CHANGES IN RUNNING SPEED AND STEP VARIABLES MEASURED BY INERTIAL SENSORS DURING MARATHON

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This study quantified endurance performance for a wide range of running population by measuring running speed and step variables using inertial sensors during marathon. The total of ninety-one runners (71 males and 20 females) participated in this study and step variable data was measured by attaching inertial sensor, developed by Casio, at the sacrum. Runners were classified into sub-groups (3, 4, 5 & 6), based on race time. One-way RM ANOVA witnin sub-groups showed a significant decrease in running speed, step length, and vertical oscillation through the race but step frequency remained stable for most of the runners. The Sub 3 group showed high vertical stiffness in the initial stage of the race but significantly decreased throughout the race. Other groups showed significant decrease in running speed but no significant change in vertical stiffness. It might suggest that good runner could adjust vertical stiffness to keep optimal step length and running speed.

KEYWORDS: inertial sensor, marathon, vertical stiffness, step length, step frequency.

INTRODUCTION: Marathon is getting popular in Japan not only for competitive purpose but also for fun run. However, most of the runners have suffered from running injuries and difficulty of improving their running performance. It would be valuable to have suitable knowledge of running mechanics for a wide range of running performances during the marathon. There are few studies about running mechanics during marathon race, which have only conducted motion analysis on pre- and post the race (Morin et al. 2011) or at some points of the race (Chan-Roper, et al. 2012).

In recent technological advancements, small size, lower-power and high-performance inertial sensors have been developed which can be attached to the runners for performance evaluation during marathon. Otani et al. (2016) and Enomoto et al. (2017) has presented an accurate and precise inertial sensor, developed by 'Casio', to measure running motion of distance runners and to evaluate running technique. The sensor was attached to the sacrum of the runner to get biomechanical data during marathon race and post-processing of the motion data was done to determine running speed and step variables (step length, step frequency, vertical oscillation, and contact time).

Generally, we know that it is hard for the runner to keep efficient running pace during marathon due to fatigue. To achieve efficient pace, fatigue-resistance is developed by more frequent training and long-distance runs. This study hypothesized that suitable knowledge about running mechanics from the view point of step variables may be helpful in keeping efficient running speed along with traditional fatigue-resistance development training. There exist several studies in literature, examining the relationship between step variables and fatigue, but limited knowledge about the interaction of step variables to keep efficient running speed. We also don't know whether it is better for a runner to shorten contact time or not. Therefore, we conducted this study to get useful information about running technique to keep running speed with fatigue for a wide range of marathon population.

METHODS: Total of ninety-one runners (71 males and 20 females) were recruited from a group of the training program for the marathon race (mean± SD, range: age 38.4±13.6, 20 - 71 yrs.; 1.69±0.6 m, 1.55 – 1.85 m; 59.8±8.6 kg, 45 – 85 kg). Before the race, they were given enough information to understand the aim and risks of this study and written informed consent was obtained from all subjects. Subjects were also asked about their estimated marathon completion time before the start of the race.

The 'Casio sensing unit', we used, incorporated three sensors (triple-axis accelerometer, triple axis gyro, and triple-axis magnetometer) to give nine degrees of inertial measurement. The sensor had a compact size (41.5x55.3x9.5 mm), low weight (31.7 g) and was attached to the sacrum of the runner, using a clip with the running shorts or tights. The sampling frequency of 200 Hz was selected and inertial data was stored in the internal memory of the sensing unit. Running distance was calculated using the on-board GPS unit and was verified with the time and distance data by the sensor and the official time in each 5 km.
Running speed, step length (SL) and frequency (SF), contact time (t_c) and vertical oscillation (VO) were calculated using proprietary algorithms, developed by Casio, on inertial sensor data and are not disclosed here as per the protected rights. However, vertical stiffness was calculated by the following equations (Morin et al., 2005).

$$K_y = \frac{F_{\max}}{\Delta y}$$

$$F_{\max} = m.g.\frac{\pi}{2}.\left(\frac{t_f}{t_c} + 1\right)$$

$$\Delta y = \frac{F_{\max}.t_c^2}{m.\pi^2} + g.\frac{t_c^2}{8}$$

t_c: contact time, t_f: flight time, Δy: vertical displacement of the center of mass from foot contact to a minimum height, m: runner's mass, g: gravitational accerelation.
For statistical analysis, runners were classified in four sub-groups (sub 3, 4, 5 & 6), based on their marathon completion time. A one-way repeated measures ANOVA was used to determine significant difference in step variables within the sub-groups against completion distance of 8km, 22km and 36 km of the marathon race.

