ORIGINAL ARTICLE

Influence of a slow-start on overall performance and running kinematics during 6-h ultramarathon races.

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Running head: Pacing and running kinematics during 6-h ultramarathon.

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Abstract

The aim of this study was to describe the pacing during a 6-h ultramarathon (race 1) and to investigate whether a slow-start affects performance, running kinematic changes, ratings of perceived exertion (RPE) and fatigue (ROF) (race 2). After a critical speed test, participants completed two 6-h ultramarathons. Race 1 (n = 16) was self-paced, whereas in race 2 (n = 10), athletes performed the initial 36 min at speeds 18% below the mean speed of the initial 36 min of race 1. In race 1, participants adopted an inverse sigmoid pacing. Contact times increased after 1 h, and flight times decreased after 30 min (all $P \leq 0.009$); stride length reduced after 1 h 30 min (all $P = 0.022$), and stride frequency did not change. Despite the lower speeds during the first 10% of race 2, and higher speeds at 50% and 90%, performance remained unchanged (57.5 ± 10.2 vs. 56.3 ± 8.5 km; $P = 0.298$). However, RPE and ROF were lowered for most of race 2 duration (all $P < 0.001$). For the comparison of kinematic variables between races, data were normalised by absolute running speed at each time point from 1 h onwards. No differences were found for any of the kinematic variables. In conclusion, decreasing initial speed minimises RPE and ROF, but does not necessarily affect performance. In addition, running kinematic changes do not seem to be affected by pacing manipulation.

Keywords: competitive behaviour; effort distribution; ultra-endurance; performance; biomechanics; running gait.

Introduction

Pacing, as the distribution of work-rates during an exercise, has been suggested to be crucial for athletes aiming to achieve optimal racing outcomes (Abbiss and Laursen, 2008). Therefore, studies have described pacing during ultramarathons ranging from 100 to 161 km (Hoffman, 2014; Knechtle, Rosemann, Zingg, Stiefel, & Rüst, 2015; Lambert, Dugas, Kirkman, Mokone, & Waldeck, 2004; Parise and Hoffman, 2011; Renfree, Crivoi do Carmo, & Martin, 2016; Tan, Tan, & Bosch, 2016), and during time-based 24-h ultramarathons (Bossi et al., 2017; Takayama, Aoyagi, & Nabekura, 2016). Yet, none of them has done so in a 6-h ultramarathon. Given that 6 h is considered to be the minimum duration for ultramarathon races (Zaryski and Smith, 2005), it is surprising the lack of specific pacing studies.

The best ultramarathon performances have been associated with more even pacing, with conservative initial running speeds, no matter the distance or duration (Bossi et al., 2017; Hoffman, 2014; Knechtle et al., 2015; Lambert et al., 2004; Parise and Hoffman, 2011; Renfree et al., 2016; Takayama et al., 2016; Tan et al., 2016). Interestingly, our recent study found an inverse correlation between initial running speeds (normalised to the total race average) and overall performances during 24-h ultramarathons, suggesting athletes should perhaps start conservatively to increase total distance covered (Bossi et al., 2017). This hypothesis remains untested. Pacing has been shown to be regulated internally by the central nervous system (Konings and Hettinga, 2018), and thus, ratings of fatigue (ROF) (Micklewright, Gibson, Gladwell, & Al Salman, 2017) and/or perceived exertion (RPE) (Borg, 1982) may play a role in its regulation. Surprisingly, these measures have not been used to investigate the relationship between pacing and performance during ultramarathon running.

Typically, runners experience long-lasting fatigue during ultramarathons (Martin et al., 2010), which is associated with several changes in running patterns (Degache et al., 2013; Giovanelli, Taboga, & Lazzer, 2016; Morin, Samozino, & Millet, 2011; Vernillo et al., 2014), presumably to avoid excessive muscle damage (Millet, Hoffman, & Morin, 2012; Vernillo, Millet, & Millet, 2017). The process of pacing optimisation should not disregard the impact changes in running kinematics could have on performance. Again, the ultramarathon literature lacks studies investigating the influence of different types of pacing on running kinematics.

The first aim of this study was to describe pacing, ROF and RPE development, and running kinematic changes during a 6-h ultramarathon race. We hypothesised that positive pacing would be found, with continuously increasing ROF and RPE. Based on a previous study (Giovanelli et al., 2016), we also hypothesised that changes in running kinematics would occur after ~4 h. The second aim of this study was to investigate through an interventional design whether a slow-start would affect ROF and RPE development, running kinematic changes and performance. We hypothesised a slow-start would attenuate ROF and RPE development, possibly affecting running kinematic changes and consequently improving overall performance.

