The validity and reliability of commercially available resistance training monitoring devices : A systematic review

Crang, Zachary L., Duthie, Grant, Cole, Michael H., Weakley, Jonathon, Hewitt, Adam and Johnston, Rich D.

Accepted manuscript. Crang, Zachary L., Duthie, Grant, Cole, Michael H., Weakley, Jonathon, Hewitt, Adam and Johnston, Rich D.. (2021). The validity and reliability of commercially available resistance training monitoring devices : A systematic review. *Sports Medicine*. 51, pp. 549-565. https://doi.org/10.1007/s40279-020-01399-1

RUNNING HEAD: Validity and reliability of wearable microtechnology

TITLE: The validity and reliability of wearable microtechnology for intermittent team sports: a systematic review

[a]Zachary L. Crang, [b]Grant Duthie, [a]Michael H. Cole, [a,c]Jonathon Weakley, [a]Adam Hewitt and [a,c]Rich D. Johnston,

[a]School of Behavioural and Health Sciences, Australian Catholic University, Brisbane, Australia

[b]School of Behavioural and Health Sciences, Australian Catholic University, Strathfield, Australia

[c]Institute of Sport, Leeds Beckett University, Leeds, United Kingdom

Corresponding author:

Zachary Crang

School of Behavioural and Health Sciences,

Australian Catholic University,

Brisbane, Queensland, Australia, 4014

Email: Zachary.crang@myacu.edu.au

Phone: +61 420687562

Abstract

Background Technology has long been used to track player movements in team sports, with initial tracking via manual coding of video footage. Since then, wearable microtechnology in the form of global and local positioning systems have provided a less labour-intensive way of monitoring movements. As such, there has been a proliferation in research pertaining to these devices.

Objective A systematic review of studies that investigate the validity and/or reliability of wearable microtechnology to quantify movement and specific actions common to intermittent team sports.

Methods A systematic search of CINAHL, MEDLINE and SPORTDiscus was performed; studies included must have been (1) original research investigations; (2) full-text articles written in English; (3) published in a peer-reviewed academic journal; and (4) assessed the validity and/or reliability of wearable microtechnology to quantify movements or specific actions common to intermittent team sports.

Results A total of 384 studies were retrieved and 187 were duplicates. The titles and abstracts of 197 studies were screened and the full-text of 88 manuscripts were assessed. A total of 62 studies met the inclusion criteria. An additional 10 studies, identified via reference list assessment, were included. Therefore, a total of 72 studies were included in this review.

Conclusion There are many studies investigating the validity and reliability of wearable microtechnology to track movement and detect sport specific actions. It is evident that for the majority of metrics, validity and reliability is multi-factorial, in that it is dependent upon a wide variety of factors including wearable technology brand and model, sampling rate, type of movement performed (e.g. straight-line, change of direction) and intensity of movement (e.g. walk, sprint). Practitioners should be mindful of the accuracy and repeatability of the devices they are using when making decisions on player training loads.

Key Points

- Wearable microtechnology validity and reliability is dependent upon a wide variety of factors including brand, sampling rate, type of movement performed and intensity of movement.
- When making decisions on player training loads, practitioners should bear in mind the accuracy and precision of the devices they are using when (1) determining which metrics to track; (2) progressing or regressing an individual's training; (3) providing 'top up' sessions to players based on comparisons to planned loads or other players.
- Global navigation satellite systems (GNSS) generally possess suitable validity for measuring distance during team sport movements; while validity can be compromised when straight-line and frequent change of direction movements are performed in isolation for devices with a sampling rate < 10-Hz.
- Practitioners should utilise GNSS with a sampling rate ≥ 10-Hz to minimise the error associated with distance measures, particularly when movements are performed in isolation (e.g. during rehabilitation drills).
- Global navigation satellite systems generally possess suitable validity for measuring peak velocity during straight-line sprinting.
- Local positioning systems appear to be a suitable alternative to GNSS for measuring common metrics (e.g. total distance, average speed), as long as they are set-up correctly, although further research must be performed to establish the true validity and reliability of these systems for other measures (e.g. peak velocity).
- Intra-device reliability is poorly researched; these studies report a combination of biological and technological variation (intended measure) of the device. As such, the true intra-device reliability is difficult to determine in most instances.

1 Background

The importance of tracking athlete training intensity and volume to manage fatigue [1], fitness [2-3], injury [4-5] and performance [6-7] has been well established. Subjective ratings of exertion and heart rate are collected to provide an indication of an athlete's internal response to training [8], while player movements have historically been tracked via manual coding of video footage [9-10] or with semi- or fully automated systems to gain an understanding of the amount of training performed (i.e. external training load). However, the limitations associated with these tracking tools led to the development of wearable microtechnologies that allow for numerous metrics to be collected, and measured in both real-time, and downloaded following each session; helping quantify the external loads that athletes are exposed to [11]. Since wearable microtechnologies were introduced to track players' movements, they have become central to sport science, with GNSS, local positioning systems (LPS) and inertial measurement units (IMU) all used across a variety of sports.

Sports that commonly use GNSS and LPS technology to track external loads include rugby league, rugby union, soccer, Australian football, American football, basketball and netball [12]. Total distance, velocity-based threshold distance, velocity (peak, instantaneous, average), accelerations and decelerations are commonly collected metrics [12-13]. The majority of GNSS devices are equipped with a triaxial accelerometer (typically 100-Hz) capable of measuring acceleration in three axes (x, y, z) to compute a composite vector magnitude (*g* force) [12], termed accelerometer load. Some devices also include gyroscopes and magnetometers, which coupled with the accelerometer and termed IMUs, have been used to develop algorithms for the autodetection of sport specific events such as physical collisions in rugby league [14-15], scrum, ruck, and one-on-one tackle detection in rugby union [14, 16], and balls bowled in cricket [17]. Given that GNSS, LPS and IMU tracking devices house multiple sensors collecting various information, they can be collectively referred to as wearable microtechnology.

Over the last decade, there has been a proliferation in research investigating the association between external training load (measured by wearable devices) and player injury risk [4, 18-21], physical fitness [2, 22], in-season availability [23], match activity [24] and technical performance [6, 24]. In turn, practitioners are using the information collected by these devices to minimise injury risk, while increasing physical fitness, in-season availability, physical match activities and technical performance. Therefore, it is important that these devices are both valid and reliable in their measurements, allowing stakeholders to make well-informed decisions.

The validity of an instrument is defined as its ability to measure what it is intended to measure with accuracy and precision [25]. This is typically quantified by comparing the output of the respective instrument to the ‘gold-standard’ or criterion measure. Typical measures of validity include bias (relative and absolute), standard error of the estimate (SEE), standard error of measurement (SEM) and typical error (TE) expressed as a coefficient of variation (CV) [26]. However, when data is received as a time series, other measures such as the root mean square error (RMSE) and mean absolute error (MAE) can be used and expressed as a percentage.

The reliability of an instrument denotes its ability to reproduce measures on separate occasions when it is known that the measure of interest should not fluctuate [27]. Otherwise termed ‘intra-device’ or ‘test-retest’ reliability, this is important when tracking and identifying ‘meaningful’ changes over a specified period (i.e. within player). Further, when the measures of numerous devices are compared (i.e. a squad of players), ‘inter-device’ or ‘between device’ reliability is important. Typical measures of reliability include TE expressed as a CV and intra-class correlations (ICC) [26]. Intra-class correlations quantify the association between two variables that have a permanent degree of relatedness [28], while CV describes the variability between multiple data sets [29].

In 2016, a review of the studies that had examined the validity and reliability of GNSS for quantifying team sport movements was conducted [26]. However, this review did not consider the validity and reliability of other common wearable microtechnology (i.e. LPS). Further, the advances that have been made in GNSS manufacturing since this review have seen numerous changes to these devices and a general increase in the number of units available to the consumer. Given the steady growth of wearable microtechnologies, importance placed upon their output by practitioners, and the commensurate increase in research assessing the validity and reliability of these devices since this earlier review (pre-2017 = 86 studies vs. post-2017 = 76 studies), an updated review of the literature is warranted. Therefore, the aim of this review was to identify and appraise peer-reviewed studies that investigated the validity and/or reliability of wearable microtechnology to quantify movement and specific actions common to intermittent team sports.

2 Methods

2.1 Search Strategy

This systematic review was prepared in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [30]. The academic databases SPORTDiscus, CINAHL and Medline were systematically searched from earliest record to March 2020 to identify English-language peer reviewed original research studies that investigated the validity and/or reliability of wearable microtechnology to quantify movement patterns commonplace to intermittent team sport. Studies were identified by searching abstracts, titles and key words for pre-determined terms relevant to the scope of this review (Table 1). All search results were extracted and imported into a reference manager (EndNote X9, Thomson Reuters, Philadelphia, PA, USA).

INSERT TABLE 1 NEAR HERE

2.2 Selection Criteria

The duplicate studies were removed, and the titles and abstracts of all remaining studies were scanned for relevance by two authors (ZC & RJ). Studies that were deemed beyond the scope of the review were removed. The full text of the remaining studies were then assessed for eligibility. To be eligible for inclusion, studies must have (1) been original research investigations; (2) full-text articles written in English; (3) published in a peer-reviewed academic journal; and (4) assessed the validity and/or reliability of wearable microtechnology to quantify movement or specific actions common to intermittent team sports (e.g. rugby league, rugby union, Australian football, handball, basketball, soccer, cricket). 'Validity' and 'reliability' were defined using the definitions previously outlined in this review and elsewhere [25, 27]. If it was deemed that a study did not meet the inclusion criteria, it was removed from the analysis. The reference list of all eligible studies was then manually searched for any studies that were not retrieved in the initial search. If a study was identified, it was subjected to the same assessment as previously described.

