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ScienceDirect

Procedia Engineering 00 (2016) 000–000

www.elsevier.com/locate/procedia

11th conference of the International Sports Engineering Association, ISEA 2016

Accuracy of postural human-motion tracking using miniature inertial sensors

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Abstract

Balance control in upright position has direct impact on shooting performance in various competitive activities like archery, rifle shooting, etc. Feet positions and global posture of the athlete change between each shooting activities. Information and short time feedback about the variation of the centre of mass of the athlete during the time before the shoot appears essential for learning and developing skills in shooting sports. In this aim, the purpose of the study was to explore the accuracy and reliability of a motion analysis system which uses the technology of inertial sensors (MVN Biomech system, Xsens). The MVN Biomech system is composed of 17 miniature inertial centrals attached to the full body. The validation procedure consisted in comparing the data of twenty subject's centre of mass directly extracted from the MVN Biomech system with those given by an optoelectronic system (Vicon) composed of 8 infrared camcorders. The centre of mass computed by both system was calculated using the same anthropometric model. For each subject, the comparison of mean position of the centre of mass was performed in three quiet standing of 30 s. Paired t-test, r correlation coefficient test and root mean square (RMS) were used to compare the accuracy between both devices. The results of paired t-test showed a significant difference between the measurements ($p < 0.0001$) in each component of the mean centre of mass position. Correlation between the tool's measurements was significant and better than $r > 0.99$ on each component. RMS computation shows mean difference between tools equal to 5.45 mm on X component, 3.25 mm on Y component and 0.73 mm on Z component. The result of the MVN Biomech system appears accurate comparing to the optoelectronic system. The small differences could be explained by the relative motion of the respective sensors and markers of both systems on the soft tissues of the subject. If the MVN Biomech system was preliminary developed to explore the subject's motion, the result of the present study showed that this system could also be used in order to estimate posture or micro-movements like postural sway during shooting activities.

Peer-review under responsibility of the organizing committee of ISEA 2016
Keywords: MVN Biomech, 3D kinematic analysis, posture, accuracy, centre of mass

1. Introduction

To perform, high level shooters are characterized by smaller body sway amplitudes in upright posture during bipedal standing archery [1], riffle [2] and pistol shooting [3]. On biomechanical point of view, body and arm postural sways are the main factors that influence shoot accuracy [4,5]. Center of pressure fluctuations and its velocities move slowly during skills shooting [6]. The relationship between performance in sport and posture have usually evaluated centre of pressure fluctuations using force plates [7] or pressure sensor carpets. However, centre of pressure fluctuations do not help the coach to understand the specific segment's postural coordination of the athlete in order to improve feedback shooting. Moreover, these devices are not accommodated to estimate postural sway during complex movement. For example, skilled dancers raising unilateral leg movement to an angle of 45 degrees performed while standing showed better postural sway compared to beginners [8].Improving the feedback quality involve to estimate the global subject's centre of mass and each segment movement.

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Peer-review under responsibility of the organizing committee of ISEA 2016.

Optoelectronics systems are usually used to realize accurate measurements of human motion centre of mass and segments. Few recent study presented force plate measurements associated to optoelectronic system in order to estimated postural sway in elite performance [9]. Optoelectronic recording constrains the measurements to the laboratories or are very invasive in term of calibration time, marker positioning on the subject, marker digitalization and tracking, etc. Force plates and optoelectronics system measurements are not always in agreement with sport training or mobile applications [10–13]. For the seven past years, devices with small sensors have been increasingly used to measure human motion in sport. For example, Xsens proposes to measure specific human motion in sport training using 17 connected inertial sensors (MVN Biomech). Only two studies have explored the accuracy of MVN Biomech [10,14]. More data clearly needs to be collected from MVN Biomech to examine its accuracy. In this aim, the purpose of the study is to investigate the accuracy and reliability of MVN Biomech estimating centre of mass position during upright posture. Data of the MVN Biomech system (Xsens Technologies BV, Enschede, Nederlands) was compared with the reference device Vicon Motion system (Vicon Motion systems, Oxford, UK).

2. Method

The experiment took place inside the laboratory of Superior School of Osteopathy Paris. Twenty healthy subjects (10 male and 10 female) voluntarily participated to this study. All subjects were asked to perform three quiet stances in natural position, arms along his body, looking forward, during thirty seconds followed by a vertical jump. Kinematic data were collected simultaneously with a MVN Biomech system and Vicon systems (fig. 1). At all, sixty upright postures were studied.

