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Comparison of the Pace Pattern for the World and Japanese Elite 1500 m Runners

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Abstract

Purpose: In order to identify the difficulties with the race patterns of Japanese elite runners, race patterns of world-class runners and those of Japanese elite runners were compared using running speed, stride frequency, stride length, flight time, contact time, and body center of mass in a 1500 m race. **Methods:** During the race, 18 male runners in the 1500 m race in official competitions were videotaped using video cameras at a sampling rate of 60 Hz (World Athletics Championships, Japanese Athletics Championships, and All Japan Inter-University Track & Field Championships, Finals). The average running speed, stride length and frequency, contact time, flight time, and the center of mass (Δy) were calculated for every 100 m by reading the video frames. **Results:** 1) World runners have a higher average speed ($p=0.06$), stride length ($p<0.01$), contact time ($p<0.01$), and body center of mass displacement ($p<0.05$) than Japanese runners, and Japanese runners have a higher average stride frequency ($p=0.16$) and flight time ($p=0.40$). 2) Divide the 1500 m distance into three sections (L1: 0-500 m, L2: 500-1000 m, L3: 1000-1500 m). The speed, stride frequency, and stride length of the two groups are L3>L2>L1, flight time is L1> L2> L3, the center of mass displacement is L1> L2> L3, and world runners contact time is the largest in the L1 section (L1>L2>L3), whereas the Japanese runners contact time is largest in the L2 section (L2>L1>L3). 3) The relationship between mechanical variables and the running speed of the World and Japanese runners was analyzed. Except for the Japanese runners' stride length and speed with no significant correlation ($r=0.428$, $p=0.112$), the speed of the two groups of runners had a significant positive correlation with stride frequency, stride length ($p<0.01$), and a significant negative correlation with the contact time, flight time, and body center of mass displacement ($p<0.01$). **Conclusions:** This study examined the World and Japanese 1500 m pacing profiles and found distinct 1500 m pacing profiles for world (Slow-Fast) runners and Japanese runners (Fast-Slow-Fast). Improving the initial speed and sprint performance of the race, as well as increasing stride length, have become critical issues for Japanese runners to overcome in the future.

Keywords

1500 m, Running speed, Pace pattern, Japanese and world runner

1. Introduction

The 1500m race is an official track event and a middle-distance race. Runners compete over three-and-three-quarter laps of a 400 m track. The performance of Japanese athletes in the 1500 m has recently been improved. However, compared with the world level, Hicham El Guerrouj set the world record of 3:26.00 in Rome in 1998, and

Genzebe Dibaba set the world record of 3:50.07 in Monaco in 2015, while Japanese 1500 m records are still far behind. It can be said that setting the record of 1500 m is a critical topic in Japanese athletics The JAAF has been researching running speed, stride frequency, and stride length for the official 1500 m races since the World Championships in Athletics in 1991 (Enomoto et al., 2005). During the men's 1500 m race at the 1992 World Championships in Athletics (Tokyo), Mtsuo et al. (1992) filmed and investigated the changes in running speed, stride frequency, and stride length in every 100 m of the race. It has been suggested that the change in stride frequency plays a vital role in the 1500 m running speed of world elite runners. Hanley et al. (2019) investigated the successful pacing profiles of Olympic and IAAF World Championship middle-distance runners in qualifying rounds and finals. They stated that the speed generally characterizes a successful 1500 m runner in the final 200 m, not by speeding up but by avoiding slowing down, and that they usually use J-shaped pacing in 1500 m races.

For the 1500 m race, most research focuses on physiological studies of athlete performance (Aragón et al., 2016). Among them, Ferri et al. (2011) concluded that both the maximal capacity of muscle to extract O_2 from the blood and the end-exercise blood lactate accumulation are important predictors of best performance in a 1500m run. Even the race analysis across the middle-distance running literature is always focused on the final surge of the race, indicating that the speed generally characterizes a successful 1500 m runner in the final 200m, not by speeding up but by avoiding slowing down (Thiel et al., 2012; Mytton et al., 2015; Aragón et al., 2016; Casado & Renfree, 2018; Hanley & Hettinga, 2018). However, to improve the performance of the 1500 m race, it is necessary to pay attention to the final surge and analyze the whole of the race. Many race analyses have previously discussed pace strategies that focused on running speed, but it is now necessary to consider kinematic factors that affect pace. In terms of the relationships between kinematic factors and running performance, the two variables that demonstrated the strongest correlations, regardless of gender, were ground contact time and stride rate. Previously, Matsuo et al. (1992), and Enomoto et al. (2006) divided 1500 m into 100 m sections and analyzed running speed, stride frequency, and stride length, but the contact time, flight time, and body center of mass are considered to be mechanical factors affecting pace, are not investigated.

