Original Article

Detection of physical efficiency in footballers using a GPS 50 Hz and K4 Metabolimeter: a deeper understanding and literature review of metabolic power

CIRO HOSSEINI VARDE'I¹, ANTONIO CEJUDO², SAINZ DE BARANDA PILAR², GAETANO RAIOLA³, AND RICCARDO IZZO^{1,2}

1-Department of Biomolecular Sciences, School of Sport Science, Exercise and Health, University of Urbino Carlo Bo, Urbino, PU, 61029, ITALY

2-Grupo de Investigación Aparato Locomotor y Deporte. Departamento de Actividad Física y Deporte. Facultad de Ciencias del Deporte. Campus de Excelencia Mare Nostrum. Universidad de Murcia (ESPAÑA).

3-University of Salerno, ITALY.

Performed by ARGS, Advanced Research Group in Sport, School of Health and Sport Science DISB, Urbino University (IT) with K-Sport Universal-STATS, ITALY

Published online: September 30, 2020

(Accepted for publication: September 22, 2020)

DOI:10.7752/jpes.2020.05364

Abstract

The aim of this paper was to analyze the internal load of footballers, comparing the metabolic power (MP) approach by Osgnach and Di Prampero, derived from the external load detected using GPS or video tracking system, with the real metabolic effort gained with a portable metabolimeter used as a gold standard. Two different protocols were used. First protocol was performed on 20 amateur footballers from 7th Italian League (Age: $27,3 \pm 3,3$, eight: $1,77 \pm 3,4$ and weight: $80 \pm 4,5$). Subjects were running 10 minutes with two different velocities, 8 km/h and at 16 km/h (5 minutes for both) and have a 5 minutes pause between them. The type of running was circular asking the players to maintain the velocity without any changes of speed or direction; during the test, the players were analyzed using a 50Hz GPS (K-Sport Universal, Italia) and a portable metabolimeter, Cosmed K4 b2. The second protocol was performed by 20 semi-professional football players (Age: $26,3 \pm 3,6$, eight: $1,78 \pm 4,5$ and weight $77 \pm 4,3$) from a football team of 4th Italian Championship league. The change of the sample was important in order to investigate the possible differences that can be recorded between amateur and semi-professional athletes. The test protocol included 6 parts (18 minutes) inside which 2 recovery periods, one at the beginning of the test in order to evaluate the individual basal metabolism and one at the end of the test to determine the recovery time. Osgnach's MP approach results to be an invalid method for deriving the internal load of the athletes because individual physiological differences make it impossible to accurately estimate the real energy expenditure of each individual with the simple use of a pre-built formula. Another critical point of Osgnach's method is based on the formulas of Minetti et al. (2002) which were derived from a study carried out on cross-country athletes. In order to detect the true energy expenditure provided by the aerobic mechanism during training or competitions, will be necessary to integrate a respiratory rate sensor into the GPS shirts. Analysis of the player performance model (PPM) during training and match, result to be crucial to determine the performance of teams and individual players, to create specific training.

Keywords: performance analysis, metabolic power, cosmed k4 b2, GPS 50Hz, physical efficiency

Introduction

Nowadays the knowledge of the specific performance model has been placed at the base of the training protocol. Coaches, fitness trainers, and sports scientists, have to analyse, study, and after organizing the new researches, in order to plan the training program in a proper way. It is important to define that the player's performance model (PPM), has always to be updated, and varies from sport to sport, and from countries, championships, and tournaments too. In order to organize a work plan properly, it's necessary to know the real demands imposed by different sport competitions^[1]. Therefore, the knowledge of the stresses imposed by the competition and the potential quality of the athletes is of extreme importance for the definition of a project useful for the correct administration of specific workloads.

The evolution of technology applied to sport and the use of a statistical analytical system for the study of competitions and training has started to create new reference figures, that is, the Match Analyst. It is possible to define match analysis as the method of data collection that, through scientific and statistical investigation, allows to evaluate objectively, the physical and technical-tactical performance of the single athlete and the whole team; the match analysis can represent the keystone that, based on real objective data collecting, can provide the

correct parameter to a winning strategy, evidence-based, for the technical operators. Reilly and Thomas (1976) described a football competition counting the number of steps taken for each movement performed by the players (walking, running, and shooting) that could be considered one of the pioneering studies^[2]. From that starting point, the match analysis has undergone significant changes, through the notational analysis (notational analysis, which can be manual or computerized), motion analysis (which analyzes the activity and movements of athletes), and video analysis (it is practically realized with the installation of automated cameras systems inside the stadiums). Thanks to these new technologies during years were executed several studies, that took into consideration the distances traveled and the movements of the players on the pitch (Di Salvo et al, 2006^[3] and Rampinini et al., 2007^[4]). In 2010 (Osgnach et al. 2010) was proposed a new method to analyze the PPM during matches and training, this was a turning point for many sports' scientist involved in the evolution of performance analysis in soccer^[5]. Osgnach proposes a new analytic approach to football performance introducing the concept of Metabolic Power using a theoretical model introduced from Di Prampero. The model proposed by Di Prampero^[6] (2005) derived from the energy cost equation from Minetti^[7] et al. (2002), and later reworked by Osgnach (2010), although it has found numerous successes in the analysis of sports performance, it has numerous limitations and inaccuracies, as stated by the authors themselves:

- The overall mass of the runner is assumed to be located at the center of mass of the body. As such, any possible effects of the motion of the limb on the energetics of running were neglected. This is tantamount to assume that the energy expenditure associated with internal work is the same during uphill running such as during sprint running at an equal ES. This is probably not correct, because the frequency of motion is larger during sprint than during uphill running. If this is the case, the values obtained in this study represent a minimal value of the EC (energy cost) or metabolic power during the match.
- For inclines greater than +0.45, there are no data on the EC of uphill running. In this study, were not observe acceleration greater than 5 ms^{-2} , corresponding to $ES = +0.50$.

