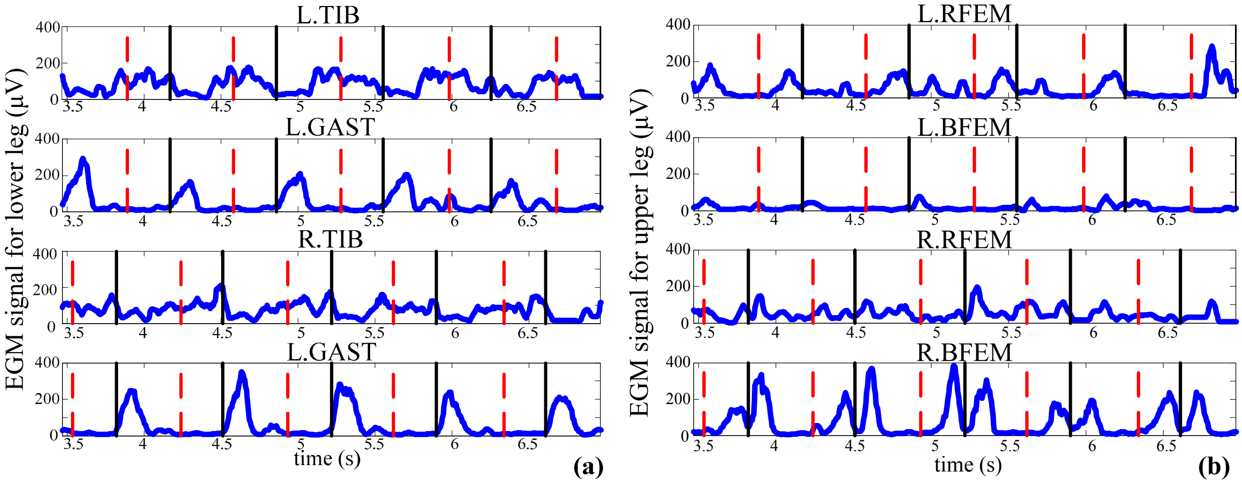
During the running trial the measured cadence was 1.3 step/s. The symmetric behavior of the two limbs can be evinced from the angle graph in **Figure 1a**, where black lines represent heel-strikes, i.e. the beginning of the stance phases, and red dashed lines represent toe-offs, i.e. the end of the stance phase and the beginning of the swing phase. The maximum knee angles measured during the stance phase (θ_f) were $\theta_{fr}=86.3°$ (right limb) and $\theta_{fl}=84.5°$ (left limb) while during the swing phase, the maximum angles (θ_s) were $\theta_{sr}=34.7°$ and $\theta_{sl}=39.6°$ for the right and left limb respectively. These values confirm the kinematic symmetric behavior during running, and are in accordance with previous studies on healthy subjects' running [9].

Figure 1. (**a**) Knee angles for a running trial. Top: left side; bottom: right side. Vertical black lines: heel-strikes; dashed red lines: toe-offs. (**b**) Knee angles for the six strides of a typical sprinting trial. Top: left side; bottom: right side. Vertical black lines: heel-strikes.



EMG data acquired during the running trial are shown in **Figure 2**. As regards the lower leg (**Figure 2a**), the gastrocnemii are activated during the stance phases but peaks on the right side are always higher (ARV=106 μV) than those on the left side (ARV=88 μV). No asymmetry, instead, was found between the right and left tibiales anterior, but the left muscle is active for a longer time (T=89.3%) with respect to the contralateral one (T=79.7%). Conversely, the upper leg (**Figure 2a**) shows a bigger asymmetry: the right biceps femoris is clearly the muscle with the highest activation (ARV=145 μV, T=63.9%), while the left biceps femoris is the less activated muscle in the entire leg, both in terms of timing (T=20.1%) and amplitude (ARV=40 μV).

