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Research article

Anthropometric, gait and strength characteristics of Kenyan distance runners

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Abstract
This study intended to take a biomechanical approach to understand the success of Kenyan distance runners. Anthropometric, gait and lower extremity strength characteristics of six elite Kenyan distance runners were analyzed. Stride frequency, relative stride length and ground contact time were measured at five running speeds (3.5 – 5.4 m/s) using a motion capture system. Isometric knee extension and flexion torques were measured at six angles and hamstrings and quadriceps (H:Q) ratios at three angular velocities were determined using an isokinetic dynamometer. These runners were characterized by a low body mass index (20.1 ± 1.8 kg·m^{-2}), low percentage body fat (5.1 ± 1.6%) and small calf circumference (34.5 ± 2.3 cm). At all running speeds, the ground contact time was shorter ($p < 0.05$) during right (170 – 212 ms) compared to left (177 – 220 ms) foot contacts. No bilateral difference was observed in other gait or strength variables. Their maximal isometric strength was lower than other runners (knee extension: 1.4 - 2.6 Nm·kg^{-1}, knee flexion: 1.0 – 1.4 Nm·kg^{-1}) but their H:Q ratios were higher than athletes in other sports (1.03 ± 0.51 at 60°/s, 1.44 ± 0.46 at 120°/s, 1.59 ± 0.66 at 180°/s). The slim limbs of Kenyan distance runners may positively contribute to performance by having a low moment of inertia and thus requiring less muscular effort in leg swing. The short ground contact time observed may be related to good running economy since there is less time for the braking force to decelerate forward motion of the body. These runners displayed minor gait asymmetry, though the difference may be too small to be practically significant. Further investigations are needed to confirm whether the bilateral symmetry in strength and high H:Q ratios are related to genetics, training or the lack of injuries in these runners.

Key words: Stride length, stride frequency, ground contact time, isometric torque, hamstrings to quadriceps ratio, asymmetry.

Introduction

Kenyan runners are well recognized for their success in distance running (Manners, 1997; Onywera, et al., 2006). As of today, male Kenyan (and East African) runners are in the top of the International Association of Athletics Federation (IAAF) world lists in all events from 800 m to the marathon (Table 1). About three quarters of the top Kenyan runners come from the Kalenjin tribe (Manners, 1997), which makes up about 12% of Kenya's population (CIA World Factbook, 2008) and approximately 1/2,000 of the world's population. Yet, they have won about three-eighths of international men's distance running prizes and three times more Olympic medals in distance running than any other whole nation (Manners, 1997). These performances have been described as "the greatest geographical concentration of achievement in the annals of sport (Manners, 1997)."

Table 1. Percentage of male Kenyan-born runners in the top 50 of the 2007 IAAF World list.

Distance	Percentage of Kenyan runners
800 m	30 %
1500 m	42 %
3 km Steeple	64 %
5 km	44 %
10 km track	54 %
10 km road	66 %
Half marathon	58 %
Marathon	58 %
Cross Country*	60%

*Data based on the 2007 IAAF World Cross Country Championship men's 12 km top 10 race results.

Researchers have attempted to gain insight into contributing factors behind the remarkable performance of these Kalenjin athletes. Their success has been hypothesized to be related to the fact that Kenyans generally live and train at high altitude (around 2000 m above sea level) influencing their oxygen capacity. However, research has not supported this hypothesis as no difference was found in maximal oxygen uptake (VO_{2max}) between elite Kenyan and Scandinavian runners (Saltin et al., 1995b) or between untrained Kenyan and Danish adolescents (Andersen et al., 1987). Another hypothesis states that the athletes' nutrition may have contributed to success in running. While Kenyan runners' diet matched the recommendations by the Food and Agriculture Organization/World Health Organization/United Nations University (FAO/WHO/UNU) for endurance athletes for macronutrients intake (Christensen et al., 2002; Onywera et al., 2004), it was far from adequate for vitamin and mineral intake (Christensen, 2005). During intense training periods prior to competition, Kenyan runners are in negative energy balance (Fudge et al., 2007; Onywera et al., 2004) leading to body mass reduction (Onywera et al., 2004) that may potentially contribute to short term success by reducing the energy cost of running. However, no association was found between nutrition and marathon performance in African runners (Peters and Goetzsche, 1997).

