Shorter Ground Contact Time and Better Running Economy: Evidence From Female Kenyan Runners

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Abstract

Mooses, M, Haile, DW, Ojiambo, R, Sang, M, Mooses, K, Lane, AR, and Hackney, AC. Shorter ground contact time and better running economy: evidence from female Kenyan runners. *J Strength Cond Res* 35(2): 481–486, 2021—Previously, it has been concluded that the improvement in running economy (RE) might be considered as a key to the continued improvement in performance when no further increase in $\dot{V}O_2max$ is observed. To date, RE has been extensively studied among male East African distance runners. By contrast, there is a paucity of data on the RE of female East African runners. A total of 10 female Kenyan runners performed 3 × 1,600-m steady-state run trials on a flat outdoor clay track (400-m lap) at the intensities that corresponded to their everyday training intensities for easy, moderate, and fast running. Running economy together with gait characteristics was determined. Subjects showed moderate to very good RE at the first (202 ± 26 $ml \cdot kg^{-1} \cdot km^{-1}$) and second (188 ± 12 $ml \cdot kg^{-1} \cdot km^{-1}$) run trials, respectively. Correlation analysis revealed significant relationship between ground contact time (GCT) and RE at the second run ($r = 0.782$; $p = 0.022$), which represented the intensity of anaerobic threshold. This study is the first to report the RE and gait characteristics of East African female athletes measured under everyday training settings. We provided the evidence that GCT is associated with the superior RE of the female Kenyan runners.

Key Words performance, East African runners

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Introduction

At any given speed, better running economy (RE) refers to a comparatively smaller rate of energy consumption (18). Running economy together with a high fractional utilization of $\dot{V}O_2max$ has been postulated to be one of the possible factors explaining East African success in middle- and long-distance running (19). Previously, it has been concluded that the improvement in RE might be considered as a key to the continued improvement in performance when no further increase in $\dot{V}O_2max$ is observed (14). To date, RE has been extensively studied among East African distance runners; however, most of these studies were exclusively conducted on male subjects only (15,18,19,26,27).

More than a decade ago, this knowledge gap on RE was first addressed by Billat et al. (3) when they conducted a study on 7 female Kenyan runners to describe their physical characteristics as measured at sea level. However, from this study (3) until the present date, a significant gap about female East African runners, RE, and their gait characteristics has existed in the scientific literature, although the success of East African female distance runners in international level has continued. Interestingly, the superiority of homogeneous group of elite Eritrean male runners' RE was not associated with gait characteristics such as ground contact time (GCT) when compared with European runners (26), and more recently, based on the results with slightly lower-level Kenyan male runners, it was hypothesized (27) that short GCTs may be contributing to the exceptional RE of Kenyan male runners.

Traditionally, RE has been evaluated on a treadmill at one particular speed for all the subjects (21); however, Fletcher et al. (9) suggested that RE should be compared between individuals at a similar relative running intensity rather than at the same running speed. They explained that comparing different athletes at the same absolute running speeds does not acknowledge differences in speed associated with the

Table 1. Physical characteristics and training profile of the subjects (mean ± SD).*

Variables	Kenyans ($n = 8$)
Age (y)	24.3 ± 4.0
Body mass (kg)	49.8 ± 4.4
Height (m)	1.64 ± 0.05
BMI ($kg \cdot m^{-2}$)	18.4 ± 1.3
IAAF score (points)	1,006 ± 90
Age when started regular training (y)	19.6 ± 2.7
Previous experience of regular training (y)	4.6 ± 6.0
Typical training volume during the previous 3 mo ($km \cdot wk^{-1}$)	87.5 ± 18.5
Longest training run during the previous 3 mo (km)	25.6 ± 4.6
Stretching (yes/no)	Yes ($n = 7$)
Weight training (yes/no)	Yes ($n = 3$)

*BMI = body mass index; IAAF= International Association of Athletics Federations.

lactate threshold or differences in substrate utilization associated with differences in exercise intensity relative to $\dot{V}O_2$max (8). Despite the fact that a strong correlation has been found between RE with track and treadmill running, there is evidence to suggest that it is more appropriate to determine RE on an outdoor track, which is a more natural training environment for athletes compared with treadmill running (21).