Methods

Participants

After providing written informed consent, sixteen runners (4 women and 12 men; age: 38.6 ± 11.3 years, height: 1.74 ± 0.7 m, body mass: 71.5 ± 12.2 kg) were recruited to take part in the first part of this study (descriptive analysis). All participants were trained runners who had been training at least 6 h per week and had completed at least one ultramarathon race (i.e. ≥ 50 km) during the 6 months preceding the data collection. Ten out of the sixteen initially recruited (2 women and 8 men; age: 40.5 ± 11.0 years, height: 1.74 ± 0.8 m, body mass: 72.0 ± 13.5 kg) completed the second part of the study (intervention). Six athletes did not participate in the third session due to the development of muscular injury before the race (n = 3), or scheduling conflicts (n = 3). The university's human research ethics committee approved the study in compliance with the Declaration of Helsinki. All participants provided written informed consent.

Study design

Participants involved in the descriptive analysis only were required to visit the testing location twice, whereas a third visit was required for those also involved in the intervention. In the first visit, anthropometric measures, familiarisation trials and a critical speed test were performed. In the following two visits, participants completed two 6-h simulated ultramarathons on a 400-m athletics track, at the same time of the day (8:00 am), but 4 weeks apart to enable enough recovery (Gaudino, Martinent, Millet, & Nicolas, 2019; Millet et al., 2011; Nicolas, Banizette, & Millet, 2011). While both races were contested as a mass-start event, the first race consisted of a self-paced race, and the second consisted of manipulated pacing during the first 36 min, followed by self-paced race. Participants were not informed about the purposes of the study until it was completed.

Visit 1 – Familiarisation and determination of critical speed

Firstly, participants had their height and body mass measured. Subsequently, they received instructions and familiarised themselves with the ROF scale (Micklewright et al., 2017), the RPE scale (Borg, 1982), the total quality recovery scale (TQR; i.e. a 6-20 scale, based on RPE, which measures psychophysiological recovery) (Kentta and Hassmen, 1998), and the motivation questionnaire (i.e. 14 statements scored on a 5-point Likert scale that measure intrinsic and success motivation; 0 = not at all and 4 = extremely) (Matthews, Campbell, & Falconer, 2001). Participants also performed three consecutive countermovement jumps (CMJ) (Bosco, Luhtanen, & Komi, 1983) as a familiarisation. They were asked to jump as high as possible on a force plate (Jump System Pro, CEFISE®, São Paulo, Brazil), with hands on their hips (i.e. no arm-swing), and a 15-s rest between attempts. The average height of the three jumps was recorded, as it has been shown to be more sensitive than the highest jump to estimate neuromuscular fatigue (Claudino et al., 2017).

To describe participants' aerobic capacity, a field-based critical speed test was performed according to Galbraith et al. (2011). This test was selected because it was more familiar to our runners compared with laboratory tests, and also because it has been recognised as a good predictor of endurance performance (Galbraith, Hopker, Cardinale, Cunniffe, & Passfield, 2014; Galbraith, Hopker, Lelliott, Diddams, & Passfield, 2014). Three time-trials of 3600, 2400 and 1200 m were performed on a 400-m athletics track, interspersed with 30-min rest periods. Participants completed a standardised warm-up (i.e. 10-min jog at a self-selected intensity) before the time-trials and were instructed to complete each one as fast as possible. They were not provided with elapsed time and each run was hand-timed to the nearest second. RPE and ROF were quantified at the end of each time-trial for familiarisation purposes. To calculate critical speed and D' (i.e. total distance covered above critical speed until task failure), a linear regression analysis was used after plotting time-trial distances and respective times. The slope and y-intercept (i.e. critical speed and D', respectively) were used to produce the model equation as $d = (CS \times t) + D'$, in which d = distance (m), CS = critical speed ($m \cdot s^{-1}$) and t = time (s).

Visit 2 and 3 – 6-h ultramarathon races

Race 1 consisted of a self-paced 6-h ultramarathon in which runners started together and were free to adjust their speed with the aim of achieving the greatest distance possible. Given the first 10% of a race seems critical for overall performance (Bossi et al., 2017), the distance covered by each athlete during the first 36 min was used to set speed targets for the first 36 min of race 2; i.e. athletes ran at constant speeds 18% slower. After the enforced-speed phase of race 2, athletes were allowed to run as desired. The 18% target was selected after termination of race 1. We decreased the initial speed for race 2 by matching it to the overall speed of race 1 (i.e. an attempt to produce an even pacing). Approximately one hour before the start, participants were informed about the speed manipulation and their individual targets for each lap of the track (e.g. 10 $km \cdot h^{-1}$ or 2 min 24 s). Two members of the research team, positioned at the starting line, used chronometers to check if athletes were running each lap at the intended speed—providing them with feedback when necessary. To analyse pacing, participants' mean running speed of each 36-min interval were percentage-normalised to their overall mean speed.

