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Influencing Factors of Pacing Variations and Performance in a 44-Kilometer Mountain Trail Race

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Abstract

Objective: This study aimed to analyse the changes in the biomechanical and psychophysiological responses, and the body mass of trailers in a small-distance (44 km and 1520 m elevation gain) trail competition performed in tropical conditions. **Methods:** Ten trained trailers (8 men, 2 females; age: 42.0 ± 5 years, body mass: 65.57 ± 5.4 kg, height: 174.9 ± 5.9 cm BMI: 21.71 ± 2.1, Maximal Aerobic Speed (MAS): 16.6 ± 2.1 $km \cdot h^{-1}$) volunteered to take part in the competition, comprising eight laps of 5.5 km. At the end of each lap, the trailers had to stop for 10 min to perform tests measuring 1) the maximal horizontal force (F0), theoretical maximal running velocity (V0) and maximal power output (PO) during a 30-m sprint; 2) the vertical oscillations and maximal relative force during a 30-s treadmill submaximal run; 3) the perceived exertion and pleasure; and 4) body mass. The pacing, stride variations and heart rate were continuously recorded during the race. **Results:** The variations of PO ($W \cdot kg^{-1}$) during the 30-m sprint and perceived pleasure were significant ($p = 0.003$ and $p = 0.02$, respectively) influencing factors of pacing. A significant decrease ($p < 0.0001$) was observed for the body mass between the first and last laps. Fraction of MAS and MAS were significantly ($p = 0.004$ and $p = 0.04$, respectively) related to the trail performance. **Conclusions:** Training programmes could be proposed that include the increase of MAS, fraction of MAS and lower limb PO. During the competition, it could be interesting to plan a drinking programme to avoid potential thermoregulatory impairment, as well as psychological strategies to increase pleasure.

Keywords

Running, Maximal Aerobic Speed, Self-Regulated Exercise, Perceived Pleasure, Power Output

1. Introduction

Trail running races, which are competitions in a natural environment with minimal paved or asphalt road (not exceeding 20% of the total course), are becoming one of the most popular disciplines in endurance running (Hoffman & Wegelin, 2009). In March 2018, a new classification of races was proposed by the International Trail Running Association (ITRA, 2018), with seven categories (from XXS to XXL) based on the bonus (ITRA points), running distances (0 to 270 km and more) and winner's approximate time (1 to 17 h and more). In trail running, self-pacing has a major influence on performance (Millet, 2011a). It is well known that self-pacing exercise can be regulated from a complex protective system, including both somatosensory feedback and anticipatory mechanisms that maintain homeostasis and prevent major physiological disturbance (Coquart et al., 2012; Noakes, 2012) or motivational intensity changes (Marcora, 2008). Recently, Kerhervé et al. (2015) observed that, during a 106-km mountain trail competition with a total elevation gain and loss of 5870 m, the trailers combined positive pacing strategies (speed decreased from the start until 70% - 90% of the total event duration) with an increase of velocity in the last 10% of the event, and an increase in rating of perceived exertion (RPE) in the last 30% of the competition. Previous studies have also suggested that changes in the stride pattern (Degache et al., 2013; Morin et al., 2011), neuromuscular alterations and perceived exertion (Fourchet et al., 2012; Giandolini et al., 2016; Lopez et al., 2011) could explain these self-regulating mechanisms in trail running. However, to the best of our knowledge, the respective effects of these variables on pacing and performance during real trail competitions have yet to be determined.

It has been reported that hydration status could have a significant influence on self-pacing during trail running. While Stearns et al. (2009) found that dehydration is associated with decreases in runners' ability to evenly pace themselves during a competitive situation, Hue et al. (2014) claimed that high performance over a 6-day, 142-km trail running race in tropical conditions was associated with increased loss in both total body water and body mass per hour. These contradictory results remain unclear and require further investigations.

Finally, the determinants of successful trailers have been extensively investigated in XL and XXL races, and the results revealed the significant influence of physiological (Millet et al., 2011b), psychological (Krouse et al., 2011) and anthropometric parameters (Hoffman et al., 2010). Balducci et al. (2017) also found that XL trail performance was significantly related to both the maximal aerobic speed (MAS) and fraction of MAS (% MAS) used in competition. However, to the best of our knowledge, the influence of these parameters is not well documented in shorter distance trail competition, especially the "S" category of the ITRA rule. In addition, the psycho-physiological and biomechanical responses, the body mass changes, and their possible impact on the health of the trailers have never been investigated during a real trail running competition performed in hot and humid environment.

Therefore, the purpose of the present study was to analyse the changes of biomechanical, physical, perceptual responses and anthropometric characteristics in trailers during a 44-km and 1520-m elevation gain trail competition performed in tropical conditions. We seek to determine the following: 1) the effects of each of these parameters on pacing and 2) the variables influencing the trail performance. The hypotheses of the study are as follows: 1) pacing is related to changes in the stride characteristics, heart rate (HR), sprint capacities, running pattern, perceptual responses and body mass, and 2) trail performance in the "S" category is related to the MAS and %MAS.

2. Methods

2.1. Participants

Ten trained trailers, having all previously participated at least in one trail of 60 km, volunteered to take part in this experimental competition. Prior to participating in the event, each trailer provided written informed consent, and the study was conducted in accordance with the ethical principles of the Declaration of Helsinki (1984) and approved by the regional ethics committee. One week before the race, the trailers performed a maximal running graded test until exhaustion on a track (Leger & Boucher, 1980) to determine their Maximal Aerobic Speed (MAS) and maximal HR. The anthropometric characteristics and trail performance of the trailers are presented in **Table 1**.