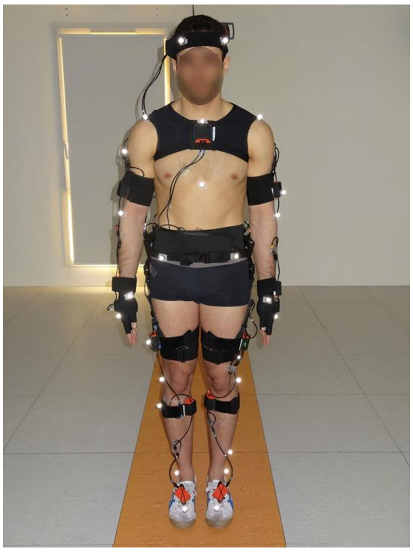

Fig. 1. Quiet stance of a Subject wearing MVN Biomech system and reflective markers of Vicon system.

The Moven system is composed of 17 miniature inertial centrals (nanotechnology inertial motion units, nIMU) attached to the body by straps. Each nIMU contains three gyroscopes, three accelerometers, three magnetometers in a 35 g box about the size of a match box. Each nIMU captures in real time the full 6 degrees of freedom of the body where it is fixed. The subjects wore the MVN Biomech straps full body which also included a wireless data link. The sampling frequency was equal to 100 Hz. Kinetic analysis was performed with the software provided by MVN Biomech software. The global subject's centre of mass of each measurement was extracted directly from the MVN Biomech software. The optoelectronic system (Vicon) consisted of eight infrared MX camcorders. A dynamic and static calibration around the area was done. Root mean square (RMS) and maximal error of three dimensional reconstructions [16] were respectively equal to 0.07 mm and 0.5 mm. The sampling frequency of the Vicon system was 100 Hz. For this experiment, 38 reflective markers were attached on the subject. According to information provided from Xsens, the global subject's centre of mass of each measurement was computed according to De Leva [15] anthropometric model associated with the kinematic data of the vicon system in order to perform a centre of mass as close as possible with that provided by the MVN Biomech software. Centre of mass data of both systems were synchronized when the subject left the ground during the vertical jump at the end of the 30 seconds of quiet standing. Each component (X, Y, Z) of the reference frame of both devices was synchronized at the beginning of recording. The validation procedure consisted in comparing the centre of mass position computed by the MVN Biomech system versus optoelectronic system (Vicon). Paired t-test was used to compare the significant difference between the centre of mass data measured by both system. The normality of the data was tested using asymmetry and kurtosis coefficients. Correlation coefficient (r) was used to estimate the relationship between the centre of mass data measured by both system. Paired t-test and root mean square (RMS) were used to define the difference and accuracy between the centre of mass variables of both devices.

3. Results

The result of the MVN Biomech system appears accurate comparing to the optoelectronic system. The centre of mass fluctuation presented similar curves especially on horizontal axis (X and Y components, fig. 2).

Correlation between the tool's measurements was significant and better than $r > 0.99$ ($p < 0.001$) on each component (X, Y, Z). The results of paired t-test showed a significant difference between the measurements ($p < 0.0001$) in each component of the mean centre of mass position. RMS computation showed mean difference on centre of mass between both tools (Vicon vs MVN Biomech) equal to 5.45 mm on X component, 3.25 mm on Y component and 0.73 mm on Z component.

