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Title: Methodological considerations when quantifying high-intensity efforts in team sport using global positioning system technology

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Abstract

Purpose: Sprints and accelerations are popular performance indicators in applied sport. The methods used to define these efforts using athlete tracking technology could affect the number of efforts reported. The study aimed to determine the influence of different techniques and settings for detecting high-intensity efforts using Global Positioning System (GPS) data. Methods: Velocity and acceleration data of a professional soccer match was recorded via 10-Hz GPS. Velocity data was filtered using either a median or exponential filter. Acceleration data was derived from velocity data over a 0.2 s time interval (with and without an exponential filter applied) and a 0.3 s time interval. High-speed running (≥4.17 $m.s^{-1}$), sprint (≥7.00 $m.s^{-1}$) and acceleration (≥2.78 $m.s^{-2}$) efforts were then identified using minimum effort durations (0.1 to 0.9 s) to assess differences in the total number of efforts reported.

Results: Different velocity filtering methods resulted in small to moderate differences (Effect Size; 0.28 – 1.09) in the number of high-speed running and sprint efforts detected when minimum duration was <0.5 s and small to very large differences (ES; -5.69 – 0.26) in the number of accelerations when minimum duration was <0.7 s. There was an exponential decline in the number of all efforts as minimum duration increased, regardless of filtering method, with the largest declines in acceleration efforts.

Conclusions: Filtering techniques and minimum durations substantially affect the number of high-speed running, sprint and acceleration efforts detected with GPS. Changes to how high-intensity efforts are defined affect reported data. Therefore, consistency in data processing is advised.

Key words: soccer, football, GPS, acceleration, sprint

Introduction

Athlete tracking systems allow the quantification of athlete movement during training or matches by measuring the distance, velocity and acceleration of an athlete. Semi-automated tracking systems measure the displacement of an athlete over time from which distance, velocity and acceleration are calculated. Global positioning system (GPS) devices measure distance travelled via positional differentiation (the change in device location with each received satellite signal). While velocity can be derived from this distance measure (distance over time), a greater accuracy and lower error is found when velocity is calculated using the Doppler-shift method (measured via the change in frequency of the satellite signal).[1] Thus, the majority of GPS manufacturers calculate velocity via the Doppler-shift method from which acceleration is subsequently derived. Athlete movements are typically recorded as the distance covered or number of discrete efforts in specific speed or acceleration categories. These categories are defined using specific speed/acceleration thresholds which may vary between users and sports. Practitioners and researchers use the distances and number of efforts performed by athletes to monitor training load,[2,3] profile physical performance during competition[4-6] and link these movements to injury[7] or match events such as scoring or conceding points[8].

Numerous validation studies have assessed the ability of GPS to measure distance and velocity which have been summarised in a recent review.[9] This is a continuous process as each new device or upgrade requires new validation. However, there is limited research regarding the various methods used to determine movement efforts. Typically, a movement effort is identified when GPS velocity/acceleration enters a specific threshold (e.g. sprint threshold) and lasts for a minimum duration, referred to as ‘dwell time’ or minimum effort duration (MED). Often the total count of efforts performed during a training session or match are reported.

Movement efforts are determined independently of GPS distance information and are calculated using purely the velocity and acceleration data. The acceleration data is typically calculated based on the GPS-derived data and not from the inertial sensors within these devices which was the case in the present study. This is a common misconception from practitioners and may cloud judgement on the data reported (insert IJSPP black box review paper reference).

The most common movement efforts reported in research and by practitioners are high-speed, sprint and acceleration efforts.[4,5,10,11] A recent survey of practitioners from high-level football clubs around the world found that acceleration variables were ranked 1st as the most commonly used metric when monitoring athletes during training.[12]

There are several methodological considerations when identifying an effort that may substantially change the number of efforts identified when tracking athletes. To determine a meaningful effort, practitioners should establish a minimum duration that velocity/acceleration must exceed the specific movement threshold. For example, if a MED of 0.5 s is set to define a sprint effort then an athlete would need to maintain a speed greater than the sprint threshold for at least 0.5 s for an effort to be recorded. This ensures that possible spikes in the GPS data due to noise, which may last 0.1 s or lower depending on the sampling frequency, are not recorded as discrete efforts. Additionally, as velocity/acceleration may oscillate around a set threshold, selecting an appropriate MED will help to ensure that only meaningful efforts are recorded. The MED for a sprint may be longer than that for an acceleration, as a high rate of acceleration is likely to be short.[13] These considerations will account for the inherent noise in GPS velocity/acceleration data and increase the likelihood that any efforts identified are real.

Another consideration when using GPS to quantify athlete movement is the use of data filtering techniques within the manufacturer software. Due to the inherent noise in raw GPS velocity data, manufacturers apply different filtering techniques to smooth velocity and acceleration data. The type of filter is often chosen at the discretion of the manufacturer and may include median, exponential, Butterworth or other filters. Additionally, acceleration data can be smoothed by widening or shortening the time interval over which it is derived from velocity with a wider interval resulting in a greater smoothening of the data. Thus, acceleration data can undergo substantial smoothing through a combination of manipulating the interval over which it was derived and applying a filter to the data as demonstrated in Figure 1. The development of filtering techniques to improve accuracy is ongoing within the athlete tracking industry via software and firmware updates. These updates may incorporate different filtering techniques which can lead to substantial changes in the movement data reported. For example, following a software upgrade large decreases in the number of acceleration efforts were detected when the same GPS data was processed.[14] Although this was not directly attributed to changes in data filtering it is likely that these differences were partially due to a change in data filtering. While some manufacturers will allow the user to customise the filter or the time interval used to calculate acceleration, in other cases this is fixed and information regarding these elements may not be available to the user. Alternatively, the raw data can be exported and analysed in custom-based software such as Matlab or Microsoft excel allowing these considerations to be defined by the user.

