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VIEWPOINT

Sacrificing economy to improve running performance—a reality in the ultramarathon?

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ULTRAMARATHONS HAVE BECOME increasingly popular in recent years. Although complex tactical and psychological-motivational factors play important roles in performance (Fig. 1), running velocity sustained over a prolonged time is directly proportional to maximal sustainable $\dot{V}O_2$ and inversely proportional to energy cost of locomotion (Cr) (4). In fact, we have demonstrated that, despite the very low intensity in ultramarathons (e.g., fraction of $\dot{V}O_{2\,\mathrm{max}}$ sustained, $F = 0.4$ to 0.5 over a 24-h race), performance still relies on $\dot{V}O_{2\,\mathrm{max}}$ and F (19). Nevertheless, factors that determine F for ultramarathons are quite different than for shorter distances. Lactate threshold (or critical velocity), thermoregulatory control, and ability to oxidize lipids are of smaller significance in ultramarathons due to the low intensity. In contrast, avoidance of muscle damage and gastrointestinal symptoms and mental abilities (e.g., internal motivation, associative/dissociative cognitive strategies, etc.) are among the main factors implicated in F for ultramarathons.

It has been argued that an exceptionally low Cr in marathon distances partly explains the supremacy of East African runners in the marathon, perhaps by delaying glycogen depletion and reducing thermal stress (13). But we believe that the lower exercise intensity in ultramarathons makes these parameters less important, whereas musculotendinous and osteoarticular damage is crucial for F. Herewith, we propose that certain measures that actually increase Cr may be more than offset through gains in F in ultramarathon running, and such a balance is essential for performance optimization. Although conceptually new relative to running, this idea was previously recognized with regard to preferred pedaling rate (24) and cross-country skiing technique (10).

Factors Accounting for Cr

Cr mainly depends on the mechanical work produced both externally, with its interplay with elastic energy (28), and internally, related to stride frequency and anthropometric factors. For instance, the exceptional Cr of East African runners has been attributed in part to their slender legs, resulting in lower internal work (17). Other anthropometric factors linked with a low Cr are short calcaneal tubers (26), long Achilles tendons (12), low body fat, high percentage of type I fibers, and long lower limbs relative to body mass (30). A high Cr has been reported in flexible runners (e.g., 2), most likely because stiffer musculotendinous structures facilitate elastic energy storage and recovery.

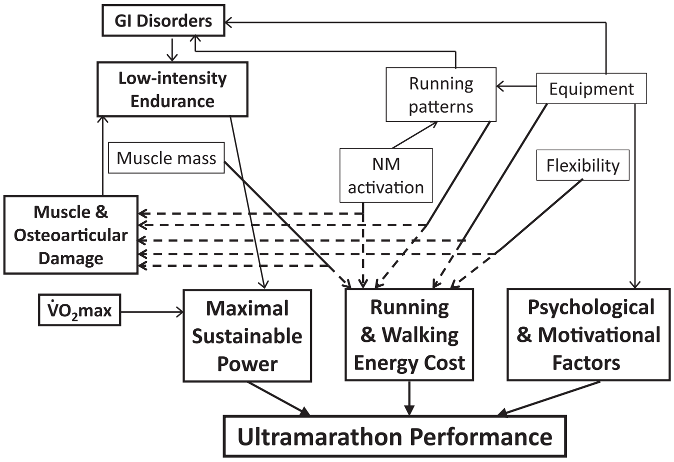

Fig. 1. Determinants of performance in ultramarathons that may be subjected to a compromise between energy cost and lower limb tissue injury (dashed lines). GI, gastrointestinal; NM, neuromuscular. Most important factors for ultramarathon performance are in bold.

Effects of Ultramarathon Running on Lower Limb Tissue

Not all peripheral consequences of ultramarathons are due to mechanical stress, as oxidative stress is likely also involved (27). However, there is little doubt that ultra-runners must develop strategies to limit tissue damage from repeated impact during running through adaptations from training and adjustments during competition. This is evident from the large increases in myoglobin, creatine kinase, C-reactive protein, and cytokines after ultramarathons (11, 15, 21). Similarly, a major effect of ultramarathon running on cartilage structures has been suggested based on examination of blood markers (14, 15). We measured significant peripheral fatigue, i.e., reductions in knee extensor and plantar flexor (PF) forces evoked by electrical stimulation, after ultramarathons (18, 21). Also detected were low-frequency fatigue (21), a noninvasive measurement of excitation-contraction failure, and severe central fatigue, which was at least partly attributed to peripheral alterations on the mediation of groups III and IV fatigue-sensitive muscle afferents with inflammation.

