POWER OUTPUT IN RUNNING – ASSOCIATION WITH RUNNING SPEED, ALTITUDE AND HEART RATE

Ćuk Ivan[1,2]*,
Marković Srđan[1],
Denić Lazar[2]

[1]Faculty of Physical Education and Sports Management, Singidunum University, Belgrade, Serbia

[2]Lokomoto Center, Belgrade, Serbia

Abstract:

In endurance sports, monitoring power output is a relatively novel practice that allows endurance athletes to quantify the work they generate during running. Therefore, the first aim of this study is to analyze the power output in the running using an ordinary GPS watch. The second aim of this paper is to investigate associations between the running speed, altitude, heart rate, and power output. The participant (age 35, height 1.87m, weight 80kg) ran continuously on trail paths in a hilly terrain for 45 minutes while wearing Garmin Fenix 3 GPS watch. Heart rate showed an initial increase with a steady rate later in the run. Running speed and power output showed variations, mainly due to an altitude change. Altitude difference showed moderate and significant negative correlation with the running speed ($p < 0.05$), while a large and significant positive correlation was revealed between altitude difference and power output ($p < 0.01$). Both endurance runners and their coaches can use power output to observe running efficiency or assess the load on skeletal muscles, which cannot be achieved by monitoring heart rate or running speed. The presented analysis can help runners recover faster, thus running more often and achieving better results.

Keywords:

Endurance, Accelerometer, Runners, Training, Recovery.

INTRODUCTION

Power output was considered an essential predictor of sports efficiency [1]. The power output was usually assessed on a cycle ergometer to predict maximal anaerobic power or capacity [2] and test force or power-velocity relationship [3]. That way, power output was only crucial for speed and power athletes (e.g., sprinters, jumpers, football, or rugby players, [4]. Moreover, these assessments were almost exclusively performed in laboratories [2], [5], thus limiting the results' practical application.

In endurance sports, cyclists and their coaches first started to monitor power output in Watts (W) to improve efficiency in training and competition [2], [6]. That allowed them to quantify the output of the work they were generating. Contrary to the fans' desires, almost all cyclists rely on power output in their training and competitions.

Correspondence:
Ćuk Ivan

e-mail:
icuk@singidunum.ac.rs

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One of the most recent examples was noticed on the Tour de France several years ago. Namely, Chris Froome, one of the most successful cyclists in the past decade, was looking in his power-meter while cycling uphill. He did not pay any attention to his opponents sprinting in front of him. Eventually, he could catch up with all of them and win.

In other endurance sports, such as running, monitoring power output is a relatively novel practice that allows endurance runners to quantify the work they generate during running [5]. Power in Watts, generated by a running human, corresponds to an output of the work during some time. So far, runners and their coaches were relying mainly on monitoring heart rate or running speed to quantify training load. However, heart rate only shows the load of the cardiovascular system and not the muscular. In addition, when monitoring the heart rate, a delay of the human system is noticed. It takes several seconds while the cardiovascular system reacts to a change in running speed or an increase in the terrain slope [7]. The heart rate can also be affected by the time of day, anxiety, weather conditions, diet, hydration, and fatigue [8]–[10]. On the other hand, running speed does not provide information on how much effort your body puts in, only the result of that effort! For example, uneven terrain significantly affects running effort, which can not be quantified by monitoring running speed.

Conversely, power output can provide runners with "real-time" information on the running effort. Moreover, power can reflect the metabolic cost of runners' efforts and assess the load on skeletal muscles [2], [11]. With the recent development of light and accurate accelerometers (in the form of foot pods), power output in the running became simple to monitor. Foot-pod comprises a triaxial accelerometer, a gyroscope, and a barometer embedded into a small shoe-mounted chip. Different foot pods (e. g., RunScribe™, Stryd™, or Myotest™) estimate running power and measure distance, running speed, cadence, or ground contact time [12]. A recent study also showed the high reliability and validity of the StrydTM foot pod (www.stryd.com). [13]. However, foot pods can be rather expensive and not easily obtainable. One of the solutions to overcome this issue could be using post hoc analysis from data extracted from an ordinary GPS watch utilized by endurance runners worldwide (both professional and recreational).

Therefore, the first aim of this study is to present a post hoc analysis of the power output in the running using an ordinary GPS watch. The second aim of this paper is to analyze possible associations between the running speed, altitude, heart rate, and power output.