Endurance running performance is positively related to type I fibres in skeletal muscles (Coyle, 1999) but this does not explain the success of Kenyan runners as muscle fibre size and composition are similar between elite Kenyan and Scandinavian runners (Saltin et al., 1995a). Recent research has evaluated the genetic expression in elite Kenyan runners but no association between their genetic makeup and performance has been confirmed (Scott et al., 2005). Another popular presumption

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is that Kenyan children run long distances to school. Compared to the general Kenyan population, elite Kenyan runners travelled further to school, mostly by running (Onywera et al., 2006). While there was no difference in aerobic trainability between Kenyan village and town boys (Larsen et al., 2005), it has been speculated that the physical activity in childhood, combined with intense training as teenagers, were related to the high aerobic capacity in Kenyan runners (Saltin et al., 1995b). Other factors that may be positively associated with African distance runners' success include their slender body shape (Larsen et al., 2004; Saltin et al., 1995a), good running economy (Saltin et al., 1995b; Weston et al., 2000), and higher fractional utilization of VO_{2max} (Weston et al., 2000).

In running, biomechanical factors can contribute to success in performance in terms of improving running economy and preventing injury (Williams, 2007). Running economy has been shown to correlate with certain gait characteristics such as stride length (Morgan et al.,1994), ground contact time (Nummela et al., 2007), vertical oscillation and lower extremity angles (Williams and Cavanagh, 1987). Lower extremity injuries are related to altered running mechanics (Willems et al., 2005) and imbalances in muscle strength (Orchard et al., 1997). It is possible that Kenyan runners run in a form that positively contributes to their superior performance and keeps them free from injury. To our knowledge, the only biomechanical study on Kenyan runners available in English is an abstract by Enomoto and Ae (2005). This study reported kinematic differences between elite Kenyan and Japanese runners and concluded that the Kenyan runners were able to swing their leg forward faster and through a greater range. Although limited data were presented in this abstract, their findings highlight that biomechanical factors may play a significant role in the success of Kenyan distance runners.

This study aimed to take a biomechanical approach to contribute to the understanding of the success of Kenyan runners. Anthropometric, gait and lower extremity strength characteristics of six elite Kenyan distance runners were analyzed.

Methods

All experimental procedures were approved by the Institutional Review Board and informed consents were obtained prior to data collection. The subjects were six elite collegiate male runners who competed for a university in the U.S. at the National Collegiate Athletic Association (NCAA) Division 1 level at the time of the study. All runners were born in the Rift Valley, Kenya and belong to the Kalenjin tribe; five of them belong to the Nandi, the Kalenjin sub-tribe that the majority of elite Kenyan runners come from (Onywera et al., 2006). Except subject 2, all runners have won at least one 'All-American' title. Table 2 presents their demographic and running background, and Table 3 describes their physical characteristics. Each year, the participants compete from roughly September through November in Cross Country and from January through June in track. During the course of the year, the amount of training sessions range from about 11 sessions and 170 km during maximum build up phases to about 7 sessions and 80 km during mid competition season.

Anthropometric measurements

Each subject's height, mass, leg length (greater trochanter to lateral malleolus), calf circumference (maximum circumference between knee and ankle) and ankle circumference (minimum circumference just above lateral malleolus) were measured. Since no bilateral difference was found, an average value of both left and right sides was calculated for each length and circumference parameter. A 3-site skinfold test (chest, abdominal and thigh) was used to calculate the body fat percentage using the Jackson and Pollock (1978) equations.