Before each race, ROF, success and intrinsic motivation, TQR, mean CMJ height and body mass were assessed to monitor runners' psychophysiological state. CMJ jumps were used to estimate neuromuscular function before and after each race, as it has been shown to have good reliability for the assessment of fatigue after exercise trials (Lombard, Reid, Pearson, & Lambert, 2017). Ambient temperature (mercury thermometer INCOTERM®, Porto Alegre, Brazil), relative humidity (thermo-hygrometer MT-242, Minipa®, Joinville, Brazil) and wind speed (anemometer GM8908 LCD, Kkmoon®, Shenzhen, China) were measured at the start and every 30 min. RPE and ROF were measured every 12 min during the first 36 min, at 1 h and every 30 min thereafter. The official racing time, number of laps and time spent in each lap were recorded by an electronic-chip system (Speedway R220 RAIN RFID, IMPINJ®, Seattle, USA) attached to runners' shoelace. Total distance covered in 6 h, and in the first 36 min, were calculated as the sum of 400-m laps completed in each duration plus the distance covered during the incomplete lap. During the last 2 min before time marks, participants were required to run while holding a small plastic cone with their ID numbers—dropping the cones on the track at the end of 36 min and 6 h, to obtain a measure of distance covered. Mean CMJ height and body mass were reassessed ~5 min after each race to quantify changes in neuromuscular power and fatigue, as well as the impact of the races on body water balance.

To analyse changes in running kinematics during the races, a digital camera (Hero 4, GoPro®, San Mateo, USA) operating at 120 Hz, with the fisheye option deactivated to remove distortion effects, was placed perpendicular to the running direction of the participants, recording a 12 m-wide section of the track. Five subsequent steps were analysed, with Kinovea® 0.8.15 software used to measure contact and flight times. The mean values of both parameters of 5 steps were then used to calculate stride frequency and length according to the equations:

$$\text{stride frequency} = 1/(\text{contact time} + \text{flight time}) \quad (1)$$

$$\text{stride length} = \text{running speed}/\text{stride frequency} \quad (2)$$

Running speed was calculated based on time to cover the 12-m section of the track. Running kinematics were assessed during the first lap, and at every subsequent 30-min time point, consistent with Giovanelli et al. (2016). For the comparison of kinematic variables between races, data were normalised by individual athlete's absolute running speed ($m \cdot s^{-1}$) at each time point from 1 h. Participants were requested to wear the same pair of shoes during both races, and were not allowed to wear calf compression sleeves to avoid running kinematic alterations (Kerhervé, Samozino, et al., 2017).

During both races, the running direction around the track was changed every hour once they reached the starting line. Runners consumed food and/or beverages *ad libitum* from a buffet provided by the research team, or by themselves. They were instructed to maintain their regular training and to refrain from high-intensity and/or high-volume training in the 48 h preceding testing sessions. Runners were also requested to report and replicate their diet, as well as to abstain from caffeine, supplements and alcohol in the last 24 h before races.

Statistical analysis

Results are presented as mean ± SD. In race 1, one-way repeated-measures ANOVAs with planned contrasts were performed to analyse pacing, ROF, RPE and running kinematics. Running kinematics were reported as percentage changes in relation to the first lap.

For the intervention, a paired t-test was performed to compare race performances and variables assessed only before each race (i.e. TQR, ROF, intrinsic and success motivation). Two-way repeated measures ANOVAs with Bonferroni pairwise comparisons were used to assess differences between races in pacing, ROF, RPE and running kinematics. We focused on the main effect of the races and the interaction effects to avoid duplicate analyses. As pacing data were percentage normalised, changes from one race to another were assessed by the interaction effect only. Partial eta squared (η_p^2) or Cohen's d were calculated as effect sizes estimates. Two-way repeated measures ANOVAs were also used to test for differences in mean CMJ height and body mass before and after each race.

Data analysis was performed using SPSS (23.0, IBM®, Armonk, USA), with statistical significance set at $P \leq 0.05$.

Results

Descriptive analysis

The critical speed and D' of the 16 athletes evaluated in visit 1 was 4.0 ± 0.5 $m \cdot s^{-1}$ and 125 ± 44 m, respectively. The mean distance covered by athletes in race 1 was 58.9 ± 9.4 km (2.73 ± 0.44 $m \cdot s^{-1}$; i.e. 68 ± 7% of critical speed). Overall analysis showed runners adopted an inverse sigmoid pacing (F = 32.90, $P < 0.001$, $\eta_p^2 = 0.69$; Figure 1a), with the highest running speeds during the first 50% of the race, and slowing afterwards when compared to the first 10% ($P \leq 0.005$).

We found a main effect of time for RPE (F = 30.27, $P < 0.001$, $\eta_p^2 = 0.67$) and ROF (F = 56.04, $P < 0.001$, $\eta_p^2 = 0.79$). Both increased consistently throughout the race ($P \leq 0.05$; Figure 1b).

A main effect of time was found for contact time (F = 9.43, $P < 0.001$, $\eta_p^2 = 0.39$; Figure 1c), flight time (F = 9.77, $P < 0.001$, $\eta_p^2 = 0.39$; Figure 1d) and stride length (F = 9.92, $P < 0.001$, $\eta_p^2 = 0.40$; Figure 1e), but not for stride frequency (F = 0.90, $P = 0.45$, $\eta_p^2 = 0.06$; Figure 1f). Contact times increased after 1 h (overall change: +12%; all $P \leq 0.009$) and flight times decreased after 30 min (overall change: -34%; all $P \leq 0.001$), whereas stride length decreased after 1 h 30 min (overall change: -13%; all $P \leq 0.022$).

