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# RESEARCH THE RELATIONSHIP BETWEEN BODY WEIGHT, RUNNING POWER, AND RUNNING EFFECTIVENESS IN AMATEUR TRAINING

*Original scientific paper*

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**Abstract**

*The development and application of technology in sports make it possible to use various data taken from portable devices to analyze and optimize the training process. In recent decades, these technological devices have become more and more perfect, and to a large extent, the data collected from them are approaching validity to the measurements carried out in laboratory conditions. A large percentage of scientific research related to endurance running involves elite athletes, and insufficient research is related to amateur runners. In the last decade, Running Power has established itself as one of the most used variables for analyzing and manipulating the training of the runner. The present study used data captured by the Stryd device for Running Power (RP – W/kg) for a specific athlete engaged in running at the amateur level, tracking the relationship with indicators of body weight and so-called running effectiveness (Running Effectiveness – RE – speed/power ratio). The data of the athlete for 4 years were studied, using variation and correlation analysis for their processing. The results show that using Running Power data from a portable device can successfully manage the training process without having to access performance studies in laboratories.*

**Keywords*:*** *running power, running effectiveness, amateur running training*

**INTRODUCTION:**

In endurance sports to date, several physiological and biomechanical markers are related to performance. A trend in functional sports is to move research out of the lab and into the natural environment, with increasingly sophisticated portable devices. The power rating has been a part of cycling for over 3 decades (https://en.wikipedia.org/wiki/Cycling_power_meter).

The revolutionary Cycling Power meter technology was adapted for bicycles in the late 1980s (Taboga, Giovanelli, Spinazzè, Cuzzolin, Fedele, Zanuso & Lazzer, 2021). This is plenty of time to develop an understanding of power, as data is used for quite a few purposes today – race pace, training, post-race analysis, and even measuring energy input ("kJ burned"), where 1kJ of work is usually used for convenience (1W = 1 J/s) equates to 1kCal. Simply put, mechanical power (P), measured in watts (W), is the variable that indicates the rate at which work is done (Olaya-Cuartero & Cejuela, 2020). In cycling, the potential for force dissipation is small as the devices are usually built into some part of the bike where the body exerts direct pressure (e.g. the pedals). As for running power, the data is not obtained directly from a power meter, as in cycling, but is estimated by a complex calculation from various mathematical formulas.
In this sense, it is still an open question to what extent the measurement of running power using portable devices is an adequate marker. Given the increased popularity of running power measurement devices, scientists, coaches, professional athletes, and amateurs should be aware that data from some of these devices are reliable enough as research shows but not yet interchangeable enough with the laboratory ones.

Concepts from cycling but applied to running became available in early 2015 when the first product to measure various metrics related to power and running efficiency appeared – Stryd, went public.
That same year, a Garmin sports watch model went public as the first from a major brand to have both GPS and a heart rate monitor. Heart rate is known to be a widely applicable and accessible metric in endurance sports, and Running Power currently remains more of a niche for tech-savvy users. However, in recent years all major sports watch brands seem to have their version of Running Power, but the Stryd device can be considered the most recommended for measuring running power compared to other devices available (Cerezuela-Espejo, Hernández-Belmonte, Courel-Ibáñez, Conesa-Ros, Mora-Rodríguez & Pallarés, 2020).
It seems that there is still no single definition of what running power is. Garmin and Polar have two different types of "mechanical power" (which is modeled against power platform measurements), and the other brands have values comparable to Stryd, which is modelled against oxygen consumption.
A 2018 study found that running power calculated by the Stryd Power Meter was not sufficiently accurate as a proxy for metabolic demand, particularly in the elite population. However, in a recreational population, this training tool may be useful for feedback on several running dynamics known to influence the running economy (Aubry, Power & Burr, 2018).
The biomechanical metrics of running performance that Stryd measures are largely validated. The generated forces can be calculated to estimate the power output when running in a

natural environment through algorithms and incorporating the runner's body weight. They use a temporal patterns algorithm in triaxial accelerometry, taking into account spatiotemporal parameters, velocity, and slope, temperature, air pressure, and others (García-Pinillos, et al., 2021).