With the above in mind, this study aimed to (a) describe the RE of the high-level female Kenyan runners and (b) determine the relationships between RE and gait characteristics measured at the individual training intensities used in their daily training regimes.

Methods

Experimental Approach to the Problem

The testing protocol consisted of 3 × 1,600-m steady-state run trials on a flat outdoor clay track (400-m lap) at an altitude (2,100 m a.s.l.), which is similar to previously used steady-state running protocols (20). Warm-up consisted of 10 minutes of low-intensity running after which runners rested for 5 minutes. Subjects were asked to run the 3 steady-state runs at the intensities that corresponded to their everyday trainings for: (a) easy (long run), (b) moderate (~anaerobic threshold), and (c) fast (interval training > anaerobic threshold). Recovery time between the runs was 3 minutes. During recovery, runners walked slowly on the track. Heart rate (HR) and expired gases were measured continuously throughout the trials using Metamax 3B (Cortex Biophysic GMBH, Leipzig, Germany), and capillary blood lactate level was measured (Lactate Scout; SKF Diagnostics, SensLab GmbH Lepzig, Germany) after each of the 1,600-m run as well as the fifth and 15th minutes of recovery after the third run trial.

Table 2. Physiological and gait characteristics of the female Kenyan runners at their individual training intensities (mean ± seconds).*

	I	II	III	Cohen's *d* I compared II	Cohen's *d* I compared III	Cohen's *d* II compared III
Speed ($km \cdot h^{-1}$)	13.6 ± 1.5	15.4 ± 0.9†	16.0 ± 0.8†‡	1.46	2.0	0.70
RE ($ml \cdot kg^{-1} \cdot km^{-1}$)	202 ± 26	188 ± 12				
$\dot{V}O_2$ ($ml \cdot min^{-1} \cdot kg^{-1}$)	45.6 ± 4.9	48.1 ± 3.6	49.5 ± 2.7†		0.99	
HR ($b \cdot min^{-1}$)	173 ± 7	182 ± 5†	189 ± 4†‡	1.48	2.80	1.55
VE ($L \cdot min^{-1}$)	73 ± 7	89 ± 12†	100 ± 12†‡	1.63	2.75	0.92
RER	0.94 ± 0.03	1.00 ± 0.06†	1.16 ± 0.07†‡	1.26	4.09	2.45
Cadence (rpm)	176 ± 6	178 ± 8	179 ± 9			
VOSC (cm)	9.0 ± 1.2	9.1 ± 1.2	8.9 ± 1.3			
GCT (ms)	215 ± 19	205 ± 10	203 ± 14			
Stride length (m)	1.36 ± 0.13	1.46 ± 0.06†	1.51 ± 0.08†	0.99	1.39	

*RE = running economy; HR = heart rate; VE = minute ventilation; RER = respiratory exchange ratio; VOSC = vertical oscillation; GCT = ground contact time.
†Significantly different from run 1 ($p < 0.05$).
‡Significantly different from run 2 ($p < 0.05$).

Subjects

A total of 10 competitive female Kenyan runners from Kalenjin tribe, competing in different distances between 800 m up to the marathon, were recruited to this study. All athletes competed in several distances, and the best performance of their ongoing season, established using the International Association of Athletics Federations (IAAF) scoring tables (30), was included in the analysis. Study procedures and protocols were approved by the research and ethics committee of Moi University (Kenya) and University of Tartu (Estonia) and conformed to the Declaration of Helsinki. All testing procedures and related risks were described before providing written informed consent to participate in the study. Athletes were requested to maintain their usual dietary intake and to refrain from alcohol 48 hours before the study began. They were also asked to abstain from hard training and competition for at least 48 hours before testing.