[Figure 1 near here]

Intervention

The critical speed and D' of the 10 athletes involved in both races was 3.9 ± 0.5 $m \cdot s^{-1}$ and 120 ± 41 m. There were no differences between races (all $P \geq 0.677$) on the mean (range) temperature, relative humidity and wind speed: 21.4ºC (19.0–25.0) vs. 21.3ºC (17.0–25.5), 75.5% (53.0–100.0) vs. 72.5% (46.0–100.0), 0.7 $m \cdot s^{-1}$ (0.0–2.2) vs. 0.7 $m \cdot s^{-1}$ (0.0–3.0). Before each race, there were no significant differences in body mass, mean CMJ height, TQR and ROF, but intrinsic and success motivation were significantly lower before the second race (Table 1). No interaction effects were evident for body mass ($F = 0.77$, $P = 0.787$, $\eta_p^2 = 0.09$) and mean CMJ height ($F = 1.25$, $P = 0.293$, $\eta_p^2 = 0.12$).

[Table 1 near here]

Performance was not different between races (57.5 ± 10.2 vs. 56.3 ± 8.5 km; t = 1.11, P = 0.298, d = 0.13; 2.66 ± 0.47 vs 2.61 ± 0.39 $m \cdot s^{-1}$), despite a difference in pacing (interaction effect: F = 3.78, P = 0.021, η_p^2 = 0.30; Figure 2a). By design, pairwise comparisons showed the normalised running speed in race 2 was lower at 10% of race duration (P < 0.001). Conversely, normalised running speed was greater in race 2 at 50% (P < 0.001) and at 90% (P = 0.034) of race duration.

We found a main effect of the race for both RPE (F = 56.31, P < 0.001, η_p^2 = 0.86; Figure 2b) and ROF (F = 27.81, P = 0.001, η_p^2 = 0.76; Figure 2c). An interaction effect was also observed for both RPE (F = 3.46, P < 0.001, η_p^2 = 0.28) and ROF (F = 2.30, P = 0.010, η_p^2 = 0.20). Pairwise comparisons showed that both parameters were lower in race 2, mainly in the first half, but also at 5 h 30 min, and at 6 h for RPE ($P \leq 0.05$).

[Figure 2 near here]

There were no significant main effects of the race for normalised contact time (F = 0.68, P = 0.432, η_p^2 = 0.07), flight time (F = 0.48, P = 0.506, η_p^2 = 0.05), stride length (F = 0.17, P = 0.688, η_p^2 = 0.02), and stride frequency (F = 2.67, P = 0.137, η_p^2 = 0.23). There were also no interaction effects for any of the kinematic variables: contact time (F = 0.43, P = 0.928, η_p^2 = 0.05; Figure 3a), flight time (F = 0.79, P = 0.639, η_p^2 = 0.08; Figure 3b), stride length (F = 0.91, P = 0.532, η_p^2 = 0.09; Figure 3c) and stride frequency (F = 0.55, P = 0.853, η_p^2 = 0.06; Figure 3d).

[Figure 3 near here]

Discussion

The results of this study demonstrated that 6-h ultramarathon runners adopt high initial speeds for the first 30% of the race, progressively decreasing speed until ~60%, and thereafter reaching a plateau. As expected, RPE and ROF increased linearly throughout the race, reaching near maximum values of ~18 and ~8, respectively. Early changes in running kinematics were observed, contradicting our hypothesis that changes would only be seen after ~4 h. We also hypothesised a slow-start intervention would improve performance. A more even pacing indeed lowered RPE and ROF, but overall performance was not affected, nor were changes in running kinematics. Intrinsic and success motivation were lower before the second race, potentially explaining the lack of performance benefit.

Descriptive analysis: Race 1

The distance achieved by participants during the first race was 58.9 ± 9.4 km, similar to other 6-h investigations, with mean distances varying from 56.2 to 61.0 km (Akimov and Son'kin, 2012; Kerhervé, McLean, Birkenhead, Parr, & Solomon, 2017; Wollseiffen et al., 2016). In our study, runners adopted an inverse sigmoid pacing; i.e. the first 30% fast (relative to the mean running speed), decreasing until ~60%, and then keeping a constant speed until the end of the race (see Figure 1a). We have previously attributed this terminology to the pacing of some ultra-runners (Bossi et al., 2017), and it is interesting to replicate Renfree's findings (Renfree et al., 2016), as this type of pacing has not been described in the scientific literature (Abbiss and Laursen, 2008). More often, our and other research groups have demonstrated reverse J-shaped (Bossi et al., 2017; Takayama et al., 2016; Tan et al., 2016) and positive pacing (Knechtle et al., 2015; Lambert et al., 2004; Parise and Hoffman, 2011; Tan et al., 2016) in ultramarathon races. This differences in pacing most likely reflect the variations in distance run, course elevation profile, environmental conditions, athletes' running performance and race competitive dynamics (Abbiss and Laursen, 2008; Konings and Hettinga, 2018). Although an even pacing has been suggested to optimise performance during prolonged exercises (Abbiss and Laursen, 2008), it is rarely adopted in practice.