A study compared running power as the dot product of ground reaction force and velocity of the body's center of mass and compared them to running power from three devices – Skillrun

(Technogym), Stryd Summit Powermeter (Stryd) and Garmin HRM-Run (Garmin), (Taboga, Giovanelli, Spinazzè, Cuzzolin, Fedele, Zanuso & Lazzer, 2021). Statistically significant linear correlations with power were found for all devices.

Another study compared five different outdoor versions and four indoor versions of running power, including – Stryd (Stryd Summit Powermeter, firmware 1.2). Concurrent validity analysis showed running power by Stryd was rated highest and showed the closest relationship with VO2 directly measured by metabolic rate (Cerezuela-Espejo, Hernández-Belmonte, Courel-Ibáñez, Conesa-Ros, Mora-Rodríguez & Pallarés, 2020).

The subject of this case study is a mid-30s amateur runner who has a 3-year data set, using primary Stryd v3 (Wind, Sv3) and recently upgraded to Stryd v4 (Next Gen, Sv4), starting from the 24th of December 2022. While there appears to be some fine difference between the data of the two, both Sv3 and Sv4 add the missing piece of the running power puzzle, which plagues both studies mentioned above – the effect of wind and air resistance on our metabolic cost. The analysis in this report will focus on raw power numbers at 5k runs, with the bonus that the majority of these runs are done during Saturday flat park runs (around a rowing channel), the distance being guaranteed to be precisely 5000m and timing being provided by the organizers (from 5kmrun.bg).

At this point he is a 19-minute 5k runner (at 84 kg), which assuming that Stryd's Running Power and Cycling Power are largely the same equals to around 390W 19 min power, or 5k with energy consumption of 23 kcal/min (or O2 consumption of ~4.7 l//min, or ~56 ml/min/kg, at 5k intensity).

*calculated using 1W=1 Cal/s; 100W/min = 6 kCal/min; 83W for a minute = 1 l/min O2.

As the test subject is the co-author of the study he made all of his data public, so the raw table will be available with the activities through the Strava website
(https://www.strava.com/athletes/31372810/training/log),
Stryd Powercenter, and Garmin Connect, as well as his profile in straffo.app site
(https://strafo.app/athletes/31372810). The datasheet with the races we prepared includes links to the activity in question in all 3 platforms - Strava, Garmin Connect, and Stryd Powercenter, whenever available.

Along with race/training run power data, there is weight data for about 80-90% of the days, measured in the morning. Weight is measured via Garmin Index scale and automatically recorded in Garmin Connect. The scale provides values for Muscle Mass, Fat Percentage, etc, which go beyond the scope of this study.

The main purpose of this study is to put through the scientific rigor concepts and understandings used by the running with power community. It's part of a series we are starting in an attempt to close the gap between Running and Cycling/enthusiasts and science studies, through further clarifying the concepts of Running Power and Critical Power/FTP.

**METHODS**

Study has been used for all runs since his v3 unit arrived in September 2019. There is a regular 5k park run that happens to be on a flat course, timing and distance are covered by the organizers, he is more or less regular, with some 5k runs in other locations, which totals 129 5k runs available for analysis.

Garmin Index scale has been used since mid-June 2019 for all days when the athlete runs, and weight is measured second thing in the morning. The results of the scale measurements are auto-uploaded to Garmin Connect (Chart 1).

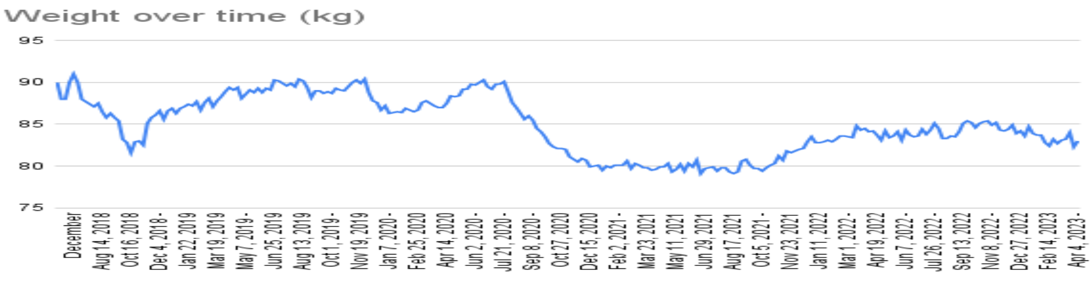


*Chart 1. Weight Overtime*

One well-known factor for athletic performance is resting heart rate, data for it is available for almost 5 years (Chart 2.).