In order to identify the difficulties of the race patterns of Japanese elite runners, which helps boost and improve the 1500 m performance of Japanese runners, the world-class male 1500 m run is compared with the Japanese elite male runners. Running speed, stride frequency, stride length, flight time, contact time, and body center of mass are examined in this study for both International and Japanese runners.

2. Methods

2.1 Participants

The male 1500 m at 2007, 2011, and 2019 World Athletics Championships (n=9) and 2019, 2020 Japanese Athletics Championships and All Japan Inter-University Track & Field Championships (n=9) were the objective analysis of this study. The runners were divided into two groups for each competition, organized by the JAAF and IAAF. Table 1 depicts the details of group information.

Table 1. Characteristics of runners in each group

Groups	age	0-400m	400-800m	800-1200m	1200-1500m	race time
World runners (n=9)	25.40±4.22	59.21±1.70s	59.81±1.57s	56.32±0.89s**	39.42±0.75s**	3.34:44±2.01s**
Japanese runners(n=9)	23.90±3.18	60.37±1.75s	60.24±1.05s	59.44±2.07s	42.00±1.57s	3.42:06±1.51s

(Mean±S.D.) * $p<0.05$: ** $p<0.01$.

2.2 Video shooting of 1500m race

It was planned to use two digital video cameras to capture the runner from the top of the building by the side of the track (Fig.1) (Kadono et al., 2008). The shooting speed was 59.94 fps, and the shutter speed was 1/60 s when shooting with a flash gun, and 1/500-1/1000 s after starting. It is recorded in MP4 format, and video analysis software reads the frame size to calculate the elapsed time and the average running speed at 100 m intervals.

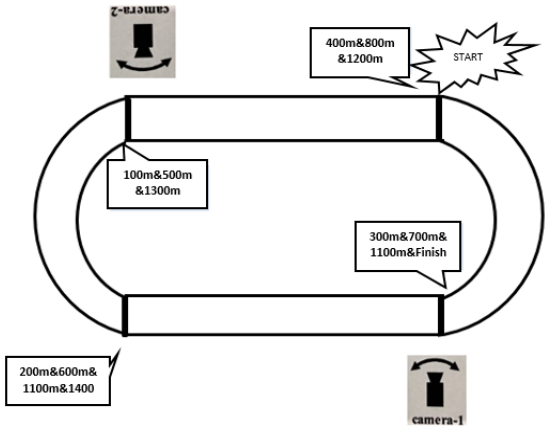

Figure 1. Section division for 1500 m race.

2.3 Calculation of variables

(1) Speed

Read the time (1/100 s) for every 100 m section from the digital video, and substitute the time for each section into Equation (1), and the speed of every 100 m section was calculated as follows:

$$\text{Speed} = \frac{100}{\text{T}} \tag{1}$$

(2) Stride frequency (SF) and Stride length (SL)

The SF for each 100 m section was calculated by reading the time required for ten steps in the 100 m section from the video and substituting it into Equation (2). The SL for each 100 m section was calculated by substituting the running speed and SF of each section obtained from Equation (1) and Equation (2) into Equation (3).

$$\text{SF} = \frac{10}{10\text{steps time}} \tag{2}$$

$$\text{SL} = \frac{\text{Speed}}{\text{SF}} \tag{3}$$

(3) Contact time (CT) and Flight time (FT)

The CT and FT for each 100 m section were calculated by reading the video frames required for ten steps in the 100 m section from the video. The shooting speed was 59.94 fps. FI is the instantaneous frame number when the foot contacts the ground, and FO is the instantaneous frame number when the foot leaves the ground. It can be obtained through Equation (4) as follows:

$$\text{CT} = \frac{\text{FI} - \text{FO}}{59.94} \text{ or } \text{FT} = \frac{\text{FO} - \text{FI}}{59.94} \tag{4}$$

(4) Body center of mass (ΔY)

