EVALUATION OF RUNNING MECHANICS USING MOTION SENSOR FOR DISTANCE RUNNERS

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The purpose of this presentation is to show three cases of standard test to evaluate running motion on a 400m track, presenting the relationship of O2 consumption with the running motion at a treadmill test, and running motion during a distance race, and to discuss the effectiveness of motion sensor as a tool for training and coaching in running. These studies show that it might be useful to evaluate running motion by comparing running parameters of standard test to real race. Furthermore, the evaluation has a possibility to give criteria for training and a prediction of the race performance to a runner and a coach.

KEY WORDS: accelerometer, oxygen consumption, running motion, performance

INTRODUCTION: Running economy and mechanics are important factors in distance running performance for a wide range of distance. It has been studied using biomechanical methods (Williams and Cavanagh, 1987; Heise and Martin, 2001; Arellano and Kram, 2014). However, those studies have been done by separate measurements of O2 consumption and running mechanics measured only in one running cycle. It seems that running economy varies by individuals, running speed, fatigue and condition of the day. Motion sensor implemented with 3 dimensional accelerometer, gyro and geomagnetic sensors which has been developed to be small and sophisticated enough to attach to the body without obstructing human movement, which might be useful to measure running mechanics in practical use.

The specification of the motion sensor used in this study is shown in Table 1 and 2. It is small enough to attach to the body during running and designed to attach on top of the sacrum with running shorts or tights. Figure 1 shows a schematic example of a motion sensor attached to the body. Table 2 shows the dynamic range and sampling frequency of the sensor.

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Table 1
Size and weight of sensor

Item	
1. Size	41.5x55.3x9.55mm
2. Weight	31.7g

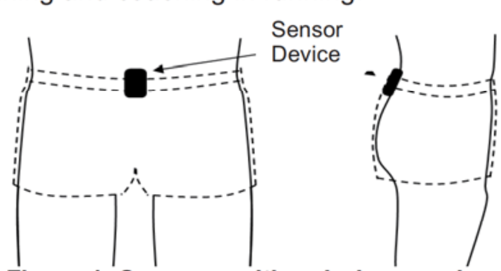

Figure 1: Sensor position during running

Table 2
Sensing specification

Item	Acceleration	Gyro	Magnetic
1. Dynamic range	+/-16g	+/-2000dps	+/-1.9gauss
2. Samplling frequency	200Hz	200Hz	16Hz

METHODS: The sensor can estimate running parameters, which are running cycle time, step frequency, contact time and vertical oscillation from raw data with the original developed software. Table 3 shows standard error and residual error for each parameter. They are compared with photo sensor (Optojump, Microgate) for cycle time, with motion analysis of video (Frame DIAS-V, DKH) for vertical oscillation and angle of the sensor, and with force platform (KISTLER) for contact time. Each error is calculated by following equations;

$$\textbf{Standard error} = \frac{\sum_{i=1}^{n}\left(\left|X_i - T_i\right|\right)}{n}$$

$$\textbf{Residual error} = \frac{\sum_{i=1}^{n}\left(X_i - T_i\right)}{n}$$

n **: Number of measurement sample**
Xi **: Reference data**
Ti **: Sensor estimate data**

Table 3
Running parameters

Item	Standard error	Residual error
1.Running cycle	3.25ms	-1.52ms
2.Angle of sensor Longitudinal axis	1.43°	1.18°
3.Angle of sensor Lateral axis	0.78°	0.30°
4.Vertical oscillation	0.36cm	-0.11cm
5.Contact time	5.61ms	-0.97ms

All parameters are evaluated as typical one cycle averaged from 10 cycles. Especially total impulse (TI, N/kg/min) is calculated by integration of acceleration during typical one cycle (N/kg) multiplied by cycle frequency (cycles/min).
At the treadmill test, the O2 consumption was measured in the last 30sec during 3min running. The running speed gradually increased from 3.4m/s to 5.5m/s during 5 or 6 times of treadmill running based on their lactate threshold (LT).
The standard test for evaluating running motion was designed to estimate training criteria for 5000m race. The subject runs seven sets each of 800m distance at a constant running speed. The running speed of each set was increased gradually between a short rest. Lactate threshold (LT) pace was set for 3rd round and race pace of target time was set for 5th round. If a subject set a goal of 14min 10sec for next 5000m race, the 400m pace of the test would be recommended at 92, 84, 76, 72, 68, 64, 60sec for each set of 800m.
At race measurement, the motion sensor was attached to the body of each subject and the parameters were measured in real races.

RESULTS & DISCUSSION: Figure 2 shows the relationship of VO2 with TI for typical subjects. It shows that there are high correlation coefficients in linear expression between VO2 and TI for all of the subjects. Several studies show that running economy is influenced by ground reaction force and movement of CG of the body. It is suggested that TI might be one of critical factor for individual running cost.