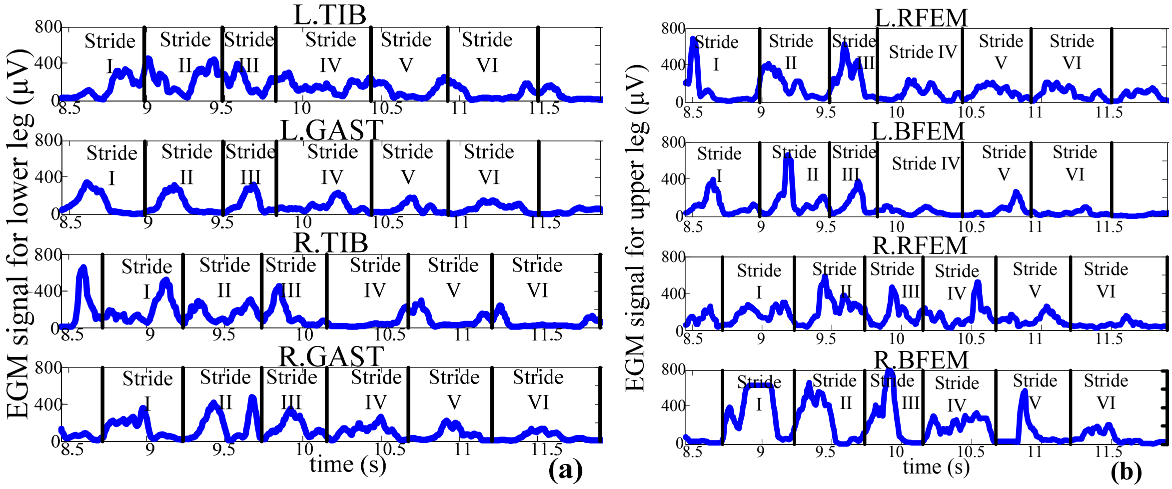
Figure 2. **(a)** Lower leg and **(b)** upper leg EMG signals during the running trial. Vertical black lines: heel-strikes; dashed red lines: toe-offs.



3.2. *Sprinting trial*

In this case the mean cadence was 2 step/s but each gait cycle showed unique characteristics compared to the six ones composing the sprinting trial, as shown in **Figure 1b**. Peak angles increase during the acceleration phase (strides I-III) and decrease during the braking phase (strides IV-VI). The first two steps of each phase (strides I, II, IV, V) show peak angles comparable with those acquired during the running trial (peak values averaged on the four strides: θ_l=94.2° ± 7.4°, left side; θ_r=86.2° ± 7.0°, right side).

Figure 3. **(a)** Lower leg and **(b)** upper leg EMG signals for the sprinting trial.



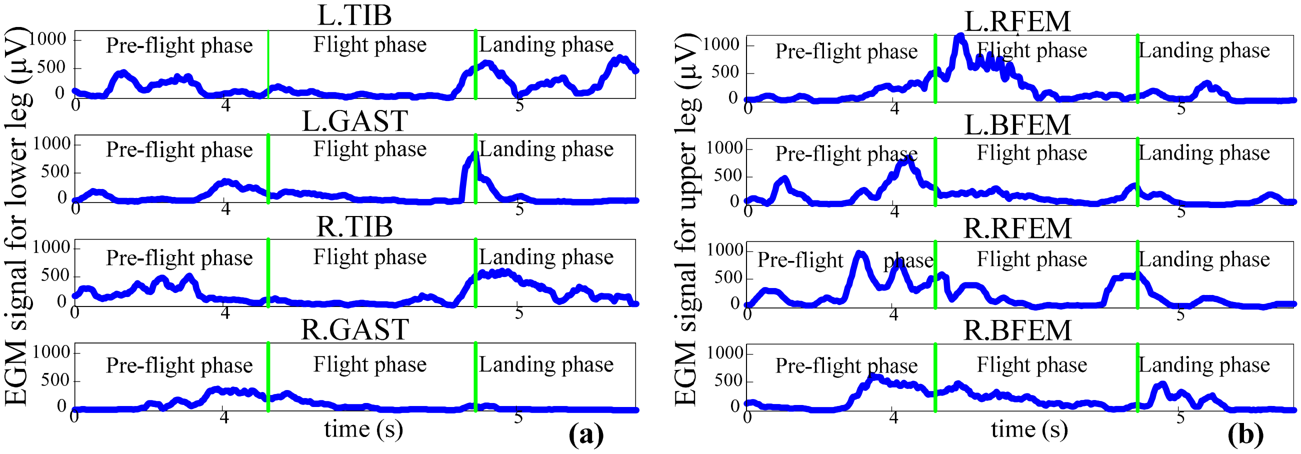
The knee angle reached the maximum values in the final phase of the acceleration (third stride), where θ_l=107.2° and θ_r=108.5°, while the end of the braking phase (last stride) was characterized by the peak values smaller than those of simple running (θ_l=56.4° and θ_r=67.1°).

