（財）日本陸上競技連盟
陸上競技研究紀要
第５巻, 102-106, 2009

Bulletin of Studies
in Athletics of JAAF
Vol.5,102-106,2009

Biomechanical analysis of the world's top distance runners of the 10,000 m final in the Osaka 2007 11th IAAF World Championships in Athletics

Yasushi Enomoto[1], Hirosuke Kadono[2], Yuta Suzuki[2], Tetsu Chiba[1], Keiji Koyama[3]
1) Kyoto University of Education), 2) University of Tsukuba 3), Juntendo University

Abstract

The purpose of this study was to reveal the biomechanical characteristics of running motion for the world's top distance runners in the men's 10000 m final at Osaka IAAF World Championships in Athletics. Bekele showed greater mean power and smaller effectiveness of mechanical energy utilization to running velocity, however increased in effectiveness at the latter of the race. Maximum, minimum and range of the thigh and shank angle showed the difference between the runners but did not change greatly throughout the race. Maximal thigh angular velocity of the recovery leg increased for Bekele, which might be critical motion for distance runners. The world's top distance runners showed a slight change of running motion and few fatigue symptoms. Even a distance runner must perform like a sprinter; it might be necessary to maintain high running speed during a race and spurt at the end. This is not only to utilize mechanical energy efficiently but also to generate more mechanical energy.

Introduction

It is an important task for success in distance running to maintain running speed over an entire race distance, however it was not unusual in those races for the winner and second place to be separated by a second. Therefore race management became a very important factor. The gold medalist not only maintained a high running speed, but in the recent distance races of the World Championships and Olympic Games the champion used two highly effective strategies: (1) changing running speed intentionally throughout the race to cause rivals to waste energy; (2) spurting sharply on the last lap like a sprinter.

From an energetic view point, both the increase in energy generation and effective utilization of energy to running velocity would be critical factors to performance of distance runners. Physiological studies have revealed the relationship of the physiological factors such as VO2max, lactate threshold and running economy to distance running performance. However, runners were evaluated by VO2max and running economy in running on a treadmill in a laboratory. Biomechanical study indicated the direct relationship of running motion to the performance in the race. Enomoto et al. (1997) suggested that the elite distance runners showed higher effectiveness of mechanical energy utilization to running velocity in a running cycle.

One of the most interesting factors about distance runners is how they sustain and manage to maintain running speed against fatigue. Elliot and Ackland (1981) showed a few kinematic variables changing during the race as a result of fatigue. Williams et al. (1991) suggested that change in running motion due to fatigue is different by individuals. However, there are few studies about changes in running motion for the world's top distance runners during the race. A study analyzing the change in running motion during the race might give useful information about the running techniques of the world's top distance runners and a new insight into training for distance runners from biomechanical viewpoint.

The purpose of this study was to reveal the biomechanical characteristics of running motion for the world's top distance runners in the men's 10000 m final at Osaka World Championships in Athletics.

Table 1 Split and lap time at each 1000m in the race.

	1. Kenenisa Bekele (ETH)		2. Sileshi Sihine (ETH)		3. Martin Irungu Mathathi (KEN)	
Distance	Split time	Lap time	Split time	Lap time	Split time	Lap time
1000	2 : 44.36		2 : 44.53		2 : 45.38	
2000	5 : 27.61	2 : 43.25	5 : 27.79	2 : 43.26	5 : 28.19	2 : 42.81
3000	8 : 13.59	2 : 45.98	8 : 13.79	2 : 46.00	8 : 14.04	2 : 45.85
4000	10 : 58.21	2 : 44.61	10 : 58.36	2 : 44.56	10 : 58.36	2 : 44.31
5000	13 : 43.41	2 : 45.20	13 : 43.62	2 : 45.27	13 : 43.76	2 : 45.40
6000	16 : 29.22	2 : 45.82	16 : 29.39	2 : 45.77	16 : 29.52	2 : 45.77
7000	19 : 13.07	2 : 43.85	19 : 13.32	2 : 43.93	19 : 13.37	2 : 43.85
8000	21 : 55.20	2 : 42.13	21 : 55.42	2 : 42.10	21 : 55.53	2 : 42.16
9000	24 : 35.79	2 : 40.59	24 : 35.96	2 : 40.54	24 : 35.54	2 : 40.01
10000	27 : 05.90	2 : 30.11	27 : 09.03	2 : 33.07	27 : 12.17	2 : 36.63

