THE TRUNK ORIENTATION DURING SPRINT START ESTIMATED USING A SINGLE INERTIAL SENSOR

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INTRODUCTION: Sprint start and block acceleration are two very important phases which could determine the result of a sprint. Tellez & Doolittle (1984) showed that these two phases account for 64% of the total result for a 100m sprint. Sprinters have to move from a crouch to a standing position, trying to reach their maximal velocity as fast as possible. Many authors have delved into the biomechanical factors concerning both phases (Fortier et al., 2005; Harland & Steele, 1997; Schot & Knutzen, 1992). Trunk orientation is considered by coaches one of the key elements in moving from the crouch to the upright position, however only a few studies focused specifically on this parameter (Čoh et al., 1998; Čoh et al., 2006; Natta et al., 2006). Moreover, the experimental setups used in the latter studies are quite cumbersome and limited in terms of acquisition volume (motion capture systems, high-speed cameras or optical contact time meters), therefore, they are hardly usable during everyday training sessions. Wearable inertial measurement units (IMU), that embed 3D linear acceleration and angular rate sensors (accelerometers and gyroscopes), can be effectively used to perform in-field biomechanical analysis of sprint running, providing information useful for performance optimisation and injury prevention. In particular, IMUs provide an estimate of body segment rotations relative to an inertia system of reference with one axis oriented as the gravitational field. The aim of this pilot study is to validate the use of a single IMU to estimate the trunk orientation angle in the progression plane during a sprint start from the blocks.

METHOD: A female subject (age=29yrs, m=56kg, h=1.71m) performed four in-lab sprint starts from regular starting blocks. The lab floor was covered with a felt carpet and the blocks were fixed directly into the floor. The two main positions of the sprint start ("on your marks", OYM and "set", SET positions) and the first three steps of each start were analysed. An IMU (Freesense, Sensorize, Italy) was positioned on the lower back trunk (T10 level). In order to limit the sensor movement relative to the underlying bone, various fixing methods were tested. Finally, a memory foam material was placed between the trunk and the sensor, which was then fixed with an elastic belt. The validation of the IMU estimates was performed by means of four retro reflective markers placed on the sensor. Their movements were tracked using a stereophotogrammetric system (Vicon MX3, Oxford, UK) considered as the reference, and the sensor global orientation was then calculated. The IMU orientation was supposed to provide information about the trunk orientation under the assumption of trunk rigidity. The movement was then analysed in the sagittal plane, as this is supposed to be aligned with the average plane of progression. After having identified the static and dynamic phases in each trial, acceleration and angular velocity measures provided by the sensor were used to identify trunk orientation as follows. When the sensor inertial acceleration was close to zero, i.e. during the sprint start static phases (OYM and SET positions), the accelerometer measured the inclination of the sensor relative to a vertical line defined according to gravity, thereafter called β. A quaternion based algorithm (Favre et al., 2006) was implemented in order to compute β (usually referred to as pitch). Conversely, when the sensor underwent a motion that generated inertial accelerations, i.e. during the dynamic phases (transitions between OYM and SET positions, and blocks acceleration) the trunk orientation angle β was estimated integrating the angular velocity signal provided by the gyroscopes. This allowed for the reduction of the integration interval and, thus, for a decrease of drift errors associated with the numerical integration process. In order to test the accuracy of the estimated angles during the static phases, an average value of the pitch angle β during the OYM and SET positions was considered: β_{OYM} and β_{SET}, respectively. The average of the absolute difference between the reference and the IMU estimates (e=|Vicon-IMU|), referred to as error (e), was calculated both for β_{OYM} and β_{SET}. To assess the curves similarly, the Root Mean Square Error (RMSE) between the reference and the estimated angles was computed.

Moreover, in order to take the curve temporal shift into account, the Pearson's product-moment correlation coefficient (r^2) was also calculated.

RESULTS: The Pearson's correlation coefficient and the Root Mean Square Error (mean and standard deviation) between reference and IMU angle estimates were respectively: r^2 = 0.992±0.006 and RMSE = 0.149±0.051deg. Trunk orientation angle curves for one trial, obtained from the reference measurement (solid line) and the IMU (dashed line) are shown in Figure 1. The pitch angle was considered to be zero when the sensor was in a horizontal position; clockwise rotations correspond to positive angles. Reference and sensor estimates, and absolute error (e) for β_{OYM} and β_{SET} are reported in Table 1 (mean and standard deviation).