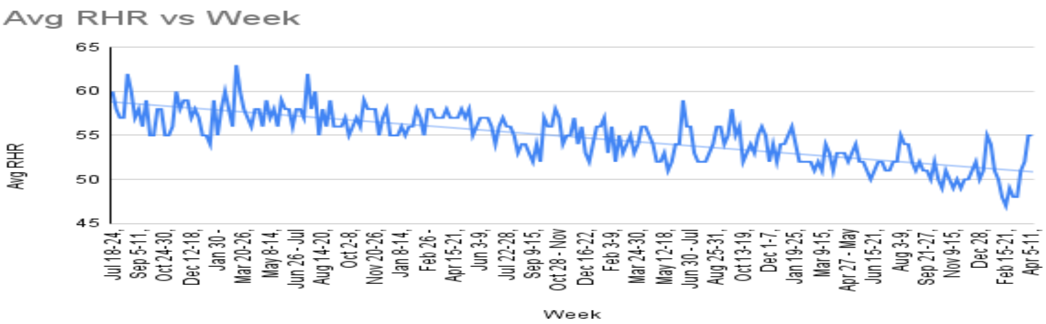


*Chart 2: Resting Heart Rate over time*

We are looking into whether the raw Watts number properly represents the improvements in running performance, regardless of the fairly big (and expected for amateurs) range of weights (79 – 91 kg) in this timeframe, just like absolute VO2 (in l/min) would indicate improvements in metabolic abilities, despite similar or worse per kg values (due to extra weight).

Since the total set of 129 runs has all kinds of noise (non-races, other tracks, etc) we picked 30 runs in the same location, with finish times between 19 and 23 minutes and no overly optimistic starts, ending up in walking. To make matters worse, Stryd v3 and Stryd v4 are used and there appears to be a small, but not insignificant, difference between the two models, so the focus is only on the data from Stryd v3, where 20 such runs are available. For Stryd v4 we only have 10 runs matching this criteria, so we will wait for a bit more data to be collected and publish it separately.

**Running Effectiveness** is gaining popularity in coaching circles. It was introduced by Andrew Coggan in favor of software for planning, tracking, and analyzing the training and competition process in functional sports (https://www.trainingpeaks.com/blog/wko4-new-metrics-for-running-with-power).

Running effectiveness is calculated as the ratio of speed (in m/s) to power (in W/kg, or (Nm/s)/kg), resulting in the units of kg/N. It can be viewed as the inverse of the effective horizontal retarding force that a runner must overcome to achieve a particular speed. For most experienced runners, running effectiveness is typically close to 1 kg/N. Running effectiveness may be lower in novice or fatigued runners since they do not travel as fast for a given power output or must generate more power to achieve the same speed (https://www.trainingpeaks.com/blog/wko4-new-metrics-for-running-with-power).

The Stryd power meter is a pioneer in the field and provides the following measures in real-time: pace, running power output (PO), vertical oscillation, elevation, distance, ground contact time (GCT), and leg spring stiffness (LSS), (Imbach, Candau, Chailan & Perrey, 2020).

Since this metric does not appear to have been used in studies thus far, we also want to shed more light on how important this parameter is and to figure out the correlation it has with the statistics reported by Stryd – maybe there is an easier way to get a general idea whether someone's running effectiveness has room for improvement, or not…

Many of the runs of our athletes are done with Nike Tempo Next % or Nike Vaporfly shoes which have issues with Stryd placement, sometimes the Air Power is underreported. Furthermore, all runs after the 24th of December 2022 are with Stryd v4 (and all prior – with v3) and one of the differences appears to be slightly higher air power in Sv4 (but there are others, which we have yet to fully understand), this is why we are sticking to Sv3 data – only. Since some runs have problematic Air Power readings (2%, where 4% would have been expected) we are adding Wind-Free power and Wind-Free Running Effectiveness, thus comparing against Running Effectiveness for Stryd v2, the version of Stryd that does not report air power.