2.3 Data Extraction and Analysis

All relevant data were extracted into a Microsoft Excel (2016; Microsoft Corp, Redmond, WA, USA) spreadsheet by two of the authors (ZC & RJ). The data extracted from each study included: study type (e.g. validity or reliability), wearable device(s) used, sampling rate, movements performed, criterion measure (where relevant) and relevant findings (e.g. CV, bias). The heterogenous nature of the studies to be identified prevented further data analysis (e.g. meta-analysis). In addition, further analysis would require the extraction of the raw means ± SDs, which was not typically reported in inter-device reliability studies.

2.4 Research Quality Assessment

The quality of research was assessed by the same two authors (ZC & RJ) using a modified version of the Downs and Black checklist [31] (Table 2). This method is valid for assessing the methodological quality of observational study designs [31] and has been previously used by systematic reviews pertaining to sport science [32]. Quality was assessed a total of either eight, nine or ten items depending on the study design (e.g. validity *vs.* validity and reliability). Items were scored on a scale from '0' (unable to determine, or no) to '1' (yes). Quality scores were expressed relative to the best attainable score for each respective study, in which "100%" indicates the highest study quality.

INSERT TABLE 2 NEAR HERE

3 Results

3.1 Identification of Studies

The systematic search retrieved a total of 384 studies in which 187 were removed as duplicates. The titles and abstracts of the remaining 197 studies were screened and in turn, 109 were deemed as clearly outside the scope of the review. As such, they were removed and the full manuscript of the remaining 88 studies were assessed. In turn, it was identified that 62 studies met the inclusion criteria. An additional 10 studies, identified via reference list assessment, were also included. Therefore, a total of 72 studies were included in this review. The identification process is outlined in Figure 1.

INSERT FIGURE 1 NEAR HERE

3.2 Research Quality

The quality of the research investigating the validity and/or reliability of wearable microtechnology when assessed against a modified version of the Downs and Black checklist [31] ranged from a score of 64 to 100% (mean ± SD; 86.4 ± 10.8%) (Supplementary Table 1). The items that were not satisfied most frequently were seven (deviations [i.e. SD, CI, LoA] of primary results reported), 18 (statistical analysis employed [e.g. SEE, CV, SEM, RMSE] is suitable and clearly reported) and 20 (criterion measure valid and reliable [e.g. 3D motion analysis]).

3.3 Study Characteristics

The studies in this review investigated the validity and reliability of wearable microtechnology such as GNSS (*n* = 47 studies), LPS (*n* = 12 studies) and IMUs (*n* = 23 studies). The results of the studies examining the validity (*n* = 59 studies; Supplementary Table 2 to 10), inter-device reliability (*n* = 25 studies; Supplementary Table 11 to 18) and intra-device reliability (*n* = 22 studies; Supplementary Table 19 to 25) are presented based on the metric assessed, while further grouped within-table by the device examined. Common metrics include total distance (Supplementary Table 2, 11 and 19), velocity-based threshold distance (Supplementary Table 3, 12 and 20), peak velocity (Supplementary Table 4, 13 and 21), instantaneous velocity (Supplementary Table 5 and 14), average speed (Supplementary Table 6, 15 and 22) and acceleration/deceleration-based metrics (Supplementary Table 9, 16, 23). Further metrics include collision frequency (Supplementary Table 7), sport specific events (e.g. cricket bowling) (Supplementary Table 8), accelerometer load (Supplementary Table 17 and 24), and others (Supplementary Table 10 and 18).

4 Discussion

The aim of this systematic review was to identify and subsequently appraise studies that investigated the validity and/or reliability of wearable microtechnology to quantify movement and specific actions common to intermittent team sports. Most validity studies identified in this review did not use, 'gold standard' (i.e. high-speed 3D motion capture systems [e.g. VICON [Oxford Metrics, Ltd, Oxford, United Kingdom]], radar) criterion measures. Thus, to establish the true validity of wearable microtechnology, this should be a focus of future research. In examining the findings of studies in this review, precedence should be given to those using 'gold-standard' criterion measures. Intra-device reliability was poorly researched, with studies relying on human participants to perform the exact same movement repeatedly, which is unlikely to occur. Consequently, the 'intra-device reliability' reported consists of both biological and technological variation, and the true intra-device reliability cannot be determined.

Given the heterogenous nature of the statistical analysis employed between studies, it is difficult to provide collective interpretations of validity and reliability. However, for the purpose of the review, validity and reliability were generally deemed ‘suitable’ or ‘accurate’ if the error or variation was below 10%, as seen in previous research pertaining to wearable microtechnology [26, 33].

4.1 Validity

In the validity studies, statistical analysis (e.g. null hypothesis test, ICC, Pearson’s correlation co-efficient) that does not provide sufficient detail about the magnitude and direction of error were used as the primary analysis in some instances (13.6% of validity studies). In addition, simply examining the average difference (i.e. bias) between two measures is also problematic when dealing with time series data. For example, the time series could fluctuate significantly above and below the true value, yet a small bias or error could be reported by the positives and negatives cancelling each other out. In turn, to suitably assess the validity (e.g. SEE, SEM, CV, RMSE) and reliability (e.g. CV) of wearables, an assessment of the residuals must be incorporated in the future.

4.1.1 Total distance

The results for this section are displayed in Supplementary Table 2.

4.1.1.1 Global Navigation Satellite System

The majority of devices are able to accurately quantify total distance during shuttle-like activities [34-40], continuous movements that do not incorporate frequent directional change [35, 37-48], and team sport circuits [34, 42-44, 48-57]. However, when movements are performed in isolation, validity appears to be impacted by various factors. Indeed, 1-Hz validity is compromised during straight-line movements that are performed over short-distances (e.g. < 40 m) [52, 58], while 5-Hz validity appears superior for ‘GPSports’ (SEE = 2.6 – 10.5%, CV = 4.8 – 8.1%) and ‘WIMU’ (bias = -8.0 – 1.4%) manufacturers compared to ‘Catapult’ (Catapult, SEE = 2.9 – 30.9%) [37, 52, 57, 59]. Overall, validity improves as the distance travelled increases [37, 52, 57, 59], while frequent directional change appears to degrade accuracy [40, 52, 58]. One study has reported that a 5-Hz device is valid during some direction change protocols, however, the null hypothesis test to assess validity does not provide the magnitude of the error, which may in fact be substantial [40]. It appears that the velocity in which movements are performed also plays a role, with validity reducing as movement velocity increases [47, 52].

Sampling rate is clearly important to the validity of a unit's measurements, with the margin of error generally smaller for devices that have higher frequencies (≥ 10-Hz), compared to 1- and 5-Hz devices. However, given the heterogenous nature of the studies in question, it is difficult to make direct comparisons. Indeed, it appears that most devices with sampling frequencies of ≥ 10-Hz are not heavily influenced by short straight-line movement [17, 34, 36, 40, 43-44], frequently repeated change of direction [34, 36, 41-42, 46] or high-movement velocity [39, 41, 44]. Interestingly, one study has shown a significant difference between the output of both 10-Hz 'MinimaxX S4' and 15-Hz 'SPI-ProX' units when compared with high-speed 3D motion analysis system during activities incorporating various types of directional change [40]. Although a true 'gold-standard' criterion was used, this study employed a null hypothesis test in isolation to quantify validity, and therefore the magnitude of any error cannot be ascertained. Thus, more consideration must be given to the findings of studies that use a suitable statistical analysis while making comparisons to a true gold-standard criterion [34]. Nonetheless, practitioners should utilise devices with a sampling rate ≥ 10-Hz to minimise the error associated with distance measures, particularly when movements are performed in isolation (e.g. during rehabilitation drills).

4.1.1.2 Local Positioning System

Only 10 studies have investigated the accuracy of LPS to measure distance. These devices are accurate during continuous movement with limited directional change [41], shuttle activities [34], team sport circuits [34, 51, 60-61], direction change courses [41, 60-65], short straight-line movements [62-65], small sided games [34] and match-play (basketball) [66]. Therefore, it appears that LPS is not compromised by frequent change of direction [41, 60-65], short-distance movement [62-65] or high-movement velocities [41, 60-65]; findings that are in contrast to some traditional GNSS devices. Although it is encouraging that a system has been reported as accurate during match-play, the criterion (trundle wheel) method that was used in this study is vulnerable to human measurement error [66]. Nonetheless, these systems appear accurate during a variety of movements replicating match-play, when compared to 'gold-standard' 3D motion analysis [34, 62, 65]. Unlike GNSS however, LPS systems require careful set-up in line with the manufacturer recommendations. Indeed, when set-up 'sub-optimally' (i.e. system asymmetrical, small distance between nodes and testing area), the errors are much larger (bias = 15.0 – 29.5%), compared to 'optimal' set-up (bias = 0.5 – 1.8%) [63]. In terms of validity, LPS is a suitable and potentially superior alternative to GNSS for quantifying distance.

4.1.2 Velocity-based threshold distance

The results for this section are displayed in Supplementary Table 3.

4.1.2.1 Global Navigation Satellite System

Practitioners will regularly discretise data into velocity-based thresholds, such as low-, moderate- and high-speed activity. The literature investigating the accuracy of GNSS to measure velocity-based threshold distance is small, with only three different devices examined. This is likely attributable to the expensive nature of the criterion system (high-speed 3D motion analysis) required. It is crucial that further research is conducted in this area, given practitioners frequently use 'high-speed' running metrics to make decisions about injury risk and prevention [4, 20]. The issue with threshold-based distance, is the discretisation of a continuous variable into a categorical one, which can result in a large amount of information loss through over-simplification of data. Further, noise in the data can produce skewed results [67]. To maintain the accuracy of time series data, a specific algorithm should be used, but in most cases, is not [68]. While there is a plethora of statistical techniques available to discretise data, such as change point analysis, this methodical approach has typically not been used for GNSS timeseries data. This is potentially due to a lack of understanding of complex methods, where selecting the correct number of intervals or zones is a difficult task [69]. The accuracy of a device is also influenced by the validity of the segmentation algorithm used to discretise the time series data into specific activities (e.g. distance above 5.5 $m \cdot s^{-1}$). If the segmentation algorithm is inaccurate, this will impact the returned metrics. Therefore, the segmentation algorithm must also be validated to ensure that the distances we are measuring during the activities reflect those that we originally intended to examine.

