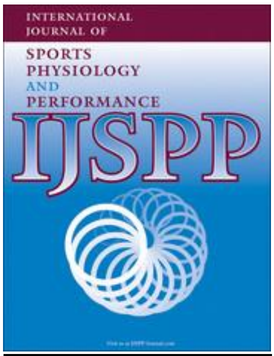

In press

Title: **Player tracking technology: half-full or half-empty glass?**

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1. Abstract

With the ongoing development of (micro) technology, player tracking has become one of the most important components of load monitoring in team sports. The three main objectives of player tracking are the following: i) better understanding of practice (provide an objective, *a posteriori* evaluation of external load and locomotor demands of any given session or match), ii) the optimisation of training load patterns at the team level and iii) decision making on individual players training programs to improve performance and prevent injuries (e.g., top-up training vs. un-loading sequences, return to play progression). This paper, discusses the basics of a simple tracking approach and the need for the integration of multiple systems. The limitations of some of the most used variables in the field (including metabolic power measures) will be debated and innovative and potentially new powerful variables will be presented. The foundations of a successful player monitoring system are probably laid on the pitch first, in the way practitioners collect their own tracking data, given the limitations of each variable, and how they report and utilize all this information, rather than in the technology and the variables *per se*. Overall, the decision to use any tracking technology or new variable should always be considered with a cost/benefit approach (i.e., cost, ease of use, portability, manpower / ability to impact on the training program).

2. Introduction

With the ongoing development of (micro) technology, player tracking has become one of the most important components of load monitoring in team sports.[1] The scientific literature has grown exponentially over the last decade, and it is very difficult to find an elite team not using the minimum of GPSs, semi-automatic camera or radio-frequency systems, either in isolation or in combination during both training and matches.[1] The three main objectives of player tracking are likely the following: i) better understand practices (provide an objective, *a posteriori* evaluation of external load and locomotor demands of any given session or match), ii) help with the programming of optimal training load patterns at the team level and iii) help with the decision making on individual players training programs to improve performance and prevent injuries (e.g., top-up training vs. un-loading sequences, return to play progression). While such technological advances are of evident value for practitioners and players, limitations in terms of validity and on-field usefulness are still often overlooked. There is also a feeling that people may adopt new technologies and new variables before validity, reliability and usefulness had been properly evaluated. Early and naïve adopters may often think that i) technology in itself is a solution, and ii) if they do not use the newest technologies/variables immediately they may fall behind competitors. In fact, most of the time, the introduction of new technologies and monitoring variables adds complexity and slows down systems, rather than improving them. In the present paper, we discuss the basics of a simple tracking approach and the need for the integration of multiple systems. Furthermore, we highlight the limitations of some of the most used variables in the field (including metabolic power measures) and present some innovative and powerful variables[2] that may be of importance for the future.

3. Integrating various systems

While the precise analysis of each training sequence (drill database[3]) is of infinite value for improved training prescription and programming both at the individual and team level, the simple monitoring of players overall external (locomotor) load is probably one of the most important aspects of any monitoring system.[1] There has been growing evidence to suggest that tracking overall training load accumulation during pre-season and/or its acute changes over the time (spikes in load, referring to the so-called training stress-balance or acute-to-chronic load ratio) may be key in better understanding injury risk.[4] Using the example of soccer (Figure 1), it is not unusual for some players to be tracked by 2 to 3 systems during the same week. This is likely related to the fact that GPS units, local positioning system (LPM) or radio-frequency identification (RFI) sensors are often worn during training sessions, while most teams still use semi-automatic camera systems during official matches.[5] Since a perfect between-system agreement in terms of locomotor activity (e.g., distance covered, number of accelerations) is problematic,[5] simply providing a cumulative summation of the data gathered by the different systems[6] is highly hazardous. To allow a proper evaluation of a player's overall locomotor load, and to integrate accordingly the data of different systems, practitioners are recommended to use calibration equations.[5] Such equations are meant to predict, for example, the running distance that would have been measured with a given system (e.g., GPS), while it was actually measured with another one (e.g., semi-automatic cameras during a match). While such equations are sometimes provided in the literature from large scale studies with players tracked simultaneously using different systems under different conditions (e.g., training, matches over different pitch size),[5] their usefulness is somewhat limited to the actual systems used to derive those equations; it is therefore advised that each practitioner develop their own equations using their own systems. It is also important that practitioners re-adjust these equations when updates in their technology occur (see 3.2).[7] The most relevant variables to integrate will be discussed in the following section.

