Biomechanical Considerations in Ultramarathon Running

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4th Annual Congress on Medicine & Science in Ultra-Endurance Sports

May 30, 2017
Maximal Sustainable Power

Race tactics

Psychological & Motivational Factors

Running patterns

Equipment

Low-intensity Endurance

High % type I fibers

Running

Energy Cost

Nutrition

Thermal stress

GI disorders

Muscle & osteoarticular damage

Muscle mass

VO_{2max}

Maximal Sustainable Power

Running & Walking Energy Cost

Psychological & Motivational Factors

Ultramarathon Performance

Millet et al.

J Appl Physiol, 2012
Determining factors of Cr

- Muscle efficiency
- Training history
- Anthropometry: legs diameter / mass
- Fatigue
- % body fat
- Neuromuscular & musculo-tendinous capacities
- Flexibility: + / - but rather −
- Technique
- Equipment

Saunders, Sports med, 2004
Effects of ultra-marathon on Cr

Cr in ml O₂ / kg / km

Lazzer et al. (7)
Schena et al. (20)
Millet et al. (11)
Lazzer et al. (81sh )
Lazzer et al. (6)
Fusi et al. (4)
Millet et al. (15)

Change between pre and post ultra-marathon (%)

43-km
60-km
65-km
90-km
90-km
120-km
8500-km
Possible reasons for $\uparrow$ Cr

- Higher ventilation (minor)
- Fatigue $\rightarrow$ MUs recruitment
- Muscle $\eta$
- Changes in running patterns
Effects of ultra-marathon on Cr

Cr in ml O₂ / kg / km
- Lazzer et al. (7)
- Schena et al. (20)
- Millet et al. (11)
- Lazzer et al. (8kh)
- Lazzer et al. (6)
- Fusi et al. (4)
- Millet et al. (15)

Cr in J / kg / m
- Schena et al. (20)
- Vernillo et al. (26)
- Vernillo et al. (26)
- Vernillo et al. (26)
- Fusi et al. (4)
- Gimenez et al. (5)
- Vernillo et al. (27)
- Vernillo et al. (27)
- Vernillo et al. (25)
- Vernillo et al. (25)

Change between pre and post ultra-marathon (%)
From Marlene Giandolini PhD thesis
- 5 h hilly run

- 24 h level running (treadmill)

- Ultra-Trail du Mont-Blanc 2012 (104 km / 5,800 m D+)

- Ultra-Trail du Mont-Blanc 2009 (165 km / 8,500 m D+)
- **5 h hilly run**

- **24 h level running (treadmill)**

- **Ultra-Trail du Mont-Blanc 2012 (104 km / 5,800 m D+)**

- **Ultra-Trail du Mont-Blanc 2009 (165 km / 8,500 m D+)**

- **Tor des Geants (335 km / 24,000 D+)**
Tor des Geants

Max altitude : 3200 m

Min altitude : 320 m

Duration (h)

335 km / 24000 m D+
- **5 h hilly run**

- **24 h level running (treadmill)**

- **Ultra-Trail du Mont-Blanc 2012 (104 km / 5,800 m D+)**

- **Ultra-Trail du Mont-Blanc 2009 (165 km / 8,500 m D+)**

- **Tor des Geants (335 km / 24,000 D+)**

- **Running Paris to Beijing (8,500 km)**
Running from Paris to Beijing: biomechanical and physiological consequences

Guillaume Y. Millet · Jean-Benoît Morin · Francis Degache · Pascal Edouard · Léonard Feasson · Julien Verney · Roger Oullion

Philippe Fuchs

8 500 km
161 days
Stride frequency

Duration

<table>
<thead>
<tr>
<th>Event</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 H</td>
<td>~20 H</td>
</tr>
<tr>
<td>UTMB 2012</td>
<td>~26 H</td>
</tr>
<tr>
<td>UTMB 2009</td>
<td>~38 H</td>
</tr>
<tr>
<td>Tor des Geants</td>
<td>~127 H</td>
</tr>
<tr>
<td>Paris-Beijing</td>
<td></td>
</tr>
</tbody>
</table>

Change from Pre to Post (%)

-2  0  2  4  6  8  10

University of Calgary
Center of Mass Downward Displacement

$\Delta z$

Change from Pre to Post (%)

5 H  24 H  UTMB 2009  Tor des Geants  Paris-Beijing
Peak vertical force (Fmax)

- Change from Pre to Post (%)
  - 5 H
  - 24 H
  - UTMB 2009
  - Tor des Geants
  - Paris-Beijing

