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Monitoring Locomotor Load in Soccer: Is Metabolic Power, Powerful?

Authors

M. Buchheit¹, C. Manouvrier², J. Cassirame³, J.-B. Morin⁴

Affiliations

¹ Paris Saint Germain FC, Performance, Saint-Germain-en-Laye, France

² Olympic de Marseille Football Club, Physical Performance, Marseille, France

³ Laboratory of Sport Sciences, Université de Franche-Comté, UFR STAPS Besançon, Besançon, France

⁴ Faculty of Sport Sciences, Université de Nice Sophia Antipolis, NICE, France

Key words

- soccer
- acceleration
- deceleration
- energy demands
- soccer-specific
- training load

Abstract

The aim of the present study was to examine the validity and reliability of metabolic power (P) estimated from locomotor demands during soccer-specific drills. 14 highly-trained soccer players performed a soccer-specific circuit with the ball (3 × 1-min bouts, interspersed with 30-s passive recovery) on 2 different occasions. Locomotor activity was monitored with 4-Hz GPSs, while oxygen uptake ($\dot{V}O_2$) was collected with a portable gas analyzer. P was calculated using either net $\dot{V}O_2$ responses and traditional calorimetry principles (P_{VO_2} , $W \cdot kg^{-1}$) or locomotor demands (P_{GPS} , $W \cdot kg^{-1}$). Distance covered into different speed, acceleration and P zones was recorded. While

P_{GPS} was $29 \pm 10\%$ lower than P_{VO_2} ($d < -3$) during the exercise bouts, it was $85 \pm 7\%$ lower ($d < -8$) during recovery phases. The typical error between P_{GPS} vs. P_{VO_2} was moderate: 19.8%, 90% confidence limits: (18.4;21.6). The correlation between both estimates of P was small: 0.24 (0.14;0.33). Very large day-to-day variations were observed for acceleration, deceleration and $> 20 W \cdot kg^{-1}$ distances (all CVs $> 50\%$), while average P_{O_2} and P_{GPS} showed CVs $< 10\%$. ICC ranged from very low- (acceleration and $> 20 W \cdot kg^{-1}$ distances) to-very high (P_{VO_2}). P_{GPS} largely underestimates the energy demands of soccer-specific drills, especially during the recovery phases. The poor reliability of $P_{GPS} > 20 W \cdot kg^{-1}$ questions its value for monitoring purposes in soccer.

Introduction

Monitoring players' physical activity during both matches and training is a common practice today in professional soccer [9]. The detailed analysis of match demands can be used to define training orientations and/or design soccer-specific training drills [14]. In parallel, the quantification of training sessions' physical demands is an integral part of training load management and player monitoring [10,32], permitting coaching staff to readjust training periodization on a day-by-day basis.

When it comes to monitoring external load, locomotor activities are generally assessed using global positioning systems (GPS) and/or semi-automatic video tracking systems [9]. Distance covered within different speed zones and the occurrence of demanding actions such as high-speed runs, accelerations and decelerations are the most common measures reported by sports scientists [2]. However, since distances traveled into speed zones do not account for the high energetic cost of the accelerations and decelerations, the theoretical concept of metabolic power

has been recently proposed [13,30]. The main interest of the metabolic power model is that the energetic cost of accelerations and decelerations can be added to that of the runs at constant speeds, which has been suggested to be superior to the traditional time-motion analysis variables to provide an estimate of the overall energy demands of soccer [30]. For example, the distance covered at a 'high metabolic intensity' during training [17,18] and matches [30] was shown to be actually 1.5–2 times greater when considering distance at a high metabolic power vs. high-speed running only.

While the approach has been reported to provide energy cost estimates similar to directly determined measures [30], no studies have actually validated this method for estimating energy cost and metabolic power during soccer practice against a gold standard method (e.g., indirect calorimetry). In the only study to date in the field, Stevens et al. [33] reported that locomotor-related metabolic power during shuttle runs at low speed ($7.5\text{--}10 \text{ km} \cdot \text{h}^{-1}$) was largely (-15% , $-3.5 < d < -2.5$) lower than the actual net energy demands ($\dot{V}O_2$ measures). However, shuttle runs

