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Original Article

The pace pattern of the men's 1500 m race with different levels

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Abstract:
This study investigates the relationship between the speed in the men's 1500 m run at different levels and stride length, stride frequency, contact time, flight time and centre of mass (Δy) and clarifies the relationship between pace pattern and performance among 1500 m runners by analysing the pace patterns in the official 1500 m running race with different performance levels. Twenty-one male 1500 m runners in official competitions were videotaped with video cameras at a 60-Hz sampling rate during the whole course of the race. The ratio of race time to personal records was never <98% for any runner who participated in this study. The average running speed, stride length, stride frequency, contact time, flight time and the centre of mass (Δy) were calculated for every 100 m by reading the video frames. The main results were as follows: 1) High-performance runners tend to have high speed, fast stride frequency, long stride length, short contact time and flight time, and small fluctuations in centre of body gravity. A significant correlation was found between the running speed in each group and each variable. 2) From the results of the multiple regression analysis with the 1500 m race record as the independent variable and each quarter speed as the dependent variable, it is understood that the running speed in the middle stage had the greatest effect. 3) The pace patterns were classified into three types depending on the record level: "Up–down wave type," "even–fast type," and "fast–slow–fast type." This study examined the 1500 m pace pattern at different levels; the mechanical variables of runners at different levels have different effects on their speed. Controlling the middle-stage speed is essential to improve athletes' sports performance.
Keywords: 1500 m, middle-distance running, running speed, pace pattern, running performance

Introduction

In time-event competitions, athletes' exercise process is not always constant; it will adjust depending on changes in the external environment and their physiological and psychological status. The method of setting a running pace greatly impacts setting new athletics records and winning competitions. The idea of appropriate pacing is vital in athletic performance (Foster et al., 1994). Performances of the top-3 runners, when directly compared, are within 1% of each other and even small variations in pacing strategy may substantially affect race outcomes (De Koning et al., 1999). All those competing in the finals possess highly similar skills, so pursuing adequate racing tactics is indispensable for medal winning (Keklemen et al., 2022).

Middle-distance running performance is characterised by the intermediates of biomechanical and physiological parameters, with the possibility of unique combinations of each leading to high-level performance. The relative importance of mechanical power output and energy use likely varies both between different middle-distance events and over the course of specific middle-distance events (Thompson, 2017). Several studies (Cunningham et al., 2013; Hayes & Caplan, 2012; Trowell et al., 2021) have described middle-distance running biomechanics, Folland et al. (2017) analysed both mid- and long-distance runners together and found four variables that accounted for 30.5% of their performance variability. Faster runners had a significantly smaller shank angle at touchdown (that explained 10% of the variance), smaller peak braking velocity of the pelvis during ground contact (9.9%), lower duty-factor (meaning the percentage of the total gait cycle where one foot is on the ground; 6.4%), and a more upright trunk across the gait cycle (4.2%). Trowell et al. (2019) analysed how slower middle-distance runners make initial ground contact with a more plantarflexed ankle and greater forward lean in the trunk. Several studies (Hanon et al., 2007, 2008; Ariyoshi et al., 1979; Cavanagh & Williams, 1982) described middle-distance running physiology. Ariyoshi et al. (1979) analysed three possible patterns of pacing (type 1: fast–slow; type 2: slow–fast; and type 3: steady) over a 1400 m, 4-minute 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 lead to intermediate results between type-1 and type-2 pacing. Data for oxygen debt and recovery heart rate confirmed the superiority of type-1 pacing.

Certain studies such as oxygen uptake kinetics, CP, and CS research point out that a fast start strategy can improve middle-distance performance (Robert, 2016; Jones et al., 2010). However, other studies show that the fast–slow–fast pace pattern is always used. Therefore, a fast start pace leads to greater rates of PCr breakdown

