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Running Motion Analyses in High Speed Phase for Men's 4 × 100 m Relay Team

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Abstract

The purpose of this research was to analyze high speed running motion of men's 4 × 100 m relay team members in order to improve running mechanics. Each sprinter's running technique was recorded during a 120-m dash between 60–80 m using a high-speed camera. Dartfish 2D motion analysis software was used to collect and analyze running parameters of body movement, including stride length, stride frequency, proportionality of air and ground phase, touchdown distance, pelvis angle and recovery angle. Results shows that participants' mean stride length (198 ± 11.1 cm), stride frequency (4.85 ± 0.2 steps/sec), proportionality of air and ground phase (1:1.34 ± 0.1), touchdown distance (30.5 ± 2cm), pelvis angle (167.6 ± 5.4°), and recovery angle (40.48 ± 0.9°) are lower or less advantage to optimal standard (stride length: 222 cm, stride frequency: 4.55 steps/sec, ground contact ratio: 1:1.1.52, touchdown distance: 20 cm, pelvis angle: 180°, recovery angle: 29°). From the references, it indicates that each participant's stride length, skills of ground contact, and stability of the torso are needed to be improved. Resistance, flexibility, running drills, plyometric training are proposed methods to enhance sprinting mechanics.

Keywords: Dartfish, motion analysis, sprint, athletics, high speed running

Introduction

For an elite sprinter, 100-m dash can be completed within 10 seconds, which means any mechanical error made during a race may lead to an irreversible failure. During each step, there is very little space for errors. It has been repeatedly demonstrated that the level of technique executed in the high-speed phase is the key factor in 100 meters event.

Jian (1995) stated that technical analysis of sprint mechanics has become a standard in improving elite performance. Every factor, including appropriate sprinting mechanics, makes better performance should be stressed during training sessions. If athletes are to change their motor patterns in high-speed running mechanics and thus improve their mechanical efficiency in the key parts of the race, they must develop a sound conceptual technical model. The correct running model must be introduced, rehearsed and refined. It must then be continually reviewed.

In evaluating and teaching high-speed running mechanics, the coach must give athletes key points on which to concentrate and consciously focus as they learn to re-program their motor patterns. In high speed phase, stride length and stride frequency are the two essential factors to improve running technique (Hay, 1985). Kunz and Kaufmann (1981) states, from the view of sports biomechanics, world elite sprinters are supposed to have most optimal ratio of stride length and stride frequency. To purposely make stride length shorter to increase the stride length frequency will result in worse performance and vice versa. Therefore, every sprinter has their own optimal ratio of stride length and stride frequency (Donati, 1995). Liu (2006) and Su and Fan (1994) indicated that the average stride length and frequency among sprinters in Taiwan are unbalanced. Comparing with the modern elite sprinters, the results from Taiwanese sprinters showed better performance in stride frequency, which indicated that Taiwanese sprinters do not obtain advantage from stride length. In 100 meters event, it takes 50.5 steps averagely for sprinters in Taiwan to complete while the modern elite sprinters take only 45 steps.

The sprint stride was divided into two kinematic phases: the air phase and the ground phase. From the ratio between ground and air period, the duration of the stance and flight phases can be evaluated. Mann and Herman (1985) states the time period for elite sprinters should be shorter than average sprinters, which relates to the distance between leading leg's touchdown position from body center of mass (touchdown distance). In a previous study, neutral pelvis position was demonstrated to analyze the sprinting technique at maximum velocity (Seagrave, Mouchbahani, & O'Donnell, 2009). Anterior rotation of the pelvis in high-speed running may cause the front foot landing in front of the center of mass and slow recovery of the leg cycle (Bosch & Clomp, 2005). In conclusion, it could be assumed that those key factors, including stride length, frequency, proportionality of ground contact time, pelvis angle (see Figure 1), recovery angle (see Figure 2), touchdown distance (see Figure 3) and torso angle (see Figure 4), are highly as the key to success in the event. In this study, these parameters were used to analyze the high-speed running motion. Data were then used to correct the athletes' running technique.