Previous studies have shown that pacing is mediated by RPE (De Koning et al., 2011; Konings and Hettinga, 2018), displaying linear increases throughout a task, as a function of the exercise time remaining. Accordingly, our results corroborate the hypothesis that RPE and ROF would increase continuously, reaching near maximum values at the end of an ultramarathon race. It has been suggested that pacing is regulated by a complex relationship between the central nervous and other physiological systems, and thus, RPE and ROF may play a role, by ensuring catastrophic disturbance to homeostasis does not occur (Abbiss, Peiffer, Meeusen, & Skorski, 2015).

Previous studies that analysed changes in running kinematics during ultramarathons have found varying results (Degache et al., 2013; Giovanelli et al., 2016; Morin et al., 2011; Schena et al., 2014; Vernillo et al., 2014). Indeed, our results only partially corroborate previous findings. Contact time increased after 1 h (+7%) and flight time decreased after 30 min (-34%), whereas both parameters changed (contact time: +7.1% and flight time: -

29.0%) only after 4 h 30 min during another 6-h ultramarathon (Giovanelli et al., 2016). Interestingly, no changes in flight time were found after a 5-h hilly running bout (Degache et al., 2013) and during a 24-h treadmill run (Morin et al., 2011), whereas contact time increased after the 5-h hilly running bout (Degache et al., 2013) and in the latter parts of the 24-h treadmill run (Morin et al., 2011). Moreover, stride length of our participants decreased (-13%) after 1 h 30 min of running, whereas it decreased (-5.1%) after 5 h in the study of Giovanelli et al. (2016), and after 40 km of a 60-km race in the work of Schena et al. (2014). Stride frequency did not change in our study, corroborating the findings of others (Giovanelli et al., 2016; Schena et al., 2014; Vernillo et al., 2014), and suggesting that this might be a robust parameter to progressive fatigue during this type of ultramarathon race. Given that studies analysed running kinematics during very different running conditions, it is not possible to draw an overall conclusion. Nevertheless, it has been hypothesised that changes in running kinematics are associated with exercise-induced pain as a mechanism to avoid excessive muscle damage (Millet et al., 2012; Morin, Tomazin, Samozino, Edouard, & Millet, 2012).

Intervention: Race 1 vs. Race 2

This is the first study to manipulate pacing during a simulated ultramarathon race. Runners were required to complete the first 10% of race 2 at speeds 18% slower than the self-paced race. This conservative start led runners to run faster at both 50% and 90% in comparison to race 1 (see Figure 2a). Nevertheless, they achieved the same distance.

Before both ultramarathons, participants had equivalent body mass, TQR, ROF and mean CMJ height, suggesting they were at the same psychophysiological state. Moreover, weather conditions were similar between races. Runners were however less motivated before race 2, which may explain the lack of performance improvement. All participants were informed that an intervention would take place before completing the motivation questionnaires, although they were not given details until ~1 h before the race. This may have played a role in the pre-race motivation. It could also be that having less athletes competing the second in comparison to the first race (n = 10 vs. 16) may have affected their competitiveness (Konings and Hettinga, 2018). Alternatively, 4 weeks may have been insufficient to restore athletes' motivation to perform such a demanding task. Regardless, similar performance associated with lower motivation could be viewed as a benefit. Both RPE and ROF were consistently lower during race 2 until approximately 50%, and at the penultimate time point. Importantly, RPE was also lower at 6 h. Had participants performed both trials at their best, a performance benefit may have been evident (Marcora and Staiano, 2010).

We sought to compare changes in running kinematics during the race normalised to running speed to avoid confounding effects. We found a similar pattern in both races, despite differences in ROF. This may suggest that running kinematics changes are somewhat insensitive to the development of fatigue, reflecting the speed athletes are able to sustain. This is corroborated by Morin et al. (2012), who analysed changes in running kinematics at 10 and 20 km·h^{-1}, before and after a fatiguing protocol, and found similar running gait despite decreases in maximal force production of the lower limbs.

This study is not without limitations. We did not randomise the order of the races. However, we could not predict the self-paced strategy of our runners considering the inconsistencies in the literature. An unsupervised 4-week period between races may have affected our participants' running performance. However, they were instructed to maintain their usual training programme, and so, we are confident that any possible effects were minimal, given the trained status of our runners. Moreover, the video-based method of kinematic analysis may have been insensitive to detect minor changes in the variables analysed. Future studies using inertial measurement units are therefore required to confirm our findings. Finally, we did not control participants' calorie intake before and during races, although they were requested to report and replicate their pre-race diet.

Conclusion

In 6-h ultramarathon races, runners adopt an inverse sigmoid pacing while RPE and ROF increase linearly throughout the race. Adopting a slow-start attenuates the development of RPE and ROF, but does not necessarily improve performance, as the relationship between pacing and performance is likely dependent on motivation, which we could not control for. Changes in running kinematics can occur early in an ultramarathon, associated with fluctuations in racing speed, which suggests contact and flight times, and stride length and frequency, are all somewhat insensitive to the development of fatigue.