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and consequently stimulates the system of ATP resynthesis by oxidative processes (Medbo & Tabata,1989). However, while a fast start may lead to the athlete reaching their VO_{2max} earlier, it can also cause premature fatigue. Hanon et al. (2007) 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. Starting fast enough to enhance VO_2 kinetics and quickly regulating pacing to minimise energetic cost in the middle part of the 1500 m enables acceleration at 300 m before the finish line. In research on strategies for the 1500 m race, many studies consider a U-shaped pacing strategy evident during world-record performances at meet races in the 1500 m. However, some studies believe that a J-shaped pacing profile can be observed in some competitions such as championship 1500 m races (Casado et al., 2021a, b; Hanley et al., 2019; Yang et al., 2022). However, no matter how the pacing strategies are allocated, according to the analysis of the 1500 m race position, most world champions remain within the front positions for the whole race (Lara & Del Coso, 2021a). In addition, 1500 m runners competing at championships should train and be physiologically prepared to sustain an uneven pace and produce a fast endspurt to achieve an optimal performance (Casado et al., 2020).

Moreover, we studied the mechanical factors that affect the pace of 1500 m running and analysed the post-competition blood lactate (Yang & Enomoto,2021). Eleven middle- and long-distance runners were taken as the research subjects and their mechanical factors and post-competition blood lactate values after the race were obtained using video analysis and blood lactate concentration tests. Stride length and running speed were significantly correlated ($r = 0.805$, $P < 0.01$), no correlation was found between blood lactate concentration and race time, and L3 section (800–1200 m) running speed and PBLa were significantly correlated ($r = 0.608$, $P < 0.05$). Therefore, we think that the accumulation of L3 section lactate and mechanical factors in the L3 section are the main causes for the runners' speed reduction. Although there have been many studies on the physiology and biomechanics of 1500 m runners, we found that in actual 1500 m races, there is not much research on the pace distribution for runners of different record levels. This study analyses the changes in running speed, stride frequency, stride length, flight time, contact time, and body centre of mass during the men's 1500 m race with different record levels at official competitions. Analysing the pace pattern of runners at different levels during the competition enables the analysis of the relationship between race record, pace pattern, and the factors that affect running speed. This study clarifies the changes of speed under different pace patterns and provides insights for improving runners' performance.

Methods

Participants

All competitions were hosted by JAAF. The analysed subjects are 21 male runners (Top-3 in the final) with a whole race record of less than four minutes; the ratio of race time to personal record was not <98% for any analysed runner. For comparison by record level, subjects were divided into three groups. G1 (n = 6) is 3:37.90–3:41.57. G2 (n = 8) is 3:42.44–3:43.47. G3 (n = 7) is 3:45.66–3:50.72. The average age of each group was: 26.33 ± 1.25 years in G1; 21.75 ± 2.59 years in G2, and 22.14 ± 1.88 years in G3 (Table 1).

Table 1. Race record and best record in the groups

Group	G1 (n = 6)	G2 (n = 8)	G3 (n = 7)
Age(years)	26.33 ± 1.25	21.75 ± 2.59	22.14 ± 1.88
Race record	3:40.18 ± 1.26 (3:37.90–3:41.57)	3:42.86 ± 0.33 (3:42.44–3:43.47)	3:48.30 ± 2.15 (3:45.66–3:50.72)
Best record	3:40.45 ± 1.50	3:43.17 ± 1.97	3:46.59 ± 2.66

Video shooting of 1500 m race

Two digital video cameras were used with panning to capture the runners from the top of the building by the side of the track. The shooting speed was 59.94 fps, the shutter speed was 1/60 s when shooting with a flash gun, and 1/500–1/1000 s after starting. Runs were recorded in the AVI format, and the frame size was read by video analysis software to calculate the elapsed time and the average running speed at 100 m intervals.

Calculation of variables

(1) Speed

The time (1/100 s) was recorded for every 100 m section from the digital video and substituted for each section into Equation (1) to calculate the speed of every 100 m section.

$$Speed = \frac{100}{T} \quad \text{..............................} (1)$$

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

The SF for each 100 m section was calculated by reading the time required for 10 steps in the 100 m section from the video and substituting this into Equation (2). The SL for each 100 m section was calculated by substituting the running speed and SF of each section obtained from Equations (1) and (2) into Equation (3).