2.2. Experimental Instrument

The experimental protocol (**Figure 1**) was carried out during a 44.0 km mountain trail experimental competition (corresponding to the "S" category in the ITRA classification) with a total elevation gain and loss of 1520-m during the Colorado Trail 2017 at Reunion Island in June. To investigate the pacing variations and maintain a high level of motivation during all the experimentation, the experimental protocol was designed like a real trail competition constituted by eight laps of 5.5 km with 1.9 km of hilly terrain, 1.6 km of uphill, and 2.0 km of downhill. The total elevation gain and loss was 190-m per lap. The mean running time was controlled at each lap with a microchip and manual timekeeper. At the end of each lap, the trailers had to stop in a paddock for 10 min to perform a set of tests. This study was conducted according to the recommendations of the Declaration of Helsinki. The research plan was examined and approved by the Ethics Committee of the responsible Institutional Department (University of

Table 1. Mean ± *SD* and extreme values (under brackets) of the subjects' anthropometrics, physical characteristics, and trail performance. The time spent each lap at the paddock (8 * 10 min = 80 min) has been subtracted from the running time.

Variables	(n = 10)
Gender	8 men; 2 females
Age (years)	42.0 ± 5 [36 - 52]
Level in competition	4 initiated, 5 experienced and 1 elite
ITRA points	642.9 ± 65 [564 - 776]
Height (cm)	174.9 ± 5.9 [167 - 185]
Body mass (kg)	65.57 ± 5.4 [57 - 74]
Body mass index (BMI)	21.71 ± 2.1 [20.22 - 25.65]
Maximal heart rate (bpm)	179.33 ± 10.87 [167 - 188]
Maximal Aerobic Speed (km·h^{-1})	16.60 ± 2.07 [14.00 - 19.00]
Fraction of MAS (%) used during the competition	44.75 ± 5.14 [38.70 - 50.09]
Distance traveled during the competition (km)	44.0 ± 0
Number of laps	8.0
Running time (min)	362 ± 51 [302 - 412]
Running velocity (km·h^{-1})	7.44 ± 1.14 [5.59 - 8.74]
Coefficient of variation between the slowest and fastest laps	8 ± 3 [4 - 13]

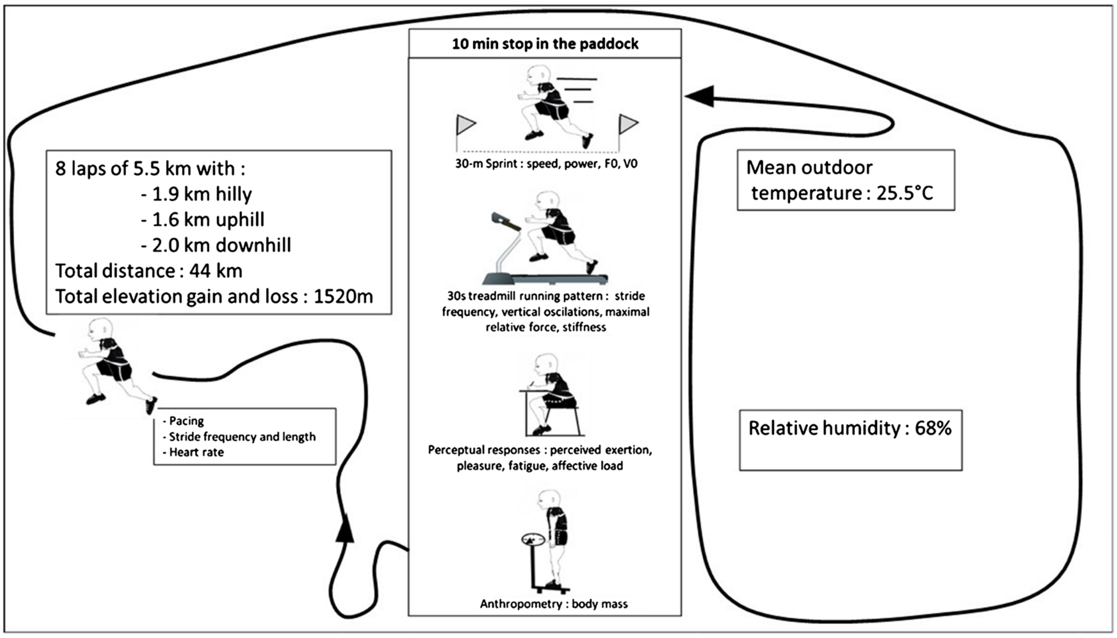

Figure 1. Schematic view of the experimental design.

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All the trailers started together at 6:00 am in tropical environmental conditions. The mean temperature was 25.5˚C, (extreme values, 20.1˚C - 30.5˚C; 68% relative humidity). Their pacing, stride variations (frequency and length) and

HR were continuously recorded during the race by considering three gradients (uphill, downhill and hilly) using a GPS tracking watch with accelerometer and HR recording (Spartan Ultra, Suunto, Vantaa, Finland). Each watch was set to record one data point every 1 s.