---Figure 1 here---

Currently it is unknown how changes to the data filtering and/or MED will directly affect the number of efforts reported. In a sports setting, any changes to these settings may substantially alter the reported values which will affect athlete monitoring, training preparation and the practitioner's interpretation of these results. In research these details are often not reported limiting both the ability to compare results across the literature and the reproducibility of the research. The aim of this study was to determine the influence of varying MED to detect high-intensity efforts in an applied sporting context. This study also examined the influence of different filtering techniques within GPS manufacturers' software on subsequent high-intensity effort detection. The practical application of this study is to provide some recommended guidelines for practitioners using such data for their daily practice.

Methods

Participants

Data were collected from six professional soccer players (23.0 ± 1.8 years,) competing in the highest league of the Netherlands (Eredivisie). As this study assessed the influence of different data analysis techniques a large sample size was not essential. Written informed consent was provided before participation in this study, which was approved by the ethics committee of KU in line with the requirements stipulated in the Declaration of Helsinki.

Design

To assess the differences of various MED methods and data smoothing filters, movement data were recorded in two different stages. The first was during controlled sprint tests of 10, 20 and 40 m under the assumption that during a maximal sprint from a static start a player should only register a single high-speed, sprint and/or acceleration effort. If more than one effort was recorded the MED could be adjudged to be too low. Only one trial for each sprint test (10, 20 and 40 m) was included in the analysis for each player (n=6). In the second stage, movement data were recorded during a competitive match in order to demonstrate how the different effort detection methods influenced the number of efforts identified in a practical way. For both stages, GPS data was downloaded and processed using two versions of the manufacturer's software, Sprint^{TM} and Openfield^{TM}, which each used different filtering techniques.

Methodology

GPS Data Collection

Data was collected using a commercial 10-Hz GPS device (Optimeye S5; firmware version 7.22, Catapult Sports, Melbourne, Australia) worn inside a custom made garment positioned between the scapula. Previous research has found such devices to have acceptable levels of reliability and validity for assessing velocity.[15] Prior to data collection, the devices were left outside in an open area for 30 minutes to allow satellite connection and checked to ensure a satellite 'lock' had occurred prior to placing on the soccer players. The sprint testing was conducted on an outdoor natural grass pitch and the match data was collected in the team’s home stadium. The average ± SD number of satellites and horizontal dilution of position during the sprint testing was 14.0 ± 0 and 0.74 ± 0.01, respectively, and for the match data collection was 15.0 ± 0.6 and 0.70 ± 0.10, respectively. These values have been suggestive of being acceptable for good GPS signal coverage based on the manufacturer’s recommendations.[16]

GPS Data Analysis

Subsequent data was downloaded and exported using two versions of the manufacturer's software, Sprint^{TM} (version 5.1.7) and Openfield^{TM} (version 1.12.0, Catapult Sports, Melbourne, Australia). The following describes the different filtering techniques applied by the manufacturer's software in order to calculate the GPS velocity and subsequently

GPS acceleration data that is used to quantify player movement. The raw GPS velocity data is calculated using the Doppler-Shift method. The Sprint™ software filters the raw GPS velocity data using a median filter (GPS Vel_{sprint}), while the Openfield™ software filters the raw GPS velocity data using an exponential filter (GPS $Vel_{openfield}$).

The GPS acceleration data is derived from GPS velocity data. In the Sprint™ software the user can select the time interval over which acceleration (GPS $Accel_{sprint}$) is derived from GPS Vel_{sprint} (referred to in the software as Smoothing Filter Width). In this study, time intervals of 0.2 ($Accel_{sprint\_0.2}$) and 0.3 s ($Accel_{sprint\_0.3}$) were used. No additional filters are applied to $GPSAccel_{sprint}$ after the time interval has been selected. In the Openfield™ software GPS acceleration is derived from GPS $Vel_{openfield}$ using the 0.2 s time interval that is fixed within the software. Data is then filtered further using an exponential filter (GPS $Accel_{openfield}$). All data was exported for analysis using custom-based software (Microsoft Excel).

Calculation of Movement Efforts

Movement efforts were determined from the aforementioned GPS velocity and acceleration data using the following thresholds high-speed running (≥4.17 $m.s^{-1}$), sprinting (≥7.00 $m.s^{-1}$) and acceleration (≥2.78 $m.s^{-2}$). These thresholds were selected as they are commonly used amongst the research literature.[4,5,17] High-speed running and sprint efforts were identified using the following MED 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0,7, 0.8, 0.9 and 1 s. Acceleration efforts were identified using the following MED 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1 s. All data was analysed in Microsoft Excel duplicating the methods and output from the respective software. It is worth noting that in the Sprint™ software although the minimum duration for accelerations is an open option there is an error in the software that results in odd numbers being 'rounded up' to the next decimal place (e.g. 0.1 becomes 0.2, 0.3 becomes 0.4 etc.), therefore practitioners who use this software will find 0.2, 0.4, 0.6, 0.8 and 1 s relevant.

Statistical Analysis

Data in the figures are presented as means and in tables as effect size and 90% confidence limits (CL). All data were first log-transformed to reduce bias arising from non-uniformity of error. Differences in the number of efforts recorded between each MED and differences in the number of efforts recorded between software filters were standardised using Cohen's effect size principle with 90% CL. Uncertainty in each effect was expressed as 90% CL and as probabilities that the true effect was substantially greater than the smallest important positive or negative difference. These probabilities were used to make a qualitative probabilistic mechanistic inference about the true effect using the following scale: >25 – 75%, possibly; >75-95%, likely; >95 – 99%, very likely; >99%, almost certainly.[18,19] The magnitude of a given effect was determined from its observed standardized value (the difference in means divided by the between subject standard deviation) using the following scale; <0.20, trivial; 0.20-0.59, small; 0.60-1.19, moderate; 1.20-1.99, large; ≥2.00, very large.[18,19] For clarity only effects with a likelihood >75% are presented.