$$SF = \frac{10}{10 steps\ time} \text{ ………………………… } (2)$$

$$SL = \frac{\text{Speed}}{\text{SF}} \text{ ………………………………… } (3)$$

(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 10 steps in the 100 m section from the video. The shooting speed was 59.94fps. FI is the instantaneous frame number when the foot contacts the ground, FO is the instantaneous frame number when the foot leaves the ground; CT and FT can be obtained using Equation (4).

$$CT = \frac{\text{FO}-\text{FI}}{59.94}\ or\ FT = \frac{FI-FO}{59.94} \text{ …………………… } (4)$$

(4) Rate of running speed change (%)

The rate of change is about the change from the before section to the after section. (S1–2: 0–100 m to 100–200 m; S2–3: 100–200 m to 200–300 m…S14–15: 1300–1400 m to 1400–1500 m) (Kadono et al., 2008). This can be obtained from Equation (5).

$$\text{Rate of speed change(\%)} = \left(1 - \frac{The\ variable\ before\ section}{The\ variable\ after\ section}\right) * 100 \text{ ………….. } (5)$$

(5) Body centre of mass(ΔY)

The Body centre of mass can be calculated by the contact time and flight time. Using Carrard et al., (2018) Morin et al., (2005), and McMahon and Cheng (1990) the body centre of mass (ΔY in m) was calculated from the assessments of TC, TF, running speed and from the body mass:

$$Fmax = \text{mg}\frac{\pi}{2}\left(\frac{TF}{TC}+1\right) \text{ …… …………………… } (6)$$

(6) and (7)

$$\Delta Y = \left| -\frac{Fmax}{m} * \frac{TC^2}{\pi^2} + g * \frac{TC^2}{8} \right| \text{ …… …………….. } (7)$$

Obtain (8)

$$\Delta Y = \left| -\frac{g\pi TF + g\pi TC}{2TC} * \frac{TC^2}{\pi^2} + g * \frac{TC^2}{8} \right| \text{ ………….. } (8)$$

Statistical analysis

Statistical analysis included descriptive statistics where the results were expressed as mean ± standard deviation (± SD). The significance of differences between groups was tested by t-testing for independent samples. Pearson coefficient is used to analyse the correlation between running speed and various factors. Multiple regression was used to analyse the 1500 m race record as the independent variable, with each quarter speed as the dependent variable. The statistically significant level was set to 5%.

Results

Fig. 1 shows the changes in the running speed during the 1500 m race from the different record groups. Analysing the first 400 m and the middle 700–1200 m, the speed of G1 was significantly higher than G2 or G3. The speed of G2 was very uniform from the start to 1200 m, and the speed at 1200 m started to increase until the end of the race. Their speed during the first 500 m shows that G3 was close to G2, but starting from 500 m, the speed of G3 greatly reduced until 1100 m, and their speed then rose again until the end of the race. There was no significant difference between G1 and G2 ($p = 0.27$) whereas G1 and G3 ($p < 0.01$) and G2 and G3 ($p < 0.05$) show significant differences in average speed.

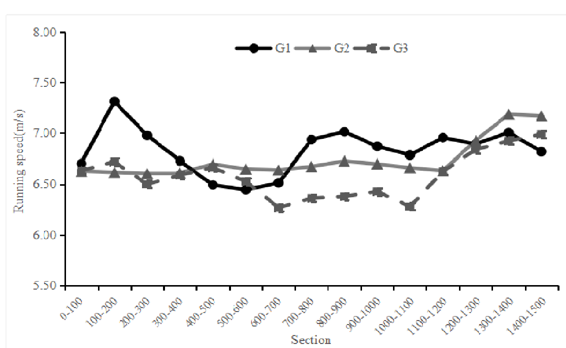


Fig. 1. Running speed during 1500 m race for the different record groups

Fig. 2 shows the rate of running speed change during 1500 m race for the different record groups. Positive and negative values indicate acceleration and deceleration, respectively. G1 accelerated the most in the S1–2 section and decelerated the most in the S2–3 section. G2 maintained a very smooth speed in the first 1300 m, there were no obvious deceleration or acceleration changes, except in the S12–14 sections where acceleration is more obvious. G3 showed the largest deceleration in the S6–7 section and the largest acceleration in the S11–12 section.