At the end of each lap, the trailers had to stop in a paddock for 10 min to record the following parameters:

- *Biomechanical parameters*:
  - Their sprint capacities during a 30-m sprint test on flat terrain with start stopping, where they were invited to give their best performance. To motivate the trailers, they were informed that their 30-m sprint performances would be considered in the final ranking for the competition. In line with Romero-Franco et al. (Romero-Franco et al., 2017), the sprints were filmed with an iPhone® 7 and analysed with the MySprint® application. The theoretical maximal horizontal force production was expressed in both absolute (F0, N) and relative ($F0_{rel}$ $N \cdot kg^{-1}$) values, and the theoretical maximal running velocity (V0) was extrapolated from the linear sprint force-velocity relationship with the application. The absolute and relative maximal power output, PO_{max} (W) and PO_{relmax} ($W \cdot kg^{-1}$), respectively (determined as $PO = F0 \times V0/4$), mean running speed ($m \cdot s^{-1}$) and maximal running speed ($m \cdot s^{-1}$) were also calculated from the application; and
  - Their running pattern during a 30-s treadmill (Domyos® T520A) running test at 12 $km \cdot h^{-1}$ with 0 degrees of elevation. In accordance with Balsalobre-Fernández et al. (2017), the running was filmed with an iPhone® 7, and the pattern was analysed with the Runmatic® application. The stride frequency (Hz), vertical oscillations (m), maximal relative force (PC) and muscle stiffness ($kN \cdot m^{-1}$) were recorded;
- *Perceptual parameters*:
  - Their perceptual responses with the rating of fatigue (ROF, Micklewright, et al., 2017) and perceived exertion (CR10, Borg, 1990);
  - Conforming to Baron et al. (2011), perceived pleasure was measured using a 0 - 10 rating scale, where 0 corresponded to "no pleasure" and 10 to "maximal pleasure". The affective load (AL) was calculated using the formula of Baron et al. (2011):

$$\text{AL} = \text{perceived exertion} - \text{perceived pleasure};$$

- *Body mass* (Tefal Premiss® weight scale), which was standardised (always the same clothes and without a backpack). After each set of tests, to avoid any influence of hypoglycaemia and hyperthermia on the development of fatigue (Nybo, 2008), the trailers were fed ad libitum with meals containing mainly carbohydrates, energy bars and drinks. The food and water intake during the trail were checked in real time by an experienced investigator to ensure that there was no major problem of energy intake during the experiment.

Due to the great number of trailers in the paddock simultaneously, it was not possible to perform all the tests for all the subjects within 10 min. Consequently, we present the full results of laps 1, 3, 5, 7 and 8. Indeed, the priority was conserving the competition's real conditions to maintain the highest possible motivation level.

2.3. Statistical Analysis

Data are reported as the means ± standard deviations (*SDs*). We performed stepwise linear regressions (XLStat software, Addinsoft, NY, USA) to examine the delta values of the variables from the independent predictors (28 variables presented in **Table 2** and **Table 3**, including the stride characteristics, HR responses, sprint capacities, running pattern, perceptual responses and body mass) of mean pacing. In addition, as the results met the statistical assumptions for using parametric statistics (i.e. homogeneity of variance and normality of the sample distribution), a one-way analysis of variance (ANOVA) with repeated measures and Tukey post hoc test (Sigmastat 11.0, Jandel Scientific Software, CA, USA) were performed to determine possible changes between laps in the mean pacing, stride characteristics, HR responses, 30-m sprint capacities, running pattern on the treadmill, perceptual responses and body mass. Effect Sizes (ES) were calculated from extreme values using the formula of Hedges (1982). A complementary two-way (5 laps × 3 gradients) repeated ANOVA and Tukey post hoc test were also performed for the pacing, HR and stride characteristics. The Pearson product-moment correlation coefficient was used to determine possible correlations between the trail performance (running velocity), MAS and fraction of MAS (%) used during the competition. A p-value < 0.05 indicated that the difference was statistically significant.

3. Results

The mean total running time was 362 ± 51 min, excluding the time spent at each lap at the paddock (8 * 10 min = 80 min). The mean velocity of participants over the total race was then 7.49 ± 1.11 $\text{km}\cdot\text{h}^{-1}$. The mean fraction of MAS (%) used during the competition was 44.75 ± 5.14.

Concerning the influencing factors of pacing, the stepwise linear regression analysis demonstrated that, among the 28 variables tested, the decrease of $\text{PO}_{\text{relmax}}$ ($\text{W}\cdot\text{kg}^{-1}$) (adjusted $r^2 = 0.58$, $t = 6.619$, $p = 0.003$) and perceived pleasure (adjusted $r^2 = 0.30$, $t = 3.370$, $p = 0.02$) between laps 1 and 8 were the independent influencing factors of mean pacing.

The statistical treatment revealed that there are significant changes in some variables during the trail running. Indeed, between the different laps (**Figure 2** and **Figure 3**, **Table 3**), the one-way ANOVA revealed a significant increase in the mean pacing ($F = 13.18$, $p < 0.0001$), perceived exertion ($F = 25.34$, $p < 0.0001$), affective load ($F = 14.36$, $p < 0.0001$) and perceived fatigue ($F = 24.94$, $p < 0.0001$) and a significant decrease in the perceived pleasure ($F = 3.59$; $p < 0.01$), mean stride frequency ($F = 6.51$, $p < 0.005$) and mean stride length ($F = 7.81$, $p < 0.001$), as well as body mass ($F = 27.33$, $p < 0.0001$, with 2.7% loss between the first and last laps). In the 30-m sprint, we observed a significant decrease in the mean speed ($F = 7.58$, $p < 0.0004$), maximal speed ($F = 7.75$, $p < 0.0004$), PO_{relmax} ($F = 4.65$, $p < 0.006$), PO_{max} ($F = 5.53$, $p < 0.002$), $F0_{rel}$ ($F = 4.23$, $p < 0.001$), and V0 ($F = 7.75$, $p < 0.0005$). No significant changes

Table 2. Mean ± *SD* of the pacing, stride characteristics and HR responses recorded during the 44-km trail competition.