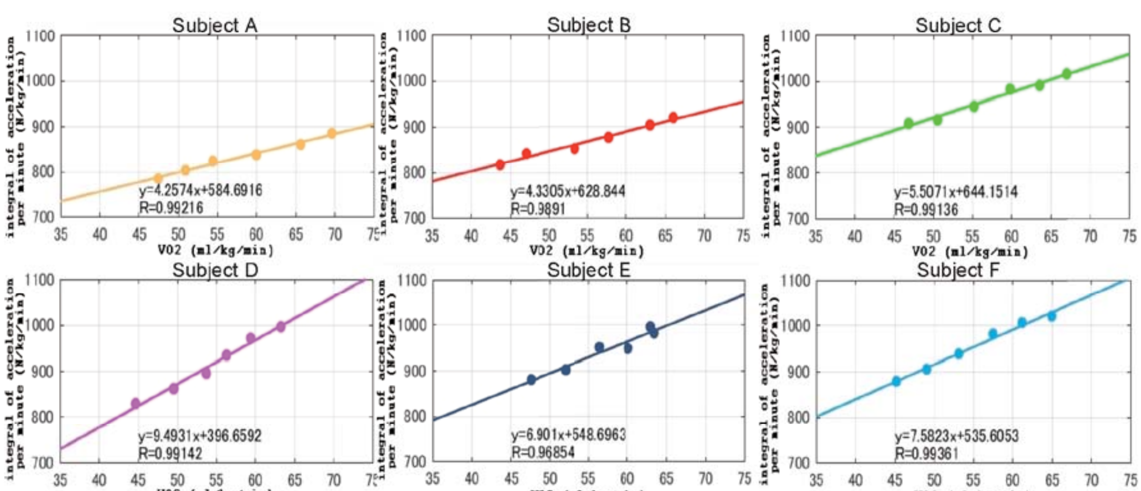

Figure 2. VO2 vs Integral of acceleration per minute

From the result of the standard running test, Figure3 shows changes in running parameters to running speed for typical subjects. It shows linear increase in step frequency and step length to running speed but decrease in vertical oscillation. Inter individual variability of TI was greater than other parameters. The recent 5000m race results of these subjects were Subject A 14'33", B 14‘53", C 14‘58", D 15‘09", E 16‘13", and F 16‘35". Good runner shows smaller TI than poor runner at same speed. In spite of linear relationship tendencies of running speed and step length, in some cases support length and non-support length have inflective points around their race speed, and furthermore, there are rapid increases of TI around the race speed on several subjects. It implies that those inflection points might be recognized as threshold for estimating race pace from running motion and the possibility to improve the running performance.

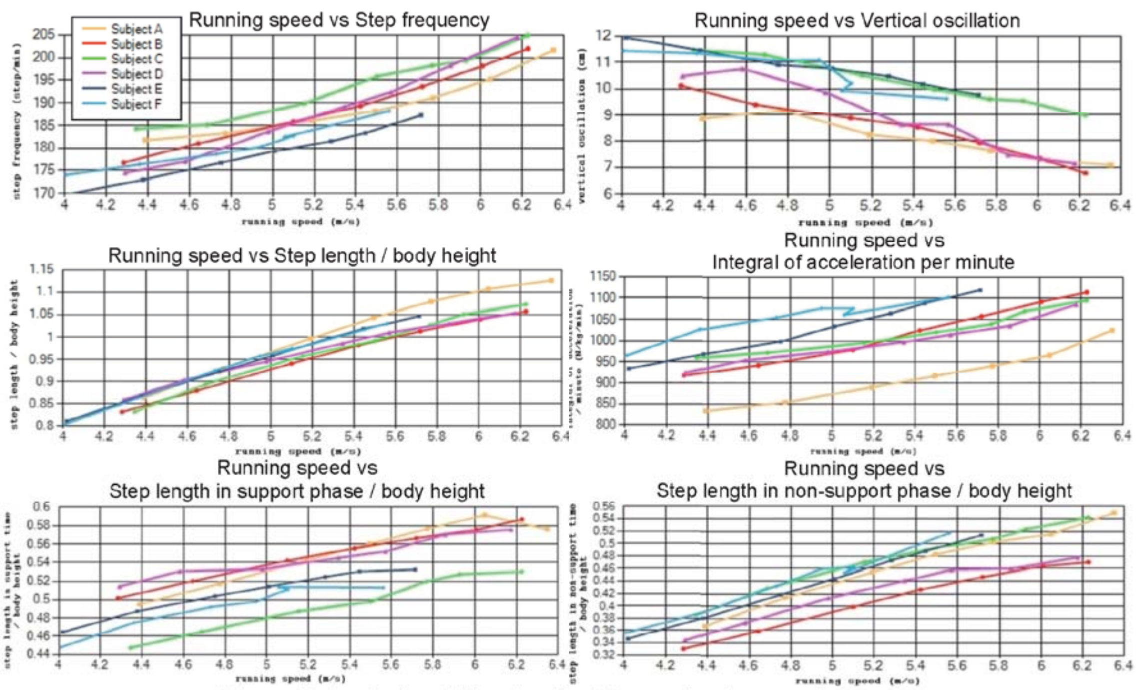

Figure 3. Analysis of Standard test for evaluating running motion

Figure 4 shows an example of changes in running speed and step frequency to distance during a race for a typical subject. The running speed decreased at 3800m and finished in 14min 33sec.

