ESTIMATION OF THE CENTER OF MASS AND PELVIS MOVEMENT IN RUNNING USING AN INERTIA SENSOR MOUNTED ON SACRUM

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The purpose of this study was to compare the center of mass and pelvis movement measured by the inertia sensor, motion capture, and ground reaction force during running. Linear movements of the center of mass and pelvis rotation were measured by motion capture system and the inertia sensor mounted on sacrum for thirteen distance runners. Vertical movement of the sensor was well coincident with the center of mass but lateral and forward/backward movements were overestimated by the sensor. The forward tilt, tangular displacement and velocity of pelvis in a running cycle were almost same in the values by motion capture and sensor with some variances by the mounted position. It would be suggested that the inertia sensor is useful to evaluate the distance running motion with filtering and modification of offset and parameter relationship for individual.

KEY WORDS: motion sensor, distance running, vertical oscillation, hip rotation

INTRODUCTION: It would be more important to improve running technique to enhance distance running performance as a level of international distance race has been developed. All levels of distance runners would like to avoid an injury caused by a lot of running distance to improve their performance and poor running technique which give numerous repetitive stress to a joint or tendon of the lower limb. It is a well-known fact that running economy is one of indices influenced distance running performance to evaluate efficient running movement. Arellano and Kram (2014) reviewed their papers to study the factors influenced running economy using task by task approach, in which muscular activities related body weight support, forward propulsion, leg swing and lateral balance can explain the change in energy cost by the task. It might imply that it would be useful to evaluate these movement for distance runners. However, the evaluation of running technique has not been frequently used for enhancing running economy and performance.

Recently a small and wireless inertia sensor is widely used to study human movement. Norris et al. (2014) reviewed the studies in which an inertial sensor was utilized to evaluate the running gait and concluded that the use of it could be accepted for those purpose. Belli et al. (1992) had tried to study that a waist movement measured by kinematic arm, which is a kind of position sensor, can represent the center of mass movement and can measure repetitive running motion and evaluate efficiency of running. We have developed an original motion sensor and software made by CASIO to evaluate distance running motion related energy cost by the sensor attached on sacrum (Otani et al., 2016). However, it is necessary to confirm reliability and validity of the parameter which can be evaluated using the inertia sensor in a range of the race speed and to investigate the cause of random and systematic error.

The purpose of this study is to compare the centre of mass and pelvis movement measured by the inertia sensor, motion capture, and ground reaction force during running and to examine the variation of the parameter to evaluate running technique.

METHODS: Thirteen male distance runners were recruited to the experiment as a subject. They were asked to run five different pace (76, 72, 68, 64, 60 s for 400 m) on the indoor straight track. Running motion after reaching the required speed was captured 20 cameras of motion capture system (VICON) at 250 Hz and ground reaction force was measured by 6

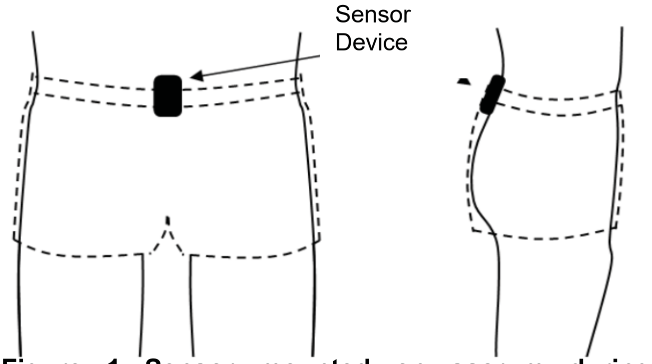

Figure 1 Sensor mounted on sacrum during running

force platforms at least in one running cycle at 1000 Hz. Retroflex markers were attached on their body and on the inertia sensor. The inertia sensor which has three axis accelerometers and three axis gyroscopes was mounted on sacrum fixed on the running short tights (Figure 1) and recorded the data in the log at 200 Hz as synchronized with other data by GPS time code. The coordinate system of the sensor was converted based on a gravitational axis after smoothing by Karman filter and hypothesized that forward/backward axis set at 0 degree of averaged angular displacement about its gravitational axis. The center of mass (CoM) and pelvis segment were calculated using Plug in Gait model of Vicon Nexus software from the maker displacement. Lateral, forward/backward, and vertical displacement of the center of mass were calculated by a difference of the maximum and minimum CoM displacement during one step and also calculated by double integration of accelerometer data converted (Sensor). It would be useful to examin the difference of CoM movement from motion capture and the inertia sensor to add data of the marker displacement on the inertia sensor (Marker). Pelvis angle calculated by Plug in model is compared to sensor angle about lateral axis and the angular velocity of pelvis is compared to angular velocity of gyroscope about vertical axis.