Results

Efforts detected during 10 -20 - 40m Sprint Tests

During the 10, 20 and 40 m sprints only one high-speed running effort was detected for each test regardless of the MED and filtering method. Similarly only one sprint effort was detected during the 40 m sprint regardless of the MED and filtering method, while no sprint efforts were detected during the 10 and 20 m sprints..

There were substantial differences in the number of acceleration efforts detected between most of the different MED during the 10, 20 and 40 m sprints (Figure 2). Notably, $Accel_{openfield}$ resulted in fewer differences across the MED (Figure 2C). A 0.2, 0.3 and 0.4 s MED resulted in the identification of more than one acceleration effort per sprint when analysed using $Accel_{sprint\_0.2}$ and $Accel_{sprint\_0.3}$ as did a MED of 0.2 s when using $Accel_{Openfield}$ (Figure 2). When comparing differences in the filtering methods, the number of acceleration efforts detected were greater for shorter MED for both $Accel_{sprint\_0.2}$ and $Accel_{sprint\_0.3}$ compared to $Accel_{Openfield}$ and lower for longer MED (Table 1). The number of acceleration efforts determined using $Accel_{sprint\_0.3}$ was lower for shorter MED compared to when using a 0.2 s interval, however these differences became unclear as the MED increased (Table 1).

---Figure 2 here---

Efforts detected during a competitive match

The number of high-speed running and sprint efforts identified during a match appeared to decline exponentially with an increase in the MED for both the Sprint^{TM} and Openfield^{TM} filtering (Figure 3). The number of high-speed running and sprint efforts identified during a match using the Openfield^{TM} filtering were higher by a small to large magnitude which declined with increasing MED from 0.1 to 0.3 s, however, from 0.6 s on the differences were either unclear or clearly trivial (Table 2).

---Figure 3 here---

There was an exponential decline in the number of acceleration efforts identified during a match as the MED increased for all filtering methods (Figure 4). The number of acceleration efforts identified using $Accel_{Openfield}$ were lower by a large to very-large magnitude for MED lower than 0.5 s compared to using both $Accel_{sprint\_0.2}$ and $Accel_{sprint\_0.3}$ (Table 2). A greater number of acceleration efforts were identified for a 0.2 and 0.3 s MED when using $Accel_{sprint\_0.2}$ compared to $Accel_{sprint\_0.3}$ and lower number for a 0.4 and 0.5 MED (Table 2).

---Figure 4 here---

Discussion

The main finding of this study was that changes in the MED as small as 0.1 s substantially affected the number of accelerations, high-speed running and sprint efforts detected during matches. A secondary finding was that the use of different filtering methods used to smooth velocity and acceleration data changed the number of efforts identified.

Of all efforts, the number of accelerations were most affected by different MED and filters. The analysis of individual sprints over 10, 20 and 40 m allowed the evaluation of different MED for acceleration efforts from a practical perspective. The MED resulting in the detection of more than 1 acceleration effort per sprint (0.2, 0.3 and 0.4 s when using Sprint™ filtering and 0.2 s when using Openfield™ filtering) could be suggested to overestimate the number of acceleration efforts occurring. However, in a competitive match MED greater than 0.5 s detected no more than 6 efforts regardless of the filtering method used (Figure 6). The duration an athlete can sustain a high rate of acceleration is very short [13] and longer MED may exclude maximal accelerations. An explanation for the detection of multiple accelerations during the sprint tests is that the manufacturer's software defines the end of an acceleration effort as when acceleration falls below the specific threshold for a single sample (0.1 s). As GPS acceleration data is subject to noise, this could result in what would practically be termed a single acceleration effort being classified as two separate efforts as can be seen in Figure 1. To test this assumption, the $Accel_{sprint\_0.2}$ and $Accel_{sprint\_0.3}$ data was reanalysed using previously established methods[4] where the end of an acceleration effort was defined as when acceleration fell below 0 $m.s^{-2}$ following the detection of an effort. As shown in Figure 5, this resulted in the detection of multiple acceleration efforts for a MED of 0.2 s only, while all other durations detected no more than a single effort, confirming the above hypothesis.

---Figure 5 here---

The method used to identify the end of the effort is just as important as the MED, however, this is often overlooked. Various methods can be used such as establishing a minimum duration for velocity/acceleration to fall below the set threshold or requiring a drop in velocity/acceleration below a percentage of the set threshold. How the end of an effort is identified should be based on the user's practical needs of the data. As an individual may continue to accelerate until their rate of acceleration falls below 0 $m.s^{-2}$, this may be a more practical definition for identifying acceleration efforts than purely quantifying the extremely short duration spent accelerating above the required threshold and may better represent the perception of an acceleration held by a coach or other support staff. This method also allows practitioners to use lower MED (e.g. 0.3 or 0.4 s) with confidence that single acceleration efforts will not be detected as multiple efforts (Figure 5A and5C). The limitation to this approach is where an athlete accelerates maximally, their rate of acceleration falls below threshold but not 0 $m.s^{-2}$ and then rises again, as this would only be considered a single effort. Practitioners can either use both methods or choose one based on their needs. An endpoint where acceleration falls below the maximum threshold may be more relevant for practitioners interested in when athletes are only working at their most energetically demanding. An endpoint where acceleration falls below 0 $m.s^{-2}$ may provide a more practical measure of acceleration efforts allowing greater contextualisation of the movement.