Saving the Legs vs. Saving Energy

Although many factors that positively affect Cr also benefit F and vice versa, this is not universally true, especially when

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considering long running distances. Here we note several factors that may adversely affect Cr but benefit F for ultramarathon running distances. In particular, these factors may enhance F through control of muscle damage, muscular fatigue, and symptoms associated with prolonged running at the expense of Cr.

Flexibility. Greater flexibility is usually linked to a higher Cr during short bouts of running so it is tempting to presume that ultramarathon runners should limit regular stretching. However, it was recently shown that flexibility training before an intense eccentric exercise attenuates exercise-induced muscle damage (1). Compliant legs may also limit low-back pain (7) and the work of bouncing viscera (3), which may potentially reduce gastrointestinal symptoms.

Leg mass. Body mass index has been shown to vary considerably among the top finishers of a 161-km trail run (9), unlike shorter distances where uniform anthropological characteristics (i.e., low body and muscle mass) are observed among elite runners up to marathon distance (13). One should consider the possibility that athletes specializing in ultra-distance running may have been less successful in the shorter distances where larger leg muscle mass may be a hindrance. Although drastically increasing internal work when running at 20 km/h as for elite marathon runners, large thighs and calves are nevertheless less detrimental at low speed (8–12 km/h for the best runners in competitions lasting 15–24 h) compared with high speed and may even have advantages in terms of resistance to muscle damage.

Stride frequency. The freely chosen stride frequency tends to be close to that which is most economical, so any manipulation of stride frequency increases Cr. However, Edwards et al. (5) recently suggested that a 10% increase in stride frequency at a given speed decreases the probability of stress fractures by 3–6%, presumably from reductions in peak loading forces (8). This also likely reduces damage to the musculoarticular system during an ultramarathon. In support of this, we observed a spontaneously increased stride frequency at the end (22) or within 3 h (23) after completion of an ultramarathon, whereas studies on shorter distances have shown a decrease in stride frequency (up to 1-h exhaustive run), no changes (marathon), or only minor increases (marathon) (22). We recently found that a runner increased his stride frequency through decreasing aerial time after running 8,500 km in 161 days (20). Because this adjustment allowed him to reduce loading rate and peak force, we speculated it was a way to limit mechanical consequences from this extreme running distance despite the detrimental effect of increasing Cr by 6%.

Shoes. Cr is reduced when running barefoot compared with shod running (e.g., 29), mostly due to shoe mass. Some have suggested that the typical modern running shoe with cushioned and elevated heel has changed the human gait pattern from a forefoot or midfoot landing pattern to a heel-strike pattern. Forefoot/midfoot strikes also induce a lower loading rate, due to the removal of the impact force peak (16). However, cushioned shoes should not be discarded by ultramarathon runners in favor of minimalist shoes that are usually worn by elite marathon runners for three reasons. First, a higher pre-activation of the PF muscles is necessary for a midfoot landing pattern. Because high levels of fatigue (strength loss ~30–40%) have been reported in the PF muscles after ultramarathons (18, 21), i.e., higher levels than after marathon running (strength loss ~15–20%), it is likely that minimalist shoes in very long distance running would enhance PF fatigue and this may in turn increase impact forces. Second, it is not known whether a midfoot strike pattern results in smaller impact forces on negative slopes that are often encountered in mountain ultramarathons races contrary to marathon courses, which are mostly flat. Finally, velocity and stride frequency are lower in ultramarathons, so heavier shoes affect Cr less in ultramarathons than in shorter distances.

Poles. Poles are commonly used in mountain ultramarathons and alleviate lower limb muscular work and activation during uphill and downhill travel (e.g., 6) but at the expense of Cr. The effects of poles on Cr may depend on several factors such as slope and pole mass (6, 25) but speed and stride rate may also be involved. As is the case for shoe mass, adding mass at the upper limbs is less detrimental at low stride rates, i.e., in ultramarathons.

Conclusion

Strategies to minimize Cr are compulsory in running events up to the marathon distance, whereas minimizing damage to lower limb tissue, muscular fatigue, and symptoms associated with prolonged running through measures that can increase Cr becomes crucial in ultramarathons. As shown in Fig. 1, the appropriate balance between a lower Cr and higher F to optimize performance in ultramarathons may favor a higher F at the expense of Cr, particularly when considering such parameters as leg stiffness and mass, stride frequency, and the use of cushioned shoes and poles.

DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the authors.

AUTHOR CONTRIBUTIONS

Author contributions: G.Y.M. prepared figures; G.Y.M. drafted manuscript; G.Y.M., M.D.H., and J.-B.M. edited and revised manuscript; G.Y.M., M.D.H., and J.-B.M. approved final version of manuscript.

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