Parameters continuously recorded	Variables	Laps					Mean	Δ Extreme Values	Changes (%)	Effect Size
		1	3	5	7	8				
Pacing	Mean pacing (km·h^{-1})	8.02 ± 1.40	7.96 ± 1.14	7.49 ± 1.15	6.94 ± 1.04^{a,b}	7.04 ± 0.96^{a,b}	7.49 ± 1.11	1.08 ± 0.48	13.5	0.88
	Uphill pacing (km·h^{-1})	6.45 ± 1.04	6.42 ± 0.74	6.02 ± 0.76	5.75 ± 0.69^{a,b}	5.58 ± 0.53^{a,b}	6.04 ± 0.71	0.87 ± 0.51	13.5	1.05
	Downhill pacing (km·h^{-1})	8.72 ± 1.82*	8.75 ± 1.38*	8.37 ± 1.46*	7.72 ± 1.30^{a,b}*	7.90 ± 1.26^{a,b}*	8.33 ± 1.37*	1.03 ± 0.47	11.8	0.77
	Hilly pacing (km·h^{-1})	8.68 ± 1.59*	8.72 ± 1.37*	8.08 ± 1.32^{b}*	7.37 ± 1.2^{a,b,c}*	7.65 ± 1.19^{a,b}*	8.10 ± 1.28*	1.35 ± 0.45	15.8	1.05
Stride characteristics	Mean stride frequency (steps·min^{-1})	157.46 ± 15.96	155.06 ± 19.64	151.20 ± 19.04	147.46 ± 21.96^{a}	146.46 ± 20.48^{a,b}	151.57 ± 19.19	11.00 ± 7.00	7.1	0.60
	Uphill stride frequency (steps·min^{-1})	147.60 ± 22.15	145.20 ± 21.84	141.60 ± 21.74	137.60 ± 25.04	134.80 ± 22.66	141.36 ± 22.10	12.80 ± 11.44	8.7	0.57
	Downhill stride frequency (steps·min^{-1})	162.00 ± 10.4	158.40 ± 17.52	157.20 ± 14.67	154.00 ± 18.65	154.40 ± 18.40	157.20 ± 15.57*	8.00 ± 4.60	5.0	0.55
	Hilly stride frequency (steps·min^{-1})	162.80 ± 17.27	161.60 ± 19.87	154.80 ± 21.48	150.80 ± 23.52^{a}	150.80 ± 22.25^{a,b}	156.16 ± 20.35*	12.00 ± 7.16	7.4	0.61
	Mean stride length (m)	0.87 ± 0.08	0.87 ± 0.04	0.83 ± 0.07	0.79 ± 0.06^{a,b}	0.81 ± 0.05^{a,b}	0.83 ± 0.06	0.08 ± 0.04	9.2	1.13
	Uphill stride length (m)	0.75 ± 0.04	0.75 ± 0.04	0.72 ± 0.06	0.70 ± 0.07	0.70 ± 0.07	0.72 ± 0.05	0.05 ± 0.03	6.6	0.88
	Downhill stride lenght (m)	0.95 ± 0.12*	0.94 ± 0.07*	0.90 ± 0.11*	0.84 ± 0.09^{a,b}*	0.87 ± 0.07^{a,b}*	0.90 ± 0.08*	0.11 ± 0.05	11.6	1.04
	Hilly stride length (m)	0.92 ± 0.09*	0.91 ± 0.06*	0.87 ± 0.07*	0.81 ± 0.06^{a,b}*	0.85 ± 0.05^{a,b}*	0.87 ± 0.06*	0.11 ± 0.05	12.0	1.44
HR responses	Mean HR (bpm)	157.50 ± 19.8	159.6 ± 20.6	159.6 ± 21.8	154.8 ± 19.1	155.8 ± 19.9	155.42 ± 19.88	4.80 ± 2.61	3.1	0.25
	% of overall maximal HR	88.92 ± 7.42	89.56 ± 7.55	89.96 ± 8.63	86.12 ± 8.95	86.58 ± 10.12	88.23 ± 8.02	3.84 ± 2.19	4.3	0.46
	Uphill HR (bpm)	161.00 ± 20.53	160.40 ± 21.00	160.40 ± 21.61	155.00 ± 18.76	155.20 ± 20.12	158.01$^{\#}$ ± 19.89	6.00 ± 6.28	3.8	0.32
	Downhill HR (bpm)	157.81 ± 21.18	156.68 ± 22.10	157.82 ± 21.56	152.42 ± 18.66	154.87 ± 21.21	155.72$^{\#}$ ± 20.70	5.40 ± 1.48	3.5	0.28
	Hilly HR (bpm)	152.21 ± 18.75	155.00 ± 19.57	152.81 ± 22.59	150.41 ± 9.91	150.48 ± 19.03	152.16 ± 19.17	4.59 ± 4.55	3.1	0.34

$^{a}p < 0.05$ compared with lap 1; $^{b}p < 0.05$ compared with lap 3; $^{c}p < 0.05$ compared with lap 5; *compared with uphill, $^{\#}p < 0.05$ compared with hilly gradient.

