CHANGE IN SHOCK ATTENUATION DURING MARATHON RUNNING

Yasushi Enomoto[1], Yuta Suzuki[2], Michael Hahn[3], Takehiro Aibara[4] and Takashi Yahata[4]

Faculty of Health and Sport Sciences, University of Tsukuba, Tsukuba, Japan[1]
Research Center for Urban Health and Sports, Osaka City University, Osaka, Japan [2]
Department of Human Physiology, University of Oregon, Eugene, USA[3]
CASIO Computer Co., Ltd., Tokyo, Japan[3]

The purpose of this study was to estimate shock attenuation during marathon running using inertial measurement units attached on the foot and sacrum. Eleven male runners were recruited as subjects from the participants of the official marathon race. Two inertial measurement units (IMUs) attached on the foot and sacrum operated at 200 Hz and stored three axis acceleration data in the memory through the marathon race. Absolute acceleration was transferred power spectrum density (PSD) by FFT and a transfer function was calculated by PSD of the sacrum relative to the foot. The results showed that the impact acceleration was recognized from 11 to 18 Hz at the foot and was attenuated between the foot and the sacrum. It is suggested that this method could be useful to evaluate shock attenuation during endurance running easily and might be used to give appropriate feedback in real time to decrease injury risk.

KEYWORDS: impact, running injury, IMUs, acceleration, transfer function

INTRODUCTION: Running is becoming more popular as a sport activity than before. Shoes and running gears have been developed by related companies in order to run efficiently and comfortably. Nevertheless, running injury rate is still high (Paquette & Melcher, 2017). Running injuries are mainly caused by trauma defined as overuse injury (Hamill et al., 2012). Running mechanics are often implicated in this trauma, including the impact load occurring at each foot strike. Many researchers have suspected that injuries may be related to the magnitude and frequency of impact loads on the body (Shorten & Winslow, 1992), but it remains challenging to reveal actual mechanism of the injury. Shock attenuation is an important aspect to reduce impact load applied to the body. Shoes and the lower limb can attenuate high magnitude shock to a certain extent.

Shock attenuation of the impact load at foot strike can be estimated using a transfer function of shock wave between the shank and the head (Shorten & Winslow, 1992). These measurement locations are considered suitable for attachment of an accelerometer on the skin with reduced vibration due to limited subcutaneous adipose tissue. For practical purposes, we considered another location easily attaching the IMUs for estimated shock attenuation.

In recent technological advancements, small size, lower-power and high-performance inertial measurement units have been developed for use in sport activities. In this study, we used IMUs developed by CASIO which are small and convenient to measure the running motion. These are operated at 200 Hz, with a GPS clock operating at 1000 Hz to synchronize with other IMUs. The system consists of IMUs with a clip to attach on the shoes and also on the runner’s shorts fitted over the sacrum (Enomoto et al. 2017).

The purpose of this study was to estimate shock attenuation during marathon running using IMUs attached on the foot and the sacrum.

METHODS: Eleven healthy male runners were recruited from the participants of an official marathon race. Mean (standard deviation) of their age, height and mass were 24.9 (5.1) years, 1.73 (0.06) m, and 59.0 (4.1) kg. They are injury free at least for a half of year and former competitive runners in college level but now keeping running for recreational level. Before the race, participants signed an informed consent after explanation of the purpose and significance of this study and the risks for them.

The IMUs developed by CASIO (mass: 32 g) were attached on the foot and the sacrum, clipped to the shoelaces using a rubber string and clipped at the running shorts over the sacrum. Three-dimensional acceleration data measured by the IMUs were stored in the internal memory at 200 Hz and synchronized by GPS time operated at 1000 Hz.
To avoid the influence of resonant frequency, acceleration data (g) at the foot and the sacrum in one support phase was extracted for further analysis at each 5km based on the split time. Data were then converted to the frequency domain by FFT using MATLAB after the number of time series data points were extracted to 256 with zero-padding, as needed. Power spectrum density (PSD, g^2/Hz) was calculated after FFT, then shock attenuation (dB) was estimated using the transfer function as described by Shorten and Winslow (1992);

$$\text{Transfer function} = 10 \cdot \log_{10}(\text{PSD}_{\text{sacrum}} \,/\, \text{PSD}_{\text{foot}}) \,.$$

A positive value indicates gain and a negative values indicates attenuation of the shock signal at the sacrum relative to the foot.