During the last few years, some studies (Stevens^[8] et al. 2014, Buchheit^[9] et al. 2015 and Robertson^[10] et al. 2016) were trying to investigate the efficiency of the MP method, using different analysis protocols comparing GPS or video-tracking output with metabolimeter detection. Stevens shows that for shuttle running, the estimated energy cost was significantly lower (13% to 16%) than the measured energy cost with K4 and for constant running, the estimated energy cost was significantly higher (6%–11%) than measured with the cited golden standard. It is important to notice that this test was performed in amateur football players. Another important study on MP was built by Buchheit (2015), they start from the assumption that the study by Stevens couldn't be considered representative enough for soccer practice, due to the fact that players did not have to use any specific technique such as passing or shooting the ball, otherwise the protocol didn't include rest periods, but the comparisons were performed during shuttle runs and continuous running. Results show that the MP method tended to very largely underestimate the actual net metabolic demands especially during the resting phases (that was 0 during resting phases for GPS measurement) and there was only a small correlation between locomotor-related metabolic power and actual net metabolic demands, with a moderate typical error of the estimate. Robertson's results (2016) revealed that the GPS metabolic power model was unable to accurately estimate MP during walking (a very large overestimation) or intermittent movement patterns that are typical of field sports (a very large underestimation). However, the GPS derived MP estimation was reasonably accurate during jogging and running.

Means and Methods

The aim of this study was to investigate through an analysis protocol the differences between MP values detected through K4 COSMED b2 (Golden Standard) and the one obtained by indirect calculation of GPS 50Hz (K-Sport Universal, Montelabbate, Italy). The idea of the project derives from a profound analysis of the specific literature, which showed the numerous inaccuracies of the theoretical model of the MP. The main critic points we try to underline and criticize are:

- The whole theory is based on the formula of Minetti et al. which investigates the energy consumption of the uphill race, but the study was developed by analyzing 10 elite athletes practicing endurance mountain racing, a sport that has a PPM rather different from footballers. Therefore, the formulas obtained are influenced by the physiological peculiarities of the athletes analyzed, which are very different from those of soccer;
- The formula does not take into account individual differences but refers to an average which obviously cannot be applied correctly to everyone, as also demonstrated in the studies listed above;
- The fitness level of the athletes, the weight, height, age, or sex (gender) of the subjects to be tested is not taken into consideration, a subject with little training, will need more oxygen to perform a certain intensity when compared to professional athletes, while in the theoretical model every human being is defined in the same way;

- The GPS obtains MP data through the displacements, therefore during the stopping phases, it does not record energetic expenditure, while in the physiological field using a metabolimeter it is possible to analyze the respiratory drift in post-exercise.

In the development of the two protocols, was used the GPS device K-Sport 50Hz (Montelabbate, Italy) and a COSMED K4 b2 portable metabolimeter, breath by breath, by COSMED (Rome, Italy), validated by McLaughlin^[11] et al. (2001). The analyzed subjects have to wear a "Hans-Rudolph" facemask with unidirectional valves and a special harness. The data, directly stored in the detection unit memory, are then transferred to the PC and analyzed using the special "Cosmed 7.0" software. Two different protocols were proposed to 20 amateur footballers from 7th Italian League (Age: $27,3 \pm 3,3$, eight: $1,77 \pm 3,4$ and weight: $80 \pm 4,5$).

The first protocol was structured, subjects had to run at 2 different velocities, 8 Km/h and at 16 Km/h, 5 minutes for both, and performing a 5 minutes pause between the two runs. Tests were performed in 3 different days in a natural grass football pitch. The type of running was circular, asking players to maintain the velocity without performing any changes of speed or direction, following some cones placed around the route. The second protocol was used in order to better define and investigate differences between MP calculated from GPS (external load) and MP from K4 (internal load), we introduced two resting periods following the idea by Buchheit et al. (2015) and using a different sample, 20 semi-professional football players (Age: $26,3 \pm 3,6$, eight: $1,78 \pm 4,5$ and weight $77 \pm 4,3$) from a football team of 4th Italian Championship league. Changing the sample was important to investigate the possible differences that can be recorded between amateur and semi-professional athletes. The test protocol was so composed: Basal Metabolism (BM) 3 minutes, analyze athlete during resting phase was useful to define the individual differences of basal metabolism, 6 Km/h Jogging: 3 minutes, 12 Km/h Running: 3 minutes; 16 Km/h Running at High Intensity: 3 minutes, Non-constant Running (NC): 3 minutes of free accelerations and decelerations and Recovery Phase (RC) 3 minutes post-exercise recovery to analyze the necessary time to come back to the initial pre-exercise conditions.

The total time of each test was 18 minutes per subject. Tests were performed around a natural football field, in 3 different days, the type of running was circular and players were asked to maintain the velocity without performing any changes of speed or direction (for the first 3 steps of the test) and for the last step, athletes were left free to accelerate and decelerate at individual will, to help running were accommodated some marks (cones) around the route. Data from K4 and GPS were at first analyzed separately with the use of the specific software, and after collected in an Excel Spreadsheet to build a pivotal table, to organize and better analyze data, Average, Standard Deviation (SD), and Standard Error (SE) were calculated. In order to obtain the MP from K4 data, the VO₂ was divided for 2,85 as reported in Osgnach et al. (2010), using this formula $K4-MP = VO_2/2,85$. The correlation coefficient (r) and Cohen's effect size (d) were calculated between the results of K4-MP and GPS-MP for all types of comparisons. Cohen's effect size (d) was interpreted as small ($>0.2 - 0.6$), moderate ($>0.6 - 1.2$), large ($>1.2 - 2.0$), very large ($>2.0 - 4.0$)^[12]. In both tests, have been using the same hardware 5 GPS 50 Hz (K-Sport Universal, Montelabbate, Italy) and one K4 b2 (Cosmed, Roma, Italy), and the velocity was live monitored with the use of specific software (K-Fitness) and live wireless antenna.