Table 3. Mean ± *SD* of the sprint capacities, running pattern on the treadmill, perceptual responses, and body mass recorded at the end of each lap.

Parameters measured at the end of each lap	*Variables*	*Laps*					*Mean*	*Δ Extreme Values*	Changes (%)	Effect Size
		1	3	5	7	8				
Sprint Capacities in a 30-m sprint	Mean running speed (Km·h^{-1})	20.54 ± 1.49	19.71 ± 1.92	18.03 ± 2.74	16.13 ± 3.5^{a,b}	16.95 ± 3.44^{a,b}	18.11 ± 2.71	4.41 ± 2.20	21.5	1.64
	Maximal running speed (Km·h^{-1})	22.92 ± 2.34	21.46 ± 2.73	19.20 ± 3.59^{a}	17.29 ± 4.3^{a,b}	17.73 ± 4.62^{a,b}	19.27 ± 3.74	5.63 ± 2.43	24.6	1.65
	Relative maximal power output (W·kg^{-1})	18.33 ± 2.08	17.39 ± 4.42	15.25 ± 5.33	11.80 ± 5.51^{a,b}	12.80 ± 6.04^{a}	14.65 ± 4.55	6.53 ± 2.70	35.7	1.57
	Absolute maximal power output (W)	1245.64 ± 190.88	1167.16 ± 291.00	1013.13 ± 321.29	774.63 ± 380.61^{a,b}	879.92 ± 387.93^{a}	1000.23 ± 279.73	471.01 ± 222.3	37.9	1.57
	Theoretical maximal absolute horizontal force F0 (N)	771.05 ± 116.90	749.47 ± 153.41	713.59 ± 185.01	603.10 ± 206.01	648.48 ± 221.65	693.01 ± 161.36	167.95 ± 115.57	21.8	1.01
	Theoretical maximal relative horizontal force F0 (N·kg^{-1})	11.25 ± 1.59	11.37 ± 1.77	10.65 ± 2.65	9.04 ± 2.94^{a,b}	9.68 ± 2.91	10.35 ± 1.88	2.33 ± 2.58	20.5	0.95
	Theoretical maximal running velocity V0 (m·s^{-1})	6.55 ± 0.67	6.19 ± 0.71	5.66 ± 0.98	5.05 ± 1.18^{a,b}	5.29 ± 1.19^{a}	5.70 ± 0.98	1.50 ± 0.46	23.0	1.56
Running pattern on the treadmill	Stride frequency (Hz)	5.18 ± 1.45	4.43 ± 1.25	4.61 ± 1.36	3.66 ± 1.37	4.63 ± 1.16	4.50 ± 1.32	1.52 ± 1.38	29.5	1.13
	Vertical oscillations (m)	0.04 ± 0.02	0.04 ± 0.01	0.04 ± 0.02	0.05 ± 0.01	0.04 ± 0.01	0.05 ± 0.01	0.01 ± 0.01	20.0	1.00
	Maximal relative force (PC)	2.38 ± 0.1	2.51 ± 0.2	2.54 ± 0.2	2.50 ± 0.2	2.56 ± 0.2	2.50 ± 0.1	0.18 ± 01	15.0	1.14
	Stiffness (kN·m^{-1})	52.40 ± 24.87	47.99 ± 27.21	53.26 ± 32.60	27.29 ± 24.52	49.05 ± 21.81	46.00 ± 11.27	25.97 ± 11.8	48.0	0.91
Perceptual responses	Perceived exertion	2.94 ± 1.33	4.44 ± 1.67	5.70 ± 1.25^{a}	7.00 ± 2.00^{a,b}	7.20 ± 2.20^{a,b}	5.44 ± 1.16	4.26 ± 2.33	60.0	2.38
	Perceived pleasure	6.40 ± 3.13	6.67 ± 2.37	5.50 ± 3.06	5.00 ± 3.32^{a,b}	5.89 ± 2.85	5.81 ± 2.80	1.67 ± 6.3	24.9	0.58
	Affective load	−3.36 ± 3.45	−2.06 ± 1.79	0.20 ± 2.97^{a}	2.00 ± 3.69^{a,b}	1.31 ± 3.70^{a,b}	-0.30 ± 2.65	5.36 ± 2.98	63.1	1.50
	Perceived fatigue	1.20 ± 1.39	2.55 ± 1.87	4.90 ± 1.37^{a,b}	5.30 ± 2.21^{a,b}	6.40 ± 2.45^{a,b}	4.07 ± 1.47	5.20 ± 2.70	82.0	2.61
Anthropometry	Body mass (kg)	64.86 ± 7.66	63.97 ± 7.4	63.51 ± 7.17	63.27 ± 7.16	63.12 ± 7.07^{a}	63.75 ± 7.29	1.74 ± 0.9	2.7	0.24

$^{a}p < 0.05$ compared with lap 1; $^{b}p < 0.05$ compared with lap 3.

($p > 0.05$) were observed for the mean HR, percentage of maximal HR, F0 in the 30-m sprint, stride frequency, vertical oscillations, maximal relative force, or stiffness measured on the treadmill.