The additional filtering used by the Openfield™ software resulted in a substantially lower number of accelerations recorded during the match. A large change in the number of accelerations detected has also been observed following a software upgrade using GPS from other manufacturers (GPSports).[14] The results of this study suggest these changes were due to the implementation of a more severe smoothing filter on the acceleration data. In this study, absolute acceleration and velocity thresholds were used to demonstrate the methodological differences when analysing GPS data. While new filters may provide a more realistic representation of acceleration and velocity efforts they may also require the user to re-evaluate the thresholds they have used to define their movements. For example, Figure 1 demonstrates the different smoothing methods used to determine acceleration result in substantially different peak acceleration values. Velocity would also show differences in the maximal values if a smoothing filter is applied, such as the exponential filter used in Openfield™. Thus, for a given threshold the greater the smoothing applied to velocity and acceleration data, the less an athlete would be expected to reach a given threshold. A possible way to address this issue may be to develop device or filter specific thresholds. If movement thresholds are based on athlete physical testing, athletes could wear the GPS during these tests allowing data to be processed for each filtering technique. For example, if the sprint threshold is defined as percentage of Maximal Sprint Speed recorded by GPS during a 40 m sprint,[20] GPS data could be reprocessed when/if a new data filter is used to maintain a consistent threshold. This will reduce the impact of changing manufacturers/software on longitudinal monitoring.

Regardless of the methods used practitioners should be aware that there is no perfect combination for detecting acceleration efforts. A lower MED will likely overestimate the number of acceleration efforts while a higher MED will likely underestimate the number of efforts. Further, applying a greater smoothing method to the data will allow lower MED to be used while a lower smoothing method may restrict the user to higher MED. Understanding the advantages and limitations of each method will allow practitioners to choose the combination that best suits their needs. It should also be acknowledged that this study has only considered maximal acceleration efforts, which primarily occur at low velocities.[4] The effect of different methods to identify low and moderate accelerations are likely to be even more pronounced as athletes are likely to have much greater oscillation around lower rates of acceleration.

The MED used to identify velocity based efforts showed smaller discrepancies than that of acceleration based efforts. Given that the 10, 20 and 40 m sprints were all maximal it is not surprising that there was no difference in the number of high-speed running or sprint efforts detected. However, during a match different MED resulted in the number of efforts decreasing in a somewhat exponential manner as duration increased (Figure 3). This is likely due to the intermittent nature of match-running where players may oscillate around specific velocity thresholds, whereas during sprint tests velocity is linearly increasing. Further, the exponential filter used in Openfield™ resulted in a greater number of efforts being identified compared to the median filter used in Sprint™. Likewise, there were more and larger differences in the number of efforts according to MED when analysed with Openfield™ compared to Sprint™. Similar to acceleration, different smoothing filters can have a substantial effect on velocity data and efforts detected, an issue which is likely to occur regardless of manufacturer where different filters are used.

Movement categories can be separated into a number of threshold bands such as running (e.g. 4.17 to 7.00 $m.s^{-1}$). However, in this study, the thresholds for high-speed running (>4.17 $m.s^{-1}$) and sprinting (>7.00 $m.s^{-1}$) were both open-ended, therefore high-speed running efforts also included sprint efforts. The use of threshold bands may be more appropriate when determining the distances covered within each band rather than the number of efforts within each band. It is difficult to determine a MED required within each band as an athlete will pass through all bands when sprinting from a low speed. Depending on the rate of acceleration this may result in multiple efforts for what is ultimately a single sprint effort. The use of efforts according to threshold bands may have limited practical application for practitioners. A similar argument could be made when considering banded rates of acceleration effort, especially as the higher the rate of acceleration, the shorter the maximal acceleration is likely to be. There is currently no consensus on how the total number of high speed or high-intensity efforts should be defined. For example, if an athlete performs 30 sprint efforts (>7.00 $m.s^{-1}$) and 50 running efforts (4.17 to 7.00 $m.s^{-1}$), 30 of which ultimately lead to sprints, should these be considered separately (i.e. 80 independent high-speed efforts) or in combination (i.e. 30 sprints and 20 running efforts)? This is an important topic with regards to profiling high-intensity movements and practitioners should make their decision based on how the information will be used.

Practical Applications

- Different data filtering methods and MED can substantially effect the number of high-intensity movements detected using GPS devices
- Practitioners and researchers should include detailed information regarding the filtering techniques and settings used to determine movement efforts in practical reports and research publications.

- If velocity or acceleration thresholds are based on physical capacities, practitioners should establish a set of reference data which can be reprocessed using different smoothing filters to adjust these thresholds accordingly.
- When defining acceleration efforts practitioners may consider defining the end of an effort as when acceleration falls below 0 $m.s^{-2}$ to provide a more practical measure
- Practitioners should use a consistent method when analysing athlete velocity and acceleration data during a season, and any changes to this method should be done at the end of the season and may be applied to retrospective data

Conclusion

Different filtering techniques and MED substantially affected the number of high-intensity efforts detected with GPS. While this study provides novel insights into this area, it is difficult to provide a recommendation for the appropriate filtering and MED to be used with high-speed running, sprinting and acceleration efforts based on the results. It is unlikely that practitioners using manufacturer software will be able to select the type of filter used, and may be restricted in their choice of MED. Practitioners and researchers should be aware that changes to filtering and MED are likely to affect reported data. The key recommendation is that practitioners maintain consistency as much as possible in their data processing. Also following a software or firmware update that affects data filtering, practitioners may consider re-analysing retrospective data to allow ongoing comparison of the data. Finally, the different filtering of velocity and acceleration data will also effect the distances athletes cover at specific thresholds and this should be explored in future research.