2. METHODS

For this study, Garmin Fenix 3 GPS watch was used (Garmin International, Inc., St. Olathe, KS, USA).

2.1. PARTICIPANTS

The analyzed participant was a recreational runner (see Table 1 for more information).

2.2. EXPERIMENTAL PROCEDURES

Before the run, participant height was measured by the Martin antropometer (±0.1 cm; Siber-Hegner, Switzerland). Weight and Body fat percentage was measured via InBody 720 (Biospace, Korea). Body mass index (BMI) was calculated as weight divided by height squared.

The participant ran continuously on trail paths in a hilly terrain for 45 minutes, covering 9,12 km. Besides wearing Garmin Fenix 3 GPS watch, he was also wearing a Garmin heart rate monitor over his chest. This run was considered as long, steady, and aerobic.

2.3. DATA ANALYSIS

Raw data were extracted using GoldenCheetah software (https://www.goldencheetah.org; Figure 1), while power output was calculated using Microsoft Office Excel 2007 (Microsoft Corporation, Redmond, WA, USA).

Figure 1 - An example of the data obtained with the GoldenCheetah software

Initially, several variables were extracted from the software to Microsoft Excel and presented in 1 Hertz (Hz), including running speed (m/s), altitude difference (m), and heart rate (bpm) used for further analysis.

For power output analysis, running velocity in meters per second (m/s) and altitude difference in meters (m) were considered. Variables were filtrated using a moving average filter with an interval of 25. Furthermore, work (ΔA) was calculated as a change of energy ΔE. Both potential (ΔEP) and kinetic energy (ΔEk) were considered. Therefore, ΔA was calculated as a sum of ΔEP and ΔEk using this formula:

$$m \times 9.81 \times \Delta h + \frac{1}{2} \times m \times v^2,$$

Equation 1 – The sum of potential and kinetic energy

where m represents runners mass in kilograms, Δh altitude difference in meters, and v velocity of the runners in m/s. Consecutively, power output in W was calculated as work over the period of time:

$$P = \frac{\Delta A}{\Delta t}$$

Equation 2 – Power output

Finally, power per kilogram of body mass was also calculated:

$$\frac{P}{kg}$$

Equation 3 – Power per kilogram

2.4. STATISTICAL ANALYSIS

Descriptive statistics were calculated as a mean and standard deviation. Pearson correlation coefficient was performed to assess the correlation between running speed, altitude difference, heart rate, and power output. All correlation coefficients were interpreted as small, r = 0.10–0.29; moderate, r = 0.30–0.49; and large, r = 0.50–1.0 [14]. The level of statistical significance was set at $p < 0.05$. All statistical tests were performed using Microsoft Office Excel 2007 (Microsoft Corporation, Redmond, WA, USA) and SPSS 20 (IBM, Armonk, NY, USA

3. RESULTS

Variable	Result
Years of age	35
Height (m)	1.873
Weight (kg)	80.0
BMI (kg/m^2)	22.8
Body fat percentage (%)	11.6
Running experience (years of age)	20
Maximum heart rate (bpm)	201
Anaerobic treshold (bpm)	180
Vo_2Max (ml/kg/min)	56

Table 1 – depicts basic anthropometric data and other essential data regarding the participant.

Distance	Running speed (m/s)		Altitude difference (m)		Heart rate (bpm)		Power (W)		Power per kg (W/kg)	
	Mean	St. Dev	Mean	St. Dev	Mean	St. Dev	Mean	St. Dev	Mean	St. Dev
1 km	3.157	0.964	0.344	3.118	140	8.75	207	31.3	2.591	0.391
2 km	3.342	1.445	-1.009	3.209	148	7.20	207	25.9	2.593	0.323
3 km	3.154	0.726	1.311	2.292	151	2.99	216	23.7	2.703	0.296
4 km	3.150	0.798	0.193	2.622	155	3.02	199	28.3	2.487	0.353
5 km	3.512	0.807	-1.225	1.958	158	1.02	228	39.1	2.850	0.489
6 km	3.219	0.397	1.430	3.502	161	0.91	220	19.0	2.756	0.237
7 km	3.470	0.820	0.373	2.825	163	0.98	244	35.1	3.053	0.439
8 km	3.422	0.597	-0.629	3.197	162	1.88	223	25.7	2.793	0.321
9 km	3.220	0.811	1.374	2.284	163	1.05	227	29.9	2.832	0.374
9.12 km	3.567	0.637	-3.636	2.719	163	0.98	190	25.2	2.380	0.315
Total	3.294	0.404	0.209	3.007	156	1.35	219	21.7	2.732	0.272

Table 2 – Results – obtained variables per kilometer and in total

Obtained variables of interest were presented in Table 2 as mean and standard deviation. Heart rate showed an initial increase with a steady rate later in the run. Since the running was performed on hilly terrain, running speed and power output showed variations, mainly due to an altitude change.