- Force (N)
  - 0
  - 400
  - 800
  - 1200
  - 1600
  - 2000

- Times (s)
  - 0
  - 0.05
  - 0.1
  - 0.15
  - 0.2
  - 0.25
  - 0.3

- Fmax
Duration seems to matter despite various environmental conditions, terrain, level running vs large elevation changes.
Running from Paris to Beijing: biomechanical and physiological consequences

Guillaume Y. Millet • Jean-Benoît Morin • Francis Degache • Pascal Edouard • Léonard Feasson • Julien Verney • Roger Oullion
Cr was slightly deteriorated

Change in running patterns to protect against running injury despite worsened Cr?
Preferred transition speed

Cost of transport (ml O₂ kg⁻¹ m⁻¹)

Horse 1

○ trot
△ gallop

Horse 2

Horse 3

Peak vertical force (body weights)

Trot-gallop transitions

Critical force

Weighted
Unweighted

Unweighted gallop

Speed (m s⁻¹)

Farley & Taylor
Science 1991
Sacrificing economy to improve running performance—a reality in the ultramarathon?

G. Y. Millet,¹ M. D. Hoffman,² and J. B. Morin¹

¹Université de Lyon, Saint-Etienne, France; and ²Department of Veterans Affairs, Northern California Health Care System and University of California Davis Medical Center, Sacramento, California

Submitted 4 January 2012; accepted in final form 2 April 2012
Endurance

Low intensity

▪ Ability to eat without nausea or GI symptoms
▪ Resistance to muscle & joint damage.

High intensity

▪ Glycogen stores
▪ Anaerobic Threshold

Energy

Economy

Leg tissue

≤ marathon

Ultra-marathon
Energy ↔ Economy ↔ Leg tissue

Pref. stride frequency ↔ Higher stride frequency

Foot strike?
Table 1. Foot strike pattern and sample size at each site.*

<table>
<thead>
<tr>
<th>Foot strike pattern</th>
<th>16.5 km, n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFS</td>
<td>1 (0.3)</td>
</tr>
<tr>
<td>MFS</td>
<td>29 (7.8)</td>
</tr>
<tr>
<td>Non-RFS</td>
<td>11 (3.0)</td>
</tr>
<tr>
<td>RFS</td>
<td>298 (79.9)</td>
</tr>
<tr>
<td>Mixed RFS/non-RFS</td>
<td>34 (9.1)</td>
</tr>
<tr>
<td>Total†</td>
<td>373</td>
</tr>
</tbody>
</table>

*FFS = forefoot strike; MFS = midfoot strike; RFS = rear-foot strike.
†Nine percent grade.
‡Totals exclude runners with an “unclassified” pattern.
To limit loading rate = be a mid-foot striker?
Midfoot/Rearfoot

Plantar flexors

PRE  POST  J+2  J+5  J+9  J+16

5H run

<table>
<thead>
<tr>
<th>Foot strike pattern</th>
<th>16.5 km, n (%)</th>
<th>90.3 km, n (%)</th>
<th>161.1 km, n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFS</td>
<td>1 (0.3)</td>
<td>3 (1.1)</td>
<td>8 (2.8)</td>
</tr>
<tr>
<td>MFS</td>
<td>29 (7.8)</td>
<td>9 (3.2)</td>
<td>15 (5.3)</td>
</tr>
<tr>
<td>Non-RFS</td>
<td>11 (3.0)</td>
<td>7 (2.5)</td>
<td>5 (1.8)</td>
</tr>
<tr>
<td>RFS</td>
<td>298 (79.9)</td>
<td>251 (89.0)</td>
<td>235 (83.9)</td>
</tr>
<tr>
<td>Mixed RFS/non-RFS</td>
<td>34 (9.1)</td>
<td>12 (4.3)</td>
<td>17 (6.0)</td>
</tr>
<tr>
<td>Total</td>
<td>373</td>
<td>282</td>
<td>280</td>
</tr>
</tbody>
</table>

*FFS = forefoot strike; MFS = midfoot strike; RFS = rear-foot strike.
†Nine percent grade.
‡Totals exclude runners with an “unclassified” pattern.
- Trend toward greater post-race blood CK values among non-RFS runners compared with RFS runners

- No relationship between strike pattern and performance

- However, top 20 finishers had greater use of a non-RFS pattern at 161.1 km than the remaining finishers
Energy ↔ Economy ↔ Leg tissue