RESULTS: Average values of five different running speeds for the subjects are 5.33±0.10, 5.59±0.12, 5.90±0.08, 6.26±0.09, 6.65±0.09 m/s. Figure 2 shows average lateral, forward/backward, and vertical movement of Sensor, Marker and CoM for the five running speed. Lateral movement of Sensor was greater than CoM, and that of Marker was increased with running speed. The forward/backward movements of Sensor and Marker were almost same but that of CoM was smaller than those for all running speed. Vertical movements of three different acquisition were almost same and gradually decreased with running speed. The standard deviations of Sensor and Marker were ranged about 1.0 cm for all speed but the CoM were 0.5 cm although those were not shown in the graph.
Figure 3 shows average pelvis and the sensor angles about lateral axis for five running speed. These were averaged in a running cycle and positive value means forward lean of pelvis. There was no change in the pelvis angles with running speed and no difference between Sensor and pelvis angles for all speeds.
Figure 4 shows angular displacement and angular velocity of Sensor and Pelvis for five running speeds. The angular displacement is difference between maximum and minimum

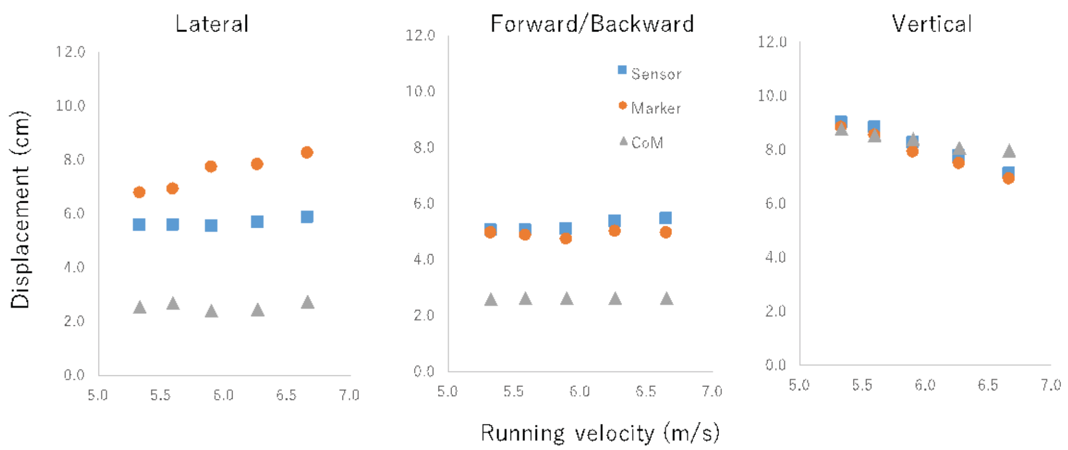

Figure 2 Lateral, forward/backward, and vertical displacement of Sensor, Marker, and CoM

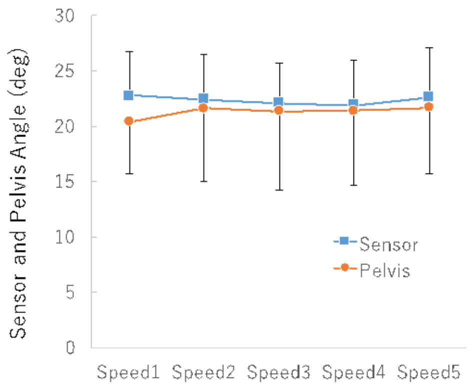

Figure 3 Sensor and Pelvis angle about lateral axis averaged in a cycle

angles in one step. The angular velocity is maximum value of the angular velocity of Sensor and pelvis in one step. The angular displacements of Sensor and pelvis were slightly increased with running speed. There was no difference between Sensor and pelvis at each speed. The angular velocities of Sensor at each speed were greater than pelvis.

DISCUSSION: The vertical movement calculated by the sensor (Sensor) was almost same as motion capture (CoM). But the lateral and forward/backward movements of the sensor were greater than motion capture. Figure 5 shows acceleration of Sensor, CoM and ground reaction force (GRF) in a running cycle for typical subject.

The acceleration of CoM and GRF were well coincident but Sensor has apparently large noise. Furthermore, lateral and forward/backward acceleration of Sensor was out of phase for CoM. The reason of that may cause of trunk movement not to influence CoM. It might be modified even in lateral and forward/backward movement by filtering and using the angular data of the sensor and could be improve vertical movement because the sensor mounted on sacrum connected to trunk movement.

The pelvis movement was well captured by the sensor. One of the most interesting thing using an inertia sensor would be the calculation of its own posture. The angle of the sensor about lateral axis was almost same as that of the pelvis calculated by the motion capture system (Figure 3). It indicates that the estimation of the gravitational axis by the sensor using the Kalman filter would be suitable in this study. Figure 6 shows the angle and angular velocity about vertical axis of the Sensor and pelvis in a running cycle for a typical subject. It shows almost same changes in both angle and angular velocity although angular velocity of the sensor has a certain noise. It would be suggested not only that the gyroscope in the sensor mounted on sacrum could measure angular velocity of pelvis but also that the estimation of gravitational axis using Kalman filter and the conversion of sensor coordinate system to global coordinate system had been valid.