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Correspondence

Dr. Martin Buchheit
Paris Saint Germain FC
Performance
4a Avenue Kennedy
78100 Saint-Germain-en-Laye
France
Tel.: +974/552/32 540/
+336 42
mb@martin-buchheit.net

may not be representative enough of soccer practice to generalize their results, and more importantly, players didn't have to pass the ball or shoot, and the protocol didn't include rest periods as is the case during any effort in soccer. Whether a similar underestimation would be seen during real soccer practice is therefore still to be examined. The level of reliability of the locomotor-related metabolic power estimation is also unknown. The aim of the present study was therefore to examine, in highly-trained young soccer players, the validity and reliability of the estimation of metabolic power (P) from locomotor demands during soccer-specific drills with the ball.

Methods

Participants

14 highly-trained young players (mean SD, 15.4±1.6 years, 177.6±6.3 cm, 68.5±5.6 kg and maximal oxygen uptake, $\dot{V}O_{2\max}$ 57.5±5.6 ml·min⁻¹·kg⁻¹) from an elite soccer academy participated in the study, which was approved by the local ethic committee and conformed with the declaration of Helsinki [20]. They provided written consent before participation, trained on average 8±2 h per week and competed at a national level in France.

Experimental overview

The players performed a soccer-specific circuit with the ball (◉ Fig. 1) at 2 different occasions within 2 weeks, at the same time of the day. The players were very familiar with the circuit, which they had all already performed at least twice the month preceding the experimentation. The training content the 2 days before the tests were highly similar (i.e., coaches replicated the same training sessions). To avoid the large variability of the locomotor responses to typical small-sided games [21], which may be problematic to assess the actual reliability of P , we chose a simplified and more controlled soccer-specific task in the form of a circuit with the ball. Since soccer is an intermittent sport, some rest periods were also introduced between the circuit repetitions. This circuit included slalom(s) with the ball, to pass and receive off a rebound wall and shot on goal. After a standardized 10-min warm-up without the ball, the players completed the soccer-specific circuit for 2 min at an average speed of 6.5 km·h⁻¹ (repeating the circuit until the work interval was complete). The players adjusted their running speed according to auditory signals timed to match the 19-m intervals delineated by the 2 external lines (◉ Fig. 1). After a 1-min recovery period, players started the experimental protocol and performed again the circuit for 1 min at speeds of 6.5, 7, and 7.5 km·h⁻¹ (with the exercise bouts interspersed with a 30-s passive recovery period). With this setting, the duration of the overall exercise test was exactly 4 min and 30 s (3×1-min exercise bouts+3×30-s recovery periods). Locomotor activity was monitored during each session with 4-Hz GPS units (VX, VX340a, Lower Hutt, New Zealand [6]), while oxygen uptake ($\dot{V}O_2$) was repeatedly collected with the same portable gas analyzer (MetaMax 3B, Cortex-Biophysik, Leipzig, Germany [28]). P was calculated using either the net $\dot{V}O_2$ responses and traditional calorimetry principles ($P_{\dot{V}O_2}$) [3] or the GPS-related locomotor demands (P_{GPS}) [30] during the entire exercise test (i.e., 4 min 30 s, ◉ Fig. 2). We chose to examine P over the entire exercise test duration (including the recovery periods between the exercise bouts) for 3 main reasons. First, from a physiological point-of-view, P has to be calculated from

total O_2 uptake. Because of the usual oxygen deficit at exercise onset, the excess post-exercise oxygen consumption (EPOC, which reflects the recovery of the body's oxygen stores and possibly some resynthesis of phosphocreatine) has to be added to the overall oxygen cost of an exercise [35]. The examination of the metabolic demands of the exercise bout only would likely result in an underestimation of the overall exercise demands. Second, it is generally accepted that rest periods are actual parts of an intermittent exercise, especially at high-intensity; without these pauses the intensity of the interval bouts cannot be sustained [8]. Third, when it comes to measuring training load, practitioners generally assess the (metabolic) demands of an overall training sequence/session, not only that of the exercise periods of the session [2]. For example, practitioners report total distance covered over a training sequence/session, which can be used to calculate average pace (i.e., m/min). Accordingly, if practitioners wanted to calculate P /min, they would examine P over an entire exercise sequence/ training session, where rest periods would definitely be included. To limit the effect of possible between-unit variability [5], players wore the same GPS during each session. While the use of a 4-Hz GPS system may be seen as a limitation of the present study (since higher sampling GPS frequencies are likely to provide more accurate measures of soccer-