In shuttle like activities (70 m bouts), 5- and 10-Hz devices can accurately measure distance that is covered while movement velocity is above 4.17 $m \cdot s^{-1}$, with a significant reduction in validity for that above 5.56 $m \cdot s^{-1}$ [38]. An increase in sampling rate to 15-Hz does not appear to improve validity [34], with a large margin of error for across a range of different thresholds (RMSE = 3.7 – 97.4%) during a team sport circuit, shuttle runs and small sided game [34]. This is potentially an issue for practitioners looking to monitor the distances their players cover at high speeds.

4.1.2.2 Local Positioning System

A LPS can accurately quantify distance that is covered within movement velocity thresholds of 0.28 – 1.7 $m \cdot s^{-1}$ and 1.7 – 4.2 $m \cdot s^{-1}$, with a large reduction in validity (RMSE = 13.9 – 207.1%) for distance captured when movement velocity is above 4.2 $m \cdot s^{-1}$ [34]. As such, it appears that the velocity-based threshold employed has a large influence on validity; decreasing as the threshold (i.e. movement velocity) becomes greater. Given only a single system has been examined, further research must be performed.

4.1.3 Peak velocity

The results for this section are displayed in Supplementary Table 4.

4.1.3.1 Global Navigation Satellite System

The accurate assessment of peak velocity is important given the association between high-speed exposures and injury risk [21]. The majority of devices appear to accurately detect peak velocity during a variety of straight-line [34, 40, 43-44, 51, 54, 58, 61, 70-75] and team sport protocols [34, 49, 51, 55]. Although significant differences have been identified between 10-Hz devices and timing gates [53, 55], the error in question is small (bias = < 2.5%), again highlighting the unsuitability of null hypothesis testing to assess validity.

Throughout change of direction protocols, it is unclear if 1- and 5-Hz devices are accurate with a mixture of findings reported [40, 58]. While it may be that change of direction degrades validity, it is also likely that the velocity attained also plays a role. For example, the velocity achieved is much lower during change of direction protocols (4.9 $m \cdot s^{-1}$) [40, 58], compared to team sport circuits or straight-line sprints (6.8 $m \cdot s^{-1}$) [70], and therefore may have an influence on accuracy. This issue appears to dissipate for devices with a sampling rate of 10-Hz and above [40].

The findings of studies using straight-line sprints are potentially more practically significant, given that the majority of peak velocities obtained during team sport match-play are obtained in open space (e.g. line break in rugby league), and often at critical match scenarios where minimal change of direction is required [76]. A significant limitation of 53.3% of studies is that timing gates are used as the criterion measurement; a method that is not capable of measuring peak velocity. Timing gates simply provide a measure of time over a set distance (i.e. distance between gates) and therefore only calculate average speed. Future research should use high-speed 3D motion capture systems or laser guns as criterion measures. Given the current evidence, modern wearable devices appear appropriate for measuring peak velocity.

4.1.3.2 Local Positioning System

There is conflicting evidence about the validity of LPS to measure peak velocity among the literature [34, 51, 61-62, 65, 75, 77]. There is a large amount of error associated with these systems during straight-line movement (trial velocities 1.7 – 5.3 $m \cdot s^{-1}$; bias = 11.8 – 13.2%), as well as shuttle runs (RMSE = 11.3%) [34, 77]. Contrastingly, a range of other systems have shown suitable accuracy (< 10%) during similar movements [34, 51, 61-62, 65, 75, 77], in particular straight-line sprinting (where true peak velocity is likely obtained) which should provide practitioners with confidence when interpreting peak velocity [61, 77]. Given there has only been five systems assessed, further research must be conducted to truly establish measurement accuracy.

4.1.4 Instantaneous velocity

The results for this section are displayed in Supplementary Table 5.

4.1.4.1 Global Navigation Satellite System

Instantaneous velocity measures appear to be accurate during straight-line movements, including sprinting [34, 74, 78-80]. However, when instantaneous velocity is assessed during specific components of a straight-line movement (e.g. timing gate splits, acceleration component, deceleration component), validity varies [74, 80]. For example, validity is poorest during initial splits (CV = 13.1% *vs.* 0.9%) for 15-Hz devices [74] while 5-Hz devices are inaccurate during decelerations from high starting movement velocities (5 - 8 $m \cdot s^{-1}$) [80]. Similarly, poor validity has been reported during accelerations performed while moving at a low continuous velocity (1 - 3 $m \cdot s^{-1}$), while accuracy improves as continuous movement velocity increases (3 – 8 $m \cdot s^{-1}$) [80]. Thus, high initial acceleration appears to compromise the validity of 5- and 15-Hz devices [74, 80], with 10-Hz possessing superior validity [78, 80]. Given that all team sports involve a large number of changes in pace, often performed at lower velocities [7], there may be an issue with using devices of sampling frequencies less than 10-Hz, for monitoring such movements.

4.1.4.2 Local Positioning System

The validity of instantaneous velocity measures from LPS have only been assessed for two systems (Clearsky T6, Inmotio) [34, 63]. The two studies reported different results, which highlighted the influence that specific manufacturing parameters (e.g. software, hardware, data filters) can have on a system's outputs. Through a team sport circuit, shuttle run and small sided game, the 'Inmotio' system was accurate [34], but when isolated change of directions were performed at speed, there was a notable reduction in validity for the 'Clearsky T6' (bias = 33.5 – 39.2%) [63], with a further reduction (bias = 74.4 – 90.8%) when the system set-up was 'sub-optimal' (system asymmetrical, small distance between nodes and testing area) [63]. This suggests that repeated change of direction compromises the validity of these systems [63]. This is likely attributed to the large and frequent changes in velocity experienced during such movements, which the system then struggles to measure. Whilst more work is required on LPS, this is an issue for quantifying velocity during change of direction movements, that are common to intermittent sports. Moreover, the careful set-up of the system that is required limits the portability of these units.

4.1.5 Average speed

The results for this section are displayed in Supplementary Table 6.

4.1.5.1 Global Navigation Satellite System

There is minimal error for 1-Hz devices during long distance (487 m), team sport circuits [56]. However, when short-distance straight-line movements are performed in isolation (e.g. ≤40 m), there is significant differences between the device and 3D motion analysis [58]. It is currently unclear if 5-Hz devices are accurate during similar movements, given conflicting findings [40, 58-59], while a variety of 10-Hz devices have shown suitable accuracy [17, 40-41, 79, 81]. Although the 'Polar Team Sensor' has shown error as high as 33% and 31% for back and chest-mounted sensors respectively [46], this device has not been investigated (n = 1) extensively, as have other devices.

When frequent change of direction is incorporated, validity is compromised for 1-, 5- and 10-Hz devices, highlighting the influence velocity change may have [40, 46, 58]. However, it appears that 'WimuPro'10-Hz devices are not influenced by direction change, and therefore may be a viable option for average speed assessment during such movements. Increasing sampling rate to 15-Hz does little to improve validity during change of direction [40], while an increase to 50-Hz appears beneficial; with superior validity compared to all other devices [36].

4.1.5.2 Local Positioning System

Local positioning systems can accurately quantify average speed during straight-line movement [41, 60, 62-63, 65, 77], change of direction [41, 60-63, 65, 77], shuttle activity [62] and team sport simulations [60-61, 77]. The set-up of the system is paramount, with a large reduction in validity (bias = 14.7 – 29.1%) for ‘sub-optimal’ set-ups (system asymmetrical, small distance between nodes and testing area), compared to ‘optimal’ (bias = 0.5 – 2.8%) [63]. Indeed, it is important that practitioners understand the correct set up of each system to ensure validity.

4.1.6 Collision detection

The results for this section are displayed in Supplementary Table 7.

4.1.6.1 Inertial Measurement Unit

Collisions are detected by the accelerometer and gyroscope housed inside the wearable device, using software-embedded algorithms [15]. The ability to detect the occurrence of a collision is likely a useful load monitoring metric for contact sports, given their association with player fatigue [82-83]. During rugby league and rugby union match-play, devices containing 100-Hz accelerometers are able to accurately detect these events, with superior accuracy when collisions are ‘heavy’, rather than ‘light’ [15, 84-86].

4.1.7 Sport specific events

The results for this section are displayed in Supplementary Table 8.

4.1.7.1 Inertial Measurement Unit

Through software embedded and consumer developed algorithms, wearable devices that contain accelerometers, gyroscopes and/or magnetometers can be used to quantify sport specific events. Cricket bowling events can be detected during match-play (sensitivity = 99.5%, specificity = 74.0%) and training (sensitivity = 99.0%, specificity = 98.1%) [17]. Notably, there is a reduction in specificity (increased recording of false positives) during match-play, which may be attributed to a greater number of fielding events performed. In rugby union, algorithms for automatically detecting scrums, rucks and one-on-one tackles appears suitable for use in both training and competition [14]. Although this accuracy is manufacturer and sport specific, with a large number of false-positive (detected an event, the event didn’t occur) tackle events identified during Australian football match-play [87].

4.1.8 Acceleration & deceleration-based metrics

The results for this section are displayed in Supplementary Table 9.

4.1.8.1 Global Navigation Satellite System

There are a variety of acceleration and deceleration derived metrics that are commonly used by practitioners in sport as a load monitoring technique. Generally, expensive high-speed 3D motion capture systems are required as a criterion; therefore, the literature is small.

Acceleration and deceleration ($m{\cdot}s^{-2}$) is generally derived from the GNSS chip housed inside the wearable, through measures of change in instantaneous velocity. In sporting applications, resultant accelerations are often classified into 'peak', 'average' and 'instantaneous' measures. These devices are currently unable to precisely quantify instantaneous acceleration, as well as distance covered when performing acceleration (> 3 $m{\cdot}s^{-2}$) and deceleration (< -3 $m{\cdot}s^{-2}$) efforts [34]. Raw average change of pace (termed, average acceleration) data extracted from 10-Hz devices are accurate [81], however when derived from the manufacturer's software, it appears to compromise validity [81]. This is likely attributable (at least in part) to the filters and smoothing methods applied to the raw data by different manufacturers. Therefore, it may be important to extract the raw data from the device when considering average acceleration measures. Although, it is likely that even this data has undergone some form of filtering already.