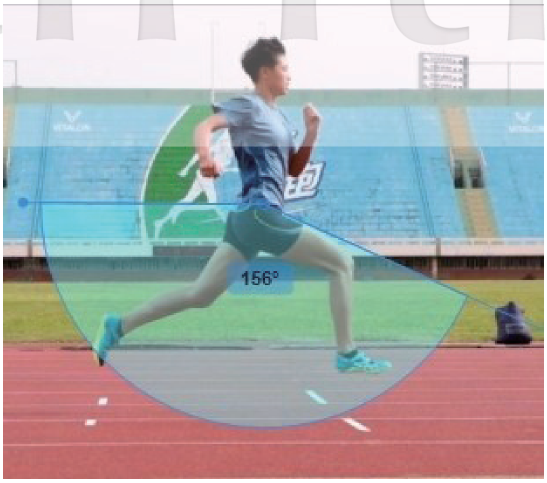

Figure 1. Pelvis angle in this study indicates the angle between the thigh and the horizontal line at the pelvic level behind the trunk.

Figure 2. Recovery angle indicates the angle between the thigh and the shin during recovery phase.

Figure 3. Touchdown distance indicates the distance between the body center of mass and the tip of foot during touchdown phase.

Figure 4. Torso angle indicates the angle between the torso and the vertical line at pelvis level.

Methods

Participants

Eight sprinters (Nationality: TPE) from the men's 4 × 100 m relay team gave written informed consent to participate in this study. Each participant's personal details, including age, experience (training years), height, weight, season best and personal best, are listed in Table 1.

Procedure

120-m maximum velocity test was performed using the Brower Timing System, which was placed on Lane 5 at the start line of the 4 × 100 m relay event on the tracks. A Distance Measuring Wheel was used to measure the 60m position of the inner line of Lane 1 from start line. A camera (JVC Hybrid GC-PX10, Japan) mounted on WT-330A tripod was placed at the 60-m position of Lane 1. A tripod's level was adjusted horizontally to the tracks. The grid of the JVC camera was aligned with the inner line of Lane 5. Tapes were used to mark 1 meter of the inner and outer lines of Lane 5 in order to allow the pixel-to-meter to properly calibrate the technique-analysis software. Before the experiment, the participants were allowed to perform their own warm-up for an hour. After the warm up, the participants were informed to move to the start line to complete the 120-m test one by one in alphabetical sequence. All participants wore spikes, standing in three-point position, and set off after traditional starting signals. Sprinters dashed 120 m with maximum effort. Running motion (sagittal plane) between 60 m to 80 m was captured by a JVC camera in 210 fps high-speed motion mode. Dartfish 2D motion analysis software pro was used to collect and analyze the running parameters of body movement, including stride length, frequency, proportionality of air and ground period, touchdown distance, pelvis angle and recovery angle.

Results

Results show that participants' mean stride length is 198 ± 11.1 cm, stride frequency is 4.85 ± 0.2 steps/sec, proportionality of air and ground phase is 1:1.34 ± 0.1. touchdown

Table 1
Participants' Information

Name	Age (year)	Experience (year)	Height/Weight (cm/kg)	SB (second)	PB (second)
A	32	16	176/70	10.60	10.29
B	27	9	175/67	10.66	10.53
C	25	10	182/74	10.56	10.28
D	24	14	183/79	10.53	10.39
E	24	12	173/68	10.60	10.55
F	23	10	185/75	10.59	10.55
G	22	5	184/78	10.59	10.59
H	17	6	175/65	10.49	10.49

Note. SB = season best; PB = personal best.

distance is 30.5 ± 2 cm, pelvis angle is 167.6 ± 5.4°, torso angle is 186.9 ± 1.8°, and recovery angle 40.48 ± 0.9° (see Table 2).