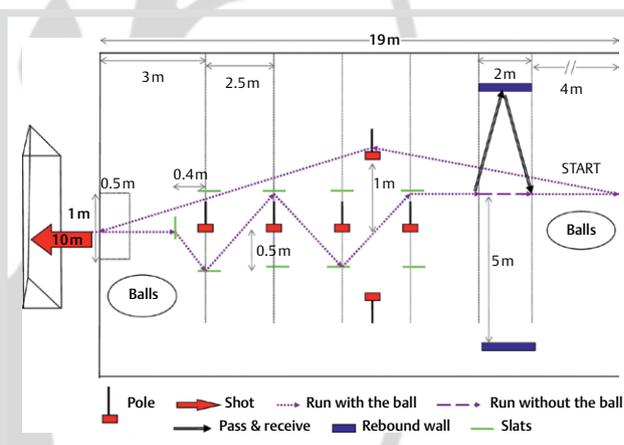


Fig. 1 Illustration of the soccer-specific circuit.

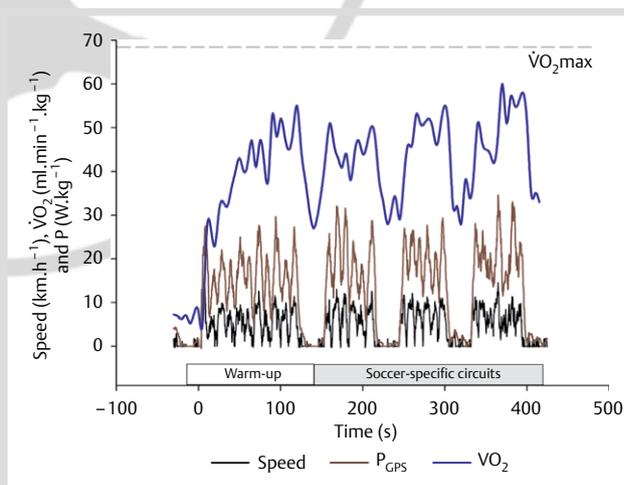


Fig. 2 Oxygen uptake ($\dot{V}O_2$), speed and metabolic power estimated from locomotor demands (P_{GPS}) during the warm-up and the 3 exercise bouts in a representative player. $\dot{V}O_{2\max}$: maximal oxygen uptake reached during an incremental test to exhaustion.

specific running activities [25,26]), sampling frequency *per se* may not be the most important factor when it comes to tracking validity: the accelerations and change of direction speed data collected with the 4-Hz VX units used in the present study were actually shown to present a comparable level of validity over a 45-Hz local positioning system (Inmotio Object tracking), a semi-automatic multiple-camera system (Prozone, 10 Hz) or another GPS brand (GPSports, 5 Hz) [6].

Metabolic demands estimated from cardiopulmonary responses

The MetaMax unit was calibrated with 2 reference gases before the experimentation. Before each measurement, the gas sensor was adjusted with one gas, while the flow sensor was calibrated with a 3-L turbine. Average net $\dot{V}O_2$ and the respiratory exchange ratio (RER) were calculated for each of the three 1-min efforts and the following 30-s recovery periods. Cardiopulmonary P_{VO_2} was assessed from the $\dot{V}O_2$ and $\dot{V}CO_2$ responses using Brockway's [3] standard equation, and then divided by body mass ($W \cdot kg^{-1}$). The RER values were <0.95 for all subjects at each trial (i.e., 0.90 ± 0.07), indicating that the energy was supplied primarily by oxidative metabolism in all test conditions.