RESULTS: The mean time of marathon for all the subjects was 4 hr 1 min 43 sec ± 55 min 32 sec and it was ranged between 2 hr 18 min 6 sec and 5 hr 57 min 8 sec. Runners were classified by completion time which grouped 16 runners to 'sub 3', 28 runners to 'sub4', 34 runners to 'sub 5' and 13 runners to 'sub 6' groups.

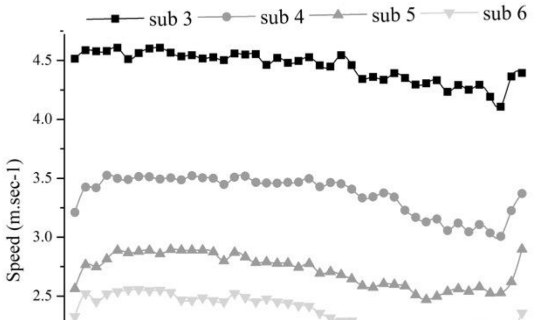

Figure 1: Changes in running speed for sub 3 to sub 6 groups during marathon.

Figure 1 showed changes in mean running speed of each 1 km run during marathon. The running speed of sub 3 was found to be greater than other groups until the end of the race. There was a significant decrease in running speed between 8 and 36 km for sub 3 and 4 and between 8 and 22 km for sub 5 and 6.
The selected runners were also classified into three groups (A, B & C), based on the running pace (ratio of the first half to the total time). The runners with a ratio above 0.49 were classified as group A (32 runners), the ratio between 0.46 to 0.49 were classified as group B (31 runners), and a ratio below 0.46 was classified as Group C (28 runners).
Table 1 shows the total number of runners in each classified group, based on time and pace. The result showed that in faster groups, more runners ran even pace. Such observation showed that better time of marathon was associated with better keeping pace.

Table 1: The number of runners for each group based on time and pace.

	A	B	C
Sub 3	11	2	3
Sub 4	12	11	5
Sub 5	9	16	9
Sub 6	0	2	11

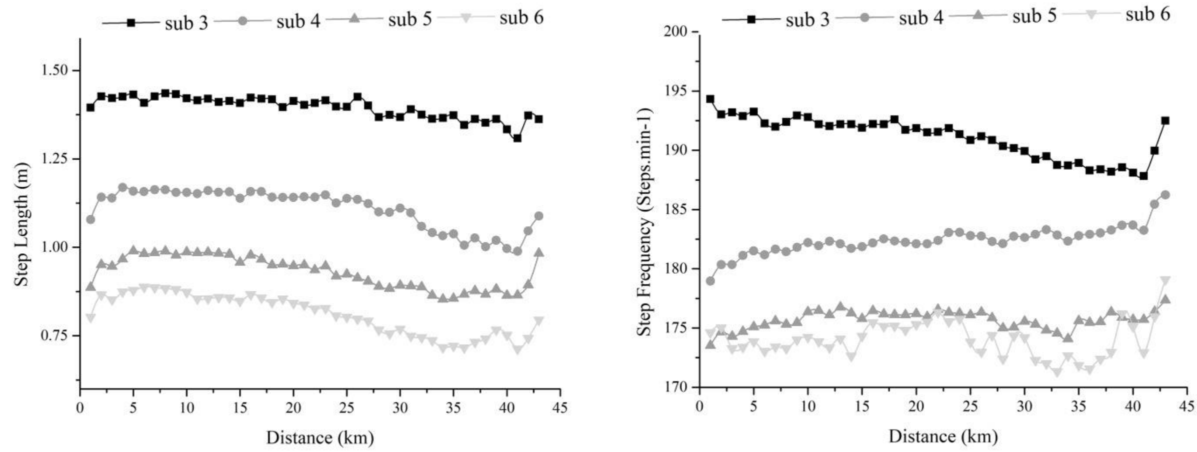

Figure 2: Changes in step length and step frequency for all groups.

Figure 2 showed changes in step length and step frequency for each group based on running distance during marathon. There was a tendency to keep step length but a significant decrease in step frequency for sub 3 was observed. Sub 4 showed a significant decrease in step length and slightly increased step frequency to keep running speed. Sub 5 and 6 show a significant decrease in step length and running speed but no significant changes in step frequency were observed.

Figure 3 showed vertical oscillation for each group. Sub 3 did not show higher values of it and no significant changes were observed until the end of the race. Sub 4 showed the higher value of it till 30km and were decreased after 30 km. Sub 6 showed a decrease in it after 20 km. Statistical analysis also reported that only significant changes in vertical oscillations were observed in sub 4, 5 and 6 groups in the later half of the race.