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Declaration of interest statement

No potential conflict of interest was reported by the authors.

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Figures Captions

Figure 1. Mean ± SD participants' pacing (panel a), development of ratings of perceived exertion (RPE) and ratings of fatigue (ROF) (panel b), and changes in contact time (panel c), flight time (panel d), stride length (panel e) and stride frequency (panel f) during the first race. Panel a: *Difference from 10%; ‡Difference from 100% ($P \leq 0.05$). Panel b: *Difference of RPE from the previous time-point; ‡Difference of ROF from the previous time-point ($P \leq 0.05$). Panels c, d, e: *Difference from the first lap ($P \leq 0.05$).

Figure 2. Mean ± SD participants' pacing (panel a) and development of ratings of perceived exertion (RPE, panel b) and ratings of fatigue (ROF, panel c) throughout each 6-h ultramarathon races (mean ± SD). *Difference between race 1 and 2 at the time-point ($P \leq 0.05$).

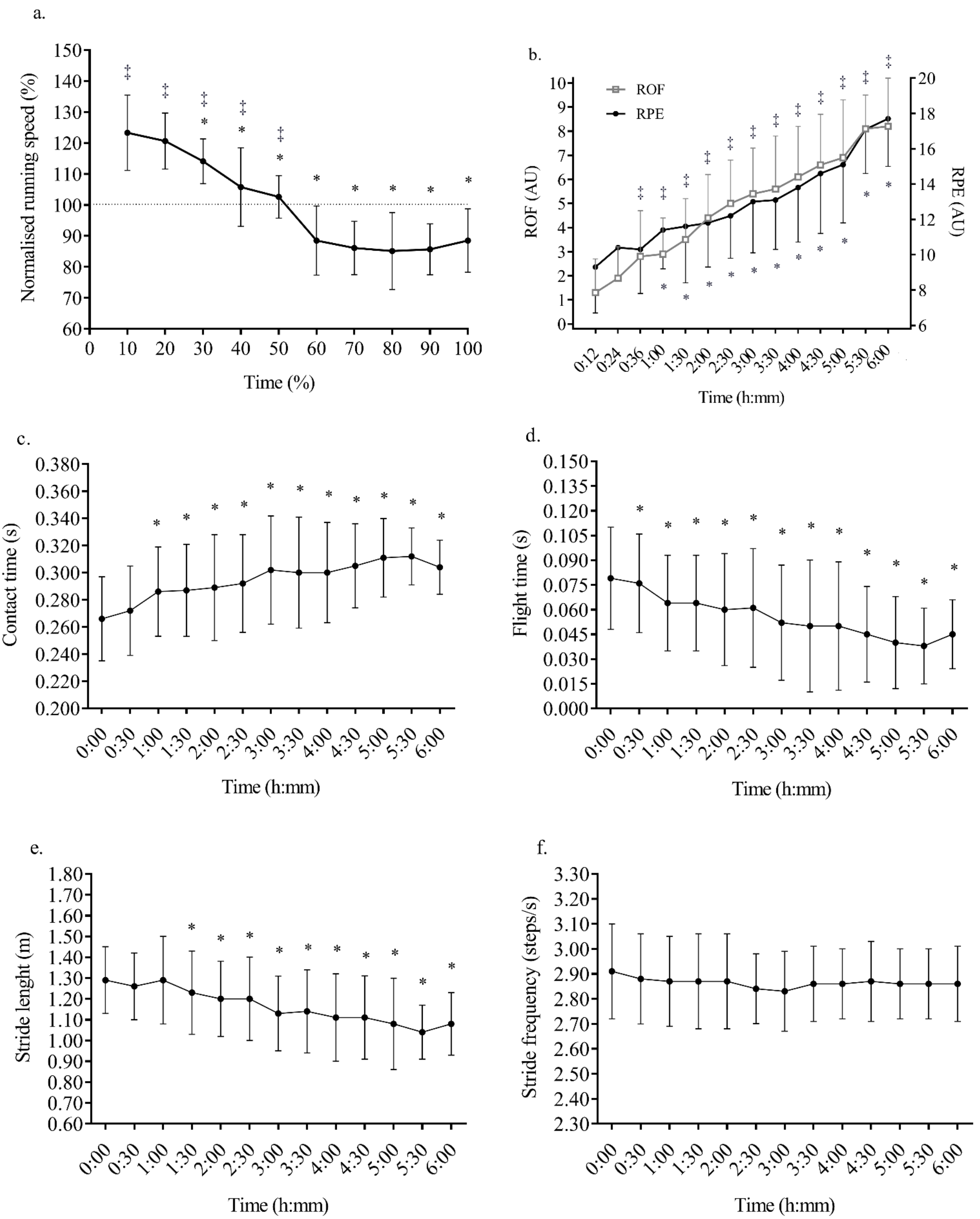
Figure 3. Mean ± SD contact time (panel a), aerial time (panel b), stride length (panel c) and stride frequency (panel d) normalised to running speed during each race.