To convert the Power (W/kg) and RE (kg/N) to Wind-free we are subtracting the Air Power percentage from the total power number, then comparing it to the m/s value. While Steve's notes indicate that RE should be compared at CP/FTP, 19–23-minute efforts are close enough to use his ranges as a general guide:

***Non-wind pod:***

*Outstanding to elite level >= 1.01*
*Above average 0.98 - 1.00*
*Average 0.95 - 0.97*
*Below average <= 0.94*

## RESULTS AND DISCUSSION

For the research, the data were processed with the statistical software IBM "SPSS Statistics" (Version 29).

A Analysis of variance of the processed results for 20/5 km runs, for 14 variables related to performance and running efficiency, is presented in tabular form (Table 1.).

The strength and direction of interaction between indicators are summarized by correlation analysis (Table 2.). There is a very strong correlation (0.97) between FP and VO, VR and cadence (-0.92), cadence correlates with almost all the indicators studied, Avg power as well.

Another issue is that the data we have without "noise" is organized up to 20 for each metric.

*Table 1. Analysis of variance of the distribution of variables*

| | n | X min | X max | R | $\overline{X}$ | S | V | As | Ex |
|---|---|---|---|---|---|---|---|---|---|
| **5 km run (sec)** | 20 | 1156 | 1378 | 222 | 1264,6 | 69 | 5,46 | -0,08 | -1,19 |
| **Avg HR (bpm)** | 20 | 161 | 185 | 24 | 174,8 | 5,98 | 3,42 | -0,43 | 0,33 |
| **Max HR (bpm)** | 20 | 172 | 203 | 31 | 192,1 | 6,92 | 3,60 | -1,18 | 2,76 |
| **Avg Power (W)** | 20 | 310 | 378 | 68 | 338,1 | 20,6 | 6,09 | 0,45 | -0,84 |
| **Weight (kg)** | 20 | 79,1 | 88,3 | 9,2 | 82,1 | 2,79 | 3,40 | 1,03 | -0,05 |
| **Cadence (steps/min)** | 20 | 179 | 197 | 18 | 188,7 | 5,81 | 3,07 | -0,41 | -1,18 |
| **Ground contact time (ms)** | 20 | 201 | 226 | 25 | 210,7 | 6,8 | 3,28 | 0,24 | -0,76 |
| **Vertical oscillation (sm)** | 20 | 1,54 | 7,32 | 1,54 | 6,42 | 0,48 | 7,48 | 0,29 | -1,16 |
| **Stride length (m)** | 20 | 1,17 | 1,36 | 0,19 | 1,26 | 0,06 | 4,76 | 0,40 | -0,98 |
| **Running effectiveness (kg/N)** | 20 | 0,936 | 0,980 | 0,044 | 0,96 | 0,01 | 1,04 | -0,23 | -0,46 |
| **Vertical ratio (Vo/Sl%)** | 20 | 4,60 | 5,84 | 1,24 | 5,10 | 0,39 | 7,65 | 0,58 | -0,95 |
| **Wind-free RE (kg/N)** | 20 | 0,965 | 1,007 | 0,042 | 0,99 | 0,01 | 1,01 | -0,39 | 0,02 |
| **Leg spring stiffness (kN/m/kg)** | 20 | 0,149 | 0,173 | 0,024 | 0,150 | 0,006 | 3,77 | 0,383 | 0,849 |
| **Form power (W/kg)** | 20 | 0,94 | 1,04 | 0,1 | 0,99 | 0,02 | 2,32 | 0,02 | -1,1 |

Note: The critical skewness and kurtosis values at n=20 and α=0.05 are equal to 1.024 and 1.985.

*Table 2. Strength and direction of the relationship between variables.*
*Simple linear Pearson correlation*