Gait characteristics

Reflective markers were placed on the heel, second metatarsal head and lateral malleolus of both feet (over shoes) of each subject. Each subject ran on a treadmill at five speeds (3.5 m/s, 4.0 m/s, 4.5 m/s, 5.0 m/s and 5.4 m/s) in a systematic order while kinematic data were collected at 240 Hz using an eight-camera motion capture system

Table 2. Demographic information, training experience and personal best record of six Kenyan runners.

Subject	Kalenjin Sub-tribe	Family running history*	Means of travel to school (age 6-14y)	Organized training (yr)	Personal Best Times† and Events
1	Nandi	Yes	Walk/Run Daily 6-13km	3.5	800m: 1:47 1500m: 3:44 10km Cross Country: 29:36
2	Nandi	Yes	Walk/Run Daily 6-13km	1.5	1500m: 3:46 5000m: 14:05 10km Cross Country: 29:19
3	Keiyo	No	Walk/Run Daily 6-13km	6	800m: 1:46
4	Nandi	Yes	Walk/Run Daily 5-10km	5	5000m: 13:48 10,000m: 28:07
5	Nandi	Yes	Walk/Run Daily 5-10km	4	5000m: 14:04 10,000m: 28:24
6	Nandi	Yes	Walk/Run Daily 13km	5	5000m: 14:02 3000m Steeple: 8:31 10km Cross Country: 28:39

* At least one family member has been a competitive runner. † Time is expressed in minutes and seconds.

Table 3. **Anthropometric measurements and body composition of six Kenyan runners.** Data are in mean (SD).

Variable	Present study	Saltin et al. (1995b)*	Fudge et al. (2007)
Age (y)	22.0 (1.8)	23 (2.1)	21.0 (2.0)
Mass (kg)	63.0 (7.3)	56.1 (1.2)	56.0 (3.4)
Height (m)	1.77 (0.06)	1.71 (0.00)	1.74 (0.03)
Body mass index ($kg·m^{-2}$)	20.1 (1.8)	19.2†	18.3 (1.3)
Leg length (m)	0.92 (0.06)		
Calf circumference (cm)	34.5 (2.3)		
Ankle circumference (cm)	20.5 (1.5)		
Sum of three skinfolds (mm)	22.3 (5.8)		
Body fat (%)	5.3 (1.6)		7.1 (2.5)

*Data on six Kenyan long distance runners measured at sea level. †Body mass index of the best Kenyan runner measured at sea level.

(Vicon, Centennial, CO, USA). Ideally we would like to use speed range that our runners would use in race (5.6 m/s to 7.5 m/s). However, the maximum speed of the treadmill in our laboratory was 5.4 m/s. We included some slower speeds for two reasons: 1) runners often use slower speeds for training, and 2) previous studies have used these speeds to test distance runners and therefore comparison among studies can be made. At each speed, time was given to the subjects to familiarize with the speed for as long as they would need. As soon as the subject indicated that he was comfortable with the speed, 30 seconds of kinematic data were recorded. Six consecutive representative gait cycles near the end of the recorded 30-second period were selected for analysis. The instants of touchdown and toe-off were visually identified based on the foot markers displacement. Ground contact time, stride frequency and stride length relative to height were then calculated accordingly to represent gait characteristics. Ground contact was defined as the duration from touchdown to toe-off for the same foot. Stride frequency measured the number of foot contacts per second. Stride length was defined as the distance from the point of touchdown of one foot to the point of touchdown of the opposite foot. ANOVA with repeated measures (leg × speed) was used to detect differences in each gait parameter. Statistical significance level was set at 0.05.