Metabolic demands estimated from locomotor responses

The 4-Hz GPS data were extracted from the original software and processed with a customized Excel spreadsheet. We then used the equation proposed by Osgnach et al. [30] to calculate locomotor-related P (P_{GPS} , $W \cdot kg^{-1}$) from speed-related measures (i.e., instantaneous speed and acceleration for each 0.25 s segment). These calculations are based on a theoretical model that allows the estimation of the energetic cost of accelerations and decelerations during intermittent maximal-intensity running accelerations [13]. The model considers maximal accelerated running on a flat surface to be mechanically equivalent to incline running at a constant velocity, where the angle of the incline is equal to the extent of forward acceleration. This method provides an "equivalent slope," which is used to calculate an instantaneous measure of the energy cost of accelerated running and an estimate of metabolic power output [29]. Distance covered was collected for different speed (total distance, distance >7.2 , 14.4 and >19.8 $km \cdot h^{-1}$), acceleration (>-3 $m \cdot s^{-2}$), deceleration (>-3 $m \cdot s^{-2}$) and P (e.g., >20 $W \cdot kg^{-1}$) zones [30].

Statistical analysis

Data in text, tables and figures are presented as mean with standard deviations and 90% confidence intervals/limits (CI/CL). All data were first log-transformed to reduce bias arising from non-uniformity error.

Between-methods standardized differences in P were calculated, using pooled standard deviations. Uncertainty in the differences was expressed as 90% CL and as probabilities that the true difference was substantially greater or smaller than the smaller practical difference (between-subjects $SD/5$) [24]. These probabilities were used to make a qualitative probabilistic mechanistic inference about the true effect. The scale was as follows: 25–75%, possible; 75–95%, likely; 95–99%, very likely; $>99\%$, almost certain. The validity analysis consisted of comparing the 2 estimates of P with P_{VO_2} used as the criterion measure. The mean bias (in % and expressed as a standardized difference based on Cohen's effect size principle using pooled standard deviations), the typical error of the estimate (TEE, both in % and standardized units) and

the magnitude of the correlations between the approaches were calculated. The typical error of measurement (TE), expressed as a CV (in % and standardized units) and the intraclass coefficient correlation (ICC) were used as measures of reliability.

Threshold values for standardized differences, typical error and TEE were >0.2 (small), >0.6 (moderate), >1.2 (large) and very large (>2) [24]. The magnitude of the ICC was assessed using the following thresholds: >0.99 , extremely high; $0.99-0.90$, very high; $0.90-0.75$, high; $0.75-0.50$, moderate; $0.50-0.20$, low; <0.20 , very low (WG Hopkins, unpublished observations). Finally, the following criteria were adopted to interpret the magnitude of the correlation: ≤ 0.1 , trivial; $>0.1-0.3$, small; $>0.3-0.5$, moderate; $>0.5-0.7$, large; $>0.7-0.9$, very large; and $>0.9-1.0$, almost perfect. If the 90% CI overlapped small positive and negative values, the magnitude was deemed unclear; otherwise that magnitude was deemed to be the observed magnitude [24].

Results

The $\dot{V}O_2$, speed and locomotor-related metabolic power responses (P_{GPS}) during the warm-up and the 3 exercise bouts of a representative player are shown in **Fig. 2**. The average net $\dot{V}O_2$ response throughout the entire exercise sequence (3 circuits repetitions plus recovery periods) was $64 \pm 11\%$ $\dot{V}O_{2max}$. The distance covered within the different speed/acceleration/deceleration/metabolic power zones during the soccer-specific exercise is presented in **Table 1**. Players covered 30 times more distance >20 $W \cdot kg^{-1}$ than while running >14.4 $km \cdot h^{-1}$ (**Table 1**).

During the exercise bouts, P_{GPS} was $23 \pm 10\%$ lower than P_{VO_2} (standardized difference, Std diff < -3). During the recovery phase P_{GPS} was $85 \pm 7\%$ lower than P_{VO_2} (Std diff < -8) (**Fig. 3**). When assessing the agreement between the 2 estimates of P (both effort and recovery phases included), the mean bias for P_{GPS} vs. P_{VO_2} was very large (-51.3% , 90% confidence limits, CL, -75.1 ; -68.5 , Std bias -6.84 , -7.47 ; -6.21), and the TEE, moderate (19.8%, 18.4; 21.6, Std: 0.97, 0.91; 1.05). The correlation between both estimates of P was small: 0.24 90%CL (0.14; 0.33). When only the exercise periods were considered, the mean bias for P_{GPS} vs. P_{VO_2} was only large (-24.3% , -28.9 ; -19.5 , Std bias -1.72 ; -2.09 ; -1.34), but the TEE, still moderate (14.2%, 12.8; 16.0, Std: 0.82, 0.74; 0.91). The correlation between both estimates of P increased (i.e., moderate: 0.58 90%CL 0.47; 0.67).