4.1.8.2 Inertial Measurement Unit

Alternatively, a more complex, but potentially accurate tool to quantify acceleration magnitude, or what is termed resultant acceleration, is through a 100-Hz tri-axial accelerometer, typically housed inside GNSS devices, which sums acceleration (*g)* in multiple axes (x, y, z) to compute a vector magnitude [88]. It is difficult to form a collective conclusion due to the hetergenous nature of studies investigating these measures, however it appears as though the filter and cut-off frequency applied to the raw data has a large influence [88-90]. Out of 6 – 25-Hz filters, 10 – 16-Hz filtered data all possessed suitable accuracy (CV < 10%) for measuring peak resultant acceleration during team sport actvities, with 12-Hz being optimal. [90]. Further, 5-Hz data with a complementary filter is superior during straight-line and change of direction for peak and average acceleration compared to 100-Hz, and 10-Hz data with a Kalman filter [89]. Despite being superior however, validity was still poor (CV > 10%) for peak resultant acceleration, but better for average acceleration (CV = 5.9 – 8.9%) [89]. However, when different filters (e.g. 3 and 10 point moving average) are applied to raw average resultant acceleration data, validity is compromised, again highlighting the influence of filter choice [91]. Measuring the vector magnitude during collision events may also be useful for contact sports when a 20-Hz filter is applied, with small error during tackle bag contact (CV = 6.5%), but a degradation in validity (CV = 11.2 – 11.3%) when contact occurs with another human [88].

4.1.8.3 Local Positioning System

Average acceleration and deceleration can be accurately quantified throughout shuttle activities and singular change of direction [62, 65]. However, validity is compromised when change of direction is performed repeatedly with a bias as large as 16.1% [62]. While average acceleration can also be quantified during straight-line activity, there is a large margin of error for average deceleration (CV = 15.0 – 21.0%, bias = -3.8 – 10.7%) [62, 65]. Peak acceleration and deceleration follow a similar pattern, with measures obtained during singular change of direction appearing relatively accurate (CV = 5.1 – 5.3%), with error increasing when direction change is performed repeatedly (bias = -12.3 – 41.1%) as well as shuttle activity (bias = -14.9 – 10.1%) [62, 65]. The accuracy of LPS for measuring peak acceleration and deceleration during straight-line movement is a little less clear, with conflicitng findings [62, 65]. This is likely due to manufacturing differences between systems and as such, it appears as though the 'Clearsky T6' system and 'Inmotio' provide suitable measures of peak acceleration and peak deceleration during straight-line movement, respectivelty. The 'Inmotio' system however is unable to accurately measure instantaneous acceleration [34].

4.1.9 Other metrics

The results for this section are displayed in Supplementary Table 10.

4.1.9.1 Global Navigation Satellite System

Measures of metabolic energy expenditure (i.e. metabolic power), are generally quantified using open circuit spirometry and radars, and can be determined from a GNSS chip using a method [92] that focuses on the energetic cost of acceleration and deceleration phases of running, based on a theoretical model [93].

There is a systematic underestimation of metabolic energy expenditure (bias = -5.94 $kcal \cdot min^{-1}$) during repeated efforts (i.e. running and collisions) [94], while measures of average metabolic power appear suitable during shuttle activity [38], but not a soccer specific circuit [95]. Therefore, it may be that collision activity degrades the validity of GNSS to quantify measures of energy expenditure [94]. Further, when metabolic power is measured using thresholds (> 20 $W \cdot kg^{-1}$, > 25 $W \cdot kg^{-1}$), there is a slight reduction in validity (CV = 9.0 – 11.6%) for 5-Hz devices, while 10-Hz is superior (CV = 4.5 – 6.2%) [38].

A method that uses speed-time derivatives to calculate sprint-mechanical properties (i.e. power output, average power, peak power, peak force) has recently come to fruition [96]. Sampling rate is important, with 20-Hz devices superior (CV = 4.5%), compared to devices sampling at 15- to 18-Hz (CV = 15.8%; SEE = 12.5 – 20.7%) for peak power output [51, 72], while peak force is inaccurate for 10- and 18-Hz, but not 20-Hz units [51].

4.1.9.2 Inertial Measurement Unit

When measures of energy expenditure are provided by accelerometers, there is a large degree of error (bias = -56.9 – 36.7%) [97-98]. Thus, GNSS devices should be used opposed to accelerometers to quantify measures of metabolic energy expenditure.

4.1.9.3 Local Positioning System

Peak force and power appear accurate when measured using LPS, although further research must be conducted to be confident in these metrics [51].

4.2 Inter-device Reliability

4.2.1 Total Distance

The results for this section are displayed in Supplementary Table 11.

4.2.1.1 Global Navigation Satellite System

There are a large number of studies that have investigated the inter-device reliability of a variety of devices, which is important to understand when comparing data between players and tracking training sessions in real-time [11]. It is clear that reliability is largely influenced by the manufacturer of the device, with 'Catapult' 1- and 5-Hz devices generally showing a large amount of variation (CV > 10%) during short-distance (< 40 m) straight-line movements [40, 52, 58, 99], rapid and frequent change of direction [40, 52, 58, 99] and match-play [99]. When such movements are performed in combination through team sport circuits, reliability does improve (CV = 1.2 – 3.6%; bias = 11.1%) [52, 54-55, 99]. While the type of movement performed (change of direction, short-distance) can impact the reliability of 'Catapult' devices, manufacturer specific parameters (e.g. hardware, software, filters) may also play an important role, with a different manufacturer showing superior reliability during similar movements with a 1-Hz device [47, 58].

Frequent change of direction, shuttle activity and short distance movement performed in isolation does little to compromise the reliability of 10-Hz devices [35, 41], although the influence of such factors are unclear for 15-Hz devices, with conflicting findings for similar movement protocols [40]. This is likely attributable to such devices possessing a true sample rate of 5-Hz, which is then interpolated to 15-Hz following collection. Nonetheless, devices sampling at a frequency of 10-Hz and above provide suitable reliability for continuous movement [41] and team sport circuits [33, 35, 51, 53, 55, 74, 100-101]. This is important as this type of protocol is reflective of the movement sequences experienced (e.g. change of direction to sprint to deceleration) during match-play, opposed to single movements performed in isolation (e.g. single change of direction), which rarely occur.

4.2.1.2 Local Positioning System

Local positioning systems provide suitable between device measures of total distance during team sport circuits [51], continuous movement [41] and change of direction [41], similar to that of GNSS.

4.2.2 Velocity-based threshold distance

The results for this section are displayed in Supplementary Table 12.

4.2.2.1 Global Navigation Satellite System

Five- 10- and 15-Hz between-device variations generally appear small (CV = 0.3 – 8.2%; bias = 10.3 – 11.6%) for velocity thresholds that capture distance covered below 5.0 $m \cdot s^{-1}$ [33, 53-55, 74, 100-101]. When comparing velocity based-threshold distance between-players, particularly sprinting distance (> 6 or > 7 $m \cdot s^{-1}$), it appears as though 15-Hz devices should be used [53, 74, 100], despite a single study reporting CV above 10% for distance covered when movement velocity is greater than 5.6 $m \cdot s^{-1}$ [53]. It is unclear however if inter-device comparisons can be made confidently for 5- and 10-Hz devices when distance is quantified using a threshold of above 5.0 $m \cdot s^{-1}$, with conflicting findings (CV = 0.5 – 112.0%) reported [33, 53-55, 101]. Collectively, the velocity threshold selected has a large influence on reliability; reducing as the velocity threshold increases [53-55, 100]. As such, practitioners should consider the variation between lower sampling devices (e.g. ≤ 10-Hz) when comparing distance covered based on high-velocity thresholds (e.g. high-speed running, sprint distance) between players.

4.2.3 Peak velocity

The results for this section are displayed in Supplementary Table 13.

4.2.3.1 Global Navigation Satellite System

The inter-device reliability of 1-Hz devices is unclear, with a single study reporting a CV range of 2.3% to 26.7% for low intensity running and frequent change of direction [58]. Through similar movement protocols, there is a further reduction in the reliability of 5-Hz devices (CV = 14.2 – 35.3%) [40, 58], however when peak velocity is attained through straight-line sprinting, reliability improves significantly (CV = 7.5 – 9.2%) [54]. The devices with a sampling rate of 10-Hz and above appear to offer superior reliability compared to devices with lower sampling rates for peak velocity detected during straight-line sprints and team sport activity [33, 51, 53, 71, 74, 100-102]. Similar to 1-Hz devices however, reliability (CV = 5.4 – 20.9%) is unclear for 15-Hz devices during frequent change of direction and low intensity running [40]. Collectively, GNSS devices offer suitable reliability during team sport activity and straight-line sprinting, but not frequent change of direction or low intensity running. A player's greatest velocity is likely attained through straight-line sprinting, either in match-play or training. As such, depending on the activity, practitioners can be confident in comparing peak velocity outputs between players.

4.2.3.2 Local Positioning System

Local positioning systems appear to offer suitable between-device reliability for detecting peak velocity [51]. Although, only one system has been investigated and thus further research must be conducted.

4.2.4 Instantaneous velocity

The results for this section are displayed in Supplementary Table 14.

4.2.4.1 Global Navigation Satellite System

Devices sampling at 5- and 10-Hz possess suitable reliability during simple straight-line sprinting [79, 91]. The reliability of 5-Hz devices appear to be compromised during sudden acceleration (CV = 9.5 – 16.2%) and deceleration (CV = 31.8%)

as well as straight-line movement between 1 and 3 $m{\cdot}s^{-1}$ (CV = 12.4%) [80]. In contrast, the inter-device reliability of 10-Hz devices appears excellent for participants completing the same movements (CV = 1.9 – 6.0%) [80]. Although suitable, there is a reduction in reliability during 'high-intensity' (> 4 $m{\cdot}s^{-2}$) accelerations (CV = 9.1%), compared to 'low-intensity' (1 – 4 $m{\cdot}s^{-2}$) accelerations (CV = 0.7 – 3.9%) [78].