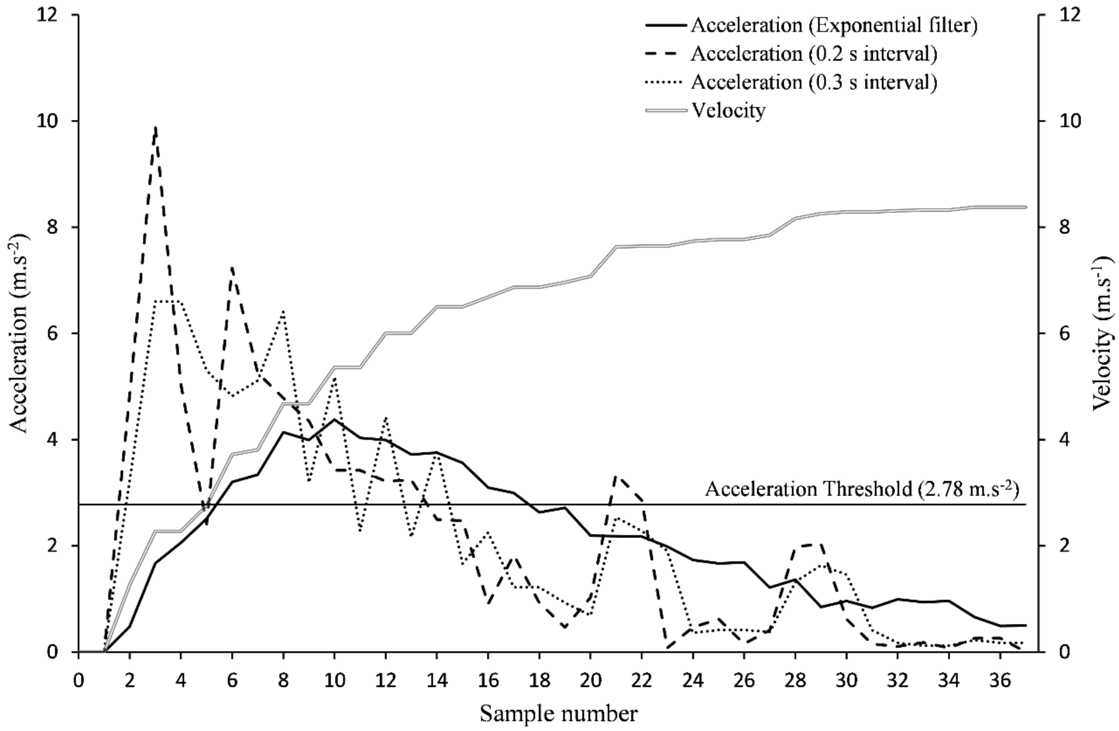

Figure 1. GPS velocity and acceleration data during a 40 m sprint effort. The graph demonstrates the smoothing effect when acceleration is derived from velocity using a different intervals (0.2 and 0.3 s) and when data is processed using an exponential filter (acceleration was derived using a 0.2 s interval). The threshold used to identify an acceleration effort is indicated by the line running parallel to the x axis at 2.78 m.s^{-2}.

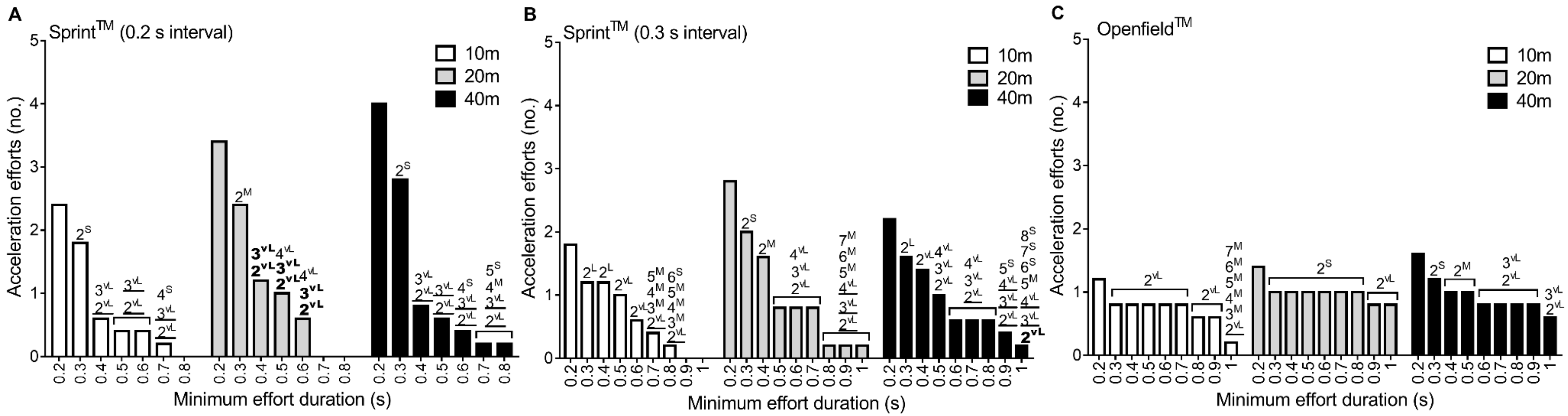

Figure 2. The number of acceleration efforts detected during 10, 20 and 40 m sprints when using different minimum effort durations and different filtering methods. The Sprint^{TM} software derives acceleration from velocity data over a 0.2 (Figure A) or a 0.3 s interval (Figure B) and Openfield^{TM} software derives acceleration from velocity data over a 0.2 s interval and then applies an exponential filter (Figure C). For each sprint test n=6._Quantitative chances of higher or lower differences between minimum effort durations are evaluated according to thresholds identified in statistical analysis; normal text = Likely, underlined text = Very likely, bold text = Almost certainly. T = Trivial effect size, S = small effect size, M = moderate effect size, L = large effect size, vL = very large effect size. 2, 3, 4, 5, 6, 7, 8 indicate an effect compared to a minimum duration of 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, respectively.