4. Tracking accelerations and high-speed running: time to slow down?

4.1. Which variable to choose from?

Considering that the ideal system does not exist yet, and that all systems have their own advantages and disadvantages, whilst still all providing more or less the same variables,[5] it may be more relevant to pick the most useful variables than to focus on the technology *per se*. To make a substantial impact on the program, it is advised to focus on the variables that i) are simple enough to be understood, and in turn, used by all practitioners at the club (ranging from the coach to players), and ii) are valid and reliable enough to be trusted when decisions have to be made. When it comes to describing the different types of tracking variables available on the market, the classification of Gray[2] stands out. He uses three distinct levels:

- Level 1: Typical distances covered in different velocity zones (‘old school’ type of analysis, provided by all technologies). Example: 345 m ran above 19.8 km/h.
- Level 2: All events related to changes in velocity: accelerations, decelerations and changes of directions (provided with more or less success by all technologies). Example: 45 accelerations over 3 $m.s^{-2}$, for a total distance of 233 m.
- Level 3: All events derived from the inertial sensors/accelerometers (micro-technology only, so unavailable with camera-derived systems). Examples: 17 impacts above 6 G, Player Load of 456 AU, stride variables (Force load on the ground, contact times), stride imbalances (4% reduced impulse force on the right leg).[8,9]

In a recent meta-analysis,[1] total distance, high-speed running, acceleration/deceleration patterns and metabolic power (MP) were the variables that were rated as the most important for elite team practitioners. Total distance is generally used as a proxy of overall training volume. High-speed running distance (also called stride work, which involves high activation of hamstring muscles) and acceleration/deceleration patterns (also called mechanical work, involving tight muscles) are believed to be the most important variables to be tracked since they refer to a more neuromuscular-oriented type of load, which is likely more linked with injury risk.[3,10,11] Metabolic power is a hybrid measure based on both Level 1 and 2 types of variables, and is meant to provide a good estimate of the overall cost of high-intensity actions while combining the actual cost of high-speed (Level 1) and accelerated (Level 2) running.[12] Unfortunately however, practitioners are left with a difficult dilemma when selecting their variables, since their validity and reliability is likely inversely related to their importance in terms of load monitoring, i.e. high-speed running, acceleration/deceleration work and metabolic power being the least valid and reliable variables.[1,13] In other words, the variables that are believed to be best are likely the least useful.[2] This does not mean that those variables should not be monitored, but rather suggests that greater care should be taken when interpreting their differences or changes (i.e., defining a larger, more conservative smallest worthwhile difference/change).[14] Also, a variable with a limited validity can still be useful if it is clearly sensitive to training or fatigue (which refers to a large signal-to-noise ratio).[15]

It is now very clear that activity patterns of players is more dependent on tactical issues (rules, coaches’ interventions, score line) than influenced by their current fitness status.[16] For this reason, locomotor-related variables (Level 1 and 2) may not be suitable for the monitoring of training status; in contrast, Level 3 types of variables can be collected irrespective of players’ activity on the pitch, and have greater potential for the monitoring of fitness and fatigue (see part 5).[8] It is however worth noting that when Level 3 variables are not available (using semi-automatic cameras or some GPS brands which do not provide such variables), some relevant information can still be gained with Level 1 and 2 variables - but only in the very specific context of highly standardized drills.[17] Figure 2 shows how a player's readiness to perform could be assessed during congested fixtures using simple running performance indicators during highly-standardized drills, i.e., during match simulation drills the days before matches (in the context of similar small-sided game formats, number of players and drill duration). Results show that the longer the between-match recovery period, the greater the match simulation activity, which mirrors the physiological and performance recovery processes in the 2-3 days following macthes.[18]

4.2 Limitations of common tracking variables, with special references to GPS systems.

In addition to potential validity and reliability issues, there are other important limitations to consider when using some of these tracking variables, including:

- Accelerations values are directly related to the time-window (duration over which the acceleration is measured, in general between 0.2 and 0.8 s, Figure 3)) and the signal filtering technique used.[13] There is unfortunately no consensus on the optimal time-window and filter to use. A simple and relevant alternative to the use of arbitrary time-windows could be to report acceleration over a meter (i.e., the base unit of length in the International System of Units).[19]
- Companies often update their data processing technique (software or unit chipset updates), which can create large differences in data output.[7] It is therefore almost impossible to hold historical databases, unless you never update your system.
- The number of GPS satellites available and their spread in the sky (geometric dilution of precision (GDOP), with the greater the spread of the satellites, the better the signal quality) in response to variations in time of day, location on earth or possible infrastructures (stadium roofs may cause partial blockage); unfortunately, however, activity reports do not readily provide this detailed information, leading to a potentially unclear representation in their readings.
- There are large differences in GPS distance recorded when using the Doppler technique vs. local coordinates – while the Doppler tends to be the preferred method today, some inconsistencies remain between brands.
- The validity of accelerations and distance into speed zones is acceleration-[20] and speed-[5] dependent; i.e., their validity decreases as the acceleration and speed increase. So to speak, variables of most importance are likely the least useful.
- Increased sampling frequency does not always translate into better precision and validity.[5]
- There are large between-unit variations (up to 50%), even between units from the same brands.[7] The direct consequence is that players should always use the same unit, and we should always remain cautious when comparing different players' data (and use larger magnitude thresholds for meaningful differences[14]).