Methods

We videotaped the runners at a fixed area on the backstretch in the men's 10000 m final in Osaka World Championships in Athletics using two digital video cameras (60 Hz) from side and front views of a runner. Another video camera was videotaped following the top group from the start to the goal to calculate the split time of each 100 m. The first place finisher of the race was Kenenisa Bekele (ETH) who is the world record holder of 10000 m, the second place finisher was Sileshi Sihine (ETH), the third place finisher was Martin Irungu Mathathi (KEN), whose height, body mass, best time of 10,000 m were 1.60 m, 54 kg, 26:17.53 for Bekele, 1.71 m, 55 kg, 26:39.69 for Sihine, 1.67 m, 52 kg, 27:08.42 for Mathathi, respectively. Running speed and step frequency were derived from the lap time of each 100 m and average time of a cycle (two steps) in each 100 m and step length was divided running speed by step frequency. Running motion of the top three runners were analyzed during a running cycle at the 600 m (stage 1), 3800 m (stage 2), 6200 m (stage 3), 8200 m (stage 4) and 9400 m (stage 5) marks using the three-dimensional motion analysis technique. After calculation of three dimensional coordinates and smoothing the coordinate data using digital Butterworth filter, the center of gravity of the body, angles and angular velocities of the segments and joints of lower limbs, mechanical energy of whole body were calculated. Effectiveness index of mechanical energy utilization to running velocity was calculated by horizontal translational mechanical energy of the body divided by mechanical work in a cycle (Enomoto et al., 1997), which was calculated by sum of energy change of each segment in each time interval (Metzler et al., 2002).

Results & Discussion

Table 1 shows the split and lap time for top three at each 1000 m during the race. Each 1000 m lap times from the start to 9000 m were almost same. There was a small difference between three runners in the last 1000 m, although no difference was found between them until the 9000 m mark. The goal time of the winner was the sixteenth fastest time (his season best time at that time) in 2007 despite the high temperature and humidity (30 degree, 65 %) in Osaka that night.

Figure 1 shows the running speed, step frequency and step length in each 400 m for the top three. Running speed of the top three was almost same until last three laps, while they suddenly sped up around 8800 m mark and time of the final lap were 55.51 s of Bekele, 58.66 s of Sihine and 62.16 s of Mathathi. Bekele was behind Mathathi and Sihine and eemed to exhaust energy before the final lap, but he sped up dramatically and left others behind. There was also no change in step frequency and step length until 9000 m. Elliot and Ackland (1981) showed that the decrease in running velocity caused by decrease in step length, while Williams et al. (1991) showed the increase in step length with fatigue eliminating an effect of running speed. Furthermore, the data of this race showed no significant change in the support time (average of right and left foot) during the race. It seems that the top three runners accomplished their best as if they were not fatigued throughout the race

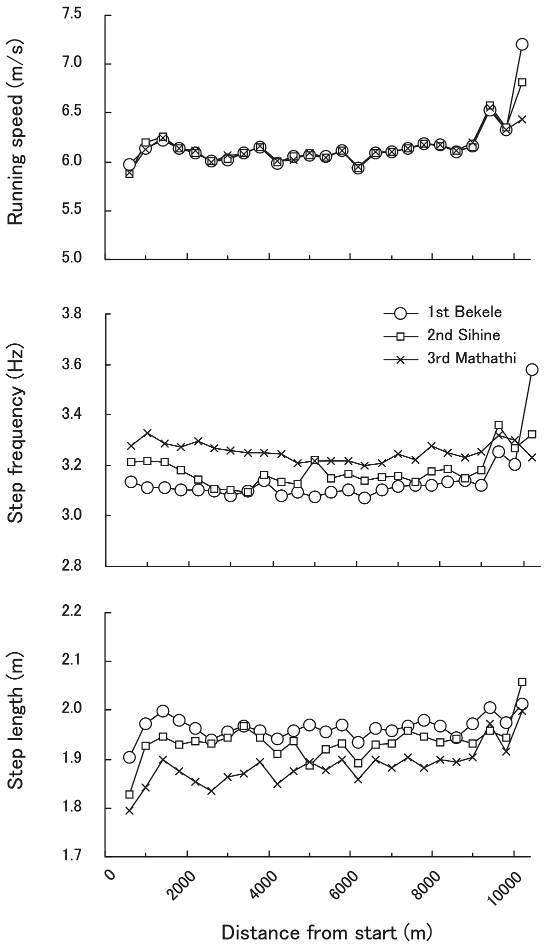

Figure 1 Running speed, step frequency and step length for top three in each 400 m during the race

despite the hot muggy conditions.