Pref. stride frequency ↔ Higher stride frequency

Fore/mid foot strike ↔ Rearfoot strike

Minimalist shoes ↔ Protective shoes
Energy ↔ Economy ↔ Leg tissue

Pref. stride frequency ↔ Higher stride frequency
Fore/mid foot strike ↔ Rearfoot strike
Minimalist shoes ↔ Protective shoes
Without pole ↔ With poles
Less flexible ↔ More flexible
Low muscle mass ↔ Higher muscle mass
Compensating strategy for decrements in propulsive capacity or protective behavior from mechanical stress?
Fatigue in ultra-marathon

Fatigue (strength loss, %PRE)

Duration (h)

Millet Sports Med 2011
Db100

Twitch
Db100

Twitch

Fatigue or pain (DOMS)?
Effects of fatigue only (no DOMS)

### Effects of fatigue only (no DOMS)

**Table 3** Constant velocity running kinetics, kinematics and spring-mass variables pre- and post-fatigue induced by repeated running sprints

<table>
<thead>
<tr>
<th>Variable</th>
<th>Pre</th>
<th>Post</th>
<th>High velocity (20 km h⁻¹)</th>
<th>Pre</th>
<th>Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>tₖ (s)</td>
<td>0.231 (0.017)</td>
<td>0.231 (0.019)</td>
<td>0.148 (0.008)*</td>
<td>0.150 (0.007)*</td>
<td></td>
</tr>
<tr>
<td>tₐ (s)</td>
<td>0.136 (0.024)</td>
<td>0.131 (0.019)</td>
<td>0.144 (0.015)*</td>
<td>0.145 (0.011)*</td>
<td></td>
</tr>
<tr>
<td>f (Hz)</td>
<td>2.73 (0.10)</td>
<td>2.80 (0.26)</td>
<td>3.44 (0.17)*</td>
<td>3.40 (0.12)*</td>
<td></td>
</tr>
<tr>
<td>Fₘₐₓ (BW)</td>
<td>2.80 (0.26)</td>
<td>2.72 (0.20)</td>
<td>3.33 (0.30)*</td>
<td>3.27 (0.21)*</td>
<td></td>
</tr>
<tr>
<td>Δz (m)</td>
<td>0.068 (0.006)</td>
<td>0.064 (0.008)</td>
<td>0.039 (0.004)*</td>
<td>0.038 (0.004)*</td>
<td></td>
</tr>
<tr>
<td>ΔL (m)</td>
<td>0.113 (0.013)</td>
<td>0.111 (0.020)</td>
<td>0.125 (0.16)*</td>
<td>0.128 (0.15)*</td>
<td></td>
</tr>
<tr>
<td>kₜᵥₑₙₜ (kN m⁻¹)</td>
<td>29.4 (4.0)</td>
<td>30.6 (5.8)</td>
<td>60.4 (7.1)*</td>
<td>61.6 (9.1)*</td>
<td></td>
</tr>
<tr>
<td>kₑₙₑ (kN m⁻¹)</td>
<td>17.8 (3.5)</td>
<td>18.6 (5.7)</td>
<td>19.2 (3.1)</td>
<td>18.5 (3.0)</td>
<td></td>
</tr>
</tbody>
</table>

Compensating strategy for decrements in propulsive capacity 
or
protective behavior from mechanical stress?
The Stretch Reflex

Muscle spindles

Disfacilitation

⇒ kinematic reorganization
Subgroup analysis


![Graph showing subgroup analysis with pre-UT and post-UT SF (Hz) data.](image-url)
Subgroup analysis


![Graph showing changes in FOOT (°) before and after UT with significant differences indicated by asterisks.](image-url)
Males vs females

Pre-UTMB

Post-UTMB

Giandolini et al. *Footwear Science* 2013
Knee extensors

Pre-Post changes (%)

MVC Db100 Db10 TwPot

Male
Female

Plantar flexors

Conclusions

- Significant alterations of running patterns can be observed after ultra-marathon running.
- In particular, \( \Delta \) aerial time and \( \Delta z \) and \( \rightarrow \) duty cycle.
- Most of these changes seem to be dependent on the duration of the ultra-marathon.
- An intense exercise inducing significant amount of fatigue but no pain does not have the same consequences on running patterns.
  \( \rightarrow \) adjustments = protective behavior
- There may be sex differences in adaptations to ultra-marathon running.
Merci

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Same trend in Europe

Hoffman et al. *Int J Hist Sports* 2010