Strength characteristics

Subjects were tested for strength of both legs on an isokinetic dynamometer (System 3 Pro, Biodex Medical System, NY, USA) after familiarization with the protocol at submaximal effort. We used isometric torque as a measure of leg strength, as well as isokinetic torque ratio to assess agonist/antagonist muscle balance. Peak isometric torque of the quadriceps and hamstrings were measured at six angles: 40°, 50°, 60°, 70°, 80° and 90° of knee flexion. Subjects performed one 3-second trial for each of the above angles with 60 s rest between trials. Peak concentric and eccentric torque of both muscle groups were measured at three angular velocities: 60°/s, 120°/s and 180°/s. Six repetitions were performed at each angular velocity and the peak value was used for evaluation. Although dynamic movements can exceed 180°/s, strength at higher velocities was not measured because such velocities are unlikely to be reached during testing on the dynamometer (Kong, 2007). From the peak isokinetic torque data, functional hamstrings to quadriceps (H:Q) ratios were calculated for each angular velocity by dividing the eccentric hamstrings torque by the concentric quadriceps torque. This functional H:Q ratio has been shown to be more appropriate for strength evaluation than the conventional ratio using concentric torques of both muscle groups (Aagaard et al., 1998). Isokinetic data on subject 4 were not available because this subject did not perform this part of the protocol as he was close to an important competition and desired to avoid any muscular soreness or fatigue that participation might cause. Thus, H:Q ratio of only five subjects was analyzed. Since paired t-tests revealed no difference in any of the strength parameters between the two legs, an average value of both sides was used. Differences in isometric torque among the six knee angles, as well as the H:Q ratio among the three angular velocities were assessed separately using a one-way ANOVA with repeated measures.

Results

Data are presented as mean (standard deviation). Table 3 compares the anthropometric measurements of the six Kenyan runners in the present study to those of elite adult Kenyan runners available in the literature.

Ground contact time during the left leg stride was significantly longer ($p < 0.05$) than that of the right leg overall (Table 4). No bilateral difference was observed in stride frequency and relative stride length and therefore the average value of both sides were presented in Table 4. As speed increased, stance time decreased while stride frequency and relative stride length increased (all $p < 0.01$).

Isometric torque of both the quadriceps and the hamstrings changed with knee angle ($p < 0.05$, Figure 1).

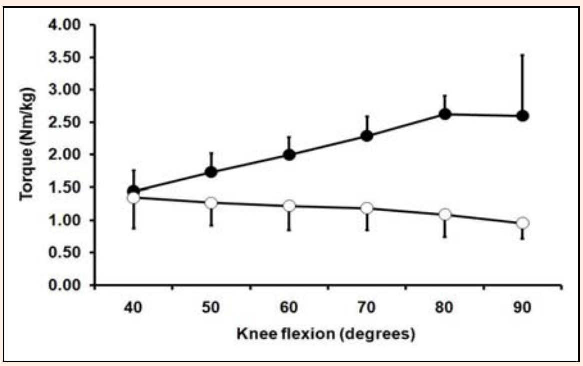

Figure 1. **Isometric torque of both the quadriceps (filled circle) and the hamstrings (empty circle) changed with knee angle.**

Table 4. Gait characteristic of six Kenyan runners at five running speeds. Data are in mean (SD).

Speed (m/s)	Ground contact time (ms)		Stride frequency (Hz)	Relative stride length
	Left	Right		
3.5	220 (25)	212 (24)	2.92 (0.17)	0.68 (0.02)
4.0	208 (25)	199 (22)	3.02 (0.18)	0.76 (0.03)
4.5	201 (21)	193 (20)	3.09 (0.17)	0.82 (0.03)
5.0	183 (27)	180 (22)	3.19 (0.18)	0.89 (0.03)
5.4	177 (26)	170 (22)	3.26 (0.20)	0.93 (0.03)

Significant main effect of leg for ground contact time ($p < 0.05$). Significant main effect of speed for all gait parameters ($p < 0.05$).

The quadriceps torque increased with muscle length, peaking around 80° to 90° of knee flexion. The hamstrings torque peaked at the most lengthened position and decreased as the muscles were shortened. Although the functional H:Q ratio increased as angular velocity increased (1.03 ± 0.51 at 60°/s, 1.44 ± 0.46 at 120°/s, 1.59 ± 0.66 at 180°/s), the difference did not reach statistical significance.