Table 1 Locomotor and metabolic demands of the soccer-specific exercise (total for 3×1 min).

Locomotor and metabolic power categories	Mean \pm SD
Total distance (m)	1 305 \pm 86
Distance >7.2 $km \cdot h^{-1}$ (m)	823 \pm 181
Distance >14.4 $km \cdot h^{-1}$ (m)	2 \pm 4
Distance >19.8 $km \cdot h^{-1}$ (m)	0 \pm 0
Distance acceleration >3 $m \cdot s^{-2}$ (m)	17 \pm 13
Distance deceleration >3 $m \cdot s^{-2}$ (m)	14 \pm 7
P_{GPS} 0–10 $W \cdot kg^{-1}$ (m)	621 \pm 103
P_{GPS} 10–20 $W \cdot kg^{-1}$ (m)	614 \pm 121
P_{GPS} >20 $W \cdot kg^{-1}$ (m)	69 \pm 39
P_{GPS} 20–35 $W \cdot kg^{-1}$ (m)	5 \pm 6
P_{GPS} >35 $W \cdot kg^{-1}$ (m)	0 \pm 2

P_{GPS} : metabolic power estimated from locomotor demands (average of both trials). $n = 14$ players \times 2 trials

The larger CVs were observed for acceleration, deceleration and >20 W.kg⁻¹ distances (all CVs >50%), while TD, average P_{VO2} and P_{GPS} showed CVs <10% (◉ Table 2). The variables with the smaller standardized TE were average P_{VO2} and P_{GPS}. ICC ranged from very low (acceleration and >20 W.kg⁻¹ distances) to high (P_{VO2}).

Discussion

In this study we examined for the first time the validity and reliability of metabolic power estimation based on locomotor responses during a soccer-specific training sequence. Our main results are as follows: 1) locomotor-related metabolic power (P_{GPS}) tended to very largely underestimate the actual net metabolic demands (assessed via indirect calorimetry, P_{VO2}), especially during the resting phases, 2) there was only a small correlation between locomotor-related metabolic power and

actual net metabolic demands, with a moderate typical error of the estimate, 3) the reliability of circuit-average locomotor-related metabolic power was moderate, and slightly better than that observed for acceleration/deceleration demands and, finally 4) the distance traveled >20 W.kg⁻¹ was poorly reliable (i.e., very large TE and very low ICC).

The soccer-specific circuit used in the present study (◉ Fig. 1) elicited moderate levels of cardiorespiratory responses (64% VO₂max), with locomotor patterns essentially restricted to low-speed movements (i.e., players covered only 2 m in average above 14.4 km.h⁻¹, ◉ Table 1). Interestingly however, players were required to accelerate and decelerate substantially, accumulating >30 m above ±3 m.s⁻² (◉ Fig. 2 and ◉ Table 1). In agreement with this, metabolic power data showed that players actually covered 70 m >20 W.kg⁻¹, an intensity that is metabolically comparable to running at a constant speed of 14.4 km.h⁻¹ [30]. Since the monitoring of high-speed running *only* would suggest that the circuit had low metabolic requirements, the advocates of the metabolic power approach would argue that such an example perfectly illustrates the interest of metabolic power monitoring, i.e., capturing highly metabolically-demanding movements, irrespective of the actual speed [12, 17, 18]. The activity profile of the present circuit was comparable to the locomotor requirements of usual training sessions [23] and matches in soccer [34, 36], which is likely related to i) the limited playing areas of most training drills (i.e., <30 m²) [22] and the somewhat limited space allowed for some playing positions during matches (e.g., central defenders) [14], which limit players' ability to reach high speeds, and ii) the technical/tactical requirements of the drills/matches that require players to regularly accelerate/decelerate to pass and receive the ball [36]. Taken together, present results suggest that the soccer-specific circuit used in the present study was representative of training/match locomotor and metabolic demands, which was required to accurately examine the validity and reproducibility of the locomotor-related metabolic power estimation.