Except for the gastrocnemii, all muscles show a T=100% activation during the first stride (acceleration phase) and the right biceps femoris showsthe biggest activity over the six strides, with a medium activation time T=87% ± 14%. However, as shown in **Figure 3**, all muscles participate in the athletic action, being active especially during the acceleration phase (steps 1-3), when ARV is higher. Even the left biceps femoris is more active during sprinting trial in respect to running trial ($ARV_{stride1}$=120 µV; $ARV_{stride2}$=168 µV; $ARV_{stride3}$=129 µV).

3.3. Jumping trial

In accordance with results from the previous described trials, during the jumping trial with legs together, no kinematics asymmetries have been found. The knees do not show noticeable differences between the two limbs in terms of pre-flight phase maximum angle (θ_l=66.2° and θ_r=66.0°) and, with an overall flight time of 0.74 s, the angular velocity of knees right after leaving the ground was ω_l=412°/s and ω_r=410°/s, for left and right sides respectively.

Figure 4. (a) Lower leg and **(b)** upper leg EMG signals for the jumping trial. The trial is divided into three phases: jump preparation; flight phase; landing phase.



Considering the muscles that activate the ankles, tibiales anterioris are more active than gastrocnemii, but all muscles are activated in a symmetric way, except for the landing phase. Here, tibiales anterioris synergistically absorb the biggest quota of energy (left ARV=301.9 µV; right ARV=348.1 µV), preserving a symmetric behavior that is instead disrupted between gastrocnemii. The right gastrocnemius in particular, only activates in a negligible way (T=11%; ARV=41 µV). Also in the upper leg, biceps co-work in a similar manner, both during the push and the landing phases. Asymmetry is clearly evident in recti femoris: during the push phase, the right rectus femoris present a bigger activation (ARV=400.5 µV, right; ARV=180.6 µV, left); conversely, in the flight phase the left rectus femoris is more active, with an ARV=354.66 µV, with respect to the right (ARV=228.0 µV).

4. Conclusions

The aim of this preliminary study was to test the use of wireless, miniaturized sensors to evaluate kinematics and muscle activation during a typical training session of an elite soccer player on the regular coaching field and the chosen setup revealed to be adequate for the task. Experimental results from IMUs have shown the symmetric kinematic behavior of both the sides of the lower limb during the three analyzed activities. Furthermore, EMG was able to unveil, especially during running and jumping, an asymmetric behavior in the two legs that was not evident from kinematics. Therefore, the outcomes of the present study open the way for a novel method for sport coaching, leading to a subject-specific training, focused on the strengthening of specific muscle groups during each task. These findings call for a more extended experimental session, enrolling a higher number of subjects, both healthy and injured, to collect baseline data and to further explore the possibility of novel approaches of athlete-specific muscular rehabilitation.

Author Contributions

All the authors conceived the study. EP and SR performed the experiments. All the authors analyzed the data and wrote the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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