As presented in Table 3, for pacing, the two-way ANOVA revealed significant lap ($F = 13.18$, $p < 0.001$) and gradient ($F = 53.63$, $p < 0.001$) effects and interactions ($F = 2.73$, $p < 0.01$). For the stride frequency, we also found significant lap ($F = 6.51$, $p < 0.005$) and gradient ($F = 19.44$, $p < 0.001$) effects, but no significant

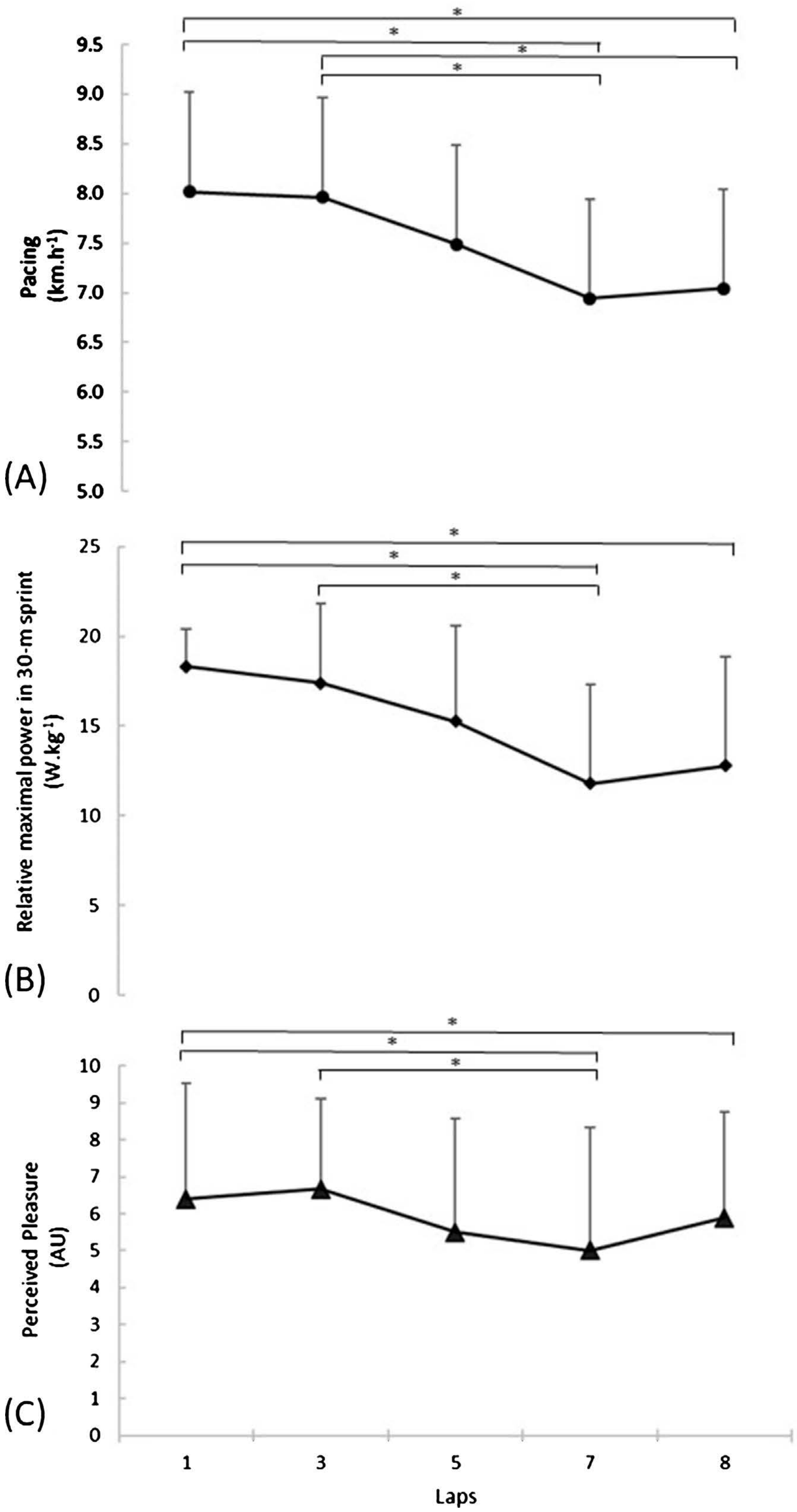

Figure 2. Evolution of pacing (panel A), relative maximal power output on a 30-m sprint (panel B) and perceived pleasure (panel C) during the trail running competition. *$p < 0.05$.

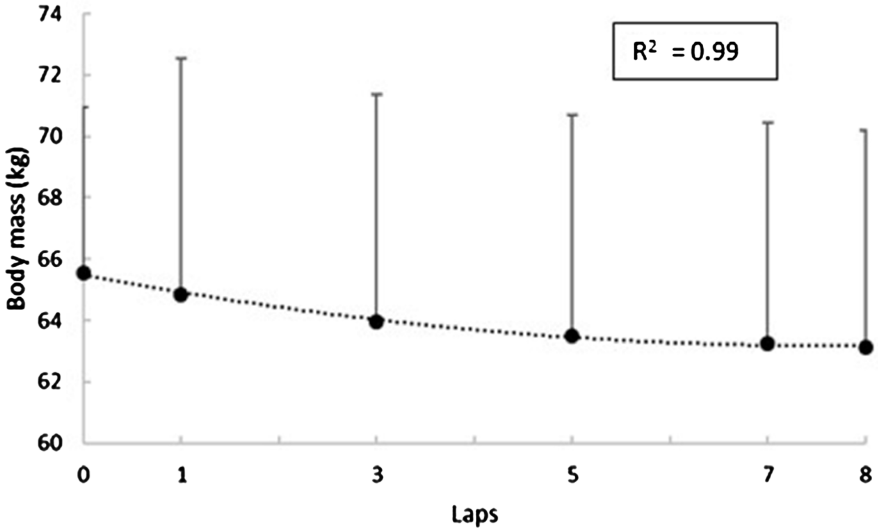

Figure 3. Evolution of the body mass before and during the trail running.

interactions ($F = 0.86$, $p = 0.55$) were observed. Concerning the stride length, we observed significant lap ($F = 8.31$, $p < 0.001$) and gradient ($F = 23.89$, $p < 0.001$) effects and interactions ($F = 2.38$, $p < 0.05$). A significant ($F = 16.58$, $p < 0.001$) gradient effect was found for HR, but neither a significant lap effect ($F = 1.20$, $p = 0.34$) nor interactions ($F = 0.78$, $p = 0.61$) were observed.