Procedures

Height (Power Tape; Lidu Hardware, Zhejiang, China) and body mass (Seca robusta 813; Seca GmbH & Co., Hamburg, Germany) of the subjects were measured to the nearest 0.01 m and 0.1 kg, respectively. From these measures, the body mass index (BMI) was calculated.

Stride parameters such as cadence, vertical oscillation (VOSC), GCT, and stride length were recorded using Garmin Fenix 3 HR monitor with Garmin HRM-run v2 heart rate belt (Garmin International, Inc., Kansas City, MO). Similar commercially available devices (Garmin HRM-run heart rate belt; Garmin International, Inc., Kansas City, MO) have recently been shown as a reliable method for measuring gait characteristics (1). Running economy was measured only during the last 2 minutes of the first and second 1,600-m runs and was expressed as ($ml \cdot O_2 \cdot kg^{-1} \cdot km^{-1}$) and calculated as follows:

$$\text{Running economy } \left(ml \cdot O_2 \cdot kg^{-1} \cdot km^{-1}\right) = 1000 \cdot \dot{V}O_2 \cdot v^{-1},$$

Where $\dot{V}O_2$ is steady-state oxygen uptake ($ml \cdot kg^{-1} \cdot min^{-1}$) and v is a running velocity ($m \cdot min^{-1}$). Steady-state $\dot{V}O_2$ was defined as an increase of less than 100 $ml \cdot O_2$ over the final 2 minutes of each stage. Two of the runners were excluded from the final analysis, as they started the first 1,600-m run with the intensity higher than their anaerobic threshold.

Statistical Analyses

Data were tested for normality distribution using the Shapiro-Wilk test. To take into account the individual differences in running speed, partial correlation (Pearson) was used to assess the relationship between the RE and gait characteristics on the first and second steady-state run trials. Differences at 3 running intensities were analyzed using repeated-measures analysis of variance with the least significant difference post hoc test. The magnitude of differences or effect sizes was calculated for significant differences using Cohen d (6) and interpreted as small (>0.2 and <0.6), moderate (≥0.6 and <1.2), and large (≥1.2 and <2) or very large (≥2.0) according to the scale proposed by Hopkins et al. (13). Calculations were performed using IBM SPSS v.20 software for Windows (SPSS, Inc., Chicago, IL). The level of significance was set at $p \leq 0.05$.