4.2.5 Average speed

The results for this section are displayed in Supplementary Table 15.

4.2.5.1 Global Navigation Satellite System

There is limited research investigating the inter-device reliability of 1-, 5- and 15-Hz devices and thus, collective reliability is unclear with a large disparity in findings for low-intensity movement with minimal direction change (CV = 2.1 – 26.2%) and change of direction (CV = 3.4 – 33.4%) [40, 58]. Specifically, with the exception of a small number of movement protocols (CV = 3.4 – 9.1%; ICC = 0.98 – 0.99), there is generally a large inter-device variation in the average speed outputs of 5-Hz devices (CV = 14.9 – 33.4%) [40, 57-58]. Devices sampling at 10-Hz appear to offer superior reliability compared to other devices, during team sport circuits [101], continuous movement with minimal direction change [41] and frequent change of direction [41].

4.2.5.2 Local Positioning System

Local positioning systems appear to offer suitable between-device reliability for detecting average speed during continuous movement with minimal direction change [41] and frequent change of direction [41]. Although, only one system has been investigated and thus further research must be conducted.

4.2.6 Acceleration & deceleration derived metrics

The results for this section are displayed in Supplementary Table 16.

4.2.6.1 Global Navigation Satellite System

The detection of acceleration and deceleration efforts has become a common load monitoring metric in intermittent team sports, with reliability generally depending on the threshold set [100-101, 103]. Devices sampling at 5-Hz possess suitable reliability (CV = 3.7 – 5.1%) when detecting low accelerations (1 – 2 $m{\cdot}s^{-2}$; 2 – 3 $m{\cdot}s^{-2}$), although reliability is compromised for accelerations above 3 $m \cdot s^{-2}$ (CV = 13.2%) [103]. Ten-hertz devices show a similar level of reliability; although significantly improve for high-intensity accelerations (CV = 6.5%) [103]. Although, when the threshold is lowered (> 1.46 $m \cdot s^{-2}$), reliability is compromised (CV = 118.2%) [101]. This is similar for 15-Hz units, with a CV as low as 5.0%, but as high as 41.0% when a threshold of above 3 $m \cdot s^{-2}$ is used [100]. Reliability is further compromised (CV = 15.0 – 52.0%) when the threshold is increased, highlighting that 15-Hz devices may not be suitable to compare high-acceleration (> 4 $m \cdot s^{-2}$) frequency between players [100].

Five- and 10-Hz devices are able to accurately detect decelerations that occur in a variety of thresholds (-1 – -2 $m \cdot s^{-2}$; -2 – -3 $m \cdot s^{-2}$; < -3 $m \cdot s^{-2}$) [103], although there is a reduction for 10-Hz when other thresholds are used (< - 1.46 $m \cdot s^{-2}$) [101]. There is also a large variation (CV = 9.0 – 82.0%) for 15-Hz devices to detect high-intensity decelerations (-3 - -4 $m \cdot s^{-2}$ and < -4 $m \cdot s^{-2}$) [100].

The reliability of 5-Hz devices to measure distance during acceleration is suitable (CV = 4.5%) for low-intensity efforts (1 – 2 $m \cdot s^{-2}$); with a reduction in reliability as the threshold increases (2 – 3 $m \cdot s^{-2}$; > 3 $m \cdot s^{-2}$) (CV = 13.4 – 17.1%) [103]. It appears that sampling rate is important, with reliability improving for 10-Hz derived data (Optimeye S5; EVO; Apex) (CV = 1.4 – 6.9%) when similar thresholds are applied [33, 103]. Similar to acceleration distance, 5-Hz device deceleration distance reliability is compromised for higher thresholds (-2 – -3 $m \cdot s^{-2}$; < -3 $m \cdot s^{-2}$) [103]. However, increasing sample rate to 10-Hz generally appears to improve reliability for these thresholds [33, 103].

All devices possess suitable reliability when measuring average acceleration, average deceleration and average acceleration/deceleration [33, 103]. Peak acceleration can also be derived from a devices GNSS chip, with reliability appearing to be influenced by manufacturer specific parameters (e.g. filters, cut-off frequencies, software) [71, 100-101], with a CV of 4.0% to 14.0% for 5- and 15-Hz devices, while improving for 16-Hz devices (CV = 6.4%). Peak deceleration, while only investigated once should not be compared between players [101].

4.2.6.2 Inertial Measurement Unit

The inter-device reliability when calculating inertial movement acceleration magnitude and subsequent frequency (> 1.5 $m \cdot s^{-1}$ – delta velocity) using tri-axial accelerometer data, is appropriate [104].

4.2.7 PlayerLoad

The results for this section are displayed in Supplementary Table 17.

4.2.7.1 Inertial Measurement Unit

PlayerLoad is a composite vector magnitude calculated from the accelerations acting upon the x, y and z axis of an accelerometer. It appears suitable to make between player comparisons for measures of PlayerLoad during team sport match-play and training [54-55, 104-105].

4.2.8 Other metrics

The results for this section are displayed in Supplementary Table 18.

4.2.8.1 Global Navigation Satellite System

It appears suitable to make between player comparisons for exertion index measurements [54-55]. In contrast, it may be problematic to make comparisons when measuring repeated high intensity efforts [54-55], and a variety of collision based metrics derived from the GNSS chip (e.g. collision velocity, momentum) (CV = 13.2%) [86]. Collision load, designed to indicate the intensity of a collision (e.g. tackle), is calculated using data collected by the GNSS and accelerometer housed inside the wearable [86]. There are however large variations (CV = 10.1%) between devices when worn during contact-based training. Further, reliability for peak power and force measures appear superior for 18-Hz devices, but not 10-Hz [51].

4.2.8.2 Inertial Measurement Unit

Impact force (*g*) measured via the accelerometer housed within the wearable device appears to largely vary between devices during contact-based training [86].

4.2.8.3 Local Positioning System

There was a small amount of variation (CV = 5.9 – 7.3%) between theoretical power and force measurements obtained from the 'Kinexon one' system during a team sport circuit [51].

4.3 Intra-device reliability

Intra-device reliability is important to understand, given the interest of tracking individualised training loads over time. Readers should be aware there are inherent limitations with most studies that have investigated the test-retest reliability of wearable microtechnology. That is, they have largely relied on participants to perform identical movements on repeated occasions. Despite closely controlling the movement paths performed, variations (outside of those reported by the device) are going to occur. Therefore, the difference in measurements between tests encompass both biological and technological variation, and the true intra-device reliability, the intended scope of these studies, cannot be determined. To understand the true test-retest reliability of wearables, the biological variation must be eliminated from the movement, by identical movements being performed on repeated occasions.

4.3.1 Total distance

The results for this section are displayed in Supplementary Table 19.

4.3.1.1 Global Navigation Satellite System

Within-player distance comparisons can be made confidently, with various devices from different manufacturers producing similar outputs on repeated occasions during team sport circuits [37, 42, 44, 48-49, 57, 95], continuous movement that does not incorporate frequent direction change [37, 41-42, 44-45, 47-48], short-distance straight-line movement (e.g. straight-line sprint) [37, 44, 57, 59], frequent change of direction [36, 41-42] and shuttle activity [37, 39] (CV = < 10%). While one study has reported 4-Hz 'VX' and 5-Hz "SPI-ProXII" devices show poor test-retest reliability, the statistical analysis employed only explored the relationship between the test-retest measures, rather than the magnitude of the difference [75], which may explain the disparity in findings compared to other studies. Further, it appears that within-player comparisons should not be made when distance is collected during a straight-line sprint using the 5-Hz 'MinimaxX'[37].

4.3.1.2 Local Positioning System

Three systems have been assessed thus far, with two showing suitable intra-device reliability during change of direction, match-play replication (wheelchair sport) and straight-line movement [41, 61]. It may be problematic to make within-device comparisons for the 'Inmotio' system, although this system has only been assessed once and thus should be further examined [75].

4.3.2 Velocity-based threshold distance

The results for this section are displayed in Supplementary Table 20.

4.3.2.1 Global Navigation Satellite System

There is limited research performed in this area given it is difficult to conduct a methodology that truly assesses intra-device reliability for velocity-based threshold distance. The reliability of 10-Hz devices appears superior to that of 1- and 4-Hz, although it is difficult to compare given the large variation among thresholds used (0.3 – 1.4 $m \cdot s^{-1}$ 1.4 – 2.8 $m \cdot s^{-1}$, 2.8 – 4.2 $m \cdot s^{-1}$, 4.0 – 5.6 $m \cdot s^{-1}$, 4.2 – 5.6 $m \cdot s^{-1}$, 5.6 – 6.9 $m \cdot s^{-1}$, > 6.9 $m \cdot s^{-1}$, < 4 $m \cdot s^{-1}$, > 4 $m \cdot s^{-1}$, > 5.6 $m \cdot s^{-1}$) [42, 70, 95]. Regardless of whether the reliability was suitable or not, the studies that have investigated this have significant limitations given the inclusion of biological error as a result of poor study design where intra-device reliability is concerned. Therefore, future research with suitable methodologies, as previously stated, must be conducted in order to form any conclusions about the intra-device reliability of velocity-based threshold distance.

4.3.3 Peak velocity

The results for this section are displayed in Supplementary Table 21.

4.3.3.1 Global Navigation Satellite System

Similar to what has been previously discussed in this section, these findings should be approached with caution given that participant peak velocity is likely to vary between trials and thus, biological error will be reported in these studies. Indeed, it appears there is minimal variation between straight-line sprinting and team sport circuit trials for 1- to 10-Hz devices [42, 57, 59, 70, 75, 106]. Change of direction however appears to degrade reliability for 4-Hz devices (ICC = 0.41 – 0.66), while superior for 10-Hz devices (CV = 0.8%) [42]. Collectively, these findings highlight the important considerations that should be given to sampling rate.