Discussion

Participants' mean stride length and frequency are 198 ± 11.1cm and 4.85 ± 0.2 steps/sec, respectively. In Sinarbargar, Hellrich, and Baker's (2010) research, it compares Usian Bolt (men's 100-m and 200-m world record holder) and other elite sprinters. The 9.90-s value was use as the criteria for choosing modern elite sprinters. Table 3 shows the comparison in average stride length and frequency between world class sprinters and participants. In Table 3, it shows that the mean frequency for modern elite sprinters is 4.55 steps/sec, Usian Bolt's frequency is 4.23 steps/sec, and Maurice Greene's frequency is 4.65 steps/sec, respectively. The participants in this study showed higher mean frequency. The frequency of the participants A and B's frequency showed higher than 5 steps/sec, which implies that frequency may not be the key factor. For stride length, modern elite sprinters' average stride length 2.22 m, Usian Bolt's stride length is 2.44 m, and Maurice Greene's stride length is 2.23 m, respectively. Participants' stride length in this study showed shorter mean stride than modern elite sprinters, Bolt and Greene. Although participants F and

Table 2
Results of Participants' Parameters

Participants	Parameters					
	Strides (m)	Frequency (steps/sec)	Proportionality of ground and air phase	Touchdown distance (cm)	Pelvis angle	Recovery angle
A	1.78	5.43	1:1.26	28	160	41.0
B	1.83	5.30	1:1.15	30	162	41.3
C	2.03	4.64	1:1.45	28	176	41.2
D	2.01	4.76	1:1.37	29	169	38.9
E	2.02	4.71	1:1.47	31	165	40.1
F	2.11	4.57	1:1.33	32	165	40.8
G	2.10	4.62	1:1.40	31	169	39.4
H	1.98	4.82	1:1.55	26	175	41.2
M ± *SD*	1.98 ± 11.00	4.85 ± 0.20	1:1.34 ± 0.10	30.5 ± 2.0	167.6 ± 5.4	40.48 ± 0.9

Table 3
Average Stride Length and Frequency among World Class Sprinters

	Mean stride (m)	Mean frequency (steps/sec)
Usian Bolt	2.44	4.23
Maurice Greene	2.20	4.65
World elite sprinter	2.22	4.55
Participants	1.98	4.85

G showed the highest stride length, 2.10 m and 2.11 m, respectively, among all participants, the world class sprinters stride length listed in Table 3 are all higher than 2.10 m. It implies that shorter stride length may lead to a poor sport performance.

Hoffman (1971) investigated the dependences of quantities, such as stride length and stride frequency, on the height of 56 male sprinters. Hoffman found that average stride length (*l*) varies with a sprinter's height (*h*) according to the linear relation $l = 1.14\ h$. In Shinabargar, Hellrich, and Baker's (2010) study, the result came to 1.21. Table 4 shows the body height (*h*), mean stride length (*l*) and proportionality constant (*l*/*h*) comparison for participants and world elite sprinters. The proportionality constant (*l*/*h*) for participants in this study is 1.14. The proportionality constant (*l*/*h*) including Usian Bolt, Maurice Greene, Yoshihide Kiryū (world junior 100-m record holder) and the mean value of modern sprinters are all above 1.20, which indicates the weakness on stride length for participants in this study on taking advantage of height. Liu and Jhen (2005) indicated that based on past research, stride length was the significant difference between athletes in Taiwan and world-class elite sprinters. In this study, the results once again show that the stride length may be an important factor for participants in this study to improve sprinting performance.

To improve stride length, several factors should be noticed, including the disadvantage of stride resulted from running technique, strength, and flexibility etc. In order to improve stride, the abilities, such as length of legs, push-off, speed, flexibility of hip and muscles, technique for swing and landing, should be taken into considerations (Pan, 2002). Hsu (1976) mentioned that the improvement of stride came from the higher knee lifting. Previous study by Liu (2006) also indicates that better joint flexibility is the major factor that makes strong stride. Another study shows that 8 weeks resistance training could have a positive effect on making a longer stride (Cronin & Hansen, 2006).