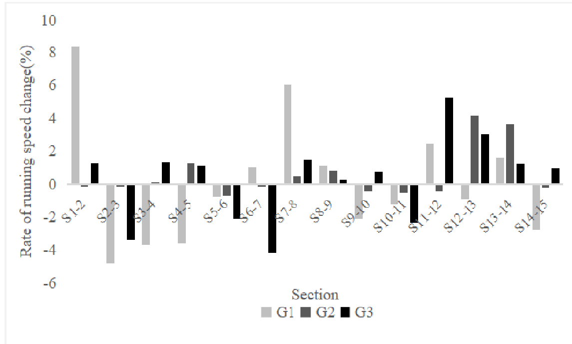
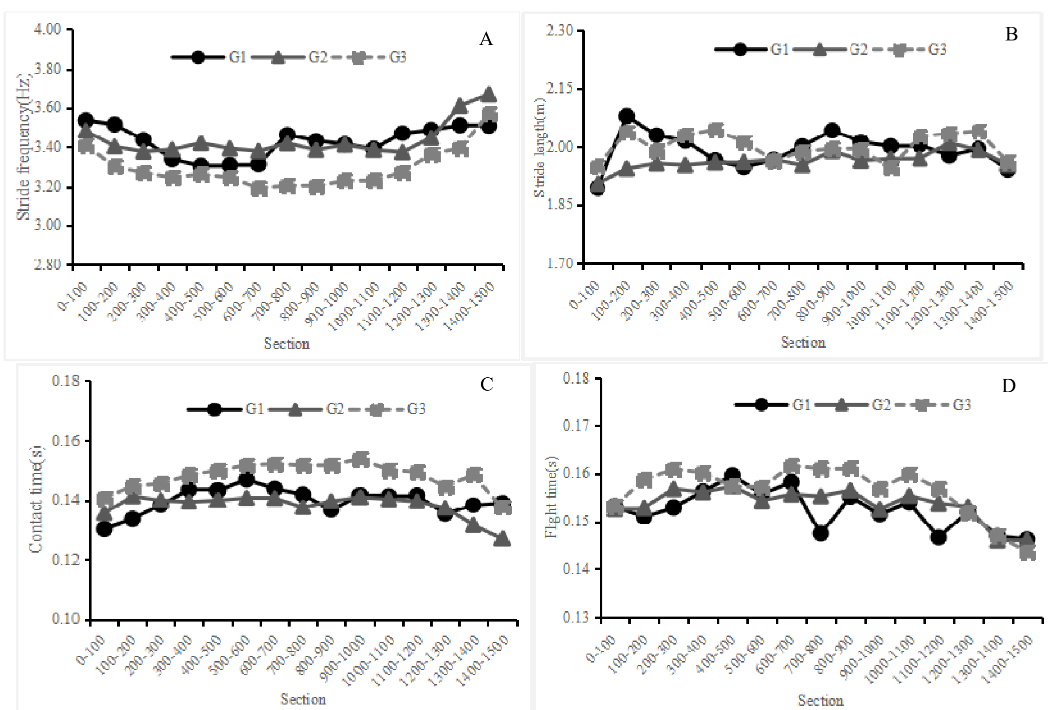


Fig. 2. Rate of running speed change during 1500 m race for the different record groups

Fig. 3A and B are diagrams of the changes in runners' stride frequency and stride length with different groups. From the stride frequency perspective, both G1 and G2 are larger than G3. For G1, the downward trend is obvious from the start to 700 m, while the 700–800 m section shows an obvious increase. The 300–1200 m section was relatively smooth for G2, and the last 300 m stride frequency increased significantly. The G3 stride frequency was obviously U-shaped, and stride frequency increased significantly starting at 1,100 m. There was no significant difference between G1 and G2 ($p = 0.83$), whereas G1 and G3 ($p < 0.01$) and G2 and G3 ($p < 0.01$) showed significant differences in stride frequency. In terms of stride length,G1 and G3 showed rapid increases in the first 200 m and then significant decreases. G3 reached its maximum at 500 m whereas G2 was relatively smooth and then gradually increased until 1300 m. In the last 200–300 m, the three groups showed different degrees of downward trends. There was no significant difference between G1 and G3 ($p = 0.53$), whereas G1 and G2 ($p < 0.05$) and G2 and G3 ($p < 0.01$) showed significant differences in stride length.