4.3 Metabolic power: powerful enough to drive Ferraris?

Since Osgnagh et al. in 2010,[12] showed the potential application of the metabolic power (MP) concept[21] for load monitoring in soccer, the interest for this variable has grown exponentially and is now used across many other team sports.[22-25] In fact, most GPS brands now offer the ability to monitor players' MP, and a majority of practitioners use this variable when reporting.[1] While we[26] have been the first to be excited about the potential of this monitoring approach, we have since reconsidered our opinion and now question its usefulness in the field to monitor elite players (i.e., "Ferraris"). This is essentially related to i) recent research findings questioning the validity of this construct in the context of team sports-specific movements and ii) the fact that it is only an incomplete metabolic measure of internal load and a too broad marker of external load.

4.3.1 What are we measuring in the end?

It has now been shown by four distinct and independent research groups that locomotor-related MP assessed via either GPS or local positioning system (P_{GPS}) differs largely from the true metabolic demands as assessed via indirect calorimetry (VO_2 measures, P_{VO2}). P_{GPS} was actually reported to be very largely greater than P_{VO2} during walking,[27] but very largely lower during shuttle runs at low speed[28] and during soccer-,[26] rugby-[29] or team-sports[27] specific circuits. While some may see the consistency of such conclusions as a kind of consensus, Osgnach et al.[30] suggested that some methodological errors may explain the underestimation of P_{GPS} reported.[26-29] Among others, they attributed our discordant results to i) the inclusion of resting VO_2 when calculating P_{VO2} (while we have in fact used net VO_2, as clearly written p1151, 2nd paragraph[26]), ii) the impact of non-locomotor actions on P_{VO2} (while team sports often include intense but static movements that logically increase systemic energy expenditure (P_{VO2}) independently of locomotor movements (P_{GPS})[31]), iii) an underestimation the anaerobic contribution to P_{VO2} (while if we had better accounted for the entire anaerobic contribution to P_{VO2}, the P_{GPS} underestimation that we reported would have been even greater, not smaller[31]) and iv) our 4-Hz GPS sampling frequency (while the other researchers have all reported the same underestimation using higher sampling frequencies i.e., 500,[28] 10[29] and 5[27] Hz). Note also that we have shown that sampling frequency *per se* was not the most important factors when it comes to precision and validity.[5] Detailed and illustrated answers to these four points have been offered elsewhere,[31] and confirm the limitations of P_{GPS} in the context of interest, i.e., monitoring team-sports specific efforts with the available technology on the market.

4.3.2. Adding value to load monitoring systems?

Considering that the agreement between P_{GPS} and P_{VO2} has only been shown to be acceptable during continuous and linear jog and runs (but neither during walking nor intermittent changes of direction runs)[27], the metabolic underestimation consistently reported[26-29] may be related to the fact that the current equation initially developed for maximal and linear sprint acceleration[21] may not be well suited for team-sport specific running patterns (e.g., including rest, irregular step frequency and stride length, turns, upper body muscle activity, static movements).[26] Additionally, if P_{GPS} was to only reflect locomotor-related metabolic activity (as opposed to a systemic measure such as P_{VO2}), what would be the value of such an impartial measure of metabolic load? This is at odds with all attempts to use P_{GPS} outputs for overall load monitoring or nutritional (post training/matches recovery) guidelines.[25] Taken together, these limitations suggest that the value of P_{GPS} *per se* to monitor training load in team sports may be questionable. Its usefulness may also be limited with respect to practitioners' expectations in the field. In fact, practitioners are likely seeking for:

- Overall estimates of internal load, which are in our views satisfactorily assessed through HR and RPE measures[1] – information on the metabolic load of exclusively locomotor-related actions as with P_{GPS} may not be comprehensive enough.
- Precise measures of external load, which directly relate to specific mechanical constraints on players' anatomy, which, in turn target specific muscle groups. This has direct implications for training, recovery and injury risk. However:
    - P_{GPS} is clearly dissociated from actual muscle activation, as exemplified by very large variations in the P_{GPS}/EMG ratio during accelerated vs. decelerate running.[19]
    - P_{GPS}, if it was to be used as a global marker of mechanical work (combining Level 1 and 2 types of variables), would not decipher the underlying mechanisms of the load – we rather use distance while accelerating, decelerating and while running at high-speed since those variables may relate directly to the load of specific muscle groups.
    - Injuries are most generally related to inappropriate volumes of accelerations[10] or high-speed running;[11] there is in contrast little evidence to suggest that spikes in overall energy consumption *per se* may play a role in injury etiology.

5. Where do we go from here?

We wished to finish with the introduction of two innovative and promising types of variables (Athletic Data Innovation analyzer, ADI, Sydney, NSW, Australia),[3,8] not cited in the meta-analysis,[1] that represent clear advances in terms of external load and fatigue monitoring. One of the greatest benefits of these variables is that, in contrast to Level 1 and 2 variables that are pacing- or player engagement-dependent, players do not need to perform maximally for these latter variables to be useful. From there, every training session becomes an assessment.