Discussion

The present study is the first to describe the gait and strength characteristics of elite Kenyan distance runners. Despite limitations as the small sample size and the fact that no control group of elite non-Kenyan runners was available, the authors feel that this study takes a first step in bridging an important gap in the literature to potentially explain the success of Kenyans in distance running from a biomechanical perspective.

The personal best times of the Kenyan runners in the present study are close to the top 100 in the world, and five of the six participants have finished in the individual top 8 of the NCAA Division 1 Championships at their event at least one occasion in the year prior to measurement. These runners correspond largely with previously reported description of elite Kenyan runners in terms of slender body type, low body mass index and slim limbs (Fudge et al., 2007; Saltin et al., 1995b). Like other elite Kenyan runners, these runners travelled to school by walking or running at young age (Onywera et al., 2006). Their percentage body fat was slightly lower than those reported by Fudge and colleagues (2007), probably due to different measurement techniques. Their calf circumferences are comparable to those of Nandi boys (Larsen et al., 2004) and such slim legs may positively contribute to good running economy. With a low moment of inertia of the leg about the hip, less muscular effort will be required in leg swing. This is also in accordance with Enomoto and Ae's (2005) findings that Kenyan runners are effective in leg swing, characterized by moving forward faster and covering a greater horizontal range compared to Japanese runners. Future research with a larger sample will need to determine whether the body type is consistently different between elite and non-elite runners.

As expected, there was an increase in stride frequency and relative stride length with speed since these gait parameters usually increase linearly for speeds up to 7 m/s (Williams, 1985). Although difference in relative stride length between Japanese and Kenyan runners was found by Enomoto and Ae (2005), numerical data were not available to allow comparison to the present study. Bilateral difference was observed in ground contact time, but not in stride frequency or stride length, suggesting some degree of gait asymmetry in these Kenyan runners. It is still debatable whether gait asymmetry is related to injuries (Zifchock et al., 2006). Due to their success, it is believed that such minor asymmetry does not negatively influence distance running performance. In addition, the right foot contact time was on average only 7 ms shorter than left foot contact time. This difference, though statistically significant, may be too small to have any practical significance.

Nummela and colleagues (2007) showed that excellent running economy can partly be explained by short ground contact time, although data within speed range used in the present study were not reported in their study. At 4.5 m/s, the ground contact time of the Kenyan runners in the present study appeared to be shorter (average 197 ms) than those measured by Clarke and colleagues (1983) on 10 male runners (average 225 ms). At 5.0 m/s, our Kenyan runners also showed shorter ground contact time (average 192 ms) compared to the values reported by Cavanagh and colleagues (1997) for 8 good and 14 elite distance runners (average 201 - 205 ms). In a recent study on 18 well-trained Finnish distance runners, the ground contact time increased from 207 ms in the start of a 5-km time trial to 220 ms at the end with the speed dropping from 5.2 m/s to 4.7 m/s (Nummela et al., 2008). The ground contact time observed at similar speeds in our Kenyan runners (197, 182 and 174 ms for 4.5, 5.0 and 5.4 m/s) were, again, much shorter than the Finnish runners. The short ground contact time may be related to good running economy in the Kenyan runners since there is less time for the braking force to decelerate forward motion of the body. Based on a mass-spring model of running (Arampatzis et al., 1999), higher leg stiffness will result in shorter ground contact time. Less economical runners are shown to possess a more compliant running style during ground contact as reflected by the low vertical stiffness (Heise and Martin, 1998). Thus, our Kenyan runners may be effective in controlling their muscle activation to maintain high leg stiffness.

We would like to address as a potential limitation that the gait characteristics observed on a treadmill may differ from those during overground running as shown by previous studies (Nelson et al., 1972; Nigg et al., 1995). There may also be some influence due to unfamiliarity of treadmill running (Lavcanska et al., 2005; Schieb, 1986) since none of the Kenyan runners in the present study train regularly on a treadmill. To reduce this influence, the investigators gave the participants time to familiarize themselves with running at each speed for as long as they would need. Data were collected only after each subject indicated that he was comfortable running at the particular speed.