It has been also found that there are variables significantly correlated to the running velocity. Indeed, a significant correlation was found between the mean running velocity and MAS ($r = 0.63$, $p = 0.04$, $t = 2.34$) and the fraction of MAS ($r = 0.81$; $p = 0.004$; $t = 3.89$).

In summary, the variations of PO ($W\cdot kg^{-1}$) during the 30-m sprint and perceived pleasure are significant influencing factors of pacing. In addition, trail running in tropical environment decreases significantly the body mass between the first and last laps. Finally, the fraction of MAS and MAS are significantly related to the trail performance.

4. Discussion

The aim of the study was determining the respective effects of biomechanical, physical, and perceptual responses and body mass changes on pacing and the influencing variables on the trail performance.

The most important finding of the present study was that, among all the variables tested in the statistical treatment, PO_{relmax} and perceived pleasure were determined to be influencing factors for the overall pacing (Figure 4). Indeed, the variations (decrease from lap 1 to lap 7 and increase at lap 8) of the PO_{relmax} on 30-m sprint results from significant alterations of both velocity and force capabilities. The decrease of force capacities has been previously reported by Millet et al. (2011b) and confirmed by Saugy et al. (2013). Recently Giovanelli et al. (2017) also noted that the trailers characterised by greater maximal lower limb power were strongly related to smaller changes in running mechanics and pacing induced by fatigue. In line with these results, Vernillot et al. (2015) proposed incorporating specific downhill locomotion in the trailers' training programmes to improve the performance-related physiological and biomechanical parameters. It could be also suggested to trail coaches to propose training programmes including power lifting sessions to increase the lower limb power output. The variations of perceived pleasure (decrease from lap 1 to lap 7 and increase at lap 8) are the second significant independent variable influencing pacing. Baron et al. (2011, 2014) previously demonstrated that pleasure and positive emotions could balance perceived exertion and allow the athlete to sustain higher exercise intensity during the effort. Goal setting by fractioning the course in different stages (Tucker & Noakes, 2009), self-talk (Mac Cormick, Meijen, & Marcora, 2015), social support (Rochat et al., 2017) or an appetising meal during the race could be interesting ways of increasing pleasure.

Although not significantly correlated to pacing, other variables (the stride variations, speed sprint capacities, perceptual responses and body mass) change significantly during trail running. Indeed, the decreases of maximal speed sprint and PO_{max}, along with the increases in perceived exertion, affective load and fatigue, suggest that the trailers have self-regulated their running velocity to avoid early exhaustion occurring before the end of the event (Foster et al., 1994; Hettinga et al., 2006). Moreover, in competition conditions, as in the present study, the trailers keep enough reserves and motivation to be able to accelerate in the last lap to outdistance their opponents. The values of affective load could confirm the existence of an emotional reserve, as previously reported by Baron et al. (2011, 2014) and Abel & Grappe (2016).

One interesting finding is the significant changes of the stride frequency and stride length observed in the different gradients, with a decrease in the running speed of -1.3 ± 0.5 km·h^{-1} (−15.8% ± 3%) on hilly, -1.1 ± 0.4 km·h^{-1} (−11.8% ± 3%) on downhill and -0.8 ± 0.5 km·h^{-1} (−13.5% ± 7.3%) on uphill gradients. Kerhervé et al. (2015) observed also a running speed decrease during a 106-km mountain ultra-trail race, with −2.9% ± 2.1% on hilly, −2.6% ± 0.9% on downhill and −1.3% ± 0.8% on uphill gradients. The difference of percentages reported in this study could be explained by the fact that the authors used the mean running speed during the race, whereas in the present study, we determined the running speed decrease in each gradient from the delta of extreme values recorded between the slowest and fastest laps.

The significant curvilinear decrease of the body mass ($F = 27.33$; $p < 0.05$, −2.7% between the first and last laps) is in accordance with Stearns et al. (2009) concerning dehydrated trailers performing a 12-km running trail in the heat (with −2.3% of body mass loss). One interesting point is that the trailers in our study were informed of their body mass loss at the end of each lap and strongly invited to drink and eat ad libitum. Despite these recommendations, the trailers continued to lose weight. This finding suggests that, in the environmental conditions of the present study, feeding ad libitum does not compensate for the body mass loss. This result has been previously reported by Stuempfle et al. (2011), who found that kilocalorie, fat, fluid and sodium consumption rates during an XL trail were significantly greater in finishers than they were in non-finishers. Therefore, we can reiterate Kenefick's suggestion (Kenefick, 2018) that when dehydration causes greater than 2% body mass loss in exercises with long duration (>90 min), a tailored, programmed drinking strategy is required to avoid potential thermoregulatory and performance impairment.