It has been suggested that metabolic power data may be used to estimate training and match energy expenditure, which could serve to individualize post-training and match nutrition strategies [12]. Our results suggest, however, that locomotor-related metabolic power may underestimate very largely the actual net energy demands of training sessions/matches. More importantly, compared with the indirect calorimetry method (considered to be the reference method), the bias was inconsistent, with the underestimation of metabolic demands being 3–4 time greater during resting periods (◉ Fig. 3). Present data are consistent with the very recent results of Stevens et al. [33], who reported locomotor-related metabolic power during shuttle

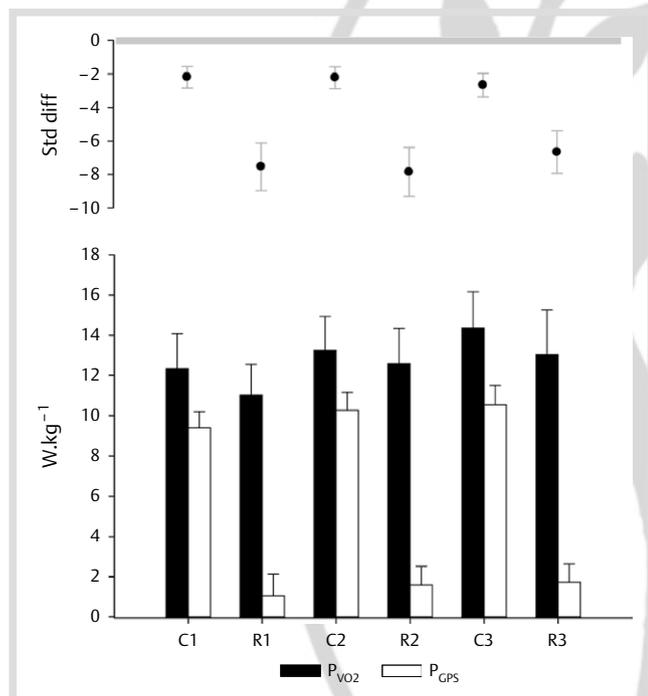


Fig. 3 Average estimated metabolic power (standard deviation) using either traditional calorimetry with oxygen uptake (P_{VO2}) or locomotor-related metabolic power (P_{GPS}) during the 3 soccer-specific circuits (C1, C2 and C3) and the subsequent recovery (R1, R2 and R3). The inserted graphs refer to standardized difference (90% confidence intervals) between the 2 methods, with the grey area representing trivial differences.

Table 2 Reliability of the locomotor and metabolic demands of the soccer-specific exercise.

	TD	D>7.2 km.h ⁻¹	D>14.4 km.h ⁻¹	Acc>3 m.s ⁻²	Dec>3 m.s ⁻²	Average P _{VO2}	Average P _{GPS}	P _{GPS} >20 W.kg ⁻¹
TE as a CV	5.8% (4.3;9.2)	22.3% (16.2;36.6)	N/A	84.7% (58.2;159.0)	58.1% (40.8;103.4)	9.3% (8.4;10.4)	8.0% (6.9;9.4)	73.6% (51.0;135.2)
Standardized TE	1.96 (1.47;3.04)	2.65 (1.98;3.4.11)	*	5.18 (3.87;5.03)	*	0.56 (0.50;0.62)	0.88 (0.77;1.04)	3.31 (2.48;5.14)
ICC	0.23 (-0.28;0.64)	0.14 (-0.36;0.58)	*	0.04 (-0.44;0.51)	-0.10 (-0.55;0.39)	0.77 (0.70;0.82)	0.57 (0.41;0.69)	0.09 (-0.40;0.54)

TE: typical error of measurement. CV: coefficient of variation. TD: total distance, D>7.2 km.h⁻¹: distance covered above 7.2 km.h⁻¹, D>14.4 km.h⁻¹: distance covered above 14.4 km.h⁻¹, Acc>3 m.s⁻²: distance covered while accelerating above 3 m.s⁻², Dec>3 m.s⁻²: distance covered while decelerating above 3 m.s⁻², P_{VO2}: metabolic power estimated from VO₂ responses, P_{GPS}: metabolic power estimated from GPS-related locomotor demands, P_{GPS}>20 W.kg⁻¹: distance covered above a P_{GPS}>20 W.kg⁻¹. #: could not be calculated since all players covered 0 m >14.4 km.h⁻¹ during the second trial. * Could not be calculated because ICC<0