| | 5 km run (sec) | Avg HR (bpm) | Max HR (bpm) | Avg Power (W) | Weight (kg) | Cadence (steps/min) | Ground contact time (ms) | Vertical oscillation (sm) | Stride length (m) | Running effectiveness (kg/N) | Vertical ratio (Vo/Sl%) | Find-free RE (kg/N) | Leg spring stiffness (kN/m/kg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **5 km run (sec)** | 1 | | | | | | | | | | | | |
| **Avg HR (bpm)** | 0,21 | 1 | | | | | | | | | | | |
| **Max HR (bpm)** | 0,17 | 0,76 | 1 | | | | | | | | | | |
| **Avg Power (W)** | -0,82 | -0,12 | -0,31 | 1 | | | | | | | | | |
| **Weight (kg)** | -0,03 | 0,05 | -0,41 | 0,50 | 1 | | | | | | | | |
| **Cadence (steps/min)** | -0,56 | -0,00 | -0,12 | 0,34 | 0,15 | 1 | | | | | | | |
| **Ground contact time (ms)** | 0,90 | 0,1 | -0,04 | -0,58 | 0,21 | -0,7 | 1 | | | | | | |
| **Vertical oscillation (sm)** | 0,33 | -0,07 | 0,15 | -0,21 | -0,29 | -0,95 | 0,46 | 1 | | | | | |
| **Stride length (m)** | -0,82 | -0,26 | -0,13 | 0,76 | -0,05 | -0,02 | -0,59 | 0,26 | 1 | | | | |
| **Running effectiveness (kg/N)** | -0,32 | 0,12 | 0,01 | 0,20 | 0,35 | 0,65 | -0,31 | -0,67 | -0,07 | 1 | | | |
| **Vertical ratio (Vo/Sl%)** | 0,80 | 0,08 | 0,21 | -0,65 | -0,25 | -0,92 | 0,8 | 0,82 | -0,34 | -0,63 | 1 | | |
| **Wind-free RE (kg/N)** | -0,61 | 0,02 | -0,23 | 0,52 | -0,31 | 0,86 | -0,6 | -0,82 | 0,13 | 0,67 | -0,88 | 1 | |
| **Leg spring stiffness (kN/m/kg)** | 0,36 | 0,27 | 0,40 | -0,61 | -0,51 | 0,10 | -0,04 | -0,1 | -0,53 | -0,15 | 0,21 | -0,13 | 1 |
| **Form power (W/kg)** | 0,16 | -0,07 | 0,19 | -0,09 | -0,36 | -0,87 | 0,26 | 0,97 | 0,41 | -0,64 | 0,70 | -0,73 | -0,07 |

*Note: The critical value of Pearson's Coefficient at n=20 and α=0.05 is equal to 0.42*