Table 1. Differences in the number of acceleration efforts detected during 10, 20 and 40 m sprints according to the filtering method used. For each sprint test n=6. Data is effect size and 90% confidence limits

	Sprint™ 0.2 vs Openfield™	Sprint™ 0.3 vs Openfield™	Sprint™ 0.2 vs Sprint 0.3
Minimum duration	**Acceleration efforts**	**Acceleration efforts**	**Acceleration efforts**
10 m Sprint			
0.2	-1.13 (-2.49 to 0.22)*	-0.64 (-1.85 to 0.57)*	-0.49 (-0.99 to 0.00)*
0.3	-0.64 (-1.59 to 0.31)*	-0.12 (-0.29 to 0.04)*	-0.51 (-1.51 to 0.49)
0.4	0.32 (-0.37 to 1.01)	-0.10 (-0.22 to 0.03)	0.42 (-0.23 to 1.07)
0.5	0.65 (-0.20 to 1.51)*	-0.05 (-0.15 to 0.06)**	0.70 (-0.11 to 1.52)*
0.6	0.62 (-0.19 to 1.43)*	0.31 (-0.35 to 0.97)	0.31 (-0.35 to 0.97)
0.7	0.99 (0.13 to 1.86)*	0.66 (-0.20 to 1.53)*	0.33 (-0.37 to 1.04)
0.8	1.18 (0.15 to 2.20)*	0.78 (-0.24 to 1.81)*	0.39 (-0.44 to 1.23)
0.9	*NA*	*NA*	*NA*
1	*NA*	*NA*	*NA*
20 m Sprint			
0.2	-1.74 (-2.32 to -1.17)***	-1.26 (-2.12 to -0.40)**	-0.48 (-1.00 to 0.03)*
0.3	-1.99 (-2.48 to -1.50)***	-1.34 (-2.57 to -0.12)*	-0.64 (-1.70 to 0.41)*
0.4	-0.39 (-1.23 to 0.44)	-1.18 (-2.20 to -0.15)*	0.78 (-0.24 to 1.81)*
0.5	0.36 (-0.59 to 1.32)	0.43 (-0.48 to 1.34)	-0.06 (-1.51 to 1.38)
0.6	0.78 (-0.24 to 1.81)*	0.39 (-0.44 to 1.23)	0.39 (-0.44 to 1.23)
0.7	*NA*	0.51 (-0.57 to 1.58)	*NA*
0.8	*NA*	2.02 (0.95 to 3.10)**	*NA*
0.9	*NA*	1.07 (-0.45 to 2.60)*	*NA*
1	*NA*	1.07 (-0.45 to 2.60)*	*NA*
40 m Sprint			
0.2	-2.26 (-3.19 to -1.33)***	-0.88 (-1.69 to -0.07)*	-1.38 (-2.19 to -0.57)**
0.3	-2.06 (-2.95 to -1.18)**	-0.67 (-2.1 to 0.76)	-1.4 (-2.33 to -0.46)**
0.4	0.61 (-0.69 to 1.91)	-0.18 (-0.42 to 0.06)	0.79 (-0.67 to 2.25)*
0.5	0.77 (-0.23 to 1.77)*	0.33 (-0.53 to 1.19)	0.44 (-0.36 to 1.24)
0.6	0.62 (-0.19 to 1.43)*	0.31 (-0.35 to 0.97)	0.31 (-0.93 to 1.55)
0.7	0.99 (0.13 to 1.86)*	0.33 (-0.37 to 1.04)	0.66 (-0.75 to 2.07)
0.8	0.99 (0.13 to 1.86)*	0.33 (-0.37 to 1.04)	0.66 (-0.75 to 2.07)
0.9	*NA*	0.64 (-0.20 to 1.48)*	*NA*
1	*NA*	0.64 (-0.20 to 1.48)*	*NA*

Negative values indicate a lower number of efforts were reported using the second software name in each column. Quantitative chances of higher or lower differences between filtering methods are evaluated according to thresholds identified in statistical analysis; * = Likely, ** = Very likely, *** = Almost certainly. NA indicates that no efforts were detected during one of the filtering methods.