Bekele showed small step frequency and large step length during the race, conversely Methathi showed large step frequency ansmall step length. Their average step lengths to body height during the race were 1.23, 1.13 and 1.13 for Bekele, Sihine and Mathathi, respectively. Bekele increased running speed by increasing in step frequency largely at the final lap. Correlation coefficients of running speed to step frequency and step length were 0.904 and 0.662 for Bekele, 0.753 and 0.492 for Sihine, and 0.377 and 0.717 for Mathathi. These results suggested that Bekele could maintain large step length during the race and change in running speed by change in step frequency, especially at last spurt.

Figure 2 shows changes in the effectiveness index of mechanical energy utilization to running velocity (EI) and mechanical power which was calculated to divide mechanical work by cycle time of top three from stage 1 to 5. EI of Bekele was smaller than the others at stage 1, then increase at stage 3 and 5. EI of Sihine and Mathathi were greater than Bekele at stage 1, but Sihine decreased

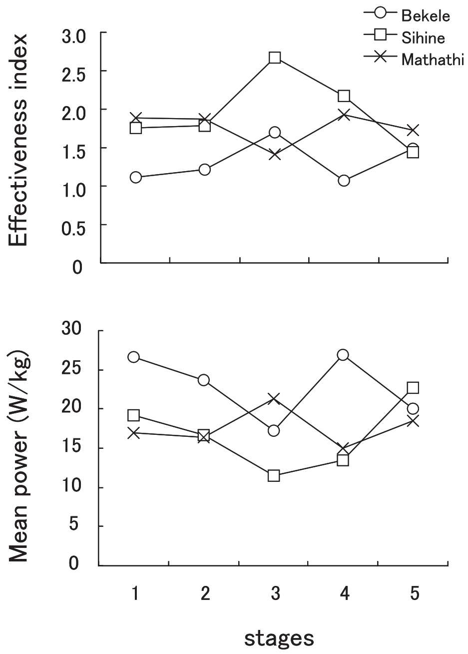

Figure 2 Changes in effectiveness index of mechanical energy and mean power of top three at each stage in the race.

in EI from stage4 to 5. Mathathi maintained EI through the race. Mean power of them doesn't show consistent change through the race. Bekele's mean power was greater than the others at stage 1 and 2. These results suggest that running motion of Bekele expended more energy but he can increased in effectiveness to maintain the running velocity and speed up at the end of the race. Mathathi may have good running technique to utilize mechanical energy effectively although he can not output more energy to speed up more at end of the race.

Figure 3 shows the changes in the maximal and minimum thigh and shank angles at each stage for the top three. Thigh and shank angle was defined as angle to the vertical (counter-clockwise is positive). Positive means swinging to the front of the body and negative means backward. The lengths of each bar indicate the range of motion of thigh and shank. The range of shank movement for Bekele was greater than the others, although the range of thigh movement for Mathathi was greater than the others from stage 1 to 5. All three runners showed minor changes in maximal and minimum angles of thigh and shank. Maximal thigh angle and the range of movement of the thigh for Mathathi gradually increased, while those of Bekele and Sihine didn't change. Maximal and minimum shank angles were maintained for Bekele but decreased for Sihine and