Data Analysis

The aim of this research was to compare the MP theoretical method approach by Osgnach et al. (2010) with a golden standard, using a portable metabolimeter to analyze VO₂ and MP values during a different type of running at a different velocity using two different protocols. The first protocol was performed by 20 amateur football players, which performed a 15 minutes test, this made: a standard warm-up, 5 minutes of circular constant running at 8 Km/h, 5 minutes of resting, and 5 minutes of circular constant running at 16 Km/h. The Efficiency percentage (E) was calculated, in order to understand the differences between internal effort (K4-MP) detected with the K4 b2 and external effort (GPS-MP) with GPS, the used formula was $E = \{[(GPS-MP - K4MP) / (GPS-MP)] * 100\}$. Table 1 shows data from the first part of the test, 8 km/h MP comparison, 10 players registered a positive comparison that means that the data from GPS were overestimating the internal load, the players were more efficient, 6 players registered a negative comparison this means that data from GPS were underestimating the internal load and 4 players registered neutral comparisons that mean that were not significant differences between GPS-MP and K4-MP.

The average data recorded for 8 Km/h test were: GPS-VO₂ $29,98 \pm 1,21$ ml/kg/min (0,27 SE), K4-VO₂ $29,99 \pm 2,38$ (0,53 SE), GPS-MP $10,52 \pm 0,42$ W/kg (0,09 SE), K4-MP $10,52 \pm 0,84$ (0,19 SE) and the E 75% . In the 8 km/h run phase, between GPS-MP and K4-MP, r was 0,41 with a d of 0. Table 2 shows data from the second part of the test, 16 km/h MP comparison, 10 players showed a positive comparison this means that GPS was overestimating the internal load, 6 players showed negative comparison this means that GPS were underestimating the internal load and 4 players showed neutral comparisons this means that no significant differences were founded. The average data recorded for 16 km/h test were: GPS-VO₂ $53,47 \pm 3,82$ ml/kg/min (0,85 SE), K4-VO₂ $52,04 \pm 6,26$ ml/kg/min (1,40 SE), GPS-MP $18,76 \pm 1,34$ W/kg (0,30 SE), K4-MP $18,26 \pm 2,20$ W/kg (0,49 SE) and the E showed a value of $8,95\%$. In the 16 Km/h run phase, between GPS-MP and K4-MP, r was 0,39 with a d of 0,27.

Table 1; Data from 8 km/h test comparison

Players	8 km/h				
	GPS-VO2	K4-V02	GPS-MP	K4-MP	E
1	31,11	29,89	10,92	10,49	3,92%
2	30,05	33,45	10,54	11,74	-11,31%
3	29,78	27,44	10,45	9,63	7,86%
4	30,11	30,18	10,56	10,59	-0,23%
5	32,20	29,30	11,30	10,28	9,01%
6	28,78	31,60	10,10	11,09	-9,81%
7	29,42	28,45	10,32	9,98	3,30%
8	31,13	30,55	10,92	10,72	1,86%
9	31,25	30,88	10,96	10,84	1,18%
10	30,65	34,66	10,75	12,16	-13,08%
11	29,00	28,65	10,18	10,05	1,21%
12	28,88	30,67	10,13	10,76	-6,20%
13	30,01	30,11	10,53	10,56	-0,33%
14	31,45	29,55	11,04	10,37	6,04%
15	29,50	26,45	10,35	9,28	10,34%
16	27,88	26,34	9,78	9,24	5,52%
17	28,85	31,55	10,12	11,07	-9,36%
18	27,90	26,55	9,79	9,32	4,84%
19	30,33	29,30	10,64	10,28	3,40%
20	31,22	34,23	10,95	12,01	-9,64%
Average	29,98	29,99	10,52	10,52	5,75%
SD	1,20	2,38	0,42	0,83	---
SE	0,27	0,53	0,09	0,19	---

Table 2; Data from 16 km/h test comparison

Players	16 km/h				
	GPS-VO2	K4-V02	GPS-MP	K4-MP	E
1	47,95	45,01	16,82	15,79	6,13%
2	52,31	59,12	18,35	20,74	-13,02%
3	52,31	50,33	18,35	17,66	3,79%
4	55,00	54,78	19,30	19,22	0,40%
5	53,53	44,93	18,78	15,76	16,07%
6	48,60	55,40	17,05	19,44	-13,99%
7	44,78	36,38	15,71	12,76	18,76%
8	49,76	48,89	17,46	17,15	1,75%
9	56,00	55,44	19,65	19,45	1,00%
10	52,75	61,00	18,51	21,40	-15,64%
11	57,22	57,45	20,08	20,16	-0,40%
12	57,20	59,00	20,07	20,70	-3,15%
13	56,80	57,45	19,93	20,16	-1,14%
14	54,90	48,62	19,26	17,06	11,45%
15	54,90	48,62	19,26	17,06	11,45%
16	53,60	50,55	18,81	17,74	5,69%
17	55,37	58,00	19,43	20,35	-4,75%
18	56,58	45,95	19,85	16,12	18,79%
19	60,44	48,62	21,21	17,06	19,56%
20	49,32	55,33	17,31	19,41	-12,19%
Average	53,47	52,04	18,76	18,26	8,95%
SD	3,82	6,26	1,34	2,20	---
SE	0,85	1,40	0,30	0,49	---

It is important to notice that in both tests the same players showed the same efficiency, 10 overestimated, 6 underestimate and 4 show a neutral comparison, this means that they had the same value in K4-MP and GPS-MP, this means that in this case, a player that had an overestimated data at 8 km/h recorded another overestimation at 16 Km/h. With higher intensity grow up even the E that was 5,75% in 8 km/h test and 8,95 %, even the higher standard deviation shows us that at high intensity there is more probability to detect higher differences between GPS-MP and K4-MP. The E shows us if players have a better or worst efficiency ratio comparing the golden standard (K4) to the theoretical method by Di Prampero calculated using external effort GPS. A positive efficiency means that the player uses less energy compared to what it should theoretically use to maintain that intensity, on the other hand when a player shows a negative efficiency means that he uses more energy to respect what it should theoretically use. In 40 analysis only 7 times (17,5%) the comparisons were neutral this means that there were no differences or at least not significant ones between GPS-MP and K4-MP. Table 3 shows the full report average results from the first test.