Fig. 3C and D show the changes in the contact times and flight times of runners in the different groups. G3 shows greater contact time than either G1 or G2. The G3 contact time is obviously n-shaped. In the final 200 m, the contact time for G1 increased significantly, while G2 and G3 showed decreases. There was no significant difference between G1 and G2 ($p = 0.31$), while G1 and G3 ($p < 0.01$) and G2 and G3($p < 0.01$) showed significant differences in contact time. In terms of flight time for the first 400 m and 600–1200 m, G3 > G2 > G1. G1 showed the most significant decrease at 800 m and 1200 m. G1 and G2 ($p = 0.42$) and G2 and G3 ($p = 0.10$) had no significant differences, whereas G1 and G3($p < 0.05$) showed a significant difference in flight time. Fig.3E shows the changes in body centre of mass (Δy) during the 1500 m race for the different record groups, revealing G3 > G1 or G2. The increase before 400 m for G1 is larger and the decrease at 700–800 m is obvious. G2 and G3 decreased significantly in the last 300 m. There was no significant difference between G1 and G2 ($p = 0.71$), whereas G1 and G3 ($p < 0.01$) and G2 and G3 ($p<0.01$) showed significant differences in body centre of mass.



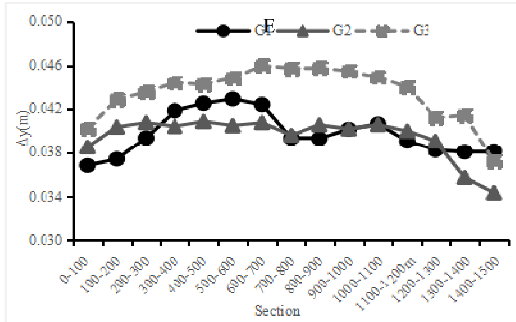


Fig. 3. Changes in running speed, stride frequency, stride length, contact time, flight time, and body center of mass (Δy) during the 1500 m race for the different record groups.

Discussion

Dividing the 1500 m race into four sections (L1: 0–400 m; L2: 400–800 m; L3: 800–1200 m); L4: 1200–1500 m), Table 2 shows the average distribution values of all variables for the runners in each section. In terms of speed, all runners were slower in the second and third sections. For stride frequency and contact time, the body centre of gravity displacement also changed with the second and third section speed. If the stride frequency was slower, then the contact time was longer and the body centre of gravity displacement was larger. The stride length in the first and second sections was shorter and the flight time in the second section was longer.

Moreover, through the analysis of pace pattern in the competition of the runners with different levels, Table 3 shows that the speed of each section influences the competition results. Multiple regression was used to analyse the 1500 m race time as the independent variable and the running speed in each section was the dependent variable. From the perspective of the influence of the four sections on the three groups of runners, the L2 and L3 sections had a greater impact on the G2 (middle group) and G3 (slow group) runners. For the G1 (fast group) runners, the L1 section speed had a greater impact on the race.

Table2. Mean and standard deviation for each variable

Section	L1 (0–400 m)	L2 (400–800 m)	L3 (800–1200 m)	L4 (1200–1500 m)
Speed (m/s)	6.70 (0.09)	6.58 (0.07)	6.66 (0.06)	6.98 (0.07)
SF (Hz)	3.39 (0.06)	3.33 (0.02)	3.35 (0.01)	3.51 (0.07)
SL (m)	1.98 (0.04)	1.98 (0.01)	1.99 (0.01)	1.99 (0.03)
CT (s)	0.140 (0.003)	0.145 (0.001)	0.144 (0.001)	0.137 (0.002)
FT (s)	0.155 (0.002)	0.157 (0.001)	0.155 (0.002)	0.148 (0.003)
Δy (m)	0.041 (0.001)	0.042 (0.001)	0.042 (0.0004)	0.038 (0.001)
%Speed	99.62 (1.27)	97.71 (0.98)	98.97 (0.86)	103.70 (1.02)
%SF	100.10 (1.63)	98.28 (0.67)	98.86 (0.39)	103.68 (1.92)
%SL	99.76 (1.86)	99.66 (0.43)	100.35 (0.67)	100.31 (1.33)
%CT	98.86 (2.01)	102.07 (0.73)	101.42 (0.67)	96.88 (1.70)
%FT	100.80 (1.22)	101.62 (0.95)	100.59 (1.30)	95.97 (2.03)
%Δy	99.31 (3.22)	103.74 (1.26)	102.11 (0.98)	93.12 (3.19)

※Values show mean± standard deviation.