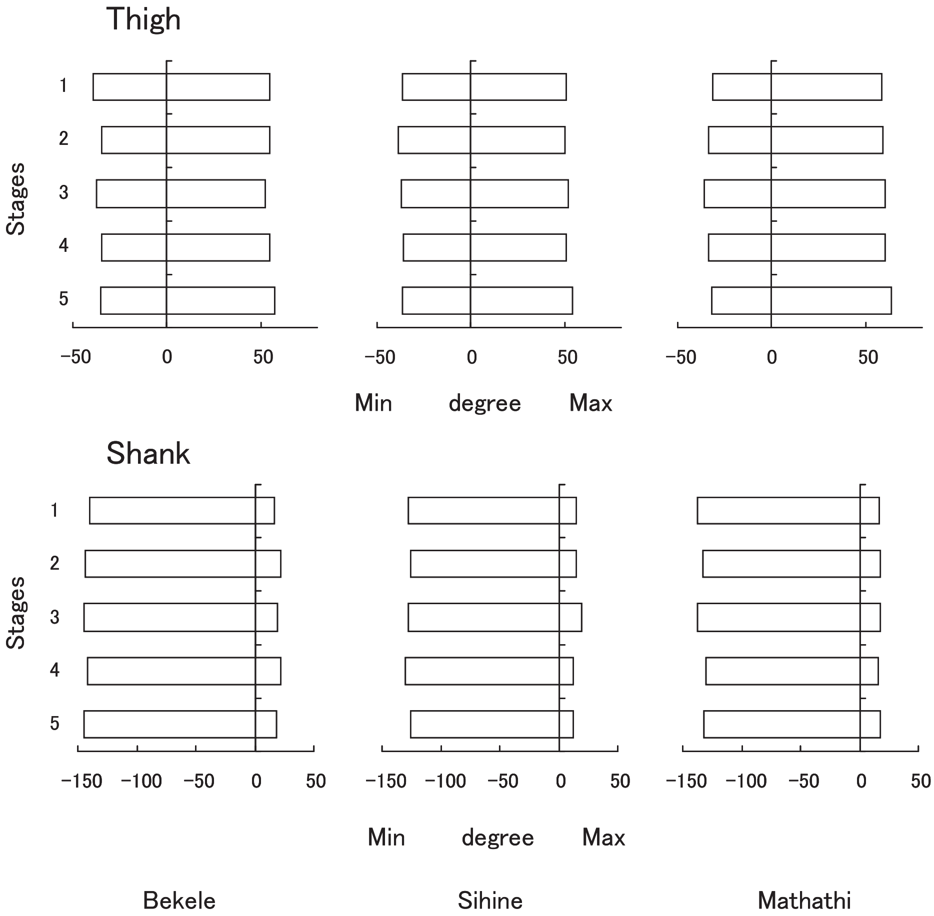

Figure 3 Maximum and minimum angles of the thigh and shank for the top three runners at each stage in the race.

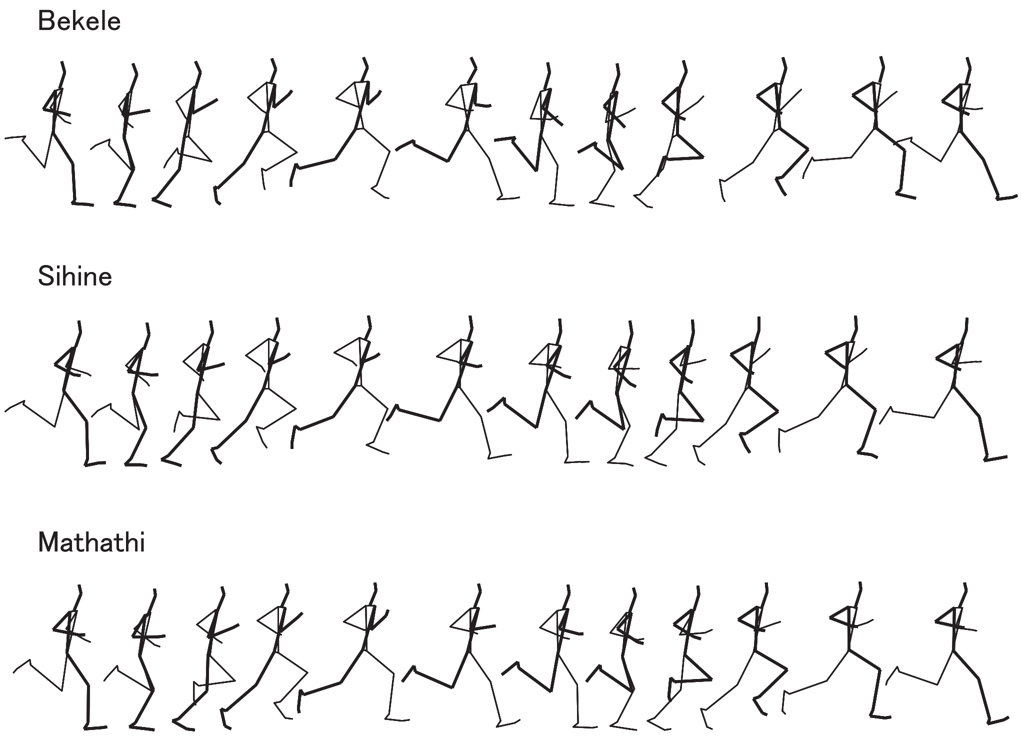

Figure 4 Stick pictures of the top three runners at 8200m mark (stage 4) in the race.