RESULTS: Two of the eleven participants did not complete the race. The average completion time for the remaining 8 subjects was 3:15 (range: 2:46 – 4:38). All IMUs remained attached throughout the race for all subjects. An exemplar participant who kept running through the race but slightly decreased running speed is shown in Figure 1. The running speeds at each 5 km for this participant were 11.2, 12.5, 12.5, 12.4, 12.4, 12.3, 12.5, 10.7, 11.4 (last 2.195 km) km/h, with a finish time of 3:29.

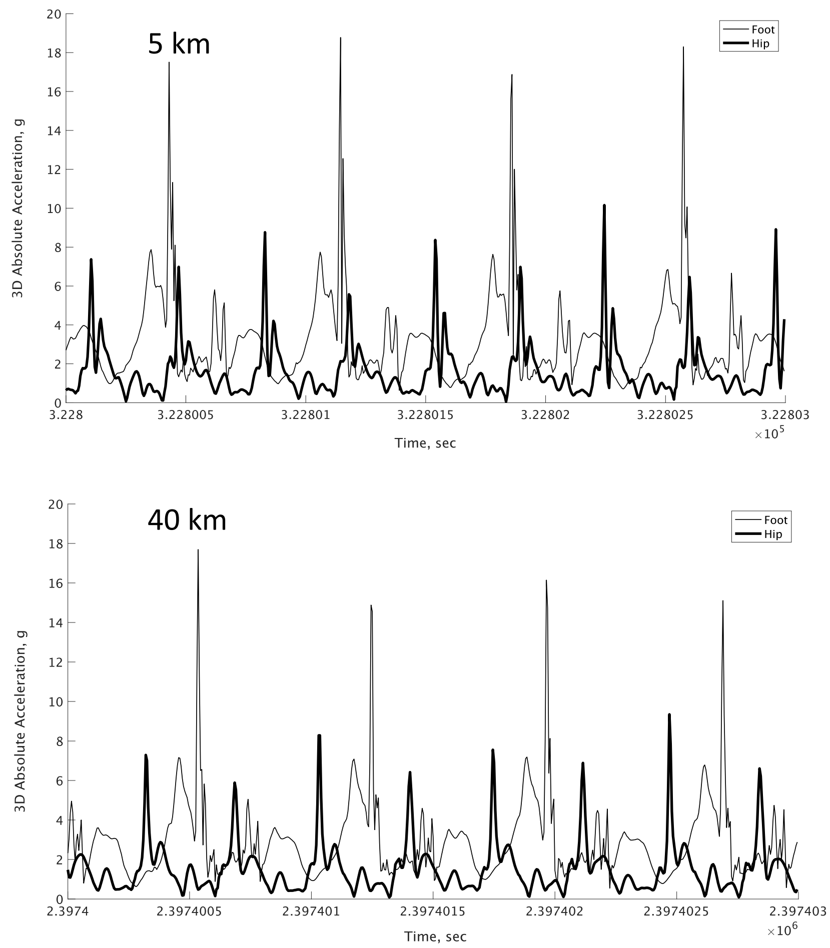

Figure 1: Exemplar absolute resultant acceleration measured by IMUs on the foot and sacrum at 5 km (upper) and 40 km (bottom).

Figure 1 shows an exemplar plot of absolute resultant acceleration measured by IMUs attached on the shoes (foot) and shorts (sacrum). The peak acceleration on the foot and sacrum were about 17 and 9 g at 5 km and 15 and 8 g at 40 km, respectively.
Figure 2 shows power spectrum densities of the absolute resultant acceleration signal on the foot and sacrum (PSD_{foot} and PSD_{sacrum}) at each 5 km for an exemplar subject. There are three observable peaks at the foot but only one at the sacrum. The first peak might be influenced by the resonant frequency common to running motion. The second and third peaks are observed at approximately 8 and 14 Hz, respectively, which corresponds with active loading and impact peaks (Hamill, et al., 1995). It was also observed that the peak of PSD_{foot} at 8 Hz decreased through the race, the highest value is 0.120 g^2/Hz at 10 km and the lowest value is 0.061 g^2/Hz at 35 km.