Table 3; Average data from the first test, E, r and d value divided by phases

Phase	GPS-VO2	K4-V02	GPS-MP	K4-MP	E	r	d
6 km/h	29,98 ± 1,20	29,99 ± 2,38	10,52 ± 0,42	10,52 ± 0,83	5,75%	0,41	0
16km/h	24,48 ± 0,68	23,66 ± 0,74	8,59 ± 0,24	8,30 ± 0,26	8,95%	0,39	0,27

The second protocol was performed by 20 semi-professional football players, they performed an 18 minutes test, the protocol was so composed: Basal Metabolism Analysis (BM) 3 minutes, analyzing athletes during resting phase in standing position was useful to define the individual differences of basal metabolism, 6 Km/h Jogging: 3 minutes, 12 Km/h Running: 3 minutes, 16 Km/h High Intensity Running: 3 minutes, Non-constant Running (NC) 3 minutes of free accelerations and decelerations and Recovery Phase (RC) 3 minutes of recovery post-exercise in standing position to analyze the time useful to come back to the initial pre-exercise conditions. Table 4 shows an example of the individual analysis of one player, in this specific case, is possible to notice that at 6 km/h the GPS-MP was overestimated but that in the following velocity 12 km/h, 16 km/h and N.C there was an underestimation, the percentage of efficiency increases with increasing of test intensity. It is obvious that in all the tests the BM and the RC part showed a 0 value in GPS-V02 and consequently in K4-MP, this shows the greater criticality of the theoretical method of Osgnach et al. (2010), that use external effort to evaluate the MP.

Table 4; Example of data from the second protocol test

Player	Steps	GPS-VO2	K4-V02	GPS-MP	K4-MP	E
1	BM	0	4,66	0	1,6	---
1	6 km/h	24,22	23,55	8,5	8,3	2,8%
1	12 km/h	41,45	43,45	14,5	15,2	-4,8%
1	16 km/h	50,44	54,43	17,7	19,1	-7,9%
1	N.C	40,44	44,46	14,2	15,6	-9,9%
1	RC	0	18,44	0	6,5	---

A high value in K4-MP during the RC step shows that that athlete had a slow recovery in the post-exercise phase, this data can help coaches to individualize the adequate training to improve and work on individual shortcomings. Table 5 shows data from the BM phase, as was known, GPS data detected GPS-V02 and GPS-MP as 0, this because GPS uses external load data to calculate these parameters. In this case there is no possible comparison, average of K4-V0² was $4,74 \pm 0,50$ ml/kg/min (0,11 SE) and K4-MP $1,66 \pm 0,18$ W/kg (0,04 SE). This analysis suggests us the idea that to better define the individual GPS-MP, could be possible to evaluate the BM and after using the specific GPS software to set up the individual value for every player, in order to subtract it to the instant output like in this example formula, $\text{GPS-MP} = (\text{GPS-VO}_2^2 - \text{BM})/2,85$. Table 6 shows data from 6 km/h phase, average data were: GPS-VO2 $24,48 \pm 0,68$ ml/kg/min (0,15 SE), K4-V02 $23,66 \pm 0,73$ ml/kg/min (0,16 SE), GPS-MP $8,59 \pm 0,23$ W/kg (0,05 SE), K4-MP $8,30 \pm 0,25$ W/kg (0,06 SE) and E 3,70%. In the 6 Km/h run phase, between GPS-MP and K4-MP, r was 0,58 with a d of 1,20. The E shows us that 14 players recorded an overestimation of GPS-MP, 5 players show a neutral comparison that means that the GPS was able to detect data near or equal to the K4-MP and only 1 player shows an underestimation of the GPS-MP.

Table 5; Players Data from BM phase

BM					
Players	GPS-VO2	K4-V02	GPS-MP	K4-MP	E
1	0	4,66	0	1,64	---
2	0	3,68	0	1,29	---
3	0	3,88	0	1,36	---
4	0	4,70	0	1,65	---
5	0	4,56	0	1,90	---
6	0	5,22	0	1,83	---
7	0	4,33	0	1,52	---
8	0	4,29	0	1,51	---
9	0	5,66	0	1,99	---
10	0	5,34	0	1,87	---
11	0	4,44	0	1,56	---
12	0	4,37	0	1,53	---
13	0	4,77	0	1,67	---
14	0	5,26	0	1,85	---
15	0	4,88	0	1,71	---
16	0	4,76	0	1,67	---
17	0	5,13	0	1,80	---
18	0	5,33	0	1,60	---
19	0	4,90	0	1,72	---
20	0	4,50	0	1,58	---
Average	0	4,73	0	1,66	---
SD	0	0,50	0	0,17	---
SE	0	0,11	0	0,04	---