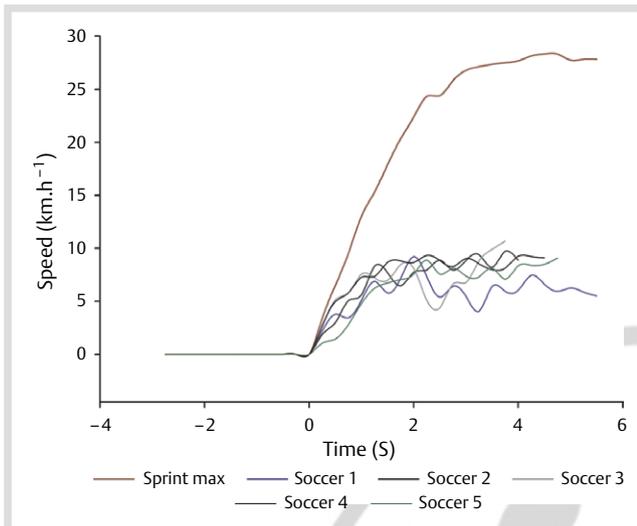


Fig. 4 Acceleration patterns during the soccer-specific drills as compared with a standardized maximal sprint initiated from a standing start without the ball.

runs at low speed ($7.5\text{--}10\text{ km}\cdot\text{h}^{-1}$) to be very largely ($\sim 15\%$, $-3.5 < d < -2.5$) lower than the actual net energy demands (VO_2 measures). While it is believed that increases in GPS sampling rate may reduce the error in P_{GPS} estimates in comparison with a speed radar system [31], the present underestimation of P_{GPS} during the exercise bouts in comparison to P_{VO_2} is unlikely related to the low sampling rate of our 4-Hz GPS systems, since Stevens et al. [33] reported the same trends with data collected at 500 Hz (and then resampled at 10 Hz before analysis). The reasons for these differences remain unclear but may be related to differences in body inclination during acceleration-deceleration phases between soccer play and maximal sprinting phases. In fact, the original method used to estimate metabolic power during sprinting [13] was based on the expected body inclination for a given slope [29], which is used as a proxy of actual acceleration demands. As shown in **Fig. 4**, both the magnitude and duration of the accelerations that occurred during the soccer-specific circuit were lower and shorter than during a maximal sprint, which could be a source of explanation for the inconsistent P_{GPS} values. Additionally, the original method is based on a modeling of speed-time curves via a mono-exponential function, which is based on maximal sprint acceleration (from zero to maximal running speed), which might not be systematically the case during typical soccer-specific drills (**Fig. 4**). Therefore, should this exponential increase in speed not be reached, the equations estimating metabolic power according to di Prampero's model [13] might not apply correctly in soccer-specific situations such as those studied here. Finally, when dribbling or turning for example, non-locomotor muscles may be highly activated [7] and increase, in turn, the overall metabolic demands independently of the actual locomotor-related demands. The reasons for the underestimation of metabolic demands during the recovery phases are more straightforward. Since the locomotor-related approach is based on (changes in) speed, it obviously cannot predict any metabolic activity when the body is not moving. In the present study, VO_2 remained high during the recovery periods, reflecting a prolonged energy turn-over after exercise (excess post-exercise consumption) likely aimed at assisting metabolic recovery (e.g., replenishment of phosphocreatine stores) and paying the O_2 debt contracted at exercise onset. A

limitation of the indirect calorimetry approach used is that we did not directly account for a possible anaerobic energy contribution to the overall metabolic power estimation (i.e., accelerations); however, 1) the low RER values (0.90) suggest that the exercise was mainly aerobic and 2) excess post-exercise VO_2 values (which can be used as an indirect measure of the anaerobic energy provision [35]) were included in the calculation of the average metabolic power. It seems therefore that the present findings question the use of the locomotor-related metabolic power approach to assess energy expenditure during soccer-specific movements with the present technology (4-Hz GPS), and especially during rest/inactive periods; this is unfortunate considering the inherently intermittent nature of soccer.