Lateral movement of Marker was greater than Sensor (Figure 2). It may be caused by the sensor rotation about vertical axis. The forward/backward and vertical movement of Sensor and Marker were almost same and it seems that Sensor is different from CoM and GRF shown in Figure 5. These results may suggest that the sensor mounted on sacrum must not coincide with CoM but could be well captured the movement of it. It may be possible to improve validity of the data calculated the sensor mounted on sacrum as to modify the parameters by combination of acceleration and angular velocity data.

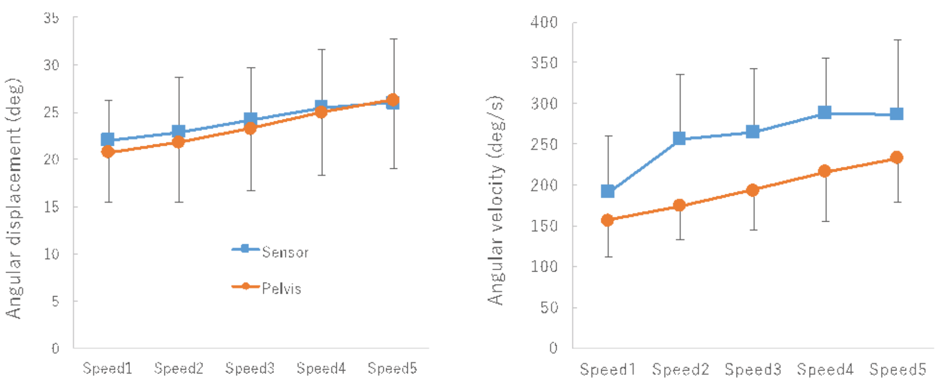

Figure 4 Sensor and Pelvis angular displacement and angular velocity about lateral axis.

CONCLUSION: It is clear that vertical movement and pelvis rotation about vertical axis using the inertia sensor mounted on sacrum can be accepted for evaluation of distance runner. However, it left for future study that lateral and forward/backward movement can calculate validity and individually. The findings of this study may imply that the validity of the parameter to evaluate distance running motion would be improved by combining of acceleration and gyroscope data.

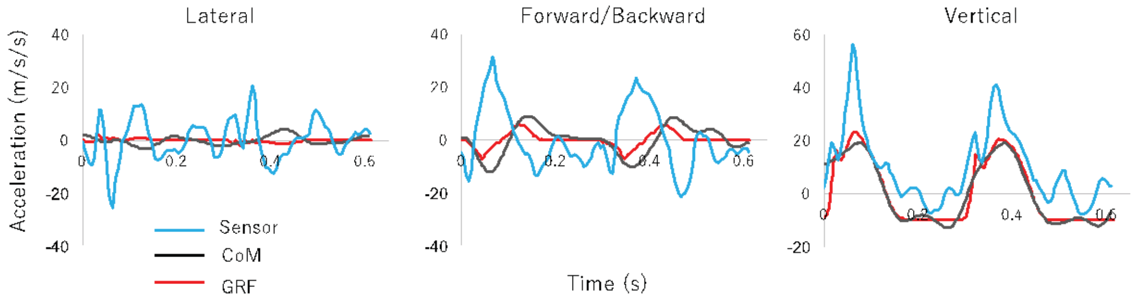

Figure 5 Acceleration of lateral, forward/backward, and vertical components of Sensor, Marker, and CoM during a running cycle for a typical subject.

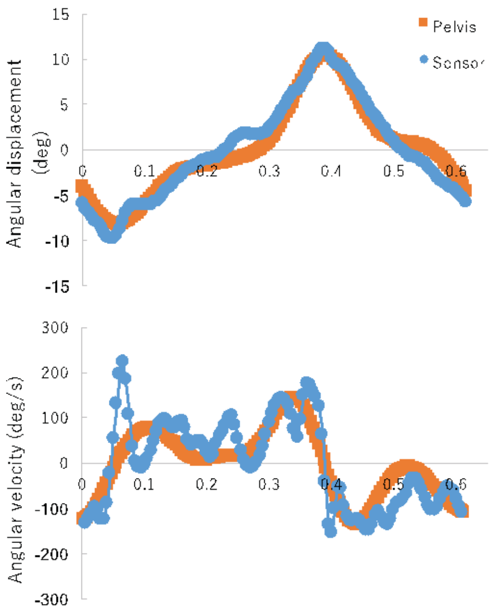

Figure 6 Angular displacement and velocity about vertical axis in a running cycle for a typical subject.

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