Based on Carrard et al. (2018), Morin et al. (2005), McMahon and Cheng (1990) showed that the body center of mass could be calculated using the contact time and flight time, as shown below:

$$\Delta y = \left| -\frac{g\pi TF + g\pi TC}{2TC} * \frac{TC^2}{\pi^2} + g * \frac{TC^2}{8} \right| \tag{5}$$

(5) Rate of running speed change (%)

The rate of change is how about changed from before to after section. (S1-2:0–100 m-100–200 m; S2-3:100-200 m-200–300 m.....S14-15:1300–1400 m-1400–1500 m) (Kadono et al., 2008). It can be obtained in Equation (6).

$$\text{Rate of speed change}(\%) = \left(1 - \frac{Thevariablebeforesection}{Thevariableaftersection}\right) * 100 \tag{6}$$

2.4 Statistical analysis

Statistical analysis included descriptive statistics where the results were expressed as the mean±standard deviation (±SD). The significance of differences between the group was tested by t-test for independent samples. Pearson coefficient is used to analyze the correlation between running speed and various factors. The statistically significant level was set at 5%.

3. Results

It can be seen that the average speed of the international men's 1500 m run (7.01±039 m/s) is higher than the average speed of the Japanese men's 1500 m run (6.77±0.23 m/s), and there is no difference between the two groups' average speeds (p=0.06). The Japanese runners stride frequency (3.41±0.10 steps/s) is higher than the global average (3.35±0.13 steps/s), but there is no statistically significant difference between the two groups' average stride frequencies (p=0.16). The average stride length of the two groups is significantly different (p <0.01), with the world runners (2.10±0.05 m) having a longer stride than the Japanese runners (1.99±0.03 m). The contact time of the world runners (0.150±0.006 s) was longer than Japanese players (0.144±0.003 s), and significant differences were observed between the groups (p <0.01). Japanese runners (0.151±0.005 s) were longer than the world runners (0.149±0.006 s) in flight time, and there was no significant difference between the two groups (p=0.40). In terms of body center of mass displacement, world runners (0.043±0.003 m) are larger than Japanese runners (0.040±0.002 m, where a significant difference was observed between the two groups (p <0.05).

The 1500 m was divided into three sections, L1: 0–500 m, L2: 500–1000 m, and L3: 1000–1500 m (Table 2). Both groups have the highest speed in the third section (L3>L2>L1), based on the speed of the three sections. The world runners are faster than the Japanese runners in all three sections. In the L3 section, there is a significant difference between the two groups of runners (p <0.05). Regarding stride frequency, the Japanese runners are faster in each section than the world runners, with the L3 section being the largest (L3>L2>L1). The two groups of runners showed significant differences in the L2 section (p <0.05). Regarding stride length, the world runners in the three sections are larger than the Japanese runners, with both groups having the largest strides in the L3 interval (L3>L2>L1). The two groups of runners showed significant differences in the three sections (p <0.01). In terms of contact time, the world runners are longer than the Japanese runners. Among them, world runners contact time is largest in the L1 section (L1>L2>L3), and the Japanese runners have the longest contact time in the L2 section (L2>L1>L3). There were significant differences between the two groups of runners in the L1 and L2 intervals. Japanese runners have a longer flight time than world players in all three sections, and the L1 section (L1>L2>L3) has the longest flight time of the two groups. There is no significant difference in the flight time within the three sections. In all three sections, world runners have a larger body center of mass displacement (Δy) than Japanese runners. From the point of view of the center of mass displacement distribution, the two groups have the largest proportion in the first section (L1>L2>L3). The two groups significantly differ in the L1 and L2 sections (p <0.05).