- *Force load (FL).* With the ADI analyzer,[3,8] Force load refers to the sum of estimated ground reaction forces during all foot impacts, assessed via the accelerometer-derived magnitude vector. In comparison with Player/Body Load[9] (whole body load based on overall accelerometer activity) or total distance, FL reflects only locomotor-related impacts and provides better estimates of overall foot work and impulses, especially when the sessions include static movements and little displacements (e.g., toros, football tennis, free kicks).

a. In relation to the actual distance covered (TD/FL) or the average velocity (V/FL) during a given drill, Force load can be used for at least two purposes: i) assess neuromuscular/running efficiency (greater the ratio, better the efficiency)[32] and ii) provide new insights into the mechanical demands of on-field running drills, such as the main direction of force application; i.e., large vs. small ratios standing for more horizontal vs. more vertical forces applications, respectively, Figure 4). As shown in Figure 4, when comparing for the first time the mechanical demands of different 15-m sprint conditions, the V/FL ratio decreases with the increased need for horizontal force production.
b. Force load can also be compared between right and left legs, and stride imbalance can be tracked during any type of locomotive actions (e.g., specifically while accelerating vs. running at high speed, which likely relates to the use and potential weaknesses of different muscle groups).[8] This is obviously very relevant during the return to play period (Figure 5) and to track eventual muscle strength deficits in yet healthy players.[33]

- *Stride characteristics* (contact and flight time, also calculated from accelerometer data). From these simple variables it is now possible to accurately calculate vertical stiffness,[8] which has been shown to decrease substantially with neuromuscular fatigue.[34,35] The constant monitoring of stride characteristics (or at least ground impact-related lower leg vertical activity[36]), more preferably during standardized running bouts,[32] offers a new alternative to the V/FL ratio and provides new perspectives for the field monitoring of neuromuscular status. Another very practical aspect of the present stride variables is that accelerometers can be used indoor (i.e., no GPS signal needed), allowing their use for almost every type of run-based type of sports (e.g., basketball, handball).

6. Conclusion

Monitoring players' overall external training load is only possible through the integration of the different technologies used in combination in most clubs (e.g., GPS and semi-automatic camera tracking for training and matches, respectively).[5] Until new solutions are developed, the use of club-specific calibration equations is probably the "lesser of all evils", but practitioners would still be faced with the downside of technology and/or computing advances (e.g., firmware or software updates),[7] which ultimately compromises long term monitoring plans. When it comes to monitoring training status, Level 1 and 2 tracking data may only be worthy in the context of highly standardized drills.[17] In contrast, pacing-free Level 3 variables (e.g., stride parameters, Force load[8]) may offer a greater sensitivity, although more research is still warranted to confirm this hypothesis. Considering that the perfect tracking system still does not exist,[5] and given the numerous limitations of the most advocated variables (accelerations, metabolic power, see section 3), the foundations of a successful players monitoring system should focus on the manner in which practitioners collect their own tracking data, their understanding of the limitations of each variable, and how they report and utilize all this information, rather than in the technology and the variables *per se*. Furthermore, the validity and reliability and the practical interpretation of tracking variables should never be overlooked; the most useful tracking variables are very likely those that can be understood and in turn, used by all practitioners at the club. Our opinion is that before adopting new pieces of technology or variables, practitioners should assess their usefulness first, in order to ensure worthwhile incorporation into their program. Overall, the decision to use any tracking technology or new innovative variable should always be considered with a cost/benefit approach (i.e., cost, ease of use, portability, manpower / ability to impact on the training program). Technology should be preferred over simpler methods only when unique and important information can be obtained (e.g., the percentage of maximal speed reached during a session, which may directly impact injury risk,[37] can't be assessed via session-RPE). Anecdotally, very successful coaches still make most of their decisions based on information as simple as accumulated training and playing time! We are nevertheless confident that in the future, with the advances in terms of micro technology, the development of new tracking variables and appropriate sport-science support,[38] even those coaches would start to see the glass half-full.