4.3.3.2 Local Positioning System

Consistent with GNSS devices, there is a significant reduction in reliability for frequent and singular change of direction (ICC = -0.09 – 0.32), while improving when such movement is removed (CV = 1.6 – 2.7%; ICC = 0.97) [61, 75]. The degradation in reliability observed may not be caused by the device itself, but rather due to it being more difficult to perform similar peak velocities on repeated occasions for movements involving frequent change of direction compared to simple straight-line sprints.

4.3.4 Average speed

The results for this section are displayed in Supplementary Table 22.

4.3.4.1 Global Navigation Satellite System

Average speed measures show strong test-retest associations (ICC = 0.94 – 0.99) and small variations (bias = 0.00 $km \cdot h^{-1}$; CV = 1.6 – 2.1%) during a wide variety of movement courses. [36, 41, 57, 59].

4.3.4.2 Local Positioning System

It appears that a LPS serves as a viable option to measure average speed when considering intra-device reliability, as systems have shown very small variations (ICC = 0.94 – 0.99) for different movement protocols, with CV ranging from 0.4 to 0.5% [41, 61].

4.3.5 Acceleration and deceleration-based metrics

The results for this section are displayed in Supplementary Table 23.

4.3.5.1 Global Navigation Satellite System

The literature investigating intra-device reliability when quantifying peak acceleration is small, with that derived from a GNSS chip via time motion analysis possessing poor test-retest associations (ICC = -0.7 – 0.49) [75]. This is consistent for distance covered while performing acceleration and deceleration efforts [95].

4.3.5.2 Inertial Measurement Unit

There is only small within-device variations (CV = 5.0 – 5.2%) when peak acceleration magnitude (*g*) measured via the accelerometer housed inside a GNSS device is considered [59]. The ability to detect an acceleration magnitude above 5 *g* is superior during a 10 m sprint (CV = 4.7%) as opposed to 30 m (CV = 14.2%) [59]. This may be reflective of the magnitude obtained, in that the magnitude achieved in the 30 m sprint (8.3 *g*) is much larger than that during 10 m (7.3 *g*), which the device may not be able to tolerate [59].

4.3.5.3 Local Positioning System

A single local positioning system produced varying test-retest measures for peak acceleration which may suggest poor test-retest reliability [75], although further research must be conducted where the same peak acceleration occurs repeatedly to establish this.

4.3.6 PlayerLoad

The results for this section are displayed in Supplementary Table 24.

4.3.6.1 Inertial Measurement Unit

The reproduction of PlayerLoad values have been shown during shuttle activity [107], treadmill running [108] and sport specific movements [109-110].

4.3.7 Other metrics

The results for this section are displayed in Supplementary Table 25.

4.3.7.1 Global Navigation Satellite System

Measures of average metabolic power derived from a GNSS chip are repeatable, although, when based on a threshold (> 20 $W \cdot kg^{-1}$), reliability is poor [95].

5 Conclusion

There are many studies investigating the validity and reliability of wearable microtechnology to track movement and detect sport specific actions. It is evident that, for the majority of metrics, validity and reliability is multi-factorial, in that it is dependent upon a wide variety of factors including wearable technology brand, sampling rate, type of movement performed (e.g. straight-line, change of direction) and intensity of movement (e.g. walk, sprint). As such, it is difficult to form any definite conclusions regarding the overarching validity and reliability of wearable microtechnology devices. However, practitioners should be mindful of the accuracy and repeatability of the devices they are using when making decisions on player training loads. For example, if prescribing 'top-up' drills at the end of a training session based on the high-speed distance players have performed during training, these differences should be interpreted relative to the error of the device. Similarly, when prescribing increments in training load in a rehabilitation setting, the speeds and distances performed by a player need to be interpreted with the within-device error accounted for.

It is important that future validity research compares the outputs of wearable devices with a true 'gold-standard' criterion for each metric respectively (e.g. high-speed 3D motion capture system for distance covered). While cost effective, the criterion measures commonly used in the reviewed research (e.g. measuring tape, timing gates) possess inherent validity issues, and therefore may contribute to the reported measurement error of the wearable devices.

Many of the differences between data generated from wearable technology and that of criterion measures, like VICON, may be attributed to the filtering and smoothing of the data [89]. Studies have shown that the filtering of data can have a large impact on the results obtained and therefore this should be considered in future studies. Accessing the raw data of both practical and criterion measures and performing the same filtering processes on both data sets would allow for more equitable comparisons. Unfortunately, the selection of the appropriate smoothing cut-off frequency is complex and there are no definitive guidelines. The movements that are being performed is an important aspect to consider, with a trade-off between removing noise in the data whilst maintaining resolution to quantify the metrics of interest.

Most research pertaining to the intra-device reliability of wearable devices, is poor. This is due to methodological issues (e.g. test-retest movements are not identical); as such, the studies in this review assess the combined technological and biological variation between movements, rather than the technological variation alone. In order to measure technological variation, future research must ensure that an identical movement construct (i.e. velocity, distance) is performed on multiple occasions. Given that humans are unlikely to be able to perform such a precise task, we may have to rely on other technology (e.g. model train set). Alternatively, examining the stability of the validity (i.e. assessing validity on multiple occasions), would also provide an indication of test-retest reliability, and should be emphasised in future research. These aspects of future research are vital given the important decisions that are made on the progression or regression of an individual's training loads.

Data Availability Statement

All of the extracted data are included in the manuscript and supplementary files.

Compliance with Ethical Standards

Funding

No sources of funding were used to assist in the preparation of this article.

Conflicts of Interest

Zachary Crang, Grant Duthie, Michael Cole, Jonathon Weakley, Adam Hewitt and Rich Johnston declare they have no conflicts of interest relevant to the content of this review

Author Contributions

ZC, RJ, GD, MC, JW and AH were involved in the formulation of the review. ZC and RJ performed the quality assessment on all the papers. MC and GD were also consulted on quality assessment as needed. ZC wrote the majority of the manuscript, with all other authors reviewing the manuscript.

References

1. Thorpe RT, Strudwick AJ, Buchheit M, Atkinson G, Drust B, Gregson W. The influence of changes in acute training load on daily sensitivity of morning-measured fatigue variables in elite soccer players. Int J Sports Physiol Perform. 2017;12:107-13.
2. Fitzpatrick JF, Hicks KM, Hayes PR. Dose-response relationship between training load and changes in aerobic fitness in professional youth soccer players. Int J Sports Physiol Perform. 2018;13:1365-70.
3. Harrison PW, Johnston RD. Relationship between training load, fitness, and injury over an Australian rules football preseason. J Strength Cond Res. 2017;31:2686-93.
4. Drew MK, Finch CF. The relationship between training load and injury, illness and soreness: a systematic and literature review. Sports medicine. 2016;46:861-83.
5. Eckard TG, Padua DA, Hearn DW, Pexa BS, Frank BS. The relationship between training load and injury in athletes: a systematic review. Sports medicine. 2018;48:1929-61.
6. Gastin PB, Fahrner B, Meyer D, Robinson D, Cook JL. Influence of physical fitness, age, experience, and weekly training load on match performance in elite Australian football. J Strength Cond Res. 2013;27:1272-9.
7. Johnston RD, Murray NB, Austin DJ. The influence of pre-season training loads on in-season match activities in professional Australian football players. Sci Med Football. 2019;3:143-9.
8. Halson SL. Monitoring training load to understand fatigue in athletes. Sports medicine. 2014;44:139-47.
9. Nettleton B, Sandstrom E. Skill and conditioning in Australian rules football. Aust J Phys Educ. 1963;29:17-30.
10. Reilly T, Gilbourne D. Science and football: a review of applied research in the football codes. J Sport Sci. 2003;21:693-705.
11. Johnston RD, Hewitt A, Duthie G. Validity of real-time ultra-wideband global navigation satellite system data generated by a wearable microtechnology unit. J Strength Cond Res. 2020;34:2071-5.
12. Cummins C, Orr R, O’Connor H, West C. Global positioning systems (GPS) and microtechnology sensors in team sports: a systematic review. Sports Medicine. 2013;43:1025-42.
13. Varley MC, Gabbett T, Aughey RJ. Activity profiles of professional soccer, rugby league and Australian football match play. J Sport Sci. 2014;32:1858-66.
14. Chambers RM, Gabbett TJ, Gupta R, Josman C, Bown R, Stridgeon P, Cole MH. Automatic detection of one-on-one tackles and ruck events using microtechnology in rugby union. J Sci Med Sport. 2019;22:827-32.
15. Hulin BT, Gabbett TJ, Johnston RD, Jenkins DG. Wearable microtechnology can accurately identify collision events during professional rugby league match-play. J Sci Med Sport. 2017;20:638-42.
16. Chambers RM, Gabbett TJ, Cole MH. Validity of a microsensor-based algorithm for detecting scrum events in rugby union. Int J Sports Physiol Perform. 2019;14:176-82.
17. McNamara DJ, Gabbett TJ, Chapman P, Naughton G, Farhart P. The validity of microsensors to automatically detect bowling events and counts in cricket fast bowlers. Int J Sports Physiol Perform. 2015;10:71-5.
18. Hulin BT, Gabbett TJ, Lawson DW, Caputi P, Sampson JA. The acute: chronic workload ratio predicts injury: high chronic workload may decrease injury risk in elite rugby league players. Brit J Sport Med. 2016;50:231-6.
19. Colby MJ, Dawson B, Heasman J, Rogalski B, Gabbett TJ. Accelerometer and GPS-derived running loads and injury risk in elite Australian footballers. J Strength Cond Res. 2014;28:2244-52.
20. Jones CM, Griffiths PC, Mellalieu SD. Training load and fatigue marker associations with injury and illness: a systematic review of longitudinal studies. Sports medicine. 2017;47:943-74.
21. Malone S, Roe M, Doran DA, Gabbett TJ, Collins K. High chronic training loads and exposure to bouts of maximal velocity running reduce injury risk in elite Gaelic football. J Sci Med Sport. 2017;20:250-4.
22. Taylor RJ, Sanders D, Myers T, Abt G, Taylor CA, Akubat I. The dose-response relationship between training load and aerobic fitness in academy rugby union players. Int J Sports Physiol Perform. 2018;13:163-9.
23. Murray NB, Gabbett TJ, Townshend AD. Relationship between preseason training load and in-season availability in elite australian football players. Int J Sports Physiol Perform. 2017;12:749-55.
24. Johnston RD, Murray NB, Austin DJ. The influence of pre-season training loads on in-season match activities in professional Australian football players. Science and Medicine in Football. 2019;3:143-9.
25. Malone JJ, Lovell R, Varley MC, Coutts AJ. Unpacking the black box: Applications and considerations for using GPS devices in sport. Int J Sports Physiol Perform. 2017;12:S2-18-S2-26.
26. Scott MT, Scott TJ, Kelly VG. The validity and reliability of global positioning systems in team sport: A brief review. J Strength Cond Res. 2016;30:1470-90.
27. Hopkins WG. Measures of reliability in sports medicine and science. Sports Medicine. 2000;30:1-15.
28. McGraw KO, Wong SP. Forming inferences about some intraclass correlation coefficients. Psychol Methods. 1996;1:30-46.
29. Abdi H. Coefficient of variation. Encyclopedia of Research Design. 2010.
30. Moher D, Liberati A, Tetzlaff J, Altman DG, Altman D, Antes G, Atkins D, Barbour V, Barrowman N, Berlin JA. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement (Chinese edition). Chin J Interg Med. 2009;7:889-96.