Table 2. Running speed and mechanical variables in each section

Section	L1(0-500m)		L2(500-1000m)		L3(1000-1500m)	
	World	Japanese	World	Japanese	World	Japanese
Speed(m/s)	6.75(0.24)	6.64(0.08)	6.81 (0.20)	6.70(0.16)	7.48 (0.20)	6.99 (0.23)*
SF(steps/s)	3.27(0.10)	3.36(0.03)	3.29(0.05)	3.37(0.05)*	3.48 (0.09)	3.51(0.12)
SL(m)	2.07 (0.03)	1.98(0.03)**	2.07(0.03)	1.99 (0.03)**	2.15(0.02)	1.99(0.01)**
CT(s)	0.154(0.001)	0.144(0.001)*	0.153(0.002)	0.146(0.002)**	0.144(0.003)	0.141(0.005)
FT(s)	0.153(0.004)	0.155(0.002)	0.151(0.002)	0.153(0.003)	0.144(0.005)	0.146(0.005)
Δy(m)	0.045(0.003)	0.042(0.001)*	0.044(0.001)	0.041(0.001)*	0.039(0.001)	0.039(0.003)
%Speed	96.19 (3.36)	98.02(1.25)	97.22(2.91)	98.86(2.37)	106.59(2.90)	103.12(3.40)
%SF	97.56 (2.96)	98.35(0.94)	98.32(1.49)	98.84(1.37)	104.11(2.70)	102.80(3.59)
%SL	98.65 (1.21)	99.66(1.73)	98.90(1.60)	100.01(1.38)	102.45(1.03)	100.33(0.74)*
%CT	102.27(4.28)	100.39(1.27)	101.91(1.87)	101.45(1.37)	95.81(1.98)	98.16(3.20)
%FT	102.65(2.37)	102.48(1.25)	101.17(1.37)	101.07(1.90)	96.17(3.30)	96.46(3.61)
%Δy	104.88(6.30)	102.75(1.87)	103.10(3.14)	102.23(2.62)	92.03(4.67)	95.02(6.41)

Mean±(S.D.). * p <0.05; **p <0.01.

Fig. 2 depicts the changes in the running speed during the 1500 m race for the two groups. Except for 300 and 400 m, the world runners are faster than the Japanese runners. Among them, there was no significant difference between the 400–1000 m in the two groups. There was a substantial difference between the two groups in the 300 m before the start and the last 500 m ($p < 0.05$). Especially after 500 meters, the Japanese runners are slower than the world runners. Fig. 3 shows the rate of running speed change during the 1500 m race for the two groups. A positive value indicates acceleration, while a negative value indicates deceleration. After the start of the world runners, the deceleration was more prominent in the S1-2, S2-3, and S9-10 sections. The acceleration of S10-11 and S11-12 is more visible. The Japanese runners decelerated significantly during the S9-10 section in the middle of the race, and the final sprint showed a significant acceleration in the S12–13 and S13–14 sections.

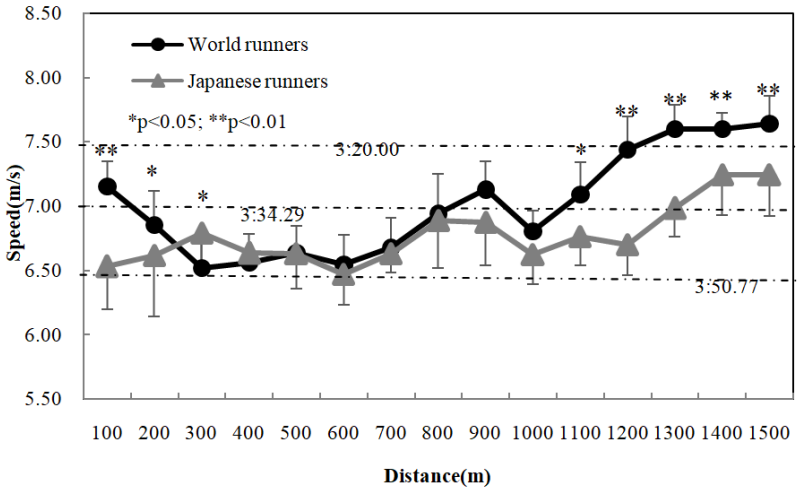

Figure 2. Changes in the running speed for the World and Japanese elite runners during the 1500 m.