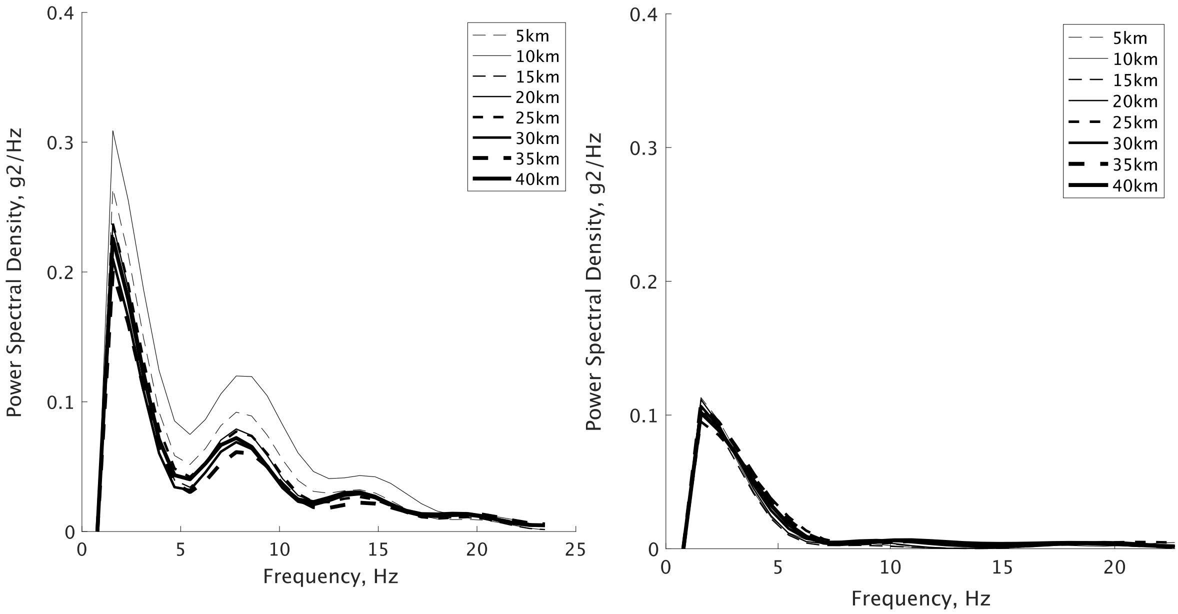

Figure 2: Power spectrum densities of the foot (left) and sacrum (right) at each 5 km for a exemplar participant.

Figure 3 shows the results of the transfer function of PSD_{sacrum} relative to PSD_{foot} (shock attenuation) at each 5 km for an exemplar participant. These data show large attenuation in the frequency range from 11 to 13 Hz at 5, 10, 15 and 20 km, however no large attenuation was observed after 25 km. The largest value from these data is -28 dB at 5 km, which is greater than values reported by Shorten & Winslow (1992) and Mercer et al. (2003) but similar to values presented by Hamill et al. (1995).

DISCUSSION: This study tried to estimated shock attenuation during marathon running using IMUs on the foot and the sacrum. We used original IMUs developed by CASIO, which have the advantages of being easy to clip, synchronize with other IMUs by GPS clock, and enough capacity to store the data over a long time. However, these sensors have disadvantages of having a low sampling frequency and slightly heavier compared to smaller IMUs. Locations for sensor placement were chosen for minimal vibration and no pain or discomfort by participants. Absolute resultant acceleration data from sensors at the foot and the sacrum throughout the race were reported for a typical participant. Peaks accelerations during stance phase were slightly higher than those reported previously (Mercer et al., 2003). Although PSD_{foot} and PSD_{sacrum} show the peak of low frequency around 3 Hz, PSD_{foot} clearly showed active and impact peaks around at 8 and 14 Hz. The greatest shock attenuation was also observed at these frequencies (Figure 3).
Decrease in shock attenuation was observed in the latter half of the race for the exemplar participant. In comparison, there is no change in shock attenuation for other participants who

sustained constant running speed throughout the race. This observation suggests that decreased shock attenuation is not necessarily associated with decreased running speed but it may be influenced by individual factors such as foot strike pattern and running motion related to foot strike. Data from IMUs may be used to give a runner the feedback in real time. If IMU systems had an algorithm to estimate shock attenuation and evaluate it against a threshold value, it might give a runner an alert of increasing injury risk. The mechanisms of decrease in shock attenuation and the relationship between shock attenuation and injury are out of the scope of this study, but we have shown the possibility of monitoring shock attenuation during running, which could give a runner useful feedback. Future research may develop feedback systems highlighting IMU measures of running mechanics related to running injury.