Table 6; Players Data from 6 km/h Jogging

Players	6 km/h				
	GPS-VO2	K4-V02	GPS-MP	K4-MP	E
1	24,22	23,55	8,50	8,26	2,77%
2	24,66	23,41	8,65	8,21	5,07%
3	25,32	23,79	8,88	8,35	6,04%
4	24,70	23,95	8,67	8,40	3,04%
5	23,89	24,66	8,38	8,65	-3,22%
6	23,79	22,56	8,35	7,92	5,17%
7	22,90	23,06	8,04	8,09	-0,70%
8	23,44	23,20	8,22	8,14	1,02%
9	24,44	23,56	8,58	8,27	3,60%
10	24,90	23,78	8,74	8,34	4,50%
11	24,67	24,32	8,66	8,53	1,42%
12	25,22	25,10	8,85	8,81	0,48%
13	25,67	24,80	9,01	8,70	3,39%
14	25,21	23,23	8,85	8,15	7,85%
15	24,69	23,56	8,66	8,27	4,58%
16	24,90	24,20	8,74	8,49	2,81%
17	23,88	22,48	8,38	7,89	5,86%
18	24,50	23,32	8,60	8,18	4,82%
19	23,98	22,50	8,41	7,89	6,17%
20	24,54	24,12	8,61	8,46	1,71%
Average	24,48	23,66	8,59	8,30	3,70%
SD	0,68	0,73	0,23	0,25	---
SE	0,15	0,16	0,05	0,06	---

Table 6 shows data from 6 km/h phase, average data were: GPS-VO2 $24,48 \pm 0,68$ ml/kg/min (0,15 SE), K4-V02 $23,66 \pm 0,73$ ml/kg/min (0,16 SE), GPS-MP $8,59 \pm 0,23$ W/kg (0,05 SE), K4-MP $8,30 \pm 0,25$ W/kg (0,06 SE) and E 3,70%. In the 6 Km/h run phase, between GPS-MP and K4-MP, r was 0,58 with a d of 1,20. The E shows us that 14 players recorded an overestimation of GPS-MP, 5 players show a neutral comparison that means that the GPS was able to detect data near or equal to the K4-MP and only 1 player shows an underestimation of the GPS-MP. Table 7 shows data from 12 km/h phase, average data were: GPS-VO2 $40,54 \pm 1,09$ ml/kg/min (0,24 SE), K4-V02 $42,42 \pm 1,75$ ml/kg/min (0,39 SE), GPS-MP $14,22 \pm 1,75$ W/kg (0,08 SE), K4-MP $14,89 \pm 0,61$ W/kg (0,14 SE) and E 5,12%. In the 12 Km/h run phase, between GPS-MP and K4-MP, r was 0,59 with a d of 1,31. The E shows us that 16 players recorded an underestimation of GPS-MP, 3 players show a neutral comparison that means that the GPS was able to detect data near or equal to the K4-MP and only 1 player shows an overestimation of the GPS-MP. Data show that raising the intensity level of the exercise, we will obtain fewer cases of overestimation, while those of underestimation will grow. Before the 6 km/h jogging speed, there were 14 cases of overestimation, while now there is only one case.

Table 7; Players Data from 12 km/h Running

Players	12 km/h				
	GPS-VO2	K4-V02	GPS-MP	K4-MP	% Efficiency
1	41,45	43,45	14,54	15,25	-4,83%
2	42,65	43,78	14,96	15,36	-2,65%
3	40,13	42,45	14,08	14,89	-5,78%
4	41,45	39,55	14,54	13,88	4,58%
5	40,89	43,43	14,35	15,24	-6,21%
6	41,34	44,60	14,51	15,65	-7,89%
7	41,66	43,63	14,62	15,31	-4,73%
8	41,55	42,56	14,58	14,93	-2,43%
9	41,89	44,66	14,70	15,67	-6,61%
10	40,90	43,23	14,35	15,17	-5,70%
11	39,79	40,23	13,96	14,12	-1,11%
12	38,99	39,45	13,68	13,84	-1,18%
13	40,33	43,32	14,15	15,20	-7,41%
14	39,76	44,33	13,95	15,55	-11,49%
15	38,79	40,21	13,61	14,11	-3,66%
16	38,56	40,30	13,53	14,14	-4,51%
17	40,44	42,30	14,19	14,84	-4,60%
18	40,12	43,34	14,08	15,21	-8,03%
19	40,15	43,43	14,09	15,24	-8,17%
20	39,88	40,22	13,99	14,11	-0,85%
Average	40,54	42,42	14,22	14,89	5,12%
SD	1,09	1,75	0,38	0,61	---
SE	0,24	0,39	0,08	0,14	---

Table 8 shows data from 16 km/h phase, average data were: GPS-VO2 $52,13 \pm 1,28$ ml/kg/min (0,29 SE), K4-V02 $55,16 \pm 1,41$ ml/kg/min (0,32 SE), GPS-MP $18,29 \pm 0,45$ W/kg (0,10 SE), K4-MP $19,35 \pm 0,50$ W/kg (0,11 SE) and E 5,93%. In the 12 km/h run phase, between GPS-MP and K4-MP, r was 0,33 with a d of 2,27. The E shows us that 19 players recorded an underestimation of GPS-MP and that only one player shows a neutral comparison that means that the GPS was able to detect data near or equal to the K4-MP. Data show that raising the intensity level of the exercise, we will obtain less or null cases of overestimation, while those of underestimation will grow. Before the 12 km/h Running speed, there was 1 case of overestimation, while now no one. Table 9 shows data from NC phase, average data were: GPS-VO2 $43,75 \pm 2,05$ ml/kg/min (0,46 SE), K4-V02 $46,99 \pm 2,76$ ml/kg/min (0,61 SE), GPS-MP $15,35 \pm 0,71$ W/kg (0,16 SE), K4-MP $16,49 \pm 0,97$ W/kg (0,21 SE) and E 9,20%. In the 12 Km/h run phase, between GPS-MP and K4-MP, r was 0,28 with a d of 1,35. The E shows us that 17 players recorded an underestimation of GPS-MP and that 3 players show an overestimation of GPS-MP, no neutral efficiencies were founded. Raising the intensity of the exercise, showed fewer cases of overestimation, while underestimation has grown.