The variation of running speed and power output was further confirmed in Table 3. Namely, altitude difference showed moderate and significant negative correlation with the running speed ($p < 0.05$; see * in Table 3). Furthermore, a large and significant positive correlation was revealed between altitude difference and power per kg ($p < 0.01$; see ** in Table 3). Other than that, no further significant correlations were observed.

4. DISCUSSION

This study aims to present a post hoc analysis of power output in the running using an ordinary GPS watch. In addition, this study aims to analyze possible associations between the running speed, altitude, heart rate, and power output. The main finding of this study suggests that power output in the running can be calculated efficiently using the data extracted from an ordinary GPS watch. Furthermore, a large and significant positive correlation was shown between altitude difference and power per kg. In contrast, a moderate and significant negative correlation between the running speed and altitude was observed.

Although power output can be monitored in real-time with the foot-pod (see Introduction for more details), the results obtained from the GPS watch seem accurate and easy to obtain after the running is complete. It is shown (Table 2) that both running speed and

	Running speed (m/s)	Altitude difference (m)	Heart rate (bpm)	Power (W)	Power per kg (W/kg)
Running speed (m/s)	1				
Altitude difference (m)	-0.472*	1			
Heart rate (bpm)	0.357	-0.083	1		
Power (W)	0.328	0.297	0.159	1	
Power per kg (W/kg)	0.200	0.569**	0.224	0.341	1

Table 3 – Correlation matrix of the assessed variables

altitude fluctuate quite a lot in trail running. Contrary to that, the heart rate per kilometer showed an initial increase with a steady rate later in the run. Since this was considered a long, steady aerobic run, the runner adjusted his pace to be even according to the heart rate, not running speed. As a result, he was running in the aerobic zone. Even pacing proves the optimal strategy for long-distance running [15]. In particular, even pacing strategy might help runners achieve a faster race time, decrease the risk of musculoskeletal injuries, and increase the pleasure of running[16]. However, when running on the hilly terrain, there is a potential contradiction what is even pace? Is it even pace regarding the cardiovascular system (i.e., even heart rate), or even running speed? By monitoring power output, runners can also achieve an even pace for the muscular system.

Furthermore, only power output can help a runner monitor its efficiency. Running efficiency seems to be a "secret weapon" of successful long-distance runners [7]. In particular, running efficiency can also help recreational runners in the increasingly popular half-marathons and marathons [17], [18]. Conversely, running speed does not provide information regarding the effort runner's body puts in, only the outcome of that effort. Running on the hilly terrain, for example, can significantly affect running effort. The effect of the trail running was particularly noticed in Table 3., where power output per kg showed a large and significant correlation with the altitude. On the other hand, both power and power per kg showed a low correlation with the running speed and heart rate. As a result, power output in the running should be monitored separately.

Several limitations can be associated with this method:

1. Only one runner was considered for this study;
2. The runner's body mass is considered when calculating power output. Since the body mass can be reduced during the long run (mainly due to excessive sweat), this can affect power output results;
3. Wind can both increase and decrease running velocity, thus affecting power output; and
4. Finally, older models of GPS watches can be prone to navigation or altitude estimation errors.

5. CONCLUSION

In conclusion, this simple analysis can be used by both endurance runners and their coaches, mainly to observe running efficiency or assess the load on skeletal muscles, which cannot be achieved by monitoring heart rate or running speed. Regular monitoring of the power output in endurance running can help runners recover faster, thus running more often and achieving better results. Specifically, by observing power output and heart rate, runners can have insight into both muscle and cardiovascular stress. Therefore, they can plan their future training routine more accurately (i.e., maximizing intensity while reducing the risk of overtraining or injury). Finally, future studies might evaluate this method compared to the previously assessed methods (e.g., Stryd or Optogait).

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