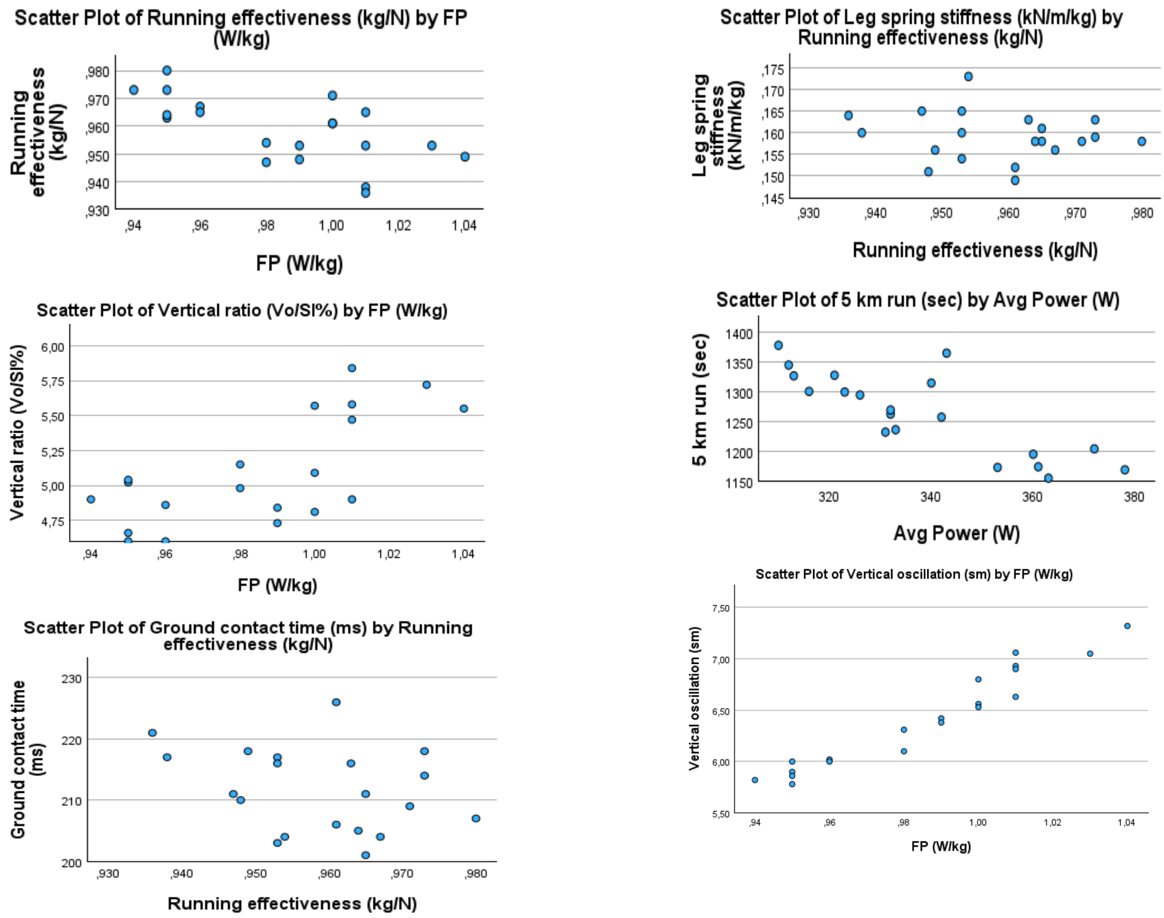


*Figure 1. Correlation between different indicators: a) form power/running effectiveness; b) form power/vertical ratio; c) running effectiveness/ground contact time; d) running effectiveness/leg spring stiffness; e) avg power/5 km run; f) form power/vertical oscillation*

Figure 1. presents correlation diagrams between some of the variables studied.

Since it all becomes too complex and conceptual, let‘s illustrate with 2 sub-maximal runs with good and bad Running effectiveness values (Table 3.):

2021/02/27: 80kg, 321W (4.01W/kg, 3.77m/s), 4:26 min/km (22:06)

2022/02/26: 83kg, 342W (4.12W/kg, 3,97m/s), 4:12 min/km (20:58)

The Running Dynamics not only differ between runs but generally differ in parts of the run, as an illustration, 2022, Jan 08, PowerCenter ID: 5084339551371264 and check it per 1km splits.

Example: the effect of ~4% RE on someone’s 5k time, swapping the combinations:

- 3.89 W/kg (WF) with 0.967 RE is 3.77 m/s or 22:06, but with improved RE to 1.005 it will be 3.91m/s (4:16 min/km), almost 10 sec/km faster for the same power, thus this person’s 5k finish time is expected to be 21:18.
- 3.96 W/kg (WF) with 1.005 RE is 3.97 m/s or 20:58, but with worsened RE to 0.967 it will be 3.83 m/s (4:21 min/km, or 9 seconds slower for the same power), thus the expected 5k finish time becomes 21:45.

Note that according to Steve Palladino’s nomenclature for WF Running Effectiveness - 0.967 is upper Average and 1.005 is borderline Elite. In reality, RE numbers as low as 0.94 (or lower) may show up.

In the case of RE = 0.94 and 3.89 W/kg (WF power) (first run), we end up with 3.66m/s or 4:33 min/km (7 sec/km slower) or 22:46 min for 5k (against 22:06 for RE = 0.967).

Thus the range from Below Average to (almost) Outstanding is 4:16 min/km to 4:33 min/km or 21:18 to 22:46 5k time, which is a quite significant gap, especially if your RE is on the lower end of the spectrum. This is only to point out how important monitoring and working on your running form is.

*Table 3. *WF = Wind-Free, there is also a small difference in air power (3% vs 4%, this is why we compare Wind-Free Running Effectiveness)*

| Date | m/s | W/kg | WF* (W/kg) | WF* RE | Cad (spm) | FP W/kg | VO (cm) | VR (%) | GCT (ms ) | FPR (%) | LSS (kg) | SL (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2021/02/27 | 3.77 | 4.01 | 3.89 | 0.967 | 182 | 1.01 | 6.93 | 5.58 | 217 | 25.23 | 0.160 | 1.24 |
| 2022/02/26 | 3.97 | 4.12 | 3.96 | 1.005 | 193 | 0.96 | 6 | 4.86 | 211 | 23.39 | 0.158 | 1.24 |

There are things, which do not meet the qualifications for publishing, but are worth mentioning:

The distance from Stryd is generally very stable if you do not have different gait patterns and use the same shoes. There are reports (including some data in this dataset), where calibrated Stryd is misreporting the distance (one of the reasons we rely on the race distance of 5000m, which is validated by the organizers). To solve this we need to have the exact Calibration Factor for each run, but this does not appear to be logged anywhere. Neither is reported if the distance came from the foot pod or GPS.