Table 3. Influence of running speed in each section

Section(G1)	Coefficients	t-Stat	Section (G2)	Coefficients	t-Stat	Section (G3)	Coefficients	t-Stat
L1	0.279*	0.348	L3	0.285*	0.290	L2	0.310***	0.243
L2	0.270	0.077	L1	0.281*	0.262	L1	0.274***	0.313
L3	0.245*	0.382	L2	0.252	0.175	L3	0.234*	0.073
L4	0.207	0.193	L4	0.182*	0.273	L4	0.182***	0.371

***p<0.001, **p<0.01, *p<0.05; Coefficients and t-Stat were one-standardised.

Each runner has an optimal stride length and stride frequency that is highly efficient and economical; this is almost the same as when a skilled runner sprints in a natural form such as during training. In a race where an athlete marked a close record for himself, as in this study, it is highly possible that the athlete could control both their stride length and stride frequency optimally, regardless of whether they did so consciously. Looking at the results of this study (Fig. 1 and Fig. 3A and B), when G1 reached their highest speed in the first 200 m, their stride length increased significantly but their stride frequency decreased instead. From the G1 running speed, for the start and finish parts, stride length has a great influence on speed, and the middle part is affected by two aspects. G2 has an average speed in the first 1200 m and their stride length and stride frequency only fluctuate a little. In the last 400 m, the increase in stride frequency coincides with their speed, while the stride length decreased. The G3 speed fluctuates significantly. From the perspective of stride length and stride frequency allocation, the stride length in the first 1300 m has a greater impact on the speed allocation, and the stride length in the last 300 m decreased and stride frequency increased, which significantly affected the pace. This shows that the stride length and stride frequency are only relatively harmonious and stable at an even pace. Typically, the stride length and stride frequency are inversely proportional. In a few cases, the stride frequency/length increase or decrease together. According to Hogberg (1952), when the running speed is close to 70–80% of the maximum, the increase in stride length is greater than the increase in stride frequency. If the running speed continues to increase, the stride frequency will increase sharply and the stride length will decrease. In terms of speed and step frequency, there was a significant positive correlation between stride frequency and running speed in each group (G1: $r = 0.73$, $P < 0.01$; G2: $r = 0.91$, $P < 0.01$; G3: $r = 0.85$, $P < 0.01$). Regarding the stride length and running speed, there was a significant correlation between the G1 speed and stride length ($r = 0.68$, $P < 0.01$), whereas this was not significant for either G2 ($r = 0.43$, $p = 0.11$) or G3 ($r = 0.44$, $p = 0.10$).

Regarding contact time, the speed of runners in each group was significantly negatively correlated with contact time (G1: $r = -0.58$, $p < 0.05$; G2: $r = -0.87$, $p < 0.01$; G3: $r = -0.70$, $p < 0.01$). G1 has the lowest speed in the 600 m section and the longest contact time. The contact time for the last 400 m of G2 gradually decreased toward the end, and the G2 acceleration was obvious in the last 400 m. G3 speed and contact time basically showed the opposite trend. The contact time was longest for G3 and shortest for G2. The flight time was significantly negatively correlated with the running speed in each group of runners (G1: $r = -0.61$, $p < 0.05$; G2: $r = -0.85$, $p < 0.01$; G3: $r = -0.86$, $p < 0.01$). G1's flight time in the 800 m and 1200 m sections decreased significantly. The flight time of each group started declining at 1,300 m; G1 had the shortest overall flight time and G3 had the longest. The body centre of mass and the running speed were significantly negatively correlated in each group of runners (G1: $r = -0.74$, $p < 0.01$; G2: $r = -0.90$, $p < 0.01$; G3: $r = -0.85$, $p < 0.01$). G3 has the largest displacement of body centre of gravity. The last 400 m of G2 and G3 decreased significantly, but the last 200 m of G1 showed an upward trend.