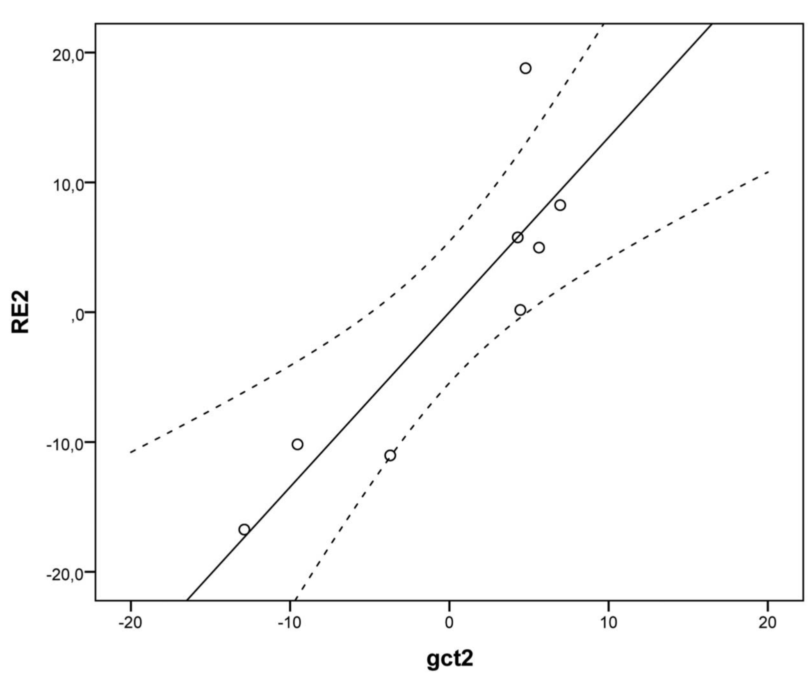

Figure 1. Partial correlation between GCT and RE at the second run ($r = 0.872$; $p = 0.010$), when controlled for the speed (unstandardized residuals). Solid line–regression line and dashed line–95% confidence interval. RE = running economy; GCT = ground contact time.

Results

The main subject and training characteristics of the female Kenyan runners who completed the study ($n = 8$) are presented in Table 1. The physiological responses indicated that the intensity of the first run on the outdoor track was below anaerobic threshold (AnT), the second one at the AnT, and the third run with an intensity above AnT. This was confirmed by respiratory exchange ratio and blood lactate values (2.6 ± 1.7; 4.9 ± 2.5; and 8.0 ± 3.3 mmol·L^{-1}; first, second, and third run, respectively) and by the fact that $\dot{V}O_2$ did not reach steady state over the last 2 minutes of the third run. Subjects showed moderate to very good RE at the first (202 ± 26 ml·kg^{-1}·km^{-1}) and second (188 ± 12 ml·kg^{-1}·km^{-1}) runs, respectively. Gait characteristics of the subjects are shown in Table 2. Partial correlation analysis revealed a significant positive relationship between GCT and RE at the second run ($r = 0.872$; $p = 0.010$), but not at the first run ($r = -0.736$; $p = 0.095$) when controlled for the speed (Figure 1).

Discussion

This is the first attempt in nearly 15 years to broaden the knowledge about high-level female Kenyan distance runners with respect to RE. Specifically looking at RE when measured in their native field conditions at the intensities used by these athletes on a daily basis. Furthermore, it is the first study to report gait characteristics of high-level female East African distance runners in relation with RE, which in turn has been proposed as one of the main contributing factors to the success of male and female East African distance runners (19). Moreover, previous studies on male East African athletes indicate that gait characteristics may be associated with RE. For instance, it has been speculated that GCT might be one of the determinants in the enhanced RE of East African male runners (27). This is consistent with the findings in the current study, where GCT was significantly correlated with RE ($p = 0.022$).

Thus, despite the limited sample size and that gait characteristics were measured at the athletes individual training intensities, we believe that this study is an important step in explaining the success of female East African distance runners. This is supported by the similarity of our subjects (e.g., body mass, height, and BMI) to those recently reported in a review discussing female and male East African runners (19) and factors to their success.

The slow component of $\dot{V}O_2$ elevates the O_2 cost of exercise and thus can even prevent the attainment of a steady state at exercise intensities above AnT (14). Therefore, RE in this study was measured over the range of submaximal running speeds at which the athlete habitually performs her continuous endurance training (i.e., only the first and second run trials of this study) and not calculated for the third run because it was clearly above the AnT. In the case study of the female World Marathon record holder, Jones (14) explained that RE values (ml·kg^{-1}·km^{-1}) are considered average around 200 (ml·kg^{-1}·km^{-1}) and values above and below this value, representing poor and good economy, respectively. Good RE (lower $\dot{V}O_2$) for a given running speed results in the utilization of a lower percentage of the athlete's $\dot{V}O_2$max while running at that speed and consequently a reduction in muscle glycogen utilization, and potentially resulting in less reliance on O_2-independent metabolism resulting in a reduction in potential metabolic acidosis, a potential fatigue-inducing factor (14).