Besides Running Effectiveness, Steve Palladino's article mentions Horizontal Power Ratio (which is 100% – Form Power Ratio), (https://www.trainingpeaks.com/blog/running-effectiveness-versus-speed-using-wko4, https://shorturl.at/atFN3).

HPR = 76-78% is near average

HPR = <76% is below average

HPR = >78% is good

HPR = >80% is likely the realm of elite world-class runners

Our observations are that generally Form Power resides around 0.92-1.1W/kg at any pace on flat runs (might have bigger or smaller numbers). At ~4-4.5W/kg runs it is possible to cover the full range above, but for runs at 5-6W/kg even 20% Form Power might be too much and suggest room for improvement.

The highest RE for faster paces (which are Critical Power for elite runners), the athlete of the research has managed to get an HPR of 85 at 2:37 min/km and 82 at 3:00 min/km with Vertical Oscillation (VO), which is much smaller than the VO reported for world-class runners (Table 3), (Jones, Kirby, Clark, Rice, Fulkerson, Wylie, Wilkerson, Vanhatalo & Wilkins, 2021). It is unclear how they measured Vertical Oscillation and whether the number can be compared with Stryd's, which tends to underestimate the value (Smith, Fullerton, Walton, Funnell, Pantazis & Lugo, 2022). In all cases, the Form Power remains 1W/kg +/- 0.1W/kg.

This suggests that we need to repeat the same study with a much bigger dataset, covering a variety of runners and abilities to better set the reference ranges for different speeds, rather than have just one set of numbers, which is supposed to be valid from 30 min 5k runner till sub 13 5000m runner. With the current data Form Power in W/kg seems to be a more stable target, compared to Form Power Ratio.

**CONCLUSIONS**

The scientific literature is still searching for a proper understanding of the concept of running power.

The application of mechanical load (i.e. extrinsic training load factors) and psychological and physiological effort (i.e. internal training load factors) are affected by training stress. In running, some extrinsic load factors, including intensity and pace, are widely used, while physiological intrinsic load factors account for scales of perceived exertion, heart rate, or blood lactate level (Paquette, Napier, Willy & Stellingwerff, 2020). Duration and intensity of exercise are easily measurable, but numerous other factors also cause stress – terrain incline, wind speed, and individual internal factors (sleep, emotional and health status, etc.).

Wearable device manufacturers detail the various parameters that provide load data for the benefit of sports activity monitoring.

In recent years, inertial measurement units (IMUs) have emerged that allow quantification of performance, providing coaches and athletes with an easy-to-use tool to monitor PW during running (Jaén-Carrillo, Roche-Seruendo, Cartón-Llorente, Ramírez-Campillo & García-Pinillos, 2020).

Advances in the knowledge of PW running endurance will allow the assessment and monitoring of power not only in the laboratory but also in field settings.

Running power is a good metric for pacing and assuming your weight setting is somewhat correct – to show improvements in your absolute abilities, regardless of what your weight is. Running Effectiveness is a very important piece of the puzzle, but as of today it generally needs to be calculated manually or using third-party platforms/software (such as RunAnalyze or WKO). Contrary to our expectations, the data analysis suggests that Leg Spring Stiffness does not affect Running Effectiveness, nor does Stride Length or Ground Contact Ratio.

Ground Contact Time is not well correlated with Running Effectiveness, and neither is running pace (for 19 runs in range 4:36 to 3:51 min/km), for this range.

The best correlation with Running Effectiveness (RE) comes from Vertical Ratio (VR) ($R^2$ = 0.77) and Cadence ($R^2$ = 0.748). The correlation between the two (0.773) is worse than the correlation between Cadence and Vertical Oscillation ($R^2$ = 0.908).

Primary data for a variety of speeds suggest that we need different ranges of Form Power Ratio for different speeds and at this point – the Form Power (in W/kg) appears to be a better first glance factor whether Running Effectiveness improvements are there for the grabs.

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