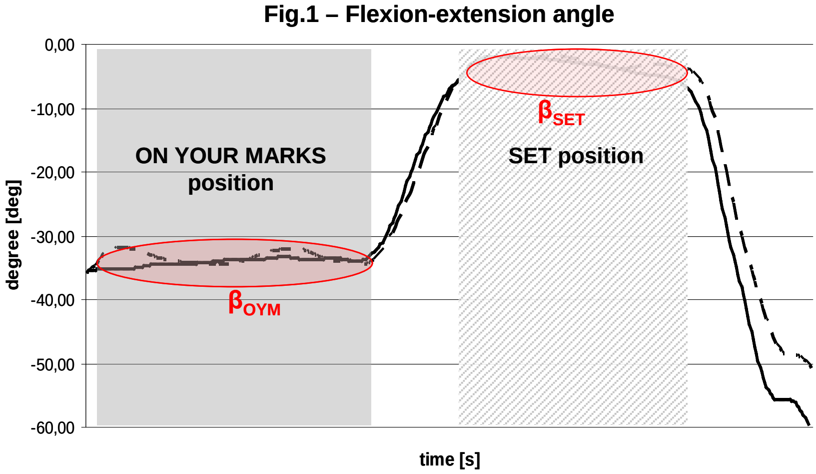

Table 1 – Absolute error between reference and IMU estimates for β_{OYM} and β_{SET}

	reference	IMU	error
β_{OYM} [deg]	-35,5±4,7	-33,8±3,4	1,1±2,1
β_{SET} [deg]	-1,1±3,2	-2,0±4,5	1,2±1,6

DISCUSSION: Average absolute errors during the static phases of the start were less than 2 deg, meaning that sensor inclination estimated from acceleration signals was accurate. The accuracy of the trunk orientation angle during the dynamic phases depends mainly on the on the integration interval duration and unit fixing. The tested memory foam material resulted in a good solution to limit the noise introduced by soft tissue oscillations. Moreover, since the subject went from the "set" to the upright position in less than three seconds, the drift errors typical of the numerical integration process were limited. This is particularly true for professional sprinters.

CONCLUSIONS: The study shows that it is possible to accurately estimate the trunk orientation angle during a sprint start from the blocks by using a single IMU. However, the effect of the assumption of trunk rigidity on errors remains to be verified. Future works will concern the validation of the method in-field and the analysis of the trunk orientation influence on performance, with the aim to use the sensor with professional sprinters during all-out sprint starts.

REFERENCES:

Coh M. et al., (1998). Kinematic and kinetic parameters of the sprint start and start acceleration model of top sprinters. *Gymnica*, 28, 33-42.

Coh, M., Tomazin, K. & Stuhec, S., (2006). The biomechanical model of the sprint start and block acceleration. *Physical Education and Sport*, 4, 103-114.

Favre J. et al., (2006). Quaternion-based fusion of gyroscopes and accelerometers to improve 3D angle measurement. *Electron. Lett.*, 42(11), 612-614.

Fortier S., et al. (2005). Starting block performance in sprinters: a statistical method for identifying discriminative parameters of the performance and an analysis of the effect of providing feedback over a 6-week period. *Journal of Sports Science and Medicine*, 4, 134-143.

Harland, M., & Steele, J. (1997). Biomechanics of the Sprint Start. *Sports Medicine*, 23(1) 11-20

Natta F., Decker L. & Boisnoir A., (2006). Caractérisation des comportements posturo-cinétiques en sprint. *Rapport du projet de rehcerche MJSVA nr. 03-006,* Laboratoire Mouvement Action et Performance, INSEP (Paris, France).

Schot, P.K. & Knutzen, K.M. (1992). A biomechanical analysis of four sprint start positions. *Research Quarterly for Exercise and Sport*, 63, 137-147.

Tellez, T., & Doolittle, D. (1984). Sprinting from start to finish. *Track Technique*, 88, 2802-2805.