Table 8; Player Data from 16 km/h High-Intensity Running

Players	16 km/h				
	GPS-VO2	K4-V02	GPS-MP	K4-MP	E
1	50,44	54,43	17,70	19,10	-7,91%
2	52,55	55,70	18,44	19,54	-5,99%
3	50,32	55,49	17,66	19,47	-10,27%
4	52,78	55,60	18,52	19,51	-5,34%
5	53,22	57,32	18,67	20,11	-7,70%
6	51,96	55,32	18,23	19,41	-6,47%
7	51,44	57,56	18,05	20,20	-11,90%
8	50,56	55,32	17,74	19,41	-9,41%
9	49,98	51,30	17,54	18,00	-2,64%
10	50,16	55,23	17,60	19,38	-10,11%
11	51,88	54,32	18,20	19,06	-4,70%
12	53,63	53,22	18,82	18,67	0,76%
13	53,44	54,32	18,75	19,06	-1,65%
14	54,33	57,30	19,06	20,11	-5,47%
15	52,68	55,45	18,48	19,46	-5,26%
16	52,33	55,45	18,36	19,46	-5,96%
17	51,99	54,33	18,24	19,06	-4,50%
18	52,33	54,43	18,36	19,10	-4,01%
19	53,34	55,43	18,72	19,45	-3,92%
20	53,21	55,69	18,67	19,54	-4,66%
Average	52,13	55,16	18,29	19,35	5,93%
SD	1,28	1,41	0,44	0,49	---
SE	0,29	0,32	0,10	0,11	---

Table 9; Players Data from Non-constant Running

Players	NC				
	GPS-VO2	K4-V02	GPS-MP	K4-MP	E
1	40,44	44,46	14,19	15,60	-9,94%
2	39,56	43,33	13,88	15,20	-9,53%
3	42,46	44,67	14,90	15,67	-5,20%
4	44,70	43,80	15,68	15,37	2,01%
5	47,23	45,60	16,57	16,00	3,45%
6	45,67	40,56	16,02	14,23	11,19%
7	45,44	48,88	15,94	17,15	-7,57%
8	43,36	48,70	15,21	17,09	-12,32%
9	42,89	48,67	15,05	17,08	-13,48%
10	41,69	47,54	14,63	16,68	-14,03%
11	43,22	48,32	15,16	16,95	-11,80%
12	41,89	47,56	14,70	16,69	-13,54%
13	42,33	46,32	14,85	16,25	-9,43%
14	43,12	45,32	15,13	15,90	-5,10%
15	43,34	48,78	15,21	17,12	-12,55%
16	44,88	46,66	15,75	16,37	-3,97%
17	45,65	52,33	16,02	18,36	-14,63%
18	46,79	50,32	16,42	17,66	-7,54%
19	45,69	48,45	16,03	17,00	-6,04%
20	44,69	49,44	15,68	17,35	-10,63%
Average	43,75	46,99	15,35	16,49	9,20%
SD	2,05	2,75	0,71	0,96	---
SE	0,46	0,61	0,16	0,21	---

Table 10 shows data from the RC phase, as was known GPS data detected GPS-V02 and GPS-MP equal to 0 because GPS use the date of the external load to calculate these parameters. In this case, there is no possible

comparison, an average of K4-V0² was $10,47 \pm 3,06$ ml/kg/min (0,68 SE) and K4-MP $3,67 \pm 1,07$ W/kg (0,24 SE). This analysis suggests us the idea that to better define the individual GPS-MP during the recovery phase following high-intensity exercises or actions, can be possible to evaluate the RC using the individual value of K4-MP detected previously with a specific test and subsequently using the specific GPS software to set up the individual value for every player. Unfortunately, this approach seems impossible for several factors: the impossibility to carry out a test at all the intensities and durations of exercise/action possible during a match or training, it is not possible to calculate precisely how much the post-exercise energy cost is kept high and does not return to baseline and that MP values are influenced by numerous external and internal variables.

Table 10; Players Data from RC phase

Players	RC				E
	GPS-VO2	K4-V02	GPS-MP	K4-MP	
1	0	18,44	0	6,47	---
2	0	9,43	0	3,31	---
3	0	11,44	0	4,01	---
4	0	9,33	0	3,27	---
5	0	10,11	0	3,55	---
6	0	8,45	0	2,96	---
7	0	8,66	0	3,04	---
8	0	9,45	0	3,32	---
9	0	9,79	0	3,44	---
10	0	10,45	0	3,67	---
11	0	11,32	0	3,97	---
12	0	9,69	0	3,40	---
13	0	8,89	0	3,12	---
14	0	10,33	0	3,62	---
15	0	19,57	0	6,87	---
16	0	8,89	0	3,12	---
17	0	7,79	0	2,73	---
18	0	8,68	0	3,05	---
19	0	9,34	0	3,28	---
20	0	9,27	0	3,25	---
Average	0	10,47	0	3,67	---
SD	0	3,06	0	1,07	---
SE	0	0,68	0	0,24	---

Table 11 shows average data from all players including the standard deviation, is possible to observe that the Egrowing up with the increase of intensity starting from to 3,70% reaching the value of 9,20%, evidencing that as the intensity increases, the individual difference in the sample increases, as physiology teaches. Also is important to highlight that between the VO2 and MP detected with GPS and K4, there is always a higher standard deviation in values measured with K4, this because the internal effort presents more differences between players and are regulated by the physiology of each individual, in the other and the GPS is modulated only by the velocity and changes of acceleration. Anyway, there was a natural standard deviation even in data from GPS because even if during tests, every player was monitored in live, is more or less impossible to keep the same speed for 3 minutes without making changes in speed or acceleration. In total 80 detections, only 9 (11,25%) showed a neutral comparison, this means that there were no differences or at least not significant ones between GPS-MP and K4-MP (Table 12).