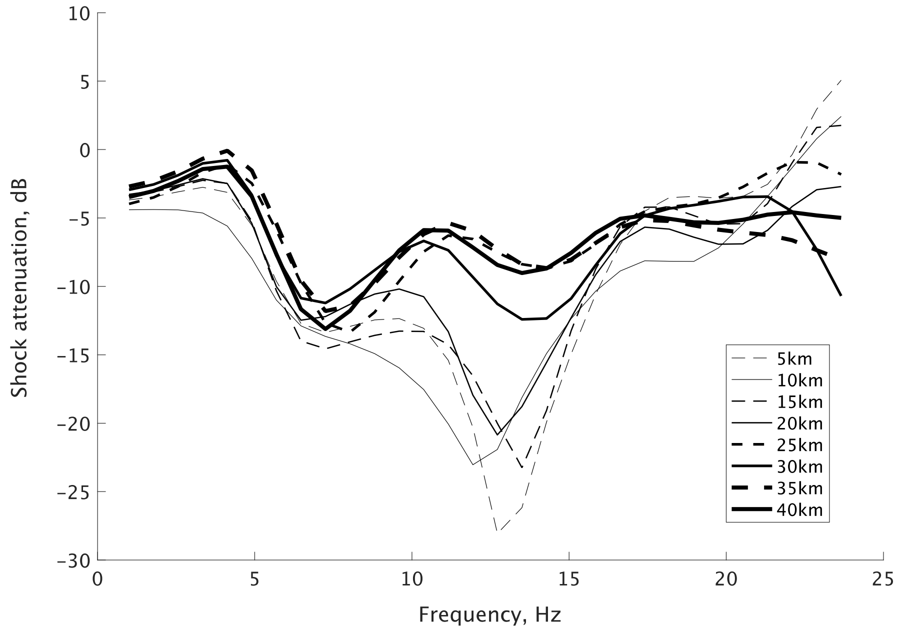

Figure 3: Results of transfer function of PSD_{hip} relative to PSD_{foot} (Shock attenuation) at 5 km to 40 km for a typical subject.

CONCLUSION: This study showed that shock attenuation of the impact decreased through marathon running especially for a fatigued runner. It is suggested that the potential of running injury risk could be evaluated by this technique and a possibility of adopt it to wearable tech which give the runner appropriate feedback in real time to avoid the risk of injury during running.

REFERENCES

Enomoto, Y., Aibara, T., Sugimoto, K., Seki, K., Yokozawa, T. & Murata, R. (2017). Estimation of the center of mass and pelvis movement in running using an inertia sensor mounted on sacrum. *Pothast, W.(Ed) Proceedings of 35th International Conference on Biomechanics in Sports,* Cologne, Germany.

Hamill, J., Derrick, T.R. & Holt, K.G. (1995). Shock attenuation and stride frequency during running. *Human Movement Science*, 14, 45-60.

Hamill, J., Palmer, C. & Van Emmerik, E.A. (2012). Coordinative variability and overuse injury. *Sports Medicine, Arthroscopy, Rehabilitation, Therapy & Technology*, 4, 45-53.

Mercer, J.A., Bates, B.T., Dufek, J.S. & Hreljac, A. (2003). Characteristics of shock attenuation during fatigued running. *Journal of Sports Sciences*, 21, 911-19.

Paquette, M.R. & Melcher, D.A. (2017). Impact of a long run on injury-related biomechanics with relation to weekly mileage in trained male runners. *Journal of Applied Biomechanics*, 33, 216-21.

Shorten, M.R. & Winslow, D.S. (1992). Spectral analysis of impact shock during running. International *Journal of Sport Biomechanics*, 8, 288-304.

ACKNOWLEDGEMENTS: Tsukuba Marathon and CASIO Computer Co. Ltd. were supported for this study.