31. Downs SH, Black N. The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. J Epidemiol Community Health. 1998;52:377.
32. Johnston RD, Black GM, Harrison PW, Murray NB, Austin D. Applied sport science of Australian football: a systematic review. Sports Medicine. 2018;48:1673-94.
33. Thornton HR, Nelson AR, Delaney JA, Serpiello FR, Duthie GM. Interunit reliability and effect of data-processing methods of global positioning systems. Int J Sports Physiol Perform. 2019;14:432-8.
34. Linke D, Link D, Lames M. Validation of electronic performance and tracking systems EPTS under field conditions. PLoS One. 2018;13:e0199519-e.
35. Nikolaidis PT, Clemente FM, van der Linden CMI, Rosemann T, Knechtle B. Validity and reliability of 10-Hz global positioning system to assess in-line movement and change of direction. Front Physiol. 2018;9:228-.
36. Padulo J, Iuliano E, Brisola G, Iacono AD, Zagatto AM, Lupo C, Fuglsang T, Ardigò LP, Cular D. Validity and reliability of a standalone low-end 50-Hz GNSS receiver during running. Biol Sport. 2019;36:75-80.
37. Petersen C, Pyne D, Portus M, Dawson B. Validity and reliability of GPS units to monitor cricket-specific movement patterns. Int J Sports Physiol Perform. 2009;4:381-93.
38. Rampinini E, Alberti G, Fiorenza M, Riggio M, Sassi R, Borges TO, Coutts AJ. Accuracy of GPS devices for measuring high-intensity running in field-based team sports. Int J Sport Med. 2015;36:49-53.
39. Rawstorn JC, Maddison R, Ali A, Foskett A, Gant N. Rapid directional change degrades GPS distance measurement validity during intermittent intensity running. PLoS One. 2014;9:e93693.
40. Vickery WM, Dascombe BJ, Baker JD, Higham DG, Spratford WA, Duffield R. Accuracy and reliability of GPS devices for measurement of sports-specific movement patterns related to cricket, tennis, and field-based team sports. J Strength Cond Res. 2014;28:1697-705.
41. Bastida Castillo A, Gómez Carmona CD, De la Cruz Sánchez E, Pino Ortega J. Accuracy, intra- and inter-unit reliability, and comparison between GPS and UWB-based position-tracking systems used for time-motion analyses in soccer. Eur J Sport Sci. 2018;18:450-7.
42. Willmott AGB, James CA, Bliss A, Leftwich RA, Maxwell NS. A comparison of two global positioning system devices for team-sport running protocols. J Biomech. 2019;83:324-8.
43. Beato M, Coratella G, Stiff A, Iacono AD. The validity and between-unit variability of GNSS units (Statsports Apex 10 and 18 Hz) for measuring distance and peak speed in team sports. Front Physiol. 2018;9:1288-.
44. Beato M, Devereux G, Stiff A. Validity and reliability of global positioning system units (STATSports Viper) for measuring distance and peak speed in sports. J Strength Cond Res. 2018;32:2831-7.
45. Edgecomb SJ, Norton KI. Comparison of global positioning and computer-based tracking systems for measuring player movement distance during Australian football. J Sci Med Sport. 2006;9:25-32.
46. Fox JL, O'Grady CJ, Scanlan AT, Sargent C, Stanton R. Validity of the Polar Team Pro Sensor for measuring speed and distance indoors. J Sci Med Sport. 2019;22:1260-5.
47. Gray AJ, Jenkins D, Andrews MH, Taaffe DR, Glover ML. Validity and reliability of GPS for measuring distance travelled in field-based team sports. J Sport Sci. 2010;28:1319-25.
48. Portas MD, Harley JA, Barnes CA, Rush CJ. The validity and reliability of 1-Hz and 5-Hz global positioning systems for linear, multidirectional, and soccer-specific activities. Int J Sports Physiol Perform. 2010;5:448-58.
49. Coutts AJ, Duffield R. Validity and reliability of GPS devices for measuring movement demands of team sports. J Sci Med Sport. 2010;13:133-5.
50. Dogramaci SN, Watsford ML, Murphy AJ. The reliability and validity of subjective notational analysis in comparison to global positioning system tracking to assess athlete movement patterns. J Strength Cond Res. 2011;25:852-9.
51. Hoppe MW, Baumgart C, Polglaze T, Freiwald J. Validity and reliability of GPS and LPS for measuring distances covered and sprint mechanical properties in team sports. PLoS One. 2018;13:e0192708.
52. Jennings D, Cormack S, Coutts AJ, Boyd L, Aughey RJ. The validity and reliability of GPS units for measuring distance in team sport specific running patterns. Int J Sports Physiol Perform. 2010;5:328-41.
53. Johnston RJ, Watsford ML, Kelly SJ, Pine MJ, Spurrs RW. Validity and interunit reliability of 10 Hz and 15 Hz GPS units for assessing athlete movement demands. J Strength Cond Res. 2014;28:1649-55.
54. Johnston RJ, Watsford ML, Pine MJ, Spurrs RW, Murphy AJ, Pruyn EC. The validity and reliability of 5-Hz global positioning system units to measure team sport movement demands. J Strength Cond Res. 2012;26:758-65.
55. Johnston RJ, Watsford ML, Pine MJ, Spurrs RW, Sporri D. Assessment of 5 Hz and 10 Hz GPS units for measuring athlete movement demands. Int J Perf Anal Spor. 2013;13:1-.
56. MacLeod H, Morris J, Nevill A, Sunderland C. The validity of a non-differential global positioning system for assessing player movement patterns in field hockey. J Sport Sci. 2009;27:121-8.
57. Muñoz-Lopez A, Granero-Gil P, Pino-Ortega J, De Hoyo M. The validity and reliability of a 5-Hz GPS device for quantifying athletes' sprints and movement demands specific to team sports. J Hum Sport Exerc. 2017;12:156-66.
58. Duffield R, Reid M, Baker J, Spratford W. Accuracy and reliability of GPS devices for measurement of movement patterns in confined spaces for court-based sports. J Sci Med Sport. 2010;13:523-5.
59. Waldron M, Worsfold P, Twist C, Lamb K. Concurrent validity and test-retest reliability of a global positioning system (GPS) and timing gates to assess sprint performance variables. J Sport Sci. 2011;29:1613-9.