The ratio between ground and air period shows the duration of the stance and flight phases. The longer touchdown distance made in maximum speed running will lead to a higher breaking force (Thompson, Bezodis, & Jones, 2009). Therefore, the touchdown distance should be minimized in ground phase for elite sprinters (Mann, 1985; Mero, Komi, & Gregor, 1992). The mean value of the ratio between ground and air period in this study is 1:1.34. Comparing with research for 100-m sprinters in the 11th Asian Games, the mean ratio between ground and air period from participants in this study is 1:1.52 (Feng & Kou, 1992), which

Table 4
Body Height, Mean Stride Length (l) and Proportionality Constant (l/h) Comparison

	Height *h* (m)	Mean stride length *l* (m)	Proportionality constant (*l*/*h*)
Usian Bolt	1.96	2.44	1.24
Maurice Greene	1.75	2.20	1.26
Yoshihide Kiryū	1.75	2.12	1.21
World elite sprinter	1.83	2.22	1.21
Participants	1.79	1.98	1.14

means Asian elite sprinters' ground phase period is shorter than participants in this study. Only one participant H showed similar value with 1:1.55.

The average touchdown distance for sprinters in this study is 30.5 cm, ranging between 26 cm to 32 cm. However, Mann (1985) indicated that the best touchdown distance should be about 15 cm, although the touchdown distance for the famous American sprinter Asafa Powell was 20 cm (Seagrave et al., 2009). Furthermore, the average touchdown distance of gold and silver medalists during high speed phase in the Finals in men's 200-m in 1984 Summer Olympic Games were 21.7 cm and 28.4 cm, respectively. On the other hand, previous study by Hunter, Marshall, and McNair (2004) showed that the mean touchdown distance of 28 male participants in sports involving sprint running was 25 cm. Different conclusions between those studies might come from different leg length of those sprinters.

Another factor that affects the touchdown distance may be the anterior rotation of the pelvis in high speed running (Bosch & Clomp, 2005). The optimal angle of the pelvis and the lifting leg is 180 degrees. In this study, the participants' pelvises were all anterior rotated. The average pelvis angle for participants was 167.7 degrees. Only participants C and H showed optimal pelvis angles which were over 170 degrees. The rest of the participants' pelvis angles were between 160 degrees and 170 degrees; the other influence is the slow recovery of the leg cycle. The neutral pelvis places the hip flexors in an ideal length tension relationship to store elastic energy and produce force during thigh recovery, assisting in reducing the time required to recover the limb through optimal range of motion (Seagrave et al., 2009). Participants average recovery angle was 40.48 degrees. This explains the deficiency of participants' lifting legs and recovery mechanics. Chu (2005) compared recovery angle for Chinese and American sprinters and found that American sprinters' recovery angle (29 degrees) is smaller than Chinese sprinters (33 degrees). Wood (1983) stated that the factor which could significantly influence sprinting performance was recovery angle. Shortening the ground contact time will decrease the horizontal impulse. The key is to keep the touchdown distance shorter so that it can minimize the breaking impulse at moment of touchdown. After pushing off, back leg should fold immediately to make the biggest stride and frequency. Comparing to the reference, participants in this study showed lower proportionality between air and ground phase, touchdown distance, pelvis and recovery angle, which might imply the biomechanical deficiency in ground phase.

Parameters used in this study could imply that participants in this study should correct technique at the ground phase. The technical quality at the ground phase attributes to ground preparation period (Seagrave et al., 2009). In ground phase the athlete must be cued to explode through the track or tear back the track surface (Seagrave et al., 2009; Thompson et al., 2009). On the other hand, results from participants A and B showed longer ground contact time. Weyand, Sternlight, Bellizzi, and Wright (2000) concluded that runners reach higher top speed by applying greater support forces to the ground in shorter time. Therefore, the power of lower body is relatively important (Wang, Yang, & Chang, 2008). Many past studies also showed that 8 weeks plyometric training could be used to improve the power of lower body (Markovic, Jukic, Milanovic, & Metikos, 2007; Rimmer & Sleivert, 2000). It could be suggested that participants in this study could use Plyometric training for improving the power of lower body.

Conclusion

Participants in this study showed insufficient stride length and skill at the ground contact, further training in resistance, flexibility, plyometric and running drills may help.

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