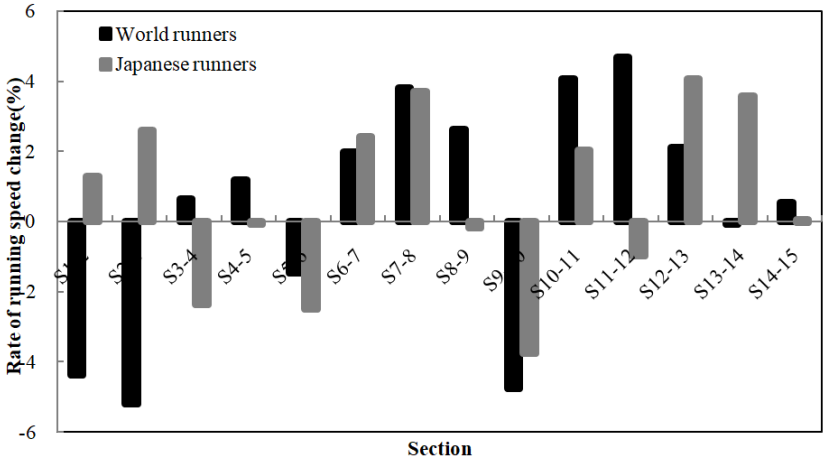

Figure 3. Changes in the rate of speed change for the World and Japanese elite runners.

Figs. 4–8 depict the changes in the stride frequency and length, contact time, flight time, and body center of mass (Δy) for the world and Japanese elite runners during the 1500 m run. Except in the 100 m and 1200 m sections, the Japanese runners have a faster stride frequency than the world runners. There was a significant difference between the two groups of runners in the 200 m and 300m sections ($p < 0.05$). The stride length of world runners is significantly larger than Japanese runners. Among them, the two groups are significantly different in the first 200 m and the last 700 m ($p < 0.05$). In terms of contact time, except for 1200 m, the world runners are larger than the Japanese runners. There is a significant difference in the section of 200–600 m ($p < 0.05$). There was no significant difference

in flight time between the two groups in each section. Except for Japanese runners in the 100 m and 1200 m sections, world runners are larger than Japanese runners in the center of mass displacement. The two groups of runners showed significant differences ($p < 0.05$) in the 200 m, 300 m, and 500 m sections.

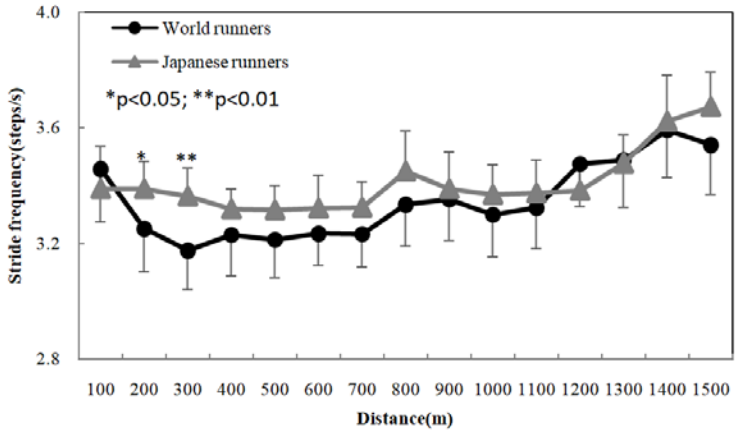

Figure 4. Changes in the stride frequency for the World and Japanese elite runners during the 1500 m race.

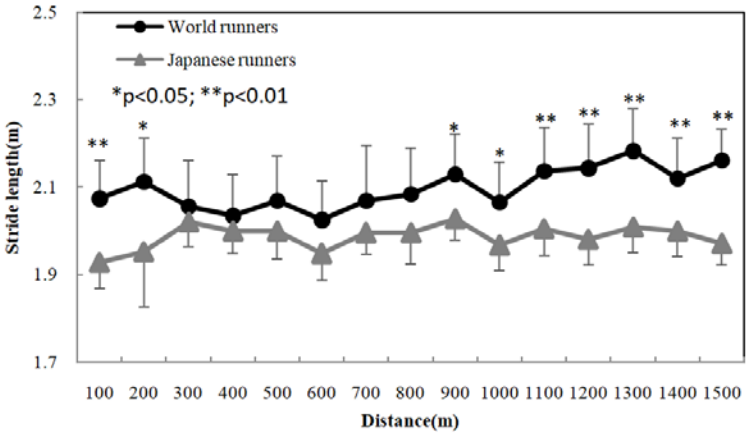

Figure 5. Changes in the stride length for the World and Japanese elite runners during the 1500 m race.