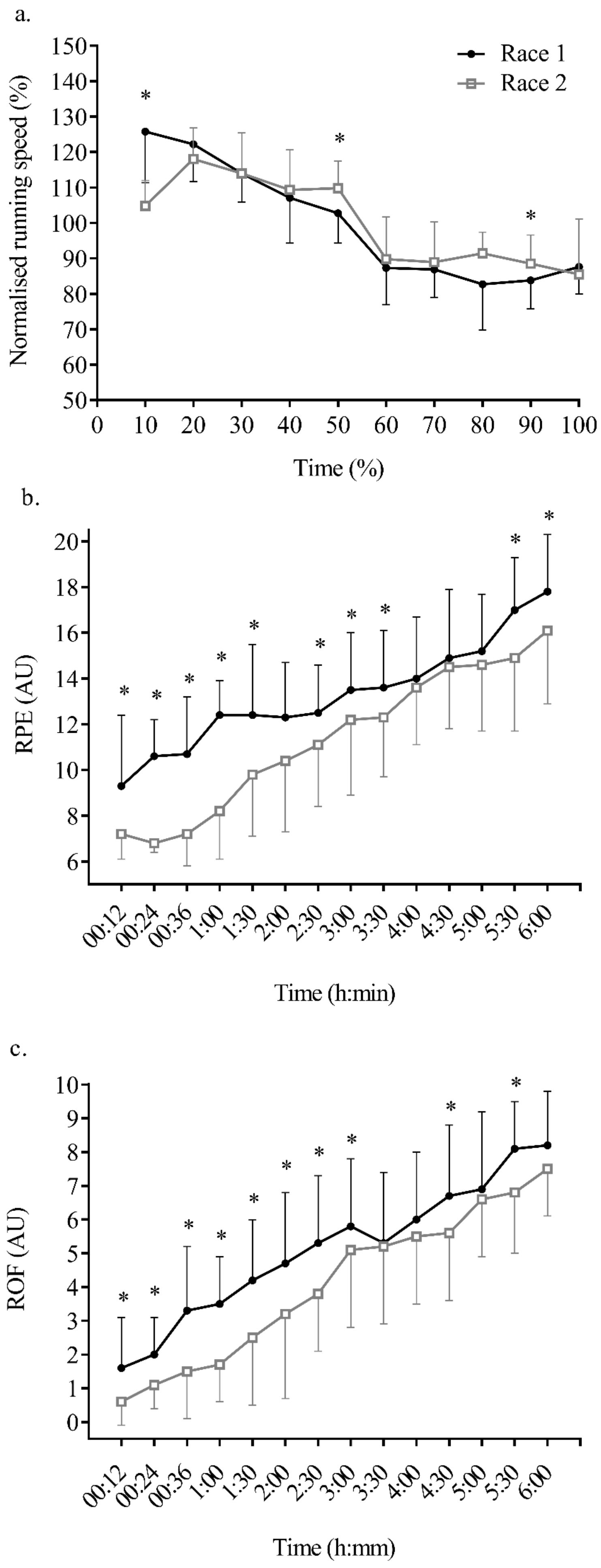
Table 1. Comparison of the measures before and after each race. *Difference between pre vs. post in the first race. #Difference between pre vs. post in the second race. †Difference in variables measured only before races. ($P \leq 0.05$).