One surprising result is the lack of significant alteration in the running pattern on the treadmill. Indeed, in the results of a 166-km mountain ultra-trail race, Morin et al. (2011) reported a significant increase in step frequency associated with reduced aerial times in trailers tested at 12 km·h^{-1} on a 7-m pressure walkway. Degache et al. (2013) confirmed these observations for a 5-h running trail, where trailers were tested, as in the present study, on a treadmill at 12 km·h^{-1}. Giovanelli et al. (2017) also observed a significant alteration of the running pattern, and especially, a decrease in aerial time after 4 h 30 min of running. This contradictory result remains unclear and requires further investigations.

Another surprising result is the lack of significant changes for the percentages of overall maximal HR, mean HR, and uphill, downhill and hilly HR between the laps. These results are in accordance with Kerhervé et al. (2015), who also reported no significant changes in HR before 70% of the total duration (around 12 h) of a 106-km running trail competition. In addition, our results seem to confirm that HR does not appear to be a significant predictor of pacing in the environmental conditions of our study.

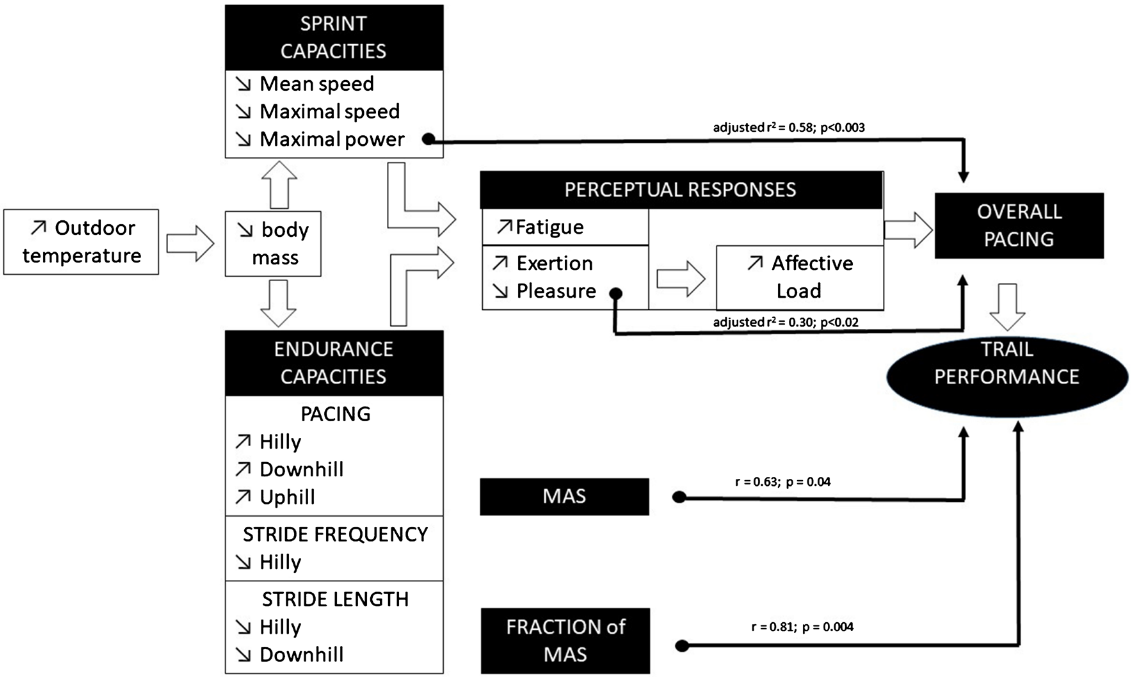

Figure 4. Holistic model of the biomechanical, physical and perceptual responses and the influencing factors of overall pacing and trail performance during an "S" mountain running trail race performed in a tropical environment. MAS: Maximal Aerobic Speed.

Our study revealed that, among the different anthropometric and physical variables recorded before the race (i.e. body mass, BMI, MAS and fraction of MAS), only the fraction of MAS and MAS were significantly correlated to the running velocity. This finding is in line with Balducci et al. (2017), who observed a significant correlation between the MAS and running time ($r = -0.89$, $p < 0.001$) in a 75-km trail with a total positive elevation of +3930 m. This result is not surprising, considering that long-distance running performance depends on several factors, especially including the VO_{2max}, fraction of VO_{2max} and energy cost of running (di Prampero et al., 1986, Wishnizer et al., 2013; Lazzer et al., 2014). Furthermore, our study confirms that the fraction of MAS used during the race is significantly related to the running trail performance, and the higher the fraction is, the better the performance will be. These findings have been previously reported by Balducci et al. (2017), suggesting that specific training sessions including MAS (e.g. interval training at MAS on the track) and fraction of MAS (endurance training under and near the anaerobic threshold) development are encouraged to increase the "S" trail running performance.

In this study, the main limitation may have been caused by the specific exercise induced in the recovery periods, when the trailers had to stop in the paddock for 10 min at the end of each lap. Although the stop in the paddock required moderate to intense exercise (30-s treadmill runs and 30-m sprint tests), it could have affected the trailers' perceptual, biomechanical and physiological responses. However, further investigations carried out on a large experimental sample, including a holistic approach with video recording of the running pattern and the perceptual responses (without any recovery period) are encouraged to confirm the results of the present study.

5. Conclusion

Our results revealed that the variations of PO_{relmax} and perceived pleasure are significant influencing factors for the overall pacing on a 44-km mountain trail. In addition, fraction of MAS and MAS were significantly related to the trail running performance.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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