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8. Figure Legends

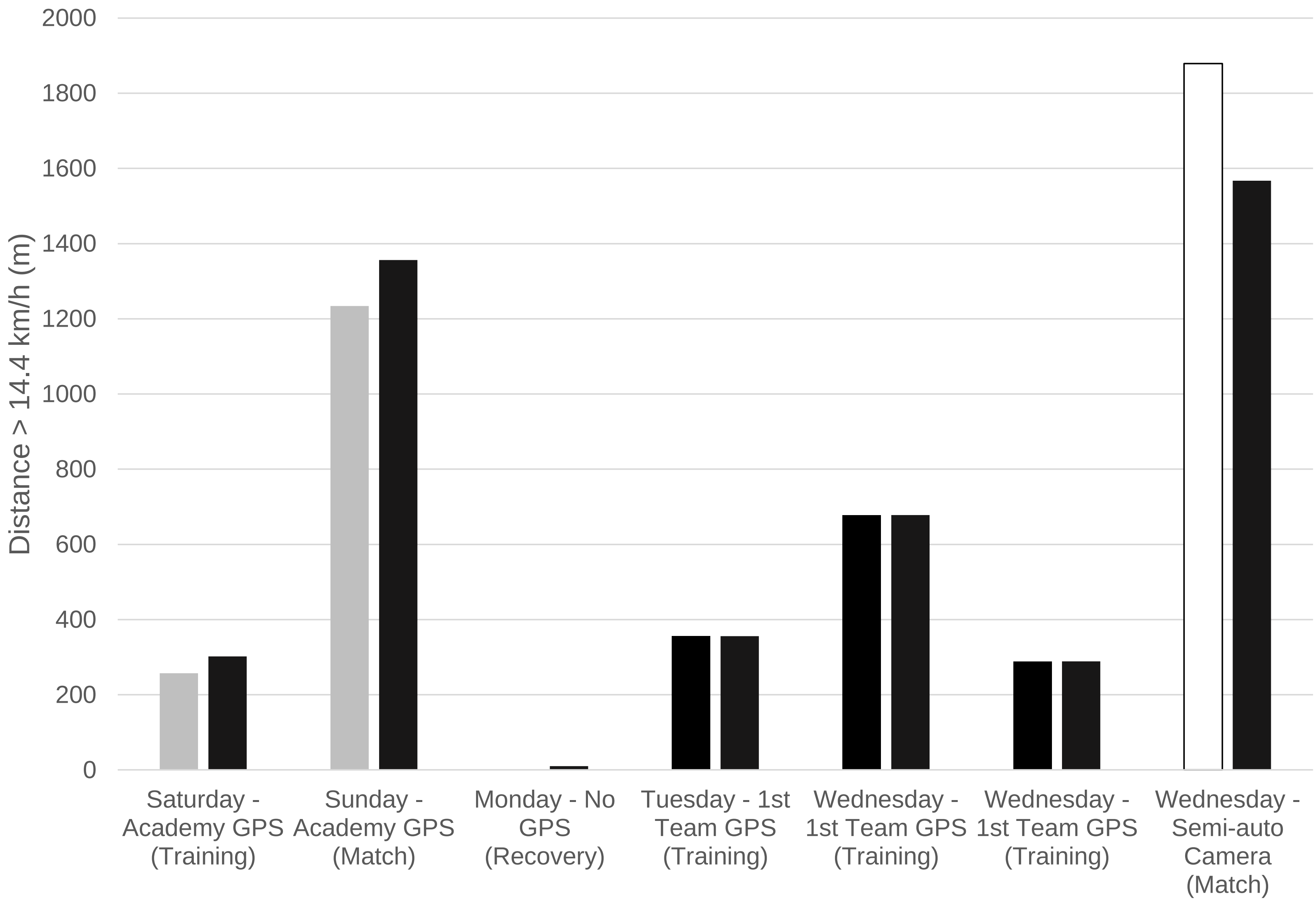
Figure 1. Distance covered above 14.4 km/h during a typical week by a representative academy player in an elite French soccer club. During this specific week, he was tracked using both the academy and 1st Team GPS systems, and the by a semi-automatic camera system during the match he played with the Pros. Left columns represent raw (as collected) data (total = 4693 m). Right columns represent the actual distance estimated via calibration equations that could have been expected to be measured if he had worn consistently the 1st Team GPS system (total = 4558 m). Note that while the academy system tends to provide lower estimates than the 1st Team system, the semi-automatic camera system provides greater values. Finally, based on historical drill data,[3] 50 m above 14.4 km/h have been added manually for the recovery session (light stride work).