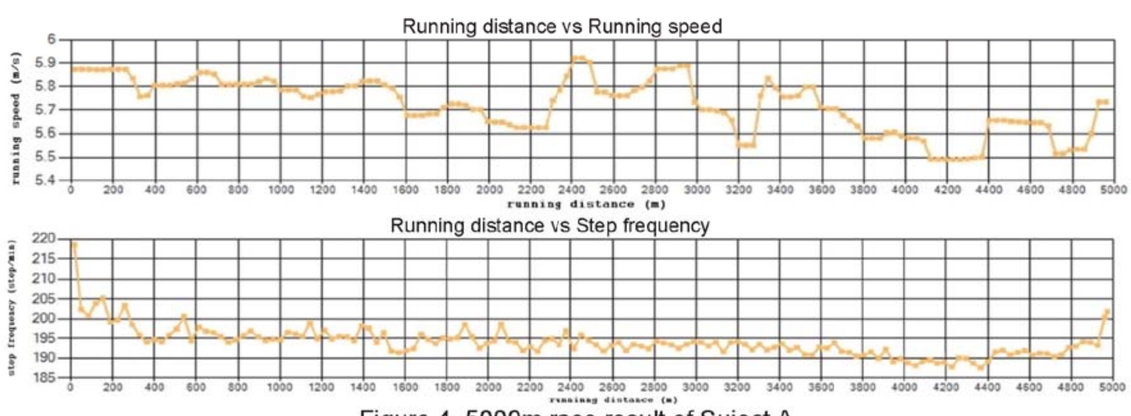

Figure 4. 5000m race result of Suject A

Figure 5 shows each running parameters against running speed. Black line indicates his average value in standard running test. Vertical oscillation and TI were greater than standard value from initial stage of the race. It is clear that step length in support phase normalized to the body height were greater in the last 1000m than the previous 4000m. It could be speculated that subject A ran in less efficient motion from the beginning of the race than usual and it caused fatigue in the latter half of the race, then running motion dramatically changed and running speed decreased at the end of the race. These results suggest that a series of analysis using motion sensor for the runner might be useful to evaluate what happened in the race and what can be done in the future training to prepare for the next race.

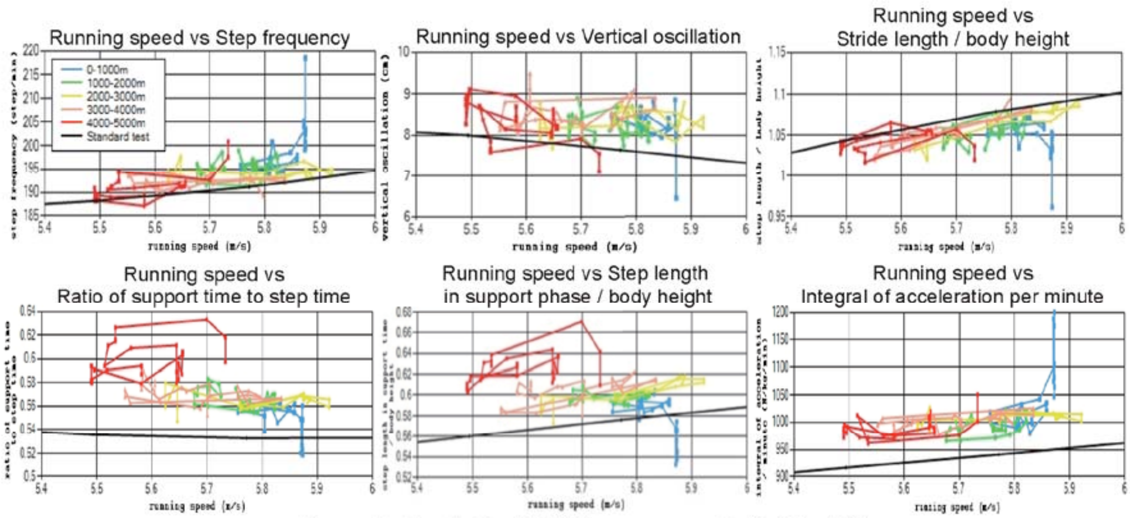

Figure 5. Analysis of 5000m race result (Subject A)

CONCLUSION:

The motion sensor developed to evaluate running motion has shown good availability for practical use. The step parameters are used to evaluate basic running mechanics with running speed and total impulse of the acceleration is one of the correlative factors to evaluate running economy for each runner. It might be necessary for standard running test and submaximal treadmill test to evaluate each runner by measuring running parameters before a race.

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