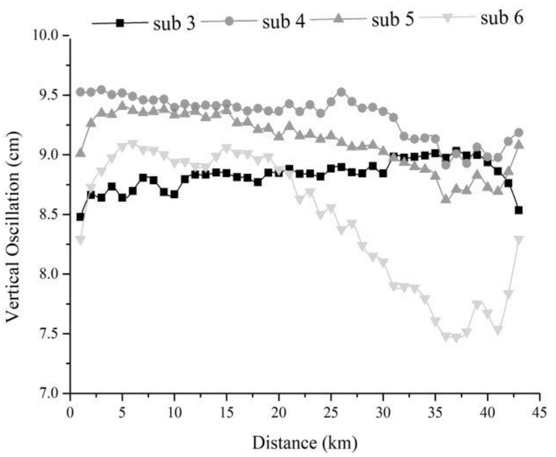

Figure 3: Changes in vertical oscillation for each group during marathon.

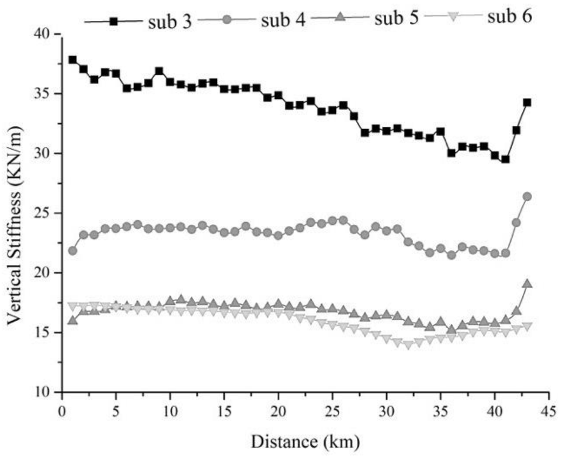

Figure 4: Changes in vertical stiffness for each group.

Figure 4 showed vertical stiffness for each sub-group. Sub 3 group showed relatively higher values of vertical stiffness than the other groups. It also showed a significant decrease in vertical stiffness through the race whereas other groups didn't show decrease in it.

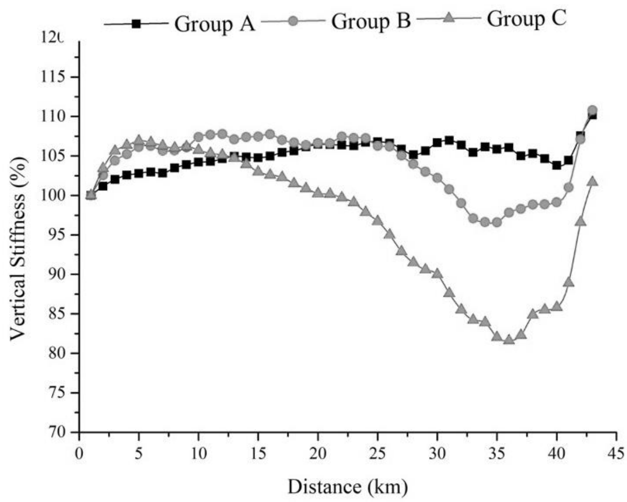

Figure 5: Normalized vertical stiffness for pacing groups

Figure 5 showed vertical stiffness for the group A, B, and C, normalized against initial 1 km. The results indicated no significant change in group A until the end of the race. Whereas group B and C showed an almost similar decrease in vertical stiffness through the race as of running speed.

DISCUSSION: Most of the sub 3 and sub 4 runners were in group A who kept the pace through the entire race. Whereas, most of the sub 5 and 6 runners were in group C who spent much time in latter half of the race. It is suggested that the better runners had an ability to keep speed through the entire marathon. While comparing the surveyed estimation time with actual marathon time, we found that those runners who could complete the race near their estimation time were able to keep running speed through the entire race. Sub 3 group showed greater running speed and step length but smaller vertical oscillation in the initial stage of the race and kept it throughout the race. Whereas other groups showed a simultaneous decrease in vertical oscillation with a decrease in running speed. Vertical stiffness of sub 3 was also found to decrease with the decrease in running speed. Whereas, other groups (4, 5 and 6) showed consistent vertical stiffness through the race despite the decrease in running speed. It might indicate that runners in sub 3 tend to utilize vertical stiffness effectively to keep optimal step length and running speed during the entire marathon. When vertical stiffness was observed in the pacing groups, Group A showed small non-significant variations throughout the race. Whereas group B and C showed the relatively high value of it in the initial stage which was found to decrease through the race. It might be suggested that stiffness adjustment to running speed is one of the key factors to keep running speed during a marathon.

CONCLUSION: This study showed evidence of the importance of pacing for a marathon for a wide range of performances. To acquire running speed effectively, a runner should run with suitable vertical stiffness. If a runner has high vertical stiffness even at low speed or keeps it despite the decrease in speed, it might lead to fatigue and decrease in running speed.

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