# THREE-DIMENSIONAL ACCELERATION DURING RUNNING IN TRAINED ATHLETES AND UNTRAINED SUBJECTS

**Kenta Goto[1], Masahiro Kawabata[1], Chiho Fukusaki[1], Ken Sasaki[1], Takahiro Mizushina[2], and Naokata Ishii[1,3]**

**Graduate School of Frontier Sciences, The University of Tokyo, Chiba, Japan[1]**
**Human R & D Center, CASIO COMPUTER CO., LTD. Tokyo, Japan[2]**
**Graduate School of Arts and Sciences, The University of Tokyo, Tokyo, Japan[3]**

The present study aimed to evaluate the three-dimensional (3D) accelerations during running in trained athletes compared to untrained subjects. Ten endurance-trained male athletes and 10 untrained male subjects wore a 3D accelerometer at the L3 level and ran on a 400-m track at three different speeds. The acceleration amplitude was calculated for each direction from the acceleration time series for 10 strides. Additionally, the positive and negative peak values of vertical and anterior-posterior accelerations were calculated. Analysis of covariance tests showed a significant difference between athletes and untrained subjects in the vertical acceleration amplitude. Significant interaction effects were found for upward acceleration and forward-backward acceleration ratio. These results suggest that athletes have characteristic patterns in the vertical acceleration and forward-backward acceleration ratio.

**KEY WORDS:** accelerometer, running gait, running skill

**INTRODUCTION:** Accelerometers are used to estimate walking gait, especially in clinical settings (Mizuike, Ohgi, & Morita, 2009; Turcot et al., 2008), but they are rarely used to analyse running gait. Our previous study (Kawabata et al., 2013) measured and evaluated three-dimensional (3D) accelerations during running; we demonstrated that 3D acceleration patterns were associated with the running gait cycle, and the running speed, running surface, and location to which accelerometers were attached affected the acceleration amplitude. These findings suggested the possibility of using accelerometers to analyse running gait in a similar manner for walking gait.

Few studies have examined the difference in 3D accelerations between trained runners and untrained subjects. McGregor, Busa, Yaggie, and Bollt (2009) assessed 3D accelerations in terms of energy expenditure, and they demonstrated that the root mean square (RMS) of the acceleration time series was larger for untrained subjects than for trained runners at the same running speed in all three axes. The acceleration amplitude has been used to estimate energy expenditure, as shown in McGregor et al.'s study and other previous studies (Brage, et al., 2004; Brage, Wedderkopp, Franks, Andersen, & Froberg, 2003). Meanwhile, it indicates force produced during exercise. Additionally, positive and negative values of 3D accelerations indicate the direction and magnitude of force production in detail. These indices will give runners objective information about their running.

The present study aimed to examine 3D accelerations during running in trained athletes in regards to acceleration amplitude and positive and negative acceleration values, and determine characteristic acceleration patterns of trained athletes compared with untrained subjects.

**METHODS:** Ten trained male distance runners and 10 untrained male subjects participated in the present study. The trained athletes belonged to a university track and field club and practiced 6 days per week. The average age, height, and mass of the trained athletes were 20.3 ± 0.9 years (mean ± SD), 172.3 ± 2.8 cm, and 55.7 ± 2.1 kg, respectively; those of the untrained subjects were 23.9 ± 1.2 years, 170.4 ± 5.3 cm, and 62.6 ± 9.7 kg, respectively. The Research Ethics Committee of The University of Tokyo approved this study. Participants' provided informed consent prior to starting the study.

Subjects ran three times on a 400-m athletic track. The running speeds were set at 12.0, 15.0, and 18.9 km/h for athletes and 8.0, 10.0, and 12.0 km/h for untrained subjects. A pacemaker led runners to maintain the running speed in the experiment.

A triaxial accelerometer was positioned at the level of the third lumbar vertebra (L3), and it was firmly secured with an elastic band. To avoid inter-examiner variability, only one examiner set and secured the accelerometer to the participants. The range and sensitivity of the accelerometer were ±8.0 g and 3.9 mg, respectively. The acceleration data were sampled at a rate of 100 Hz. The orthogonal coordinate axes of the accelerometer were set as follows: the X-axis was oriented in the medial-lateral (ML) direction, and the Y- and Z-axes were oriented in the vertical (VT) and anterior-posterior (AP) directions, respectively. Positive X, Y, and Z values represented accelerations in the left, upward, and forward directions, respectively.

Prior to data analysis, axial misalignment of the accelerometer caused by a forward trunk lean during running was corrected using trigonometry (Moe-Nilssen, 1998). Moe-Nilssen (1998) proposed the algorithm to calculate Euler angles between two coordinates based on the accelerometer values. By referring to this algorithm, we corrected Euler angles between running position and standing position. The corrected acceleration data were filtered with a second-order zero-lag low-pass Butterworth filter with a cutoff frequency of 20 Hz.

A stride was defined as two subsequent foot contacts performed by the same foot. Ten strides (20 steps) in the final stretch of the 400-m run were extracted for further analysis. For each direction of 3D acceleration, positive and negative peaks within one step were detected, and the difference between the positive and negative values was determined as the acceleration amplitude. In addition, the absolute value of the means of positive peaks and negative peaks in the VT and AP directions were calculated to determine upward and downward acceleration, and forward and backward acceleration separately. The forward-backward acceleration ratio was also calculated from division of forward acceleration by backward acceleration to estimate the ratio of propulsive to braking force during a step. Misalignment correction, filtering, and subsequent analysis were performed using MATLAB software package (The MathWorks, Inc., Natick, MA, USA).