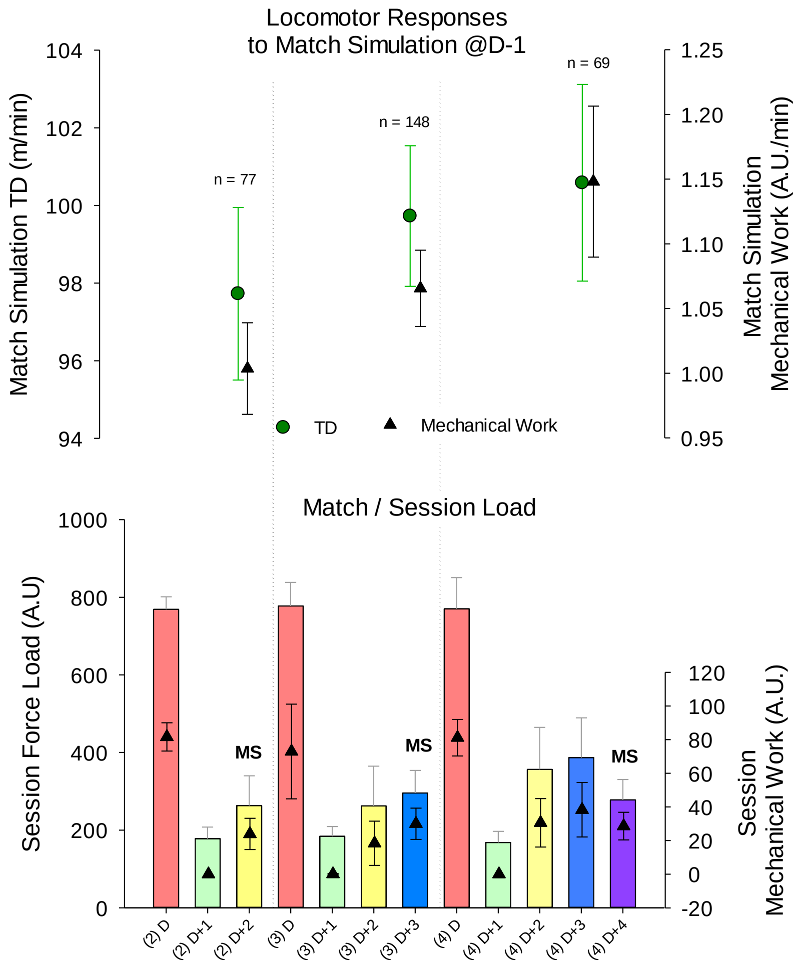
Figure 2. Upper panel: locomotor responses (total distance covered (circles) - and mechanical work (triangles) per minute) during match simulation drills (MS) the day before a match (D-1), as a function of the number of days between two consecutive matches in professional soccer players from an elite French team. Lower panel: sessions/matches Force load (bars) and mechanical work (triangles) as a function of the number of days between two consecutive matches. Match simulations: 9 vs. 9 players (2 goal keepers), 50 x 55 m, free touches, 2 x 8 min. Mechanical work is a variable provided by the ADI analyzer[3,8] as a compound measure of accelerations, decelerations and changes of directions.

Figure 3. Maximal acceleration calculated during a maximal 20-m sprint, as a function of the windows used to derive acceleration (0.2, 0.6 or 0.8s). The shorter the window, the greater the acceleration value. There are today some discrepancies between brands and practices, and there is no consensus on the optimal window duration to use. This remains an important limitation when it comes to monitoring players' 'true' acceleration capacities.

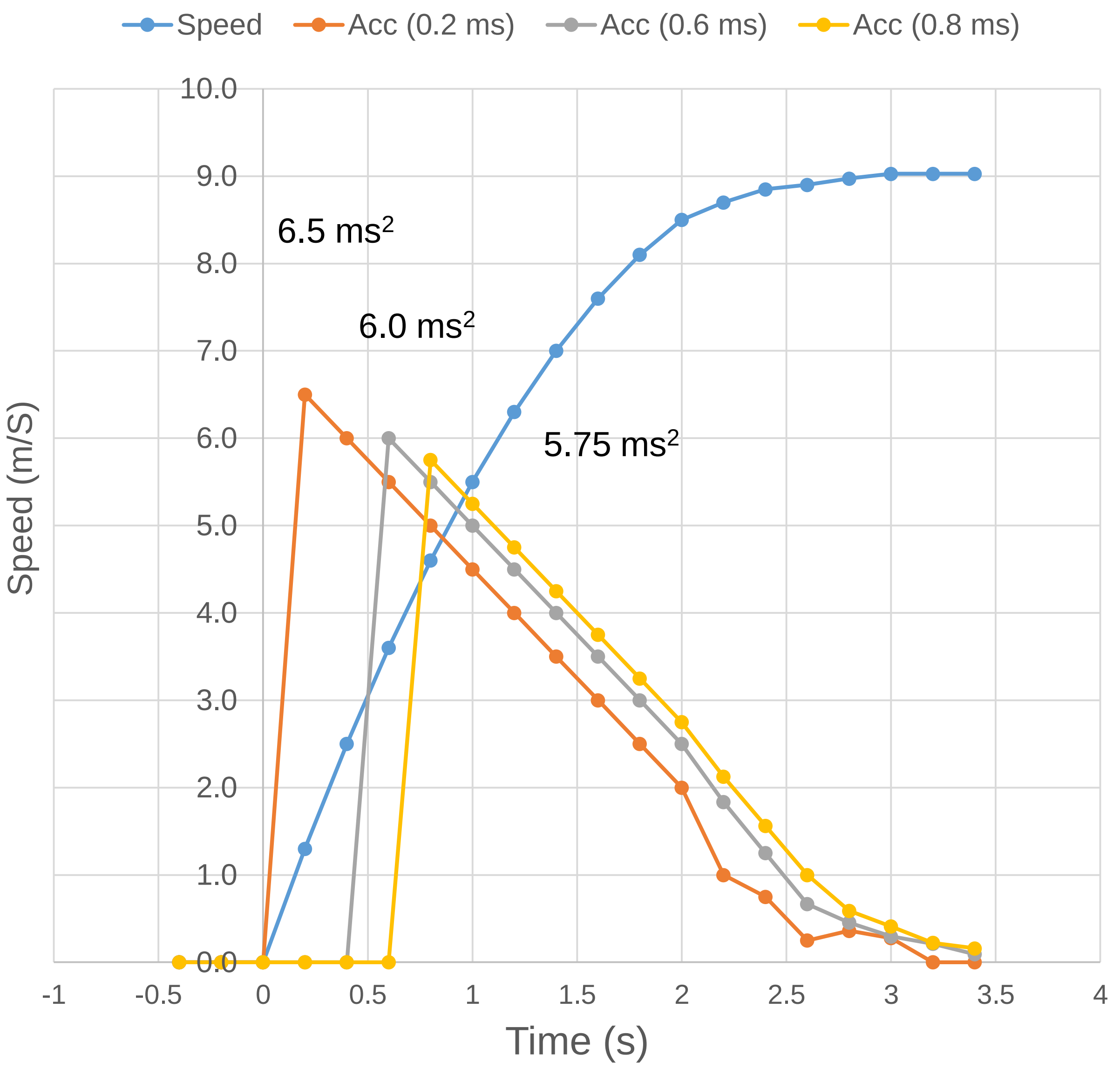
Figure 4. Maximal velocity (Vmax), maximal acceleration (Amax), Force load per meter (Force Load/m) and velocity / Force load ratio (V/FL) during maximal 15-m sprints performed either on flat terrain on a football pitch (Flat), a 4%-grade uphill slope (Uphill, same grass as the pitch), on sand (wearing wind surfing shoes), pulling the equivalent of 18 and 24 kg using the Power Sprint machine. The data were collected in 10 professional soccer players during the same training session (each data represents the average of 3 trials per condition with 90% confidence intervals).