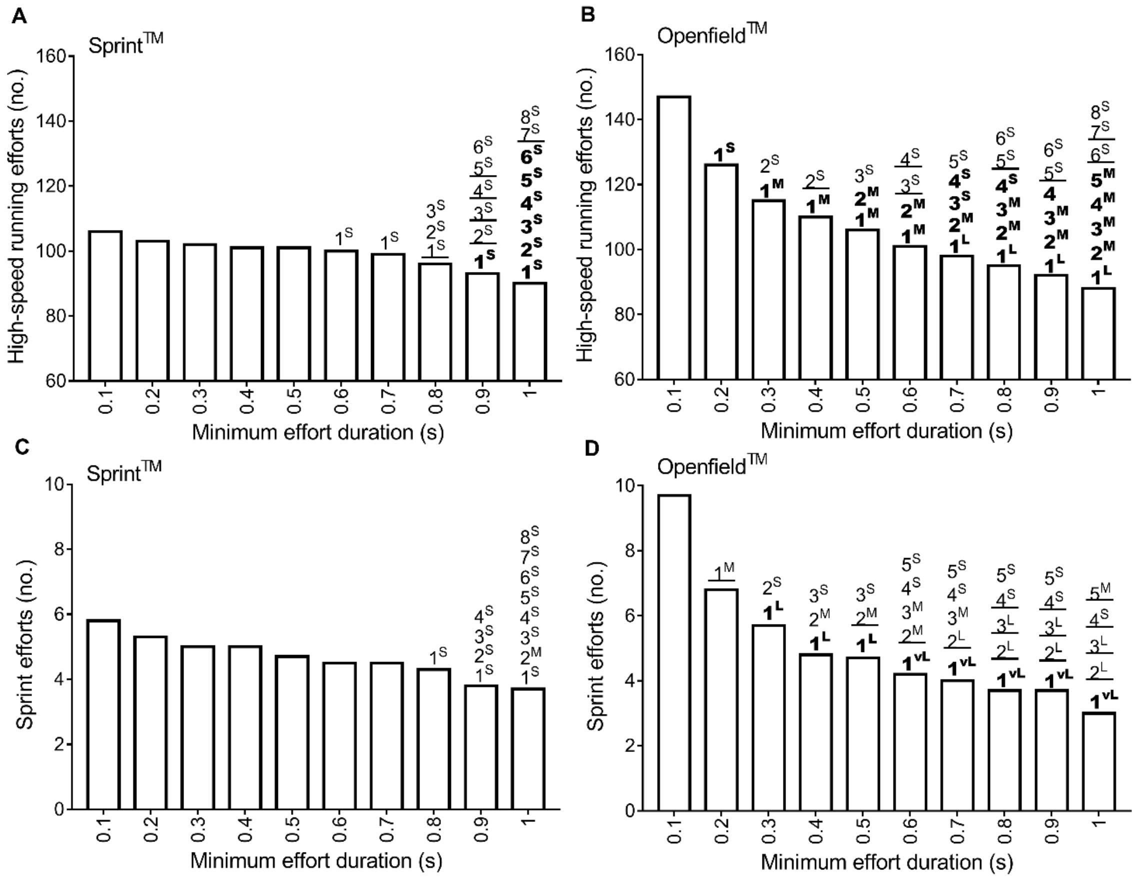

Figure 3. The number of high-speed running (Figure A and B) and sprint efforts (Figure C and D) performed by players (n=6) during a competitive match when detected using different minimum effort durations and different filtering methods. The Sprint^{TM} software uses a median filter and the Openfield^{TM} software uses an exponential filter. Quantitative chances of higher or lower differences between minimum effort durations are evaluated according to thresholds identified in statistical analysis; normal text = Likely, underlined text = Very likely, bold text = Almost certainly. S = small effect size, M = moderate effect size, L = large effect size, vL = very large effect size. 2, 3, 4, 5, 6, 7, 8, indicate an effect compared to a minimum duration of 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, respectively.

Table 2. Differences in the number of high-speed running, sprint and acceleration efforts performed by players (n=6) during a competitive match when detected according to the filtering method used. Data is effect size and 90% confidence limits

	Sprint™ vs Openfield™		Sprint™ 0.2 vs Openfield™	Sprint 0.3 vs Openfield™	Sprint™ 0.2 vs Sprint™ 0.3
Minimum duration	**High-speed running efforts**	**Sprint efforts**		**Acceleration efforts**	
0.1	1.09 (0.82 to 1.35)***	1.06 (0.41 to 1.70)**	*NA*	*NA*	*NA*
0.2	0.68 (0.5 to 0.85)***	0.50 (0.11 to 0.89)*	-5.69 (-6.51 to -4.88)***	-4.6 (-5.36 to -3.83)***	-1.09 (-1.25 to -0.94)***
0.3	0.39 (0.25 to 0.53)**	0.35 (-0.03 to 0.73)*	-5.30 (-6.12 to -4.47)***	-4.47 (-5.28 to -3.66)***	-0.82 (-0.92 to -0.72)***
0.4	0.28 (0.17 to 0.39)*	0.04 (-0.22 to 0.30)*	-2.26 (-3.03 to -1.48)***	-3.81 (-4.58 to -3.04)***	1.55 (1.33 to 1.77)***
0.5	0.17 (0.05 to 0.3)	0.008 (-0.21 to 0.37)	-0.78 (-1.29 to -0.26)**	-1.37 (-1.98 to -0.76)**	0.59 (0.24 to 0.95)**
0.6	0.04 (-0.03 to 0.12)**	-0.19 (-0.48 to 0.10)	0.55 (-0.09 to 1.20)*	0.30 (-0.48 to 1.07)	0.26 (0.02 to 0.49)
0.7	-0.04 (-0.09 to 0.01)***	-0.22 (-0.51 to 0.06)	0.44 (0.03 to 0.85)*	0.27 (-0.19 to 0.74)	0.16 (0.03 to 0.30)
0.8	-0.05 (-0.07 to -0.04)***	-0.31 (-0.59 to -0.02)	*NA*	0.18 (0.03 to 0.32)	*NA*
0.9	-0.05 (-0.15 to 0.05)**	-0.06 (-0.18 to 0.06)**	*NA*	1.06 (0.18 to 1.93)*	*NA*
1	-0.08 (-0.23 to 0.06)*	-0.22 (-0.45 to 0.01)	*NA*	*NA*	*NA*

Negative values indicate a lower number of efforts were reported using the second software name in each column. Quantitative chances of higher or lower differences between filtering methods are evaluated according to thresholds identified in statistical analysis; * = Likely, ** = Very likely, *** = Almost certainly. NA indicates that no efforts were detected during one of the filtering methods.