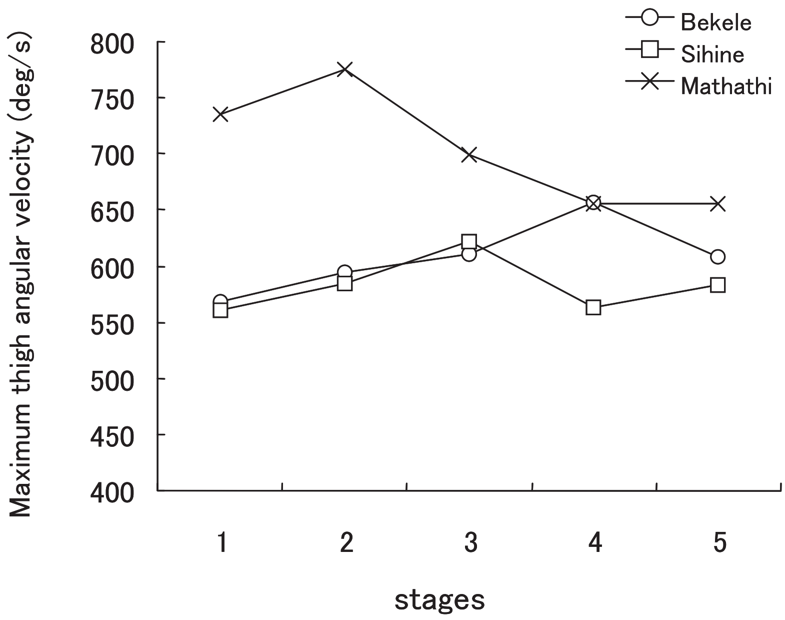

Figure 5 Change in maximum thigh angular velocity of top three runners at each stage in the race.

Mathathi.

Figure 4 shows stick pictures of the top three runners at 8200 m mark (stage 4) in the race. Thin lines indicate the left side. Bekele shows that his shank was pulled up to the thigh greatly in early recovery phase with the consequence of the decrease in minimum knee angle, and then swung forward greatly before the foot strike.

Figure 5 shows changes in maximum thigh angular velocity (MTAV) of the top three runners at each stage in the race. At stage 1 and 2 Mathathi showed greater MTAV than the others. Bekele showed the increase in MTAV gradually from stage 1 to 4. These results imply that Bekele maintain the forward swing velocity of the thigh as a result of the control on the shank motion, which might be characteristic for Bekele. Enomoto and Ae (2005) suggested that Kenyan runners swung the thigh forward faster due to flexing the knee of the recovery leg greatly. These suggested that forward swing of thigh is an important motion for distance runners.

In conclusion, the world’s top distance runners show a slight change of running motion and few fatigue symptoms. The characteristic of Bekele’s running motion was greater shank motion, which would need to expend more mechanical energy.

Like a sprinters, it might be necessary for distance runners to maintain high running speed during a race and to spurt at the end of a race to not only utilize mechanical energy efficiently but also to generate more mechanical energy.

References

Elliot B, Ackland T, Biomechanical effect of fatigue on 10000 meter running technique, Research Quarterly for Exercise and Sport, 1981; 52 (2): 160-166.

Enomoto Y, Ae M, Fujii N, Okada H, Running technique in long distance running and the effectiveness of mechanical energy utilization, Japanese Journal of Biomechanics in Sports and Exercise, 1997; 3 (1): 12-19.

Enomoto Y, Ae M, A biomechanical comparison of Kenyan and Japanese elite long distance runner's techniques, Book of abstract XXth Congress of the International Society of Biomechanics. No.852, 2005.

Williams KR, Snow R, Agruss R, Changes in distance running kinematics with fatigue, International Journal of Sport Biomechanics, 1991; 7: 138-162.

Metzler V, Arampatzis A, Brüggeman GP, Influence of 2D and 3D body segment models on energy calculations during kinematic analysis of running, European Journal of Applied Physiology, 2002; 86: 337-341.