Figure 5. Example of Force load symmetry in a players during his return to play period following a right ankle sprain. The symmetry (with errors bars standing for typical error of measurement[8]) is calculated from the Force load of all foot impacts during all accelerated running phases ($>2m.s^{-2}$) of each session. The star represents the date of the injury.

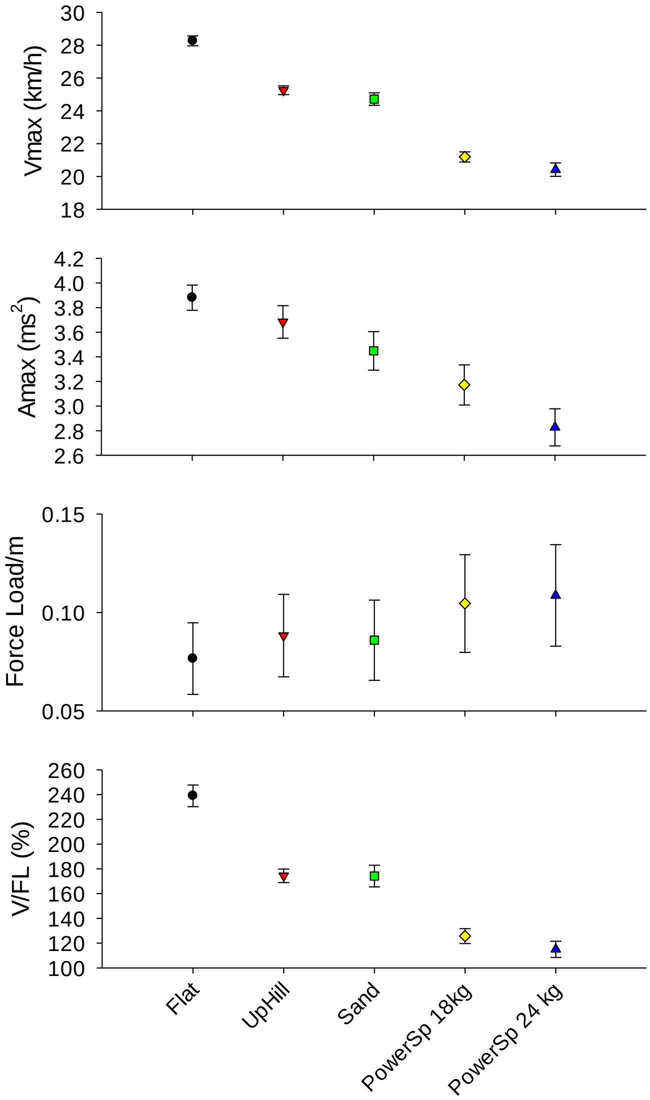

Distance > 14.4 km/h (m)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Saturday - Academy GPS (Training)
Sunday - Academy GPS (Match)
Monday - No GPS (Recovery)
Tuesday - 1st Team GPS (Training)
Wednesday - 1st Team GPS (Training)
Wednesday - 1st Team GPS (Training)
Wednesday - Semi-auto Camera (Match)