It is not surprising that no bilateral difference was found in any strength parameters because the nature of running movement is likely to put similar stress of both legs. At the same time, however, our participants displayed minor asymmetry in gait characteristics. This may suggest that minor difference in movement pattern is not caused by and/or does not lead to strength asymmetry. The isometric torque-angle relationship for both quadriceps and hamstrings correspond well with the classical force-length relationship and previously published data in terms of the curve shape and the optimal knee joint angle for force production (Ullrich and Brueggemann, 2008; Savelberg and Meijer, 2003; Yoon et al., 1991). The isometric strength of the quadriceps of the Kenyan runners (1.4 - 2.6 Nm/kg) was less than those of elite endurance runners (ranged approximately 1.5 – 3.8 Nm/kg) in Germany (Ullrich and Brueggemann, 2008) and trained runners (average 2.7 Nm/kg) in the Netherlands (Savelberg and Meijer, 2003). This suggests that leg strength is probably not a deterministic factor for success in distance running. Nevertheless, the different equipment and protocols used to measure strength among studies may also account for the different findings.

The functional H:Q ratio, although not statistically significant, shows a tendency to increase as angular velocity increased. This is in agreement with the literature (Aagaard et al., 1998; Holcomb et al., 2007), since eccentric hamstrings torque remains relatively constant while concentric quadriceps torque decreases as angular velocity increases according to the classical force-velocity relationship. A functional H:Q ratio of 1.0 or greater has been proposed as a training goal, though more specifically for minimizing anterior cruciate ligament injuries (Aagaard et al., 1998; Holcomb et al., 2007) which is relatively uncommon in runners. Hamstrings-emphasized resistance training program has been shown to be effective in improving the functional H:Q ratio from 0.96 ± 0.09 to 1.08 ± 0.11 in soccer players (Holcomb et al., 2007). The H:Q ratios measured on the Kenyan runners in the present study were greater than 1.0 at all angular velocities. It should be noted that these runners do not participate in systematic resistance training, yet their H:Q ratios were higher than those of athletes in other sports (Aagaard et al., 1998; Holcomb et al., 2007). While it is possible that the running training routine alone has lead these Kenyan runners to a good H:Q ratio, there may also be a genetic factor which cannot be addressed by the present study. Future studies comparing H:Q ratios of runners of different ethnic backgrounds and between Kenyan runners and sedentary Kenyan population will be needed to confirm these speculations. Furthermore, it is unclear whether the high H:Q ratio positively contributes to the lack of injury in the five runners that we measured.

Due to geographical limitation, no control group was available at the time of the present study. While recreational Caucasian runners may potentially serve as controls, the authors feel that this would not have been appropriate, because the effect of training is likely to exceed that due to differences related to genetic and/or geographical location. Future studies with a control group of elite non-Kenyan runners can provide more insight into the genetic and/or geographical difference in running mechanics. At the same time, comparing various levels (elite/sub-elite/non-runners) within the Kenyan population will also be valuable to determine whether an observed difference is related to race and/or training.

Conclusion

This study is the first to present gait and strength characteristics of elite Kenyan distance runners, with an aim to understand their success in performance from a biomechanical perspective. Elite Kenyan distance runners are characterized by a low body mass index, low percentage body fat and slim limbs. Overall, short ground contact time was observed in these runners, with shorter time during right foot contacts. Finally, their leg strength was relatively low compared to other runners, but they possessed high H:Q ratios compared to athletes in other sports.

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Key points

- This is the first study in the literature to analyze the biomechanical characteristics of elite Kenyan distance runners, potentially providing insight into their success in distance running.
- Their slim limbs may positively contribute to performance by having a low moment of inertia and thus requiring less muscular effort in leg swing.
- Overall, short ground contact time was observed with the right leg shorter than the left leg. This may be related to good running economy since there is less time for the braking force to decelerate forward motion of the body.
- These runners displayed symmetry in strength between the left and right legs and possessed high hamstrings to quadriceps ratios compared to athletes in other sports.

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