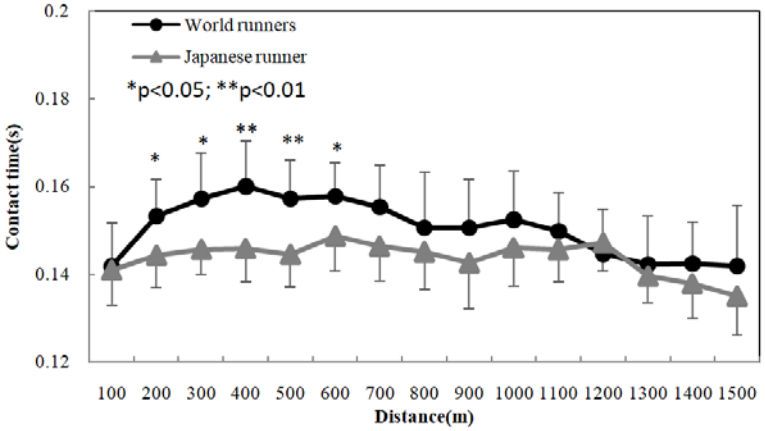

Figure 6. Changes in the contact time for the World and Japanese elite runners during the 1500 m race.

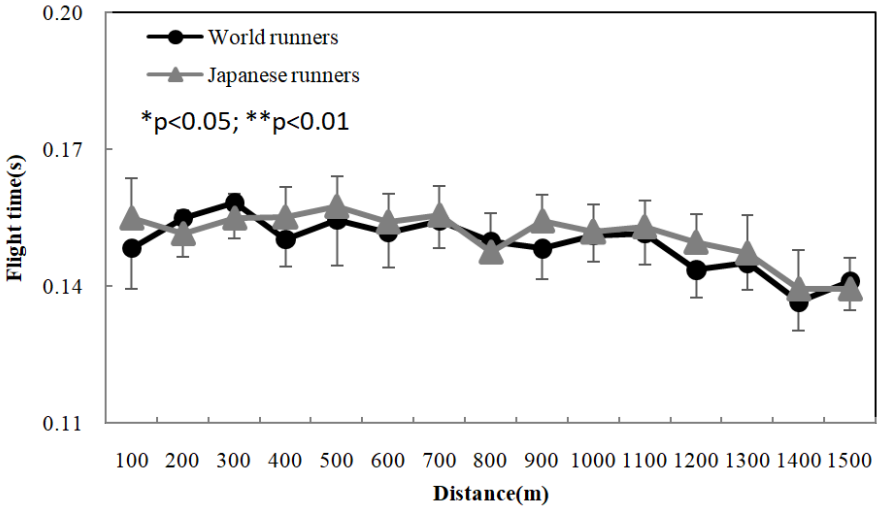

Figure 7. Changes in the flight time for the World and Japanese elite runners during the 1500 m race.

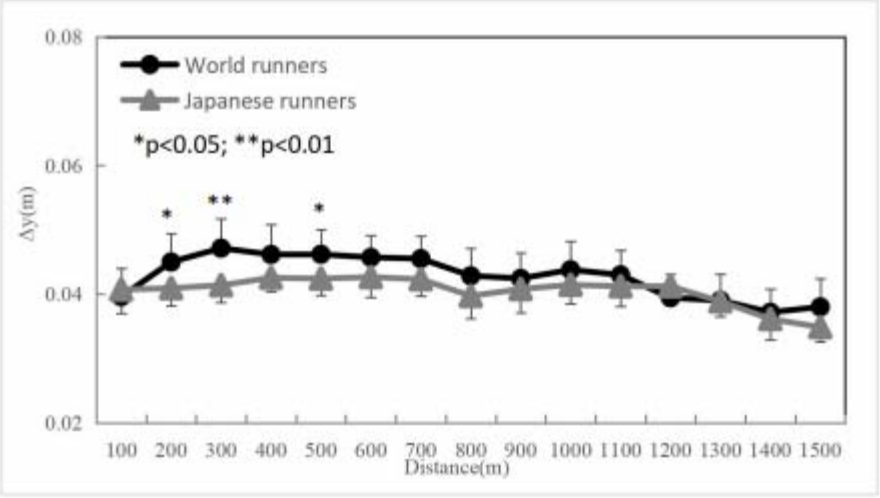

Figure 8. Changes in the body center of mass for the World and Japanese elite runner during the 1500 m race.