To date, only one study (3) has assessed the RE of female East African distance runners. They found the RE in high-level female Kenyan runners ($n = 7$) being 208 ± 14 (ml·kg^{-1}·km^{-1}) at the speed of 15.8 km·h^{-1}, which, interestingly, was not significantly different from the RE measured in male East African runners at the same relative intensity within that study (3). In a study with Caucasian runners (7), it was concluded that male runners are more economical compared with female runners at the most common velocities of running; however, at the same relative intensities, there is no difference in RE between the elite-level male and female runners. A similar conclusion was drawn from another study with Caucasian distance runners (4), where no significant difference in RE between male and female runners was noticed.

Data have been reported about the RE (speed 16 km·h^{-1}) of the women's marathon world record holder (Caucasian) over the period of 11 years of training and competing (14). Her RE improved from 205 (ml·kg^{-1}·km^{-1}) in 1992 to 175 (ml·kg^{-1}·km^{-1}) in 2003. In this study, the RE values of 202 to 188 (ml·kg^{-1}·km^{-1}) during the first and second 1,600-m runs, respectively, were in a similar range compared with previously published data about male East African runners as well as one of the best Caucasian female marathon runners (14,19). Interestingly, our female Kenyan distance runners had very good RE, despite their relatively modest number of years in training experience, which could be one of the factors in the complex interplay explaining the success in general of the female East African distance runners.

Gait characteristics such as shorter GCT, lower stride frequency, longer strides, and smaller VOSC (22,25,33) have been related to improved RE in different levels of runners. Specifically, shorter GCT has been shown to be related to superior RE because there is less time for the braking force to decelerate forward motion of the body (15,22). To this end, higher leg stiffness will result in shorter GCT (15); thus, less economical runners are shown to possess a more compliant running style during ground contact as reflected by the low vertical stiffness (12). According to the explanation by Santos-Concejero et al. (25), this is associated with greater preactivation of the shank muscles, which increases the sensitivity of the muscle spindle potentiating stretch reflexes to enhance musculo-tendon stiffness and therefore improving RE. This may be a consequence of high efficacy in the use of the recoil of elastic energy from the tendinous structures accompanied by shorter stretching and higher stretching to preactivation ratio than that has been measured in subjects with worse RE (26). A contradictory argument, however, is that short GCT is actually less economical due to the fact that faster force production is required, and thus, the metabolically more demanding fast-twitch muscle fibers are recruited (17). Sano et al. (24) explained that stretching and shortening of the Achilles tendon tissues together with activation of triceps surae muscle group were smaller in African runners compared with Caucasian controls during hopping exercise. Later (16), it has been proposed that Achilles tendon moment arm and foot lever ratio in Kenyan runners may contribute positively to their endurance RE and thus performance by reducing the required Achilles tendon force and muscle activity during running. However, it is important to note that neither of 2 studies (16,24) measured RE. Still, it has been argued that reducing the speed loss during ground contact is more important than the time in contact with the ground (17).

We found GCT of 215 ± 19; 205 ± 10; and 203 ± 14 milliseconds at the speed of 13.6 ± 1.5; 15.4 ± 0.9; and 16.0 ± 0.8 $km \cdot h^{-1}$, respectively. These values are similar to those previously measured in high-level male Kenyan runners. For example, Santos-Concejero et al. (27) found 240 ± 20 milliseconds at the speed of 12 $km \cdot h^{-1}$ and 180 ± 10 milliseconds at the speed of 20 $km \cdot h^{-1}$. Kong and de Heer (15), also within high-level male Kenyan runners, presented GCT of 216 milliseconds at the speed of 12.6 $km \cdot h^{-1}$, 204 milliseconds at the speed of 14.4 $km \cdot h^{-1}$, and 197 milliseconds at the speed of 16.2 $km \cdot h^{-1}$. Regrettably, in this latter study, they did not measure RE and hence could not relate it directly to GCT. However, in this study, we found a strong correlation between GCT and RE on the second run, which reflects the moderate training pace that athletes are using in their everyday training settings. This suggests that athletes with shorter GCT have better RE. The present results are contradictory to some recent studies with male Kenyan as well as Eritrean runners (26,27), where no relationship was found between GCT and RE. The absence of any relationships within these studies has been attributed to the homogeneity of the groups studied. Based on the previous literature and present data, it could be argued that GCT may be an important contributor to the superior RE of Kenyan female and their male counterparts.