In addition to the validity of any monitoring tool or variable, a very important and practical aspect is its reproducibility, which directly determines the marker's ability to compare training/match load and monitor changes. The absolute level of day-to-day variations (i.e., the 'noise' of measurement, generally expressed as a CV) doesn't inform directly on the actual usefulness of a variable, but it is rather its relationship with the variable 'signal' (i.e., change usually reported or that considered as meaningful in practice) that matters [4]. In the present study, while the CV for total distance (5%) was similar to that reported during small-sided games [1,21], the day-to-day variations in acceleration and deceleration were greater than previously reported (i.e., >60 vs. $10\text{--}20\%$ [1]) (**Table 2**). This may be related to protocol differences (i.e., circuit vs. small-sided games), and the fact that in the present study, players had to cover an important portion of the total distance with the ball (**Fig. 1**), which may directly but inconsistently influence acceleration/deceleration patterns. Another reason for the large variability of some of the locomotor variables may be the low sampling-frequency of our GPS system (4-Hz GPS), since CVs for high-intensity actions have been reported to decrease with sampling rate [25]. The new finding of the present study is the moderate (standardized TE) to high (ICC) reliability of the average locomotor-related metabolic power (P_{GPS}) throughout the circuits, which was similar to that of the cardiorespiratory-related metabolic power (small TE and very high ICC). In contrast, the distance traveled $>20\text{ W}\cdot\text{kg}^{-1}$, which is the variable generally used when it comes to monitor training [17,18] and game [12,27,30] metabolic demands, was poorly reliable (i.e., very large TE and very low ICC). The poor reliability of the distance traveled $>20\text{ W}\cdot\text{kg}^{-1}$ is actually not surprising, since metabolic power is calculated from both high-speed and acceleration/deceleration demands, which both showed a limited reliability (**Table 2**). A limitation of the monitoring of the distance covered into specific speed/metabolic zones compared with average speed/P throughout of sequence is that a subtle change in speed/acceleration (e.g., reaching the threshold vs. not reaching it by $0.1\text{ km}\cdot\text{h}^{-1}$) can have very large effects on the total distance into the zone, despite non-substantial change in the average locomotor work.

Overall, our results question the usefulness of the assessment of metabolic power from locomotor demands to assess the energy cost of soccer-specific exercises with the present technology (4-Hz GPS). Nevertheless, if locomotor-related metabolic power has to be used, practitioners should use drill average responses, not distance into zones. Irrespective of its limited validity and reliability, the excessive reliance on metabolic power data may also have strong conceptual limitations. First, the calculation of the locomotor-related metabolic power doesn't take into account

possible individual variations in running economy. As a result, different players with similar running/acceleration profiles all present the same estimated power. Second, computing and expressing the entire locomotor load of soccer players in a single number likely prevents a clear understanding of the mechanical origins of the load (i.e., high-speed vs. acceleration/deceleration). This is problematic for several reasons, including the need to prepare players in relation to the actual match mechanical demands: matching competitive metabolic demands during training does not guarantee an optimal preparation at the locomotor level, since the proportion of high-speed vs. low-speed movement is likely greater during matches than during training [11]. Additionally, the monitoring of the distance covered at high-speed vs. distance covered while accelerating/decelerating likely provides highly relevant information with respect to different types of acute neuromuscular and musculoskeletal loads [16], which has direct implication for training preparation, injury prevention and post-match recovery. In fact, while high-speed running likely represents a high mechanical stress for the hamstrings at their maximal length [19], acceleration (mainly concentric) and deceleration (mainly eccentric) phases likely put an additional emphasis on the quadriceps and glutei muscles (e.g., [15]). This key information is, unfortunately, overlooked when considering metabolic power as a global measure of load.

Conclusion

In conclusion, our results question the usefulness of the assessment of metabolic power from locomotor demands to assess the energy cost of soccer-specific exercises with the present technology (4-Hz GPS). Locomotor-derived metabolic power underestimated very largely the actual net metabolic demands of the drills (especially during the resting phases), and while the reliability of drill-average locomotor-related metabolic power was moderate, the distance at a high metabolic power ($>20\text{W}\cdot\text{kg}^{-1}$) showed very large typical error and a very low intraclass correlation coefficient. Further studies comparing the locomotor vs. cardiorespiratory-related metabolic power responses to matches and/or higher intensity drills (i.e., over larger pitch to reach higher running speeds without the ball, which running style may be more similar to that used for the original model) are still warranted to confirm/extend these findings. Present findings should also be confirmed in an adult population and/or with other tracking technologies [6].

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