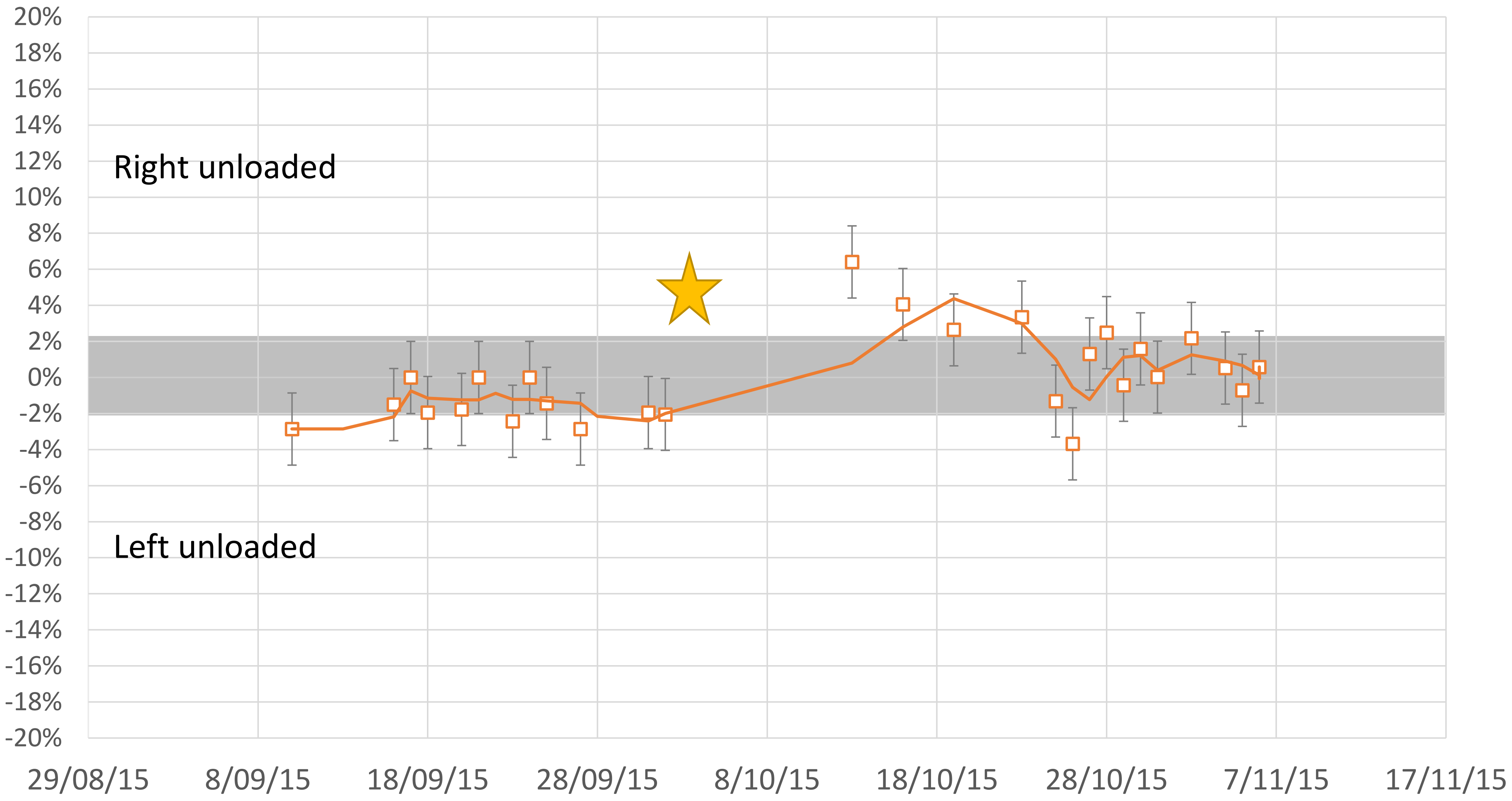
Locomotor Responses
to Match Simulation @D-1
Match Simulation TD (m/min)
Match Simulation
Mechanical Work (A.U./min)
n = 77
n = 148
n = 69
TD
Mechanical Work
104
102
100
98
96
94
1.25
1.20
1.15
1.10
1.05
1.00
0.95
Match / Session Load
Session Force Load (A.U)
Session
Mechanical Work (A.U.)
MS
MS
MS
1000
800
600
400
200
0
120
100
80
60
40
20
0
-20
(2) D
(2) D+1
(2) D+2
(3) D
(3) D+1
(3) D+2
(3) D+3
(4) D
(4) D+1
(4) D+2
(4) D+3
(4) D+4



Speed
Acc (0.2 ms)
Acc (0.6 ms)
Acc (0.8 ms)
6.5 ms2
6.0 ms2
5.75 ms2
Speed (m/S)
Time (s)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4



Vmax (km/h)
30
28
26
24
22
20
18
Amax (ms2)
4.2
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
Force Load/m
0.15
0.10
0.05
V/FL (%)
260
240
220
200
180
160
140
120
100
Flat
UpHill
Sand
PowerSp 18kg
PowerSp 24 kg



20%
18%
16%
14%
12%
10%
8%
6%
4%
2%
0%
-2%
-4%
-6%
-8%
-10%
-12%
-14%
-16%
-18%
-20%
Right unloaded
Left unloaded
29/08/15
8/09/15
18/09/15
28/09/15
8/10/15
18/10/15
28/10/15
7/11/15
17/11/15