There was an expected increase in stride frequency and more specifically in stride length over the 3 running speeds because these gait parameters increase linearly up to the speed of 7 $m \cdot s^{-1}$ (15,18,34). Mooses et al. (18) explain that increasing stride length is more efficient than increasing frequency by devoting less energy to leg acceleration, and longer legs favor longer stride length, therefore allowing for a better RE (2,29). However, this explanation is valid up to 90% of an individual maximum speed because thereafter the speed is mainly increased by increasing stride rate frequency (22). It is suggested that a cadence of 180 rpm is more economical for running compared with a lower one (5,23). However, athletes are most economical in their freely chosen stride frequency and length, which suggests that the most economical stride frequency and length are highly individual for each athlete (2,5). Literature does suggest that there is an optimal stride length "range", which trained runners can acutely adopt without compromising their RE. The cadence of the 3 different running speeds in this study was very similar to that of Kong and de Heer (15) who examined male East African runners (175, 181, and 185 rpm at the speed of 12.6, 14.4, and 16.2 $km \cdot h^{-1}$, respectively). Our findings are also supported by previous literature with elite-level Kenyan male runners, where neither stride frequency nor length was related with RE (27). However, Moore (17) suggested that caution should be taken in generalizing the principle of optimal stride length range to all runners because self-optimization seems to be a physiological adaptation resulting from greater running experience (i.e., training), meaning that for novice runners, the difference between preferred and mathematically optimal cadence is greater when compared with trained runners (8,17). Therefore, the "optimal runners' cadence" has been proposed to be a trade-off between the metabolic cost associated with the braking impulses and metabolic cost associated with leg swing (17).

Vertical oscillation refers to the range of oscillation of the center of mass from maximum to minimum during the running cycle (33). It has been shown that more economical runners at the speed of 12.9 $km \cdot h^{-1}$ present a smaller VOSC compared with less economical runners (9.12 vs. 9.60 cm, respectively) (33). Likewise, acutely increasing VOSC increases the submaximal $\dot{V}O_2$ (i.e., poorer RE) (17,32). It is important to note that even minimal changes in VOSC can result in significant increases in submaximal $\dot{V}O_2$ (10,11). Based on a literature review (17), it has been argued that RE could be improved by reducing the VOSC. This improvement could occur by reducing the metabolic cost needed to support body mass, as a smaller vertical impulse would be produced as well as improved mechanical efficiency as a low displacement of the center of mass produces a low mechanical energy cost because of a smaller amount of work being needed to perform the movement (28,31). Moore (17) concluded that female runners have a lower VOSC compared with male counterparts; however, whether women do typically have better or worse RE compared with men is not yet clear.

Because of preliminary nature and thus small sample size in this study, caution should be taken in extrapolating present findings to all female East African runners. Despite that the Garmin HRM running belt was the best available tool for the in-field study settings in Kenya, caution should be taken to directly compare gait characteristics measured with this device with more precise and specialized equipment for estimating in-field running dynamics. Thus, further research needs to be performed with more accurate devices to confirm the present findings. On the other hand, this is one of the first studies where the RE and gait characteristics of East African female athletes have been measured in their everyday natural training settings (i.e., on an outdoor track at altitude). It can be argued that high-performance level female Kenyan runners have very good inherent RE, despite their modest training experience. In addition, we provided the evidence that GCT is likely one of the factors in the complex interplay resulting in these athletes having such superior RE.

Practical Applications

We propose that tracking of the gait characteristics, measured in field conditions, could be an important parameter to follow to improve the RE of female runners.

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