4. Discussion

4.1 Pace pattern of 1500 m race between world runners and Japanese runners

In middle- and long-distance races, setting a suitable pace pattern allows a runner to gain an achievement on personal best record and timing decision to win a race. From a mechanical point of view, the effective pace is to keep a constant speed. However, constant speed is rarely shown in a real race. The method of setting a running pace has a significant impact on setting new records and winning competitions for athletes. The idea of appropriate pacing is vital to athletic performance (Foster et al., 1994). When directly compared, the performances of the top 3 runners were within 1% of each other, and even slight variations in pacing strategy may have substantial effects on the race outcome (De Koning et al., 1999). According to Adams and Bernauer (1968), pace patterns can be divided into three types: slow-fast, fast-slow-fast and steady. In an actual race, the pattern of "fast-slow-fast" is the most common pattern among the pace patterns in the 1500 m race (Hanley et al., 2019). In the 400 m running race pattern, Yamamoto et al. (2014) divided 400 m into three types according to the relative running speed: speed maintenance, intermediate,

and speed reduction. In the 800 m running speed type, Kadono et al. (2008) divided it into the first half type, Intermediate type, and second half type. Judging from the pace pattern mode of the two groups of runners in this study (Figure 9), based on the relative speed of 100%, the world runners show a "fast-slow-fast" pace strategy mode, and the Japanese runners show a "slow-fast" pace strategy mode. The world runners start fast, then reduce their speed to adjust the pace, and the sprint accelerates significantly. Japanese runners start slowly, with the sprint acceleration being a low sprint. Two groups of runners reduced their speed to 1,000 m, adjusted their pace, and prepared for the last lap. According to Sandford et al. (2019) research, the inter-relationship of surge events, tactical positioning, and kick execution may have essential implications for eventual medal-winning outcomes and require further definition. The study believes that the final surge before the race kick occurred earlier in fast (704±133 m from the finish) vs. medium (427±83 m, large difference, most likely) and slow races (370±137 m, large difference, most likely). Regardless of category, the race kick occurred on the last lap. From the results of this study, the race kick world players are within the last 500 m, and the Japanese players are within 300 m. Relative to world runners, improving the start speed and sprinting ability of Japanese runners is crucial for enhancing their race record and performance.

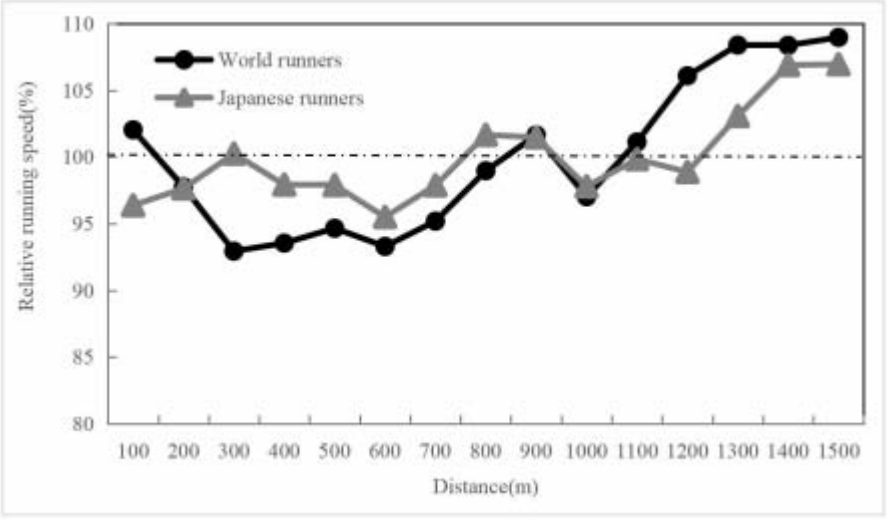

Figure 9. 1500 m pace pattern of the World and Japanese elite runner during the 1500 m race.

