Physica A 506 (2018) 290–304

Contents lists available at ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa

Humans are able to self-paced constant running accelerations until exhaustion

Véronique Billat [a], Nicolas J-B. Brunel [b], Thomas Carbillet [c,d,*], Stéphane Labbé [c], Adeline Samson [c]

[a] Unité de Biologie Intégrative des Adaptations à l'Exercice, Université Paris-Saclay, Evry, France
[b] LaMME, ENSIIE, CNRS, UEVE, Université Paris-Saclay, Evry, France
[c] Université Grenoble Alpes, Laboratoire Jean Kuntzmann, Grenoble, France
[d] Billatraining SAS, France

HIGHLIGHTS

- Humans are able to perceive three distinct accelerations (soft, medium and hard).
- Constant accelerations are obtained by the application of brief corrections.
- An Ornstein–Uhlenbeck process can model self-paced constant running acceleration until exhaustion.

ARTICLE INFO

Article history:
Received 23 June 2017
Received in revised form 29 January 2018
Available online 21 April 2018

Keywords:
Acceleration
Exercise
Running
Self-paced
Performance
Ornstein–Uhlenbeck

ABSTRACT

Although it has been experimentally reported that speed variations is the optimal way of optimizing his pace for achieving a given distance in a minimal time, we still do not know what the optimal speed variations (i.e. accelerations) are. At first, we have to check the hypothesis that human is able to accurately self-pacing its acceleration and this even in a state of fatigue during exhaustive self-pacing ramp runs. For that purpose, 3 males and 2 females middle-aged, recreational runners ran, in random order, three exhaustive acceleration trials. We instructed the five runners to perform three self-paced acceleration trials based on three acceleration intensity levels: "soft", "medium" and "hard". We chose a descriptive modelling approach to analyse the behaviour of the runners. Once we knew that the runners were able to perceive three acceleration intensity levels, we proposed a mean-reverting process (Ornstein–Uhlenbeck) to describe those accelerations: $da_t = -\theta(a_t - a)dt + \sigma dW_t$ where a is the mean acceleration, a_t is the measured acceleration at each time interval t, θ the ability of the runner to correct the variations around a mean acceleration and σ the human induced variations. The goodness-of-fit of the Ornstein–Uhlenbeck process highlights the fact that humans are able to maintain a constant acceleration and are able to precisely regulate their acceleration (regardless of its intensity) in a run leading to exhaustion in the range from 1 min 36 s to 20 min.

1. Introduction

Endurance running is considered to have played a major role in human evolution. Humans have developed the ability to fine-tune their running speed in order to run for several days and still catch their fastest prey [1]. Indeed, it has been reported

* Correspondence to: 19 chemin de Lagay, 38320 Eybens, France.
E-mail address: thomas.carbillet@gmail.com (T. Carbillet).

https://doi.org/10.1016/j.physa.2018.04.058
0378-4371/

that speed variation is the ideal way of optimizing its pace for achieving a given distance in a minimal time [2–9]. Hence, the rate at which the velocity of a body changes with time requires positive and negative accelerations and then strength variations according to Newton's second law of motion. However, there is a direct relationship between force impulse and running acceleration [10] and the minimum-jerk model [11] predicts that to save energy and optimize performance, running must be as smooth as possible and variations in acceleration must be close to 0 m s^{-3}. Furthermore, there is a clearly non-random speed fluctuation during self-paced exercise [12–15]. It has been suggested that speed variability operates through a feed forward mechanism [16] and we know that most of the races are stochastic when the velocity is not imposed [17]. Despite the large published body of work on pacing strategy and speed control, this is the first study to have examined acceleration control during running. We know that the fastest runners on middle and long-distance run with light speed variations [18–20]. Now that sensors make the recording of acceleration data easy, we would like to check if humans are able to integrate instructions in acceleration. The purpose is to take part in a runner's training and race in future studies. Given the fact that we are looking for a stochastic process to describe the ability for humans to maintain a constant acceleration and the hypothesis that self-paced accelerations lightly fluctuate around a constant value, we thought about the Ornstein–Uhlenbeck process [21]. Such process is described as a stochastic process with a mean-reverting property. The use of Ornstein–Uhlenbeck process is present in fields such as mathematical finance [22] (volatilities of asset prices and dynamics of interest rates) and biological processes [23]. Before going deeper in the effective mechanism of speed variation control during exhaustive exercise, we have to verify human's ability to maintain constant acceleration in a conscious way until exhaustion. The present study tests the hypothesis whereby humans are able to maintain a constant acceleration in a self-paced trial with no external cues regardless of the speed and the magnitude of acceleration and fatigue. For that purpose, we study more specifically the following two points:
(1) The ability for humans to maintain three different intensity levels of constant acceleration when so instructed. Those three intensities are described as "soft", "medium" and "hard" which are the instructions we gave to the runners for respectively a slow, a medium and a hard constant acceleration.
(2) The characterization of the acceleration data by introducing a new interpretation using a mean-reversing process (Ornstein–Uhlenbeck).

The paper is organized as follows. Section 2 describes the experimental protocol and presents the mathematical model. Section 3 compares the three acceleration intensities for each runner to see if we notice a genuine difference and gives an estimation of the parameters of the Ornstein–Uhlenbeck model for characterizing human accelerations. Finally, Sections 4 and 5 conclude the paper.

2. Methods

2.1. Subjects

The study population is composed of three males and two females recreational runners (aged 38 ± 3 yr., total running distance per week: 36.1 ± 4.3 km; body weight: 66.9 ± 12.4 kg and height 171.1 ± 6.7 cm). All subjects were first informed of the risks and constraints associated with the protocol and gave their written, informed consent to participation. The present study conformed to the precepts of the Declaration of Helsinki and all procedures were approved by the local investigational review board (Saint Louis Hospital, Paris, France). On a physiological aspect, we cannot compare openly males and females. Given this fact plus the sample size of the study, we choose to focus on a descriptive modelling approach to analyse the runner behaviours. No statistical tests will be applied.

2.2. Experimental design

Subjects ran alone and performed three types of track sessions until exhaustion, in random order and with a one-hour interval between sessions: the first, second and third track tests were self-paced acceleration trials at respectively slow, medium and high accelerations. We characterize those accelerations as "soft", "medium" and "hard". Velocity and acceleration were measured with a GPS-enabled accelerometer of 10 and 100 Hz the Minimax from Catapult Sports (Pty Ltd, Victoria, Australia). The GPS and accelerometer signals were sampled at 5 and 50 Hz, respectively, and averaged per second. The difference between the real distance (track) and the recorded distance (GPS) was less than 1% and 0.92% over 800 m and 1500 m, respectively. This result agrees with previous GPS studies for maximal efforts run by humans or horses [24,25].

2.3. Acceleration trials

In the self-paced acceleration trial protocol, the runners performed three freely paced acceleration sets in which they were asked to maintain constant acceleration by progressively increasing their speed until exhaustion. The trials were run at three constant acceleration values, based on ratings of perceived acceleration ("soft", "medium" and "hard"), in random order. In all of the self-paced acceleration trials, the runners started at an initial velocity between 2.2 and 3.05 m s^{-1} and then increased their velocity at three different, constant accelerations ("soft", "medium" and "hard" intensities). There was a one-hour interval between acceleration trials. In the self-paced acceleration trials set, the runners were not provided with any external information other than the distance covered. All tests were performed between 3 pm and 6 pm on wind-free, spring days (<2 m s^{-1} according to an anemometer, the Windwatch from Alba, Silva, Sweden) with a temperature of 20 °C, as in a previous study of the energetics of middle-distance running [26].