Analysis of covariance (ANCOVA) was conducted to test the difference of each acceleration parameter between the two groups with removing the bias of the running speed. Data were considered to be statistically significant if $p < 0.05$. Statistical analyses were performed using IBM SPSS Statistics 19 (SPSS Japan Inc., an IBM Company, Tokyo, Japan).

**RESULTS:** Figure 1 shows the 3D acceleration amplitude as a function of the running speed. ANCOVA tests did not show any significant interaction effects for the acceleration amplitude in the ML, VT, and AP directions. There was a significant difference between trained athletes and untrained subjects in terms of the VT acceleration amplitude ($p < 0.001$).

Downward, forward, and backward accelerations showed no significant interaction effects or significant differences between trained athletes and untrained subjects. The upward acceleration (Figure 2) and forward-backward acceleration ratio (Figure 3) showed a significant interaction effect ($p < 0.05$).

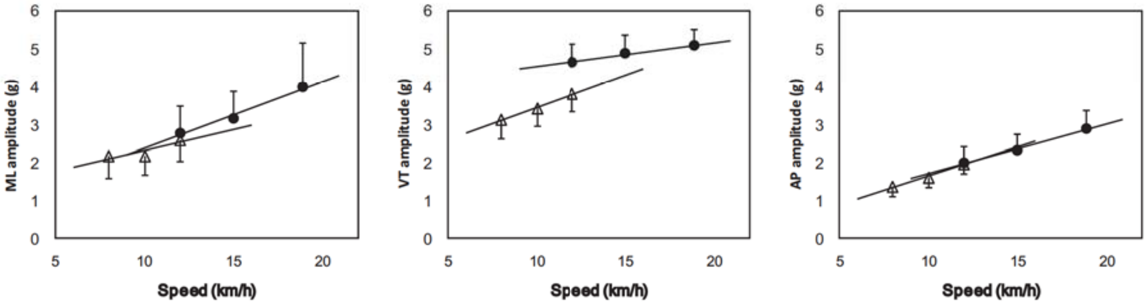

Figure 1: Three-dimensional acceleration amplitude during running in trained athletes (●) and untrained subjects (△).

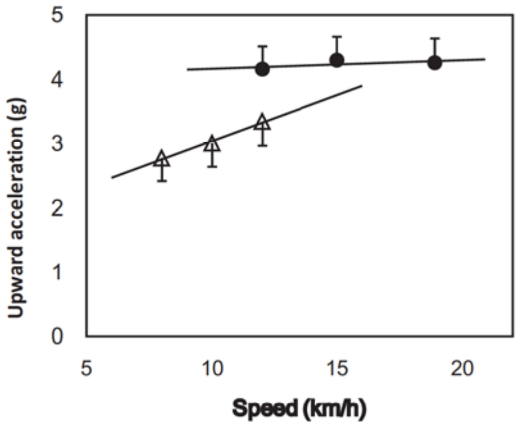

Figure 2: Upward acceleration during running in trained athletes (●) and untrained subjects (△).

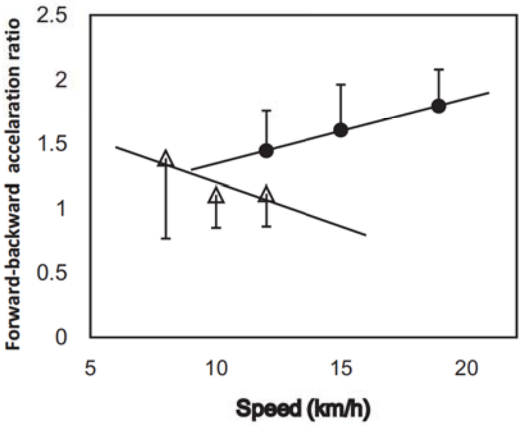

Figure 3: Forward-backward acceleration ratio during running in trained athletes (●) and untrained subjects (△).

**DISCUSSION:** The present study compared 3D accelerations during running between trained athletes and untrained subjects. Significant differences were found in the VT acceleration amplitude as well as the increase in the upward acceleration and change in the forward-backward acceleration ratio with running speed.

VT acceleration was larger, and the increase in upward acceleration with running speed was smaller in trained athletes. McGregor et al. (2009) reported a smaller acceleration RMS values in all three directions in trained athletes; our results were inconsistent with this previous study. One reason for this discrepancy may be due to where the accelerometer was attached. McGregor's study measured 3D accelerations at the top of the iliac crest; in the present study, we placed an accelerometer at the L3 level. The 3D accelerations measured at the top of the iliac crest may reflect pelvic movement (i.e., rotation) in three separate planes. In addition, McGregor et al.'s study did not correct axial misalignment during running. The vertical force against gravity is reportedly a constant at a faster running speed (Cavagna, Thys, & Zamboni, 1976; Nilsson & Thorstensson, 1989), which can account for the smaller increase in upward acceleration with running speed found in trained athletes.

An increase in the forward-backward acceleration ratio with running speed was found in trained athletes, not untrained subjects. Previous studies have reported that the breaking force is the main factor that explains running economy (Kyröläinen, Belli, & Komi, 2001), and horizontal force, especially in the propulsive phase, is correlated with the maximal running speed of distance runners (Nummela, Keränen, & Mikkelsson, 2007). The present study showed an efficient forward force generation during stance phase in trained athletes.

**CONCLUSION:** By using an inexpensive and wearable accelerometer, the present study found that endurance trained athletes had characteristic patterns in the vertical acceleration and forward-backward acceleration ratio compared with untrained subjects.

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