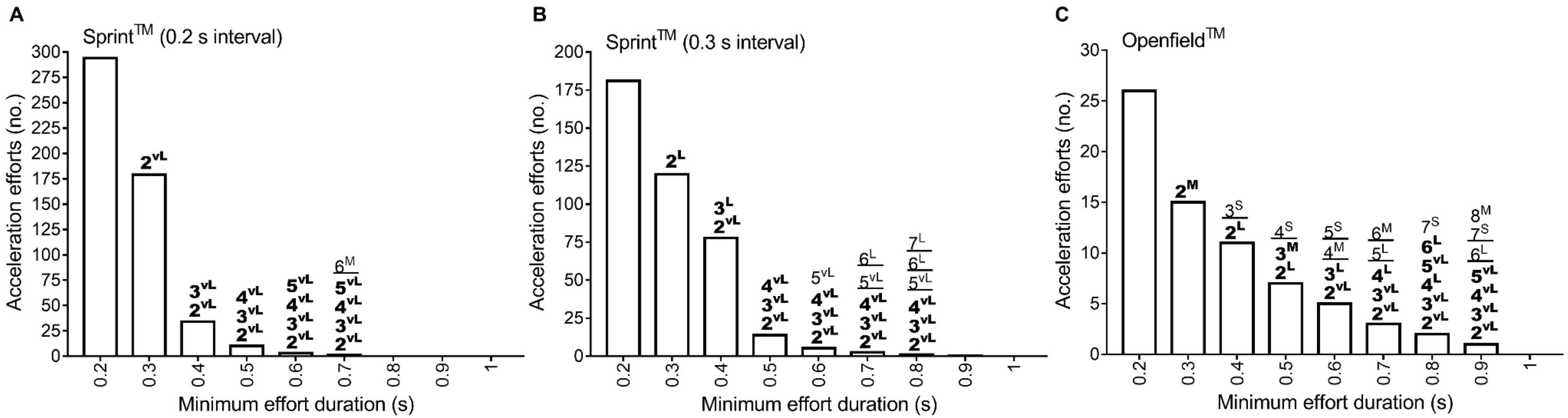

Figure 4. The number of acceleration efforts performed by players (n=6) during a competitive match when detected using different minimum effort durations and different filtering methods. The Sprint™ software derives acceleration from velocity data over a 0.2 (Figure A) or a 0.3 s interval (Figure B) and Openfield™ software derives acceleration from velocity data over a 0.2 s interval and then applies an exponential filter (Figure C). Quantitative chances of higher or lower differences between minimum effort durations are evaluated according to thresholds identified in statistical analysis; normal text = Likely, underlined text = Very likely, bold text = Almost certainly. S = small effect size, M = moderate effect size, L = large effect size, vL = very large effect size. 2, 3, 4, 5, 6, 7, 8 indicate an effect compared to a minimum duration of 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, respectively.

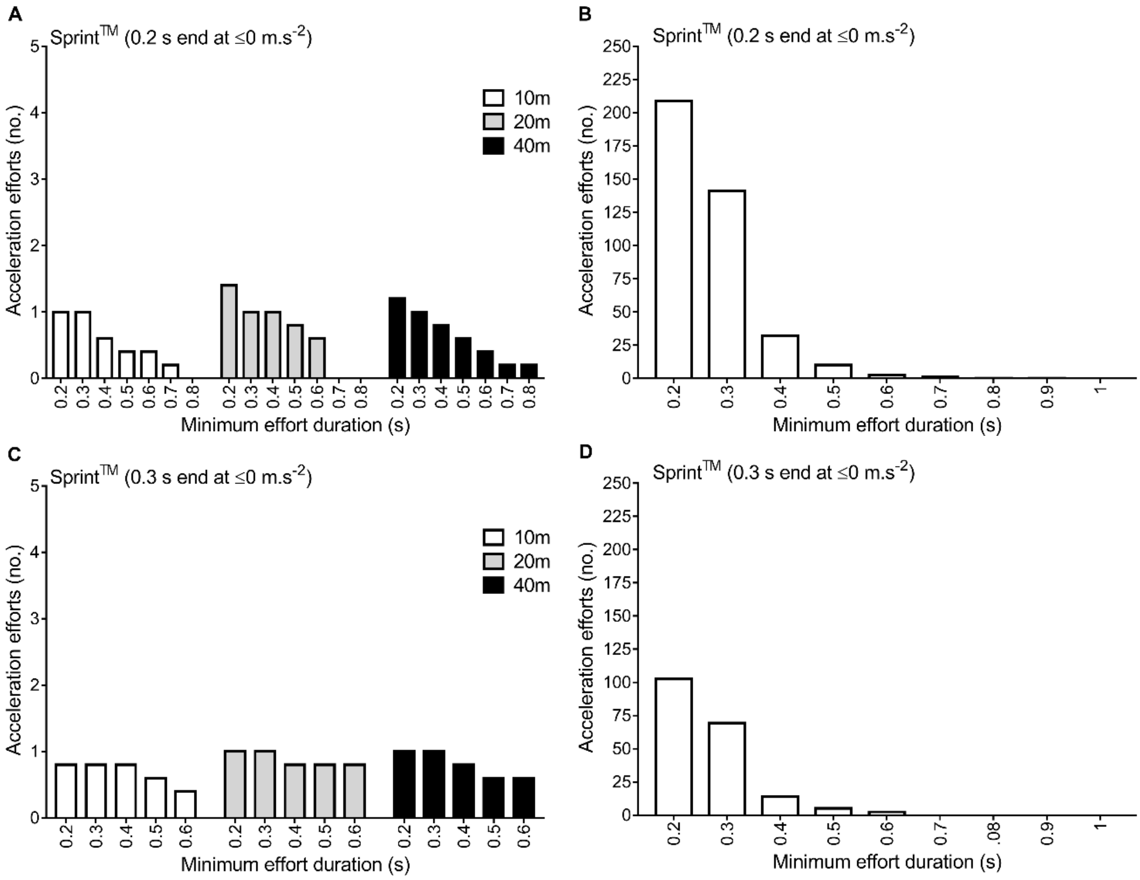

Figure 5. The number of acceleration efforts detected during 10, 20 and 40 m sprints (Figure A and C)and a competitive game (Figure B and D) when using different minimum durations. Acceleration is derived from velocity using a 0.2 s (Figure A and B) and 0.3 s (Figure C and D) interval and the end of the acceleration effort is identified when acceleration falls below or is equal to 0 $m.s^{-2}$

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