The limited laboratory data and theoretical models indicate that differences in pacing strategy are significant among competitive athletes. Further areas of study are required to understand the problems associated with pacing in athletic events. In their 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 their study, successful 1500 m runners generally separated themselves from slower athletes in the final 200 m by avoiding slowing down compared to their competitors and usually take a J-shaped pace in the 1500 m race. In middle- and long-distance races, setting a suitable pace pattern allows a runner to gain an achievement on their personal best record and timing decisions to win their race. From a mechanical point of view, the effective pace to keep is a constant speed. However, a constant speed is rarely maintained in real races. Adams and Bernauer (1968) divided pace patterns into three types: slow–fast, fast–slow–fast and steady. In actual races, the "fast–slow–fast" pattern is the most common among pace patterns. In the 400 m running race pattern, Yamamoto et al. (2014) divided 400 m into three types depending on the relative running speed: speed-maintenance type, intermediate type, and speed-reduction type. In the 800 m running speed type, Kadono et al. (2008) divided them into: first-half type, Intermediate type, and second-half type. In terms of 1500 m pace strategy, Casado et al. (2021a, b) believed that the U-shaped pacing strategy was evident during world-record performances at 1500 m meet races. Although a parabolic J-shaped pacing profile (in which the start is faster than the middle part of the race but slower than the endspurt) can be observed during championship 1500 m races. Figure 4 shows the changes in running speed for each type relative to the average race running speed as 100%. From the changes in running speed, Type 1 is an "Up–down wave type" where the runner accelerates very quickly in the first 200 m and then decelerates to 600 m. After that, the speed fluctuates up and down until the end. Type 2 is an "even–fast type" where the runner's speed is smooth in the first 1200 m and there is no obvious change. Starting at 1200 m, the runner's speed increases rapidly until the end. Type 3 is a "fast–slow–fast type" where the runner starts and ends fast, and slows during the middle of the race.

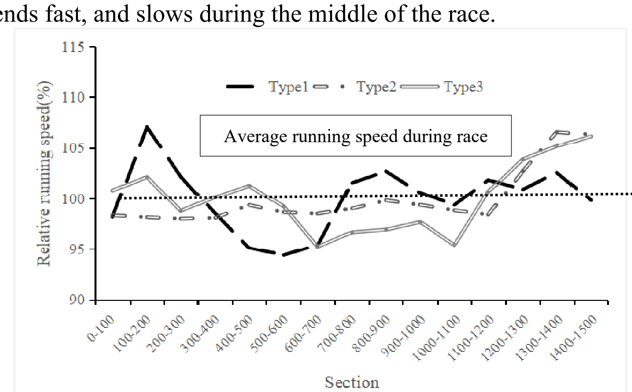


Fig. 4. Changes in relative running speed for each type

Conclusions

This study aims to clarify the relationship between pace pattern and performance in 1500 m runners by analysing the race patterns in an official competition of 1500 m runners with different performance levels. The eventual aim is to obtain basic knowledge that contributes to rational coaching decisions for 1500 m race runners.

The main results were as follows:

1) High-performance runners tend to have high speed, fast stride frequency, long stride length, short contact time and flight time, and small fluctuations in the centre of body gravity. A significant correlation was found between the running speed in each group and each variable.

2) From the results of the multiple regression, which was used to analyse the 1500 m race record as the independent variable, each quarter speed as the dependent variable, it is understood that the running speed in the middle stage has the greatest effect. This result suggests that increasing the mid-course pace level is an important factor for obtaining high performance.

3) As a result of analysis, pace patterns were classified into three types: "Up–down wave type," "even-fast type," and "fast–slow–fast type."

Regarding the pace distribution in the 1500 m race, and runners who show various pace patterns at any performance level, pace patterns should be based on the characteristics of high-performance runners' race patterns as described above. It is considered necessary to appropriately evaluate the characteristics and tasks of each individual to provide coaching tips.

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