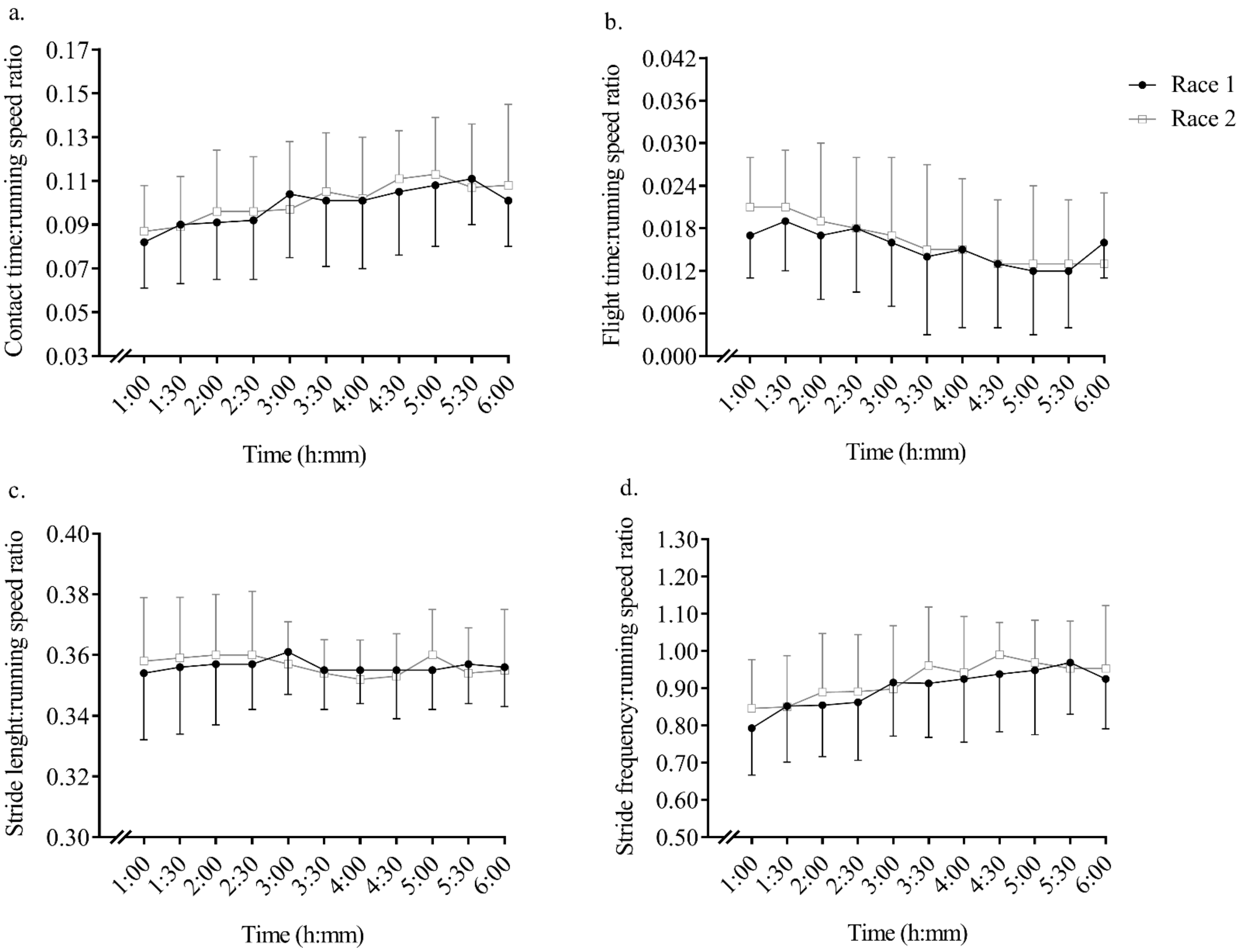
	Race 1				Race 2			
Variable	**Pre**	**Post**	***P* value**	**Cohens' *d***	**Pre**	**Post**	***P* value**	**Cohens' *d***
Body mass (kg)	72.3 ± 13.4	70.5 ± 13.2	0.011*	0.135	72.2 ± 14.1	70.5 ± 13.9	0.001#	0.015
Mean CMJ height (cm)	25.5 ± 5.9	20.2 ± 5.5	0.049*	0.929	26.5 ± 6.0	22.6 ± 5.2	0.065	0.051
TQR (AU)	18.8 ± 2.2	-			18.1 ± 1.8	-	0.322	0.348
ROF (AU)	0.6 ± 0.8	-			1.0 ± 1.0	-	0.309	0.442
Intrinsic Motivation (AU)	26.0 ± 2.1	-			25.2 ± 1.6	-	0.037†	0.429
Success Motivation (AU)	18.0 ± 4.9	-			16.5 ± 5.1	-	0.018†	0.300

CMJ: countermovement jump; TQR: total quality recovery; ROF: ratings of fatigue; AU: arbitrary units

Figures


a.
Normalised running speed (%)
Time (%)
b.
ROF
RPE
ROF (AU)
RPE (AU)
Time (h:mm)
c.
Contact time (s)
Time (h:mm)
d.
Flight time (s)
Time (h:mm)
e.
Stride lenght (m)
Time (h:mm)
f.
Stride frequency (steps/s)
Time (h:mm)


a.
Race 1
Race 2
Normalised running speed (%)
150
140
130
120
110
100
90
80
70
60
50
0
10
20
30
40
50
60
70
80
90
100
Time (%)
*
*
*
b.
RPE (AU)
20
18
16
14
12
10
8
6
00:12
00:24
00:36
1:00
1:30
2:00
2:30
3:00
3:30
4:00
4:30
5:00
5:30
6:00
Time (h:min)
c.
ROF (AU)
10
9
8
7
6
5
4
3
2
1
0
00:12
00:24
00:36
1:00
1:30
2:00
2:30
3:00
3:30
4:00
4:30
5:00
5:30
6:00
Time (h:mm)


a.
Contact time:running speed ratio
0.17
0.15
0.13
0.11
0.09
0.07
0.05
0.03
1:00
1:30
2:00
2:30
3:00
3:30
4:00
4:30
5:00
5:30
6:00
Time (h:mm)
b.
Flight time:running speed ratio
0.042
0.036
0.030
0.024
0.018
0.012
0.006
0.000
Time (h:mm)
Race 1
Race 2
c.
Stride lenght:running speed ratio
0.40
0.38
0.36
0.34
0.32
0.30
Time (h:mm)
d.
Stride frequency:running speed ratio
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
Time (h:mm)