4.2 The relationship between mechanical variables and running speed of world runner and Japanese runner

Middle distance running performance is characterized by intermediates of biomechanical and physiological parameters, with the possibility of unique combinations leading to high-level performance. The relative importance of mechanical power output and energy use will likely vary across different middle distance events and specific middle distance events (Thompson, 2017). The running speed is equal to the product of stride frequency and stride length. Generally, the stride frequency is higher, and the stride length is longer, resulting in a faster running speed. However, Hogberg (1952a, b) found that when running at 70-80% of maximum speed, the increase in stride length is greater than the increase in stride frequency. Each runner has an optimal stride length and frequency that is highly efficient and economical, and this is almost identical to when a skilled runner sprint in a natural form, such as through training. Table 3 presents the relationship between mechanical variables and the running speed of world and Japanese runners. The speed of world runners is significantly correlated with stride length and frequency ($p < 0.01$), whereas the contact time, flight time, and body center of mass are significantly negatively correlated with speed ($p < 0.01$). It implies that at high speeds, stride frequency will be high, stride length will be long, contact time and flight time will be short, and body center of mass displacement will be small. However, Japanese runners' stride length and running speed are not correlated ($r=0.428$, $p=0.112$), showing that the Japanese runners have a smaller stride length during the race, and the impact on speed is not obvious. Therefore, increasing the stride length of Japanese runners is critical to improving their performance and running speed.

Table 3. Relationship between mechanical variables and running speed

World runner	r-Coefficients	p-Value	Japanese runner	r-Coefficients	p-Value
SF	.962	.000	SF	.913	.000
SL	.879	.000	SL	.428	.112
CT	-.947	.000	CT	-.800	.000
FT	-.876	.000	FT	-.865	.000
Δy	-.968	.000	Δy	-.916	.000

4.3 Recommendations for pacing for Japanese runners

Since the turn of the century, arguments have been made that a relatively even pace was the best way to complete middle-distance sporting events. However, there were no adequate quantitative models of how pacing might influence athletic performance until recently. Ariyoshi et al. (1979) analyzed three possible patterns of pacing (type 1: fast-slow; type 2: slow-fast; and type 3: steady) were compared over a 1400 m, 4 min run. The subsequent running time to exhaustion at 370 m/min was significantly longer with a type I than with a type 2 protocol ($P < 0.05$). The steady rate pattern gave results intermediate between type 1 and type 2 pacing. Data for oxygen debt and recovery heart rate confirmed the superiority of type 1 pacing. Some studies have pointed out that a fast start strategy can improve middle-distance performance as oxygen uptake kinetics, CP, and CS research (Robert, 2016; Jones et al., 2010). But some studies showed the fast-slow-fast pace pattern is always used. In this context, the ATP-PCr system is one of the three major energy supplies for the human body, supplying energy during a fast start in a pace. Therefore, a fast start pace leads to greater rates of PCr breakdown and consequently stimulates the system of resynthesis of the ATP by the oxidative processes (Medbo & Tabata, 1989). However, whereas a fast start may lead to the athlete reaching $VO_{2\,max}$ earlier, it can also cause premature fatigue. Hanon et al. (2007, 2008) pointed out that a fast start pace can impair the overall performance. The start velocity must be inferior to 115% of vVO_{2max}, and the duration of this velocity should not exceed 25–30 s. In order to be able to accelerate 300 m before the finish line, one must start quickly enough to improve VO_2 kinetics and promptly adjust their pacing to reduce their energy expenditure during the middle of the 1500 m.

The limited laboratory data and theoretical models indicate that differences in pacing strategy are significant to competitive athletes. Further areas of study are required to understand the problems associated with pacing in athletic events. In the analysis of the Successful pacing profiles of Olympic and IAAF World Championship middle-distance runners across qualifying rounds and finals, Hanley et al. (2019) elaborated on the competition strategy through a large number of statistical analyses in the qualifying rounds and finals. According to the study, successful 1500 m runners generally separated themselves from slower athletes in the final 200 m by avoiding slowing down when compared to competitors and usually take J-shaped pacing in 1500 m race. Compared to the pace of Japanese runners and the world runners, the pace of the world runners shows a 'fast-slow-fast '(J-shaped) pace pattern, while the Japanese runners have a 'slow-fast' pattern. Japanese runners should increase their initial speed in the starting stage and improve their sprinting ability in the final 500 m. Simultaneously, increase the training of stride length. This is very important for Japanese runners to enhance their sports performance. Certainly, the best athletes should have the physiological capacity to vary the pace and respond to surges through successive competition rounds.

5. Conclusions

This study compared 1500 m pacing profiles for the World runners (Fast-Slow-Fast) and Japanese runners (Slow-Fast). Improving the initial speed and sprint performance of the race, as well as increasing stride length, have become critical problems for Japanese runners to overcome in the future. Consequently, this study clarified the differences between 1500 m Japanese runners and world runners, providing suggestions for Japanese runners and coaches.

Acknowledgements

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