Table 11; Average data from the second test, E, r and d value divided by phases

Phase	GPS-VO2	K4-V02	GPS-MP	K4-MP	E	r	d
BM	0	4,73 $\pm$ 0,50	0	1,66 $\pm$ 0,18	---	---	---
6 km/h	24,48 $\pm$ 0,68	23,66 $\pm$ 0,74	8,59 $\pm$ 0,24	8,30 $\pm$ 0,26	3,70%	0,58	1,20
12 km/h	40,54 $\pm$ 1,09	42,42 $\pm$ 1,75	14,22 $\pm$ 0,38	14,89 $\pm$ 0,61	5,12%	0,59	1,31
16 km/h	52,13 $\pm$ 1,28	55,16 $\pm$ 1,41	18,29 $\pm$ 0,45	19,35 $\pm$ 0,50	5,93%	0,33	2,27
NC	43,75 $\pm$ 2,05	46,99 $\pm$ 2,76	15,35 $\pm$ 0,71	16,49 $\pm$ 0,97	9,20%	0,28	1,35
RC	0	10,47 $\pm$ 3,06	0	3,67 $\pm$ 1,07	---	---	---

Table 12; % E results from the second test

Phase	Underestimation	Overestimation	Neutral
BM	20	0	0
6 Km/h	1	14	5
12 Km/h	16	1	3
16 Km/h	19	0	1
NC	17	3	0
RC	20	0	0

Discussion

The aim of this study was to investigate and determinate the efficiency of the MP theoretical model by Osgnach et al. (2010), previous studies were trying to make focus on this Stevens et al. (2014), Buchheit et al. (2015) and Robertson et al. (2016), obtaining different results, but still showing the lack of reliability in the determination of the MP by indirect calculation. In our case, the use of a precise protocol and a new generation of GPS gauges with a frequency of 50 Hz and the possibility to check the speed data in live, has allowed us to analyze in depth the relationship between GPS-MP and K4 -MP. To better analyze the event we proposed two different tests, the first one was performed by 20 amateur football players from 7th Italian League, and it was so composed: 5 minutes of continues running at 8 km/h, 5 minutes pause, and 5 minutes of continues running at 16 km/h, for a total 15 minutes of test for every player. The secondone was performed by 20 semi-professional football players from a football team of 4th Italian Championship league. Changing the sample was important to investigate the possible differences that can be recorded between amateur and semi-professional athletes. The test protocol was so composed: Rest Analysis (RE); 3 minutes, analyze athlete during resting phase was useful to define the individual differences of basal metabolism, 6 km/h Jogging: 3 minutes, 12 km/h Running: 3 minutes, 16 km/h Running at High Intensity: 3 minutes, Non-constant Running (NC): 3 minutes of free accelerations and decelerations and Recovery Phase (RC) 3 minutes of recovery post-exercise in order to analyze the time useful to come back to the initial pre-exercise conditions. All data from both testswere analyzed in order to evaluate the comparison between GPS-MP and K4-MP (Table 13). In the first test, 13 players the 32,5% recorded an underestimation of GPS-MP, 20 players the 50% recorded an overestimation, and 7 players the 17,5% recorded a neutral comparison. This means that the correlation between GPS-MP and K4-MP was positive only in 17,5% of cases. The 6 km/h phase showed an E of 5,75% with a lower moderate r of 0,41 and a null effect d of 0, the 16 km/h phase showed an E of 8,95% with a lower moderate r of 0,39 and a small effect d of 0,27. In the second test, 53 players, 66,3%, detected an underestimation, 18 players 22,5% detected an overestimation, and 7 players 11,2% showed a neutral comparison. This means that the correlation between GP-MP and K4-MP was positive only in 11,2% of cases. In total 66 players the 55% showed an underestimation, 38 players the 31,6% detected an overestimation, and 16 players the 13,4% showed a neutral comparison. In the 6 km/h phase showed an E of 3,70% with a moderate correlation r of 0,58 and a large effect d of 1,20, the 12 km/h phase showed an E of 5,12% with a moderate correlation r of 0,59 and a large effect d of 1,31, the 16 km/h phase showed an E of 5,93% a week correlation r of 0,33 and very large effect d of 2,27, in the end, the NC phase showed an E of 9,20% a week correlation r of 0,28 and a large effect d of 1,35. In 120 detections only the 13,4% were showing a correlation between GPS-MP and K4-MP.

Table 13; Results from the first and second protocol

Test	Underestimation	Overestimation	Neutral
<i>First</i>	13	20	7
<i>Second</i>	53	18	9
<i>Total</i>	66	38	16

Conclusions

Analyzing the external and internal effort in football is the main goal of the last decade and probably will be even for the next. The results of our researches show that the MP approach cannot be used lightly; coaches and technical staff have to know the limits of this method and don't build and analyze training and matches only using MP. The use of K4 and the comparison of K4-MP with the GPS-MP during our testspermitted us to understand that there are too many differences between the data estimated by the GPS and the directs ones derived from the K4. In the first test, 13 players the 32,5% recorded an underestimation of GPS-MP, 20 players the 50% recorded an overestimation, and 7 players the 17,5% recorded a neutral comparison. This means that the correlation between GPS-MP and K4-MP was positive only in 17,5% of cases. In the second test, 53 players the 66,3 detected an underestimation, 18 players 22,5% detected an overestimation, and 7 players 11,2% showed a neutral comparison. The correlation between GP-MP and K4-MP was positive only in 11,2% of cases. In total 66 players the 55% showed an underestimation, 38 players the 31,6% detected an overestimation, and 16 players the 13,4% showed a neutral comparison. In 120 detections only the 13,4% were showing a correlation between GPS-MP and K4-MP. These results show that the MP has considerable limitations. The use of the MP intended as a synonym of real internal load, cannot be performedlightly. To solve these problems, some companies that produce hardware and software for sport, are trying to produce new models of GPS jackets with pulmonary ventilation sensorsintegrated. The analysis of the actual lungs dilatation could allow a much more accurate MP estimation, in order to revise the current derivation method. Future researches and innovations must be done in this particular field to evaluate, the real internal player's load. Evaluating the real MP could be crucial in a holistic and preventive consideration, to individualize the right training workflow and recovery management, athlete by athlete. The analyses carried out in this study have shown numerous interesting evidence that can be summarized in:

- The Osgnach's MP approach results to be an invalid method in deriving the real internal load of the athletes, because individual physiological differences make it impossible to accurately estimate the real energy expenditure for each individual with the simple use of a pre-built formula;
- Another critical point of the current method is that it is based on the formulas of Minetti et al. (2002) which were derived from a study carried out on cross-country athletes, and the PPM in this sport is extremely different and far from football one;
- To detect the true energy expenditure provided by the aerobic mechanism all along training or competition, will be necessary to integrate a respiratory rate sensor into the GPS shirts. The problem concerning the analysis of anaerobic and anaerobic energy consumption is still open;
- The MP approach results to be close to the real value of internal effort during the low-intensity runs and walking, the more the intensity rise, the more the errors rate widens;

The PPM analysis during training and match results to be crucial to determinate the performance of teams and players, to create, more specific training divided by roles and characteristics^[13].

References

- [1] D'Ottavio S., "La prestazione del giocatore di calcio", sds- Scuola dello Sport 1992 Gennaio- Marzo, n.24.
- [2] Reilly T., Thomas V., "A motion analysis of work-rate in different positional roles in professional football match-play", J Hum Mov Stud, 2: 87 – 97, 1976.
- [3] Di Salvo V., Collins A., McNeill B., "Validation of Prozone: A new video-based performance analysis system." Int J Perf Anal Sport 2006 Jun; 6 (1), 108-119.
- [4] Rampinini, E., Coutts, A., Castagna, C., Sassi, R., & Impellizzeri, F., "Variation in top-level soccer match performance." International Journal of Sports Medicine, 2007, 28(12), 1018–1024.
- [5] Osgnach C, Poser S, Bernardini R, Rinaldo R, di Prampero PE. "Energy cost and metabolic power in elite soccer: a new match analysis approach." Med Sci Sports Exerc. 2010;42:170-178.
- [6] Di Prampero P.E., Fusi S., Sepulcri L., Morin J.B., Belli A., Antonutto G. "Sprint running: a new energetic approach." J Exp Biol. 2005; 208(Pt 14):2809–16.
- [7] Minetti A., Moia C., Roi G.S., Susta D., Ferretti G. "Energy cost of walking and running at an extreme uphill and downhill slope." J Appl Physiol. 2002;93(3):1039–46.
- [8] Stevens, T.G.A., De Ruiter, C.J., Van Maurik, D., Van Lierop, C.J.W., Savelsbergh, G.J.P., and Beek, P.J. "Measured and Estimated Energy Cost of Constant and Shuttle Running in Soccer Players", Medicine & Science in Sports & Exercise · September 2014. DOI: 10.1249/MSS.0000000000000515.
- [9] Buchheit, M., Manouvrier, C., Cassiram, J. and Morin, J.B., "Monitoring locomotor load in soccer: is metabolic power, powerful?" International Journal of Sports Medicine · September 2015 DOI: 10.1055/s-0035-1555927.
- [10] Robertson, S.J., and Gastin, P., "Metabolic Power Method Underestimates Energy Expenditure in Field Sport Movements Using a GPS Tracking System" International Journal of Sports Physiology and Performance, March 2016, DOI: 10.1123/ijsp.2016-0021.
- [11] McLaughlin, J. E., King, G. A., Howley, E. T., Bassett, D. R., & Ainsworth, B. E. (2001). "Validation of the COSMED K4 b2 portable metabolic system." International Journal of Sports Medicine, 22(4), 280-284. <https://doi.org/10.1055/s-2001-13816>
- [12] Cohen, J., (1988). "Statistical power analysis for the behavioral sciences." 2nd ed. Hillsdale, NJ: Lawrence Erlbaum; 1988.
- [13] Altavilla, G., Riel, L., Di Tore, A.P., Raiola, G. (2017) "The physical effort required from professional football players in different playing positions." Journal of Physical Education and Sport, 17 (3), 2007-2012.

All subjects were informed of the benefits and risks of the investigation.

The data collection followed the principles outlined by the Declaration of Helsinki.

Author Contributions:

- **Conceptualization:** R.Izzo and C.Hosseini Varde'i
- **Methodology:** R.Izzo, G.Raiola, A.Cejudo and C.Hosseini Varde'i
- **Validation:** R.Izzo, Sainz P. , A.Cejudo and C.Hosseini Varde'i
- **Formal analysis:** C.Hosseini Varde'i
- **Investigation:** C.Hosseini Varde'I, Sainz P.
- **Resources:** R.Izzo and C.Hosseini Varde'i
- **Data curation:** C.Hosseini Varde'i
- **Writing, original draft preparation:** R.Izzo and C.Hosseini Varde'i
- **Writing, review, and editing:** R.Izzo and C.Hosseini Varde'i

All authors have read and agreed to the published version of the manuscript.

Funding: *This research received no external funding.*

Acknowledgments: *This study did not receive any financial support or other assistance. Conflicts of Interest: The authors declare no conflict of interest.*