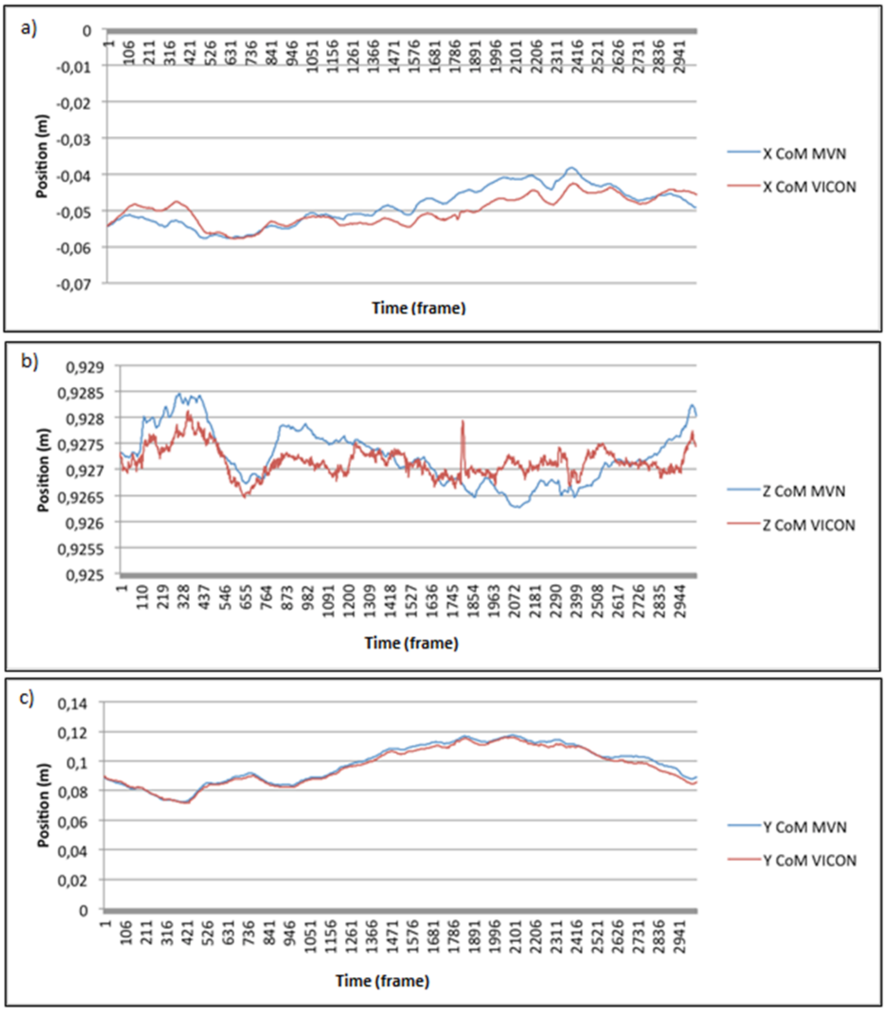

Fig. 2. Exemple of centre of mass fluctuation estimated by MVN Biomech (blue) and Vicon (red) systems observed during upright posture (a) on mediolateral axis (X component); (b) on on vertical axis (Z component) and (c) anteroposterior axis (Y component).

4. Discussion

This study compared the centre of mass position computed with MVN Biomech and Vicon systems and showed that data presented similar patterns. The result of the MVN Biomech system appeared accurate comparing to the optoelectronic system with mean difference lower than 6 mm on each component axis. However, these differences stay significant according to the paired t-test. The small significant differences could be explained by i) the relative motion of the respective sensors and markers of both systems on the soft tissues of the subject, ii) the low perturbation of the magnetic field that could involve perturbations that progressively create drift on the centre of mass computation during the computation process of the centre of mass provided by MVN Biomech system.

The correlation and RMS results showed significant and high relationships between the measurements in each component of the mean centre of mass position computed with both systems. However, the results of paired t-test showed that some precautions should be taken into account in order to compare the results of both devices. Significant error has been observed between both systems on each components axis. For studies of postural sway in sport applications, the anteroposterior and mediolateral taxis presented correct accuracy. According to the independent subsystem that interacting in postural strategies expressed in the postural modeling of inverted pendulum [18,19], the accuracy observed for both system on anteroposterior and mediolateral axis could help to discriminate the sportmen during shooting activities that involve ankle and/or hip strategy when the subject is perpendicular to the target like in archery and riffle shooting [19] and when the subject is parallel to the target like in pistol shooting. The significant differences observed between both devices could be explained by the relative motion of the soft tissues that move differently for the makers of both systems. The reflexives markers of the Vicon system were fixed on tendinous and bone zones, according to the anthropometric model [15]. The relative motion of soft tissus under the markers has been known to introduce artefacts [20] about 3 cm. The nIMU were fixed on muscular part of the segments according to MVN Biomech recommendations. The artefact associated to nIMU position could be in agreement with the maximal error that could be observed on a segment with two markers (2*3 cm). Moreover, the kalman filtering is necessary for MVN Biomech system to compute the centre of mass position. This process could be sensitive to the sensor drift of magnetometers and could create other artefacts. According to previous studies [10], a very low perturbation of the magnetic field, which contribute to the nIMU process of orientation, could introduce drift (observed on fig. 1).

5. Conclusion

If the MVN Biomech system was preliminary developed to explore the subject's motion, the result of the present study showed that this system could also be used in order to estimate posture or micro-movements like postural sway during shooting activities. In the case of sports activities where the target is placed perpendicularly to the subect, the characteristic of the activities that involves skills using ankle strategy in postural sway can be estimated by MVN Biomech system accurately. It can be assumed that the moven system could be also used even during training without restriction of area recording or light conditions.

Acknowledgements

The authors thank INSEP and ESO Paris Research managements for their respective help during this collaboration for writing this paper. We would like to thank especially Christophe Hausswirth, Jean-François Robin, Roger, Christophe and Olivier Caporossi, Serge Pin, Laurent Stubbe and Jeanine Sanchez and the research assistants.

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