60. Frencken WGP, Lemmink KAPM, Delleman NJ. Soccer-specific accuracy and validity of the local position measurement (LPM) system. J Sci Med Sport. 2010;13:641-5.
61. Rhodes J, Mason B, Perrat B, Smith M, Goosey-Tolfrey V. The validity and reliability of a novel indoor player tracking system for use within wheelchair court sports. J Sport Sci. 2014;32:1639-47.
62. Stevens TGA, De Ruiter CJ, Van Niel C, Van de Rhee R, Beek PJ, Savelsbergh GJ. Measuring acceleration and deceleration in soccer-specific movements using a local position measurement (LPM) system. Int J Sports Physiol Perform. 2014;9:446-56.
63. Luteberget LS, Spencer M, Gilgien M. Validity of the catapult clearsky T6 local positioning system for team sports specific drills, in indoor conditions. Front Physiol. 2018;9:115-.
64. Sathyan T, Shuttleworth R, Hedley M, Davids K. Validity and reliability of a radio positioning system for tracking athletes in indoor and outdoor team sports. Behav Res Methods. 2012;44:1108-14.
65. Serpiello FR, Hopkins WG, Barnes S, Tavrou J, Duthie GM, Aughey RJ, Ball K. Validity of an ultra-wideband local positioning system to measure locomotion in indoor sports. J Sport Sci. 2018;36:1727-33.
66. Leser R, Schleindlhuber A, Lyons K, Baca A. Accuracy of an UWB-based position tracking system used for time-motion analyses in game sports. Eur J Sport Sci. 2014;14:635-42.
67. Dimitrova ES, Licona MP, McGee J, Laubenbacher R. Discretization of time series data. J Comput Biol. 2010;17:853-68.
68. Geaur Rahman M, Zahidul Islam M. Discretization of continuous attributes through low frequency numerical values and attribute interdependency. Expert Syst Appl. 2016;45:410-23.
69. García S, Luengo J, Sáez JA, López V, Herrera F. A survey of discretization techniques: Taxonomy and empirical analysis in supervised learning. IEEE Trans Knowl Data Eng. 2013;25:734-50.
70. Barbero-Alvarez JC, Coutts A, Granda J, Barbero-Alvarez V, Castagna C. The validity and reliability of a global positioning satellite system device to assess speed and repeated sprint ability (RSA) in athletes. J Sci Med Sport. 2010;13:232-5.
71. Lacome M, Peeters A, Mathieu B, Bruno M, Christopher C, Piscione J. Can we use GPS for assessing sprinting performance in rugby sevens? A concurrent validity and between-device reliability study. Biol Sport. 2019;36:25-9.
72. Nagahara R, Botter A, Rejc E, Koido M, Shimizu T, Samozino P, Morin J-B. Concurrent validity of GPS for deriving mechanical properties of sprint acceleration. Int J Sports Physiol Perform. 2017;12:129-32.
73. Roe G, Darrall-Jones J, Black C, Shaw W, Till K, Jones B. Validity of 10-Hz GPS and timing gates for assessing maximum velocity in professional rugby union players. Int J Sports Physiol Perform. 2017;12:836-9.
74. Barr M, Beaver T, Turczyn D, Cornish S. The validity and reliability of 15 Hz global positioning system units for assessing the activity profiles of university football players. J Strength Cond Res. 2017;33:1371-9.
75. Buchheit M, Allen A, Poon TK, Modonutti M, Gregson W, Di Salvo V. Integrating different tracking systems in football: multiple camera semi-automatic system, local position measurement and GPS technologies. J Sport Sci. 2014;32:1844-57.
76. Faude O, Koch T, Meyer T. Straight sprinting is the most frequent action in goal situations in professional football. J Sport Sci. 2012;30:625-31.
77. Ogris G, Leser R, Horsak B, Kornfeind P, Heller M, Baca A. Accuracy of the LPM tracking system considering dynamic position changes. J Sport Sci. 2012;30:1503-11.
78. Akenhead R, French D, Thompson KG, Hayes PR. The acceleration dependent validity and reliability of 10 Hz GPS. J Sci Med Sport. 2014;17:562-6.
79. Bataller-Cervero AV, Gutierrez H, DeRentería J, Piedrafita E, Marcén N, Valero-Campo C, Lapuente M, Berzosa C. Validity and reliability of a 10 Hz GPS for assessing variable and mean running speed. J Hum Kinet. 2019;67:17-24.
80. Varley MC, Fairweather IH, Aughey RJ. Validity and reliability of GPS for measuring instantaneous velocity during acceleration, deceleration, and constant motion. J Sport Sci. 2012;30:121-7.
81. Delaney JA, Wileman TM, Perry NJ, Thornton HR, Moresi MP, Duthie GM. The validity of a global navigation satellite system for quantifying small-area team-sport movements. J Strength Cond Res. 2019;33:1463-6.
82. Johnston RD, Gabbett TJ, Seibold AJ, Jenkins DG. Influence of physical contact on neuromuscular fatigue and markers of muscle damage following small-sided games. J Sci Med Sport. 2014;17:535-40.
83. Roe G, Darrall-Jones J, Till K, Phibbs P, Read D, Weakley J, Rock A, Jones B. The effect of physical contact on changes in fatigue markers following rugby union field-based training. Eur J Sport Sci. 2017;17:647-55.
84. Gabbett T, Jenkins D, Abernethy B. Physical collisions and injury during professional rugby league skills training. J Sci Med Sport. 2010;13:578-83.
85. Kelly D, Coughlan GF, Green BS, Caulfield BJSE. Automatic detection of collisions in elite level rugby union using a wearable sensing device. Sports Eng. 2012;15:81-92.
86. MacLeod SJ, Hagan C, Egaña M, Davis J, Drake D. The use of microtechnology to monitor collision performance in professional rugby union. Int J Sports Physiol Perform. 2018;13:1075-82.
87. Gastin PB, McLean OC, Breed RVP, Spittle M. Tackle and impact detection in elite Australian football using wearable microsensor technology. J Sport Sci. 2014;32:947-53.

88. Wundersitz DWT, Gastin PB, Robertson SJ, Netto KJ. Validity of a trunk-mounted accelerometer to measure physical collisions in contact sports. Int J Sports Physiol Perform. 2015;10:681-6.
89. Roell M, Mahler H, Lienhard J, Gehring D, Gollhofer A, Roecker K. Validation of wearable sensors during team sport-specific movements in indoor environments. IEEE Sens J. 2019;19:3458.
90. Wundersitz DWT, Gastin PB, Robertson S, Davey PC, Netto KJ. Validation of a trunk-mounted accelerometer to measure peak impacts during team sport movements. Int J Sport Med. 2015;36:742-6.
91. Alexander JP, Hopkinson TL, Wundersitz DWT, Serpell BG, Mara JK, Ball NB. Validity of a wearable accelerometer device to measure average acceleration values during high-speed running. J Strength Cond Res. 2016;30:3007-13.
92. Osgnach C, Poser S, Bernardini R, Rinaldo R, Di Prampero PE. Energy cost and metabolic power in elite soccer: a new match analysis approach. Medicine & Science in Sports & Exercise. 2010;42:170-8.
93. Di Prampero P, Fusi S, Sepulcri L, Morin J-B, Belli A, Antonutto G. Sprint running: a new energetic approach. J Exp Biol. 2005;208:2809-16.
94. Highton J, Mullen T, Norris J, Oxendale C, Twist C. The unsuitability of energy expenditure derived from microtechnology for assessing internal load in collision-based activities. Int J Sports Physiol Perform. 2017;12:264-7.
95. Buchheit M, Manouvrier C, Cassirame J, Morin J-B. Monitoring locomotor load in soccer: is metabolic power, powerful? Int J Sport Med. 2015;36:1149-55.
96. Samozino P, Rabita G, Dorel S, Slawinski J, Peyrot N, Saez de Villarreal E, Morin JB. A simple method for measuring power, force, velocity properties, and mechanical effectiveness in sprint running. Scand J Med Sci Sports. 2016;26:648-58.
97. Gastin PB, Cayzer C, Dwyer D, Robertson S. Validity of the ActiGraph GT3X+ and BodyMedia SenseWear Armband to estimate energy expenditure during physical activity and sport. J Sci Med Sport. 2018;21:291-5.
98. Zanetti S, Pumpa KL, Wheeler KW, Pyne DB. Validity of the sensewear armband to assess energy expenditure during intermittent exercise and recovery in rugby union players. J Strength Cond Res. 2014;28:1090-5.
99. Jennings D, Cormack S, Coutts AJ, Boyd LJ, Aughey RJ. Variability of GPS units for measuring distance in team sport movements. Int J Sports Physiol Perform. 2010;5:565-9.
100. Buchheit M, Al Haddad H, Simpson BM, Palazzi D, Bourdon PC, Di Salvo V, Mendez-Villanueva A. Monitoring accelerations with GPS in football: Time to slow down? Int J Sports Physiol Perform. 2014;9:442-5.
101. Jackson BM, Polglaze T, Dawson B, King T, Peeling P. Comparing global positioning system and global navigation satellite system measures of team-sport movements. Int J Sports Physiol Perform. 2018;13:1005-10.
102. Beato M, de Keijzer KL. The inter-unit and inter-model reliability of GNSS STATSports Apex and Viper units in measuring peak speed over 5, 10, 15, 20 and 30 meters. Biol Sport. 2019;36:317-21.
103. Delaney JA, Cummins CJ, Thornton HR, Duthie GM. Importance, reliability, and usefulness of acceleration measures in team sports. J Strength Cond Res. 2018;32:3485-93.
104. Luteberget LS, Holme BR, Spencer M. Reliability of wearable inertial measurement units to measure physical activity in team handball. Int J Sports Physiol Perform. 2018;13:467-73.
105. Boyd LJ, Ball K, Aughey RJ. The reliability of minimaxX accelerometers for measuring physical activity in Australian football. Int J Sports Physiol Perform. 2011;6:311-21.
106. Beato M. Reliability of internal and external load parameters in 6 a-side and 7 a-side recreational football for health. J Sport Health Sci. 2018;14:709-14.
107. Fitzpatrick JF, Hicks KM, Russell M, Hayes PR. The reliability of potential fatigue-monitoring measures in elite youth soccer players. J Strength Cond Res. 2019.
108. Barrett S, Midgley A, Lovell R. PlayerLoad™: Reliability, convergent validity, and influence of unit position during treadmill running. Int J Sports Physiol Perform. 2014;9:945-52.
109. Barreira P, Robinson MA, Drust B, Nedergaard N, Raja Azidin RMF, Vanrenterghem J. Mechanical Player Load™ using trunk-mounted accelerometry in football: Is it a reliable, task- and player-specific observation? J Sport Sci. 2017;35:1674-81.
110. Van Iterson EH, Fitzgerald JS, Dietz CC, Snyder EM, Peterson BJ. Reliability of triaxial accelerometry for measuring load in men's collegiate ice hockey. J Strength Cond Res. 2017;31:1305-12.

Table 1 Search terms and key words used in each database. Searches 1, 2 and 3 were combined with 'AND'

Search 1	Search 2	Search 3
"Rugby" OR Football OR "Team Sport*" OR Soccer OR Basketball OR "Australian Rules" OR Hockey OR Cricket	"Global positioning system" OR "Local positioning system" OR "Global navigation satellite system" OR GNSS OR GPS OR LPS OR Microtechnology OR Magnetometer OR Accelerometer OR Gyroscope OR MEMS OR "Micro-electrical mechanical system" OR IMU OR "Inertial measurement unit"	Validity OR Reliability

Table 2 Modified Downs and Black quality scoring system [31]

No.	Item	Score
1	Aim/objective clearly stated	0-1
2	Outcome measures clear	0-1
3	Microtechnology details (i.e. manufacturer, model) stated	0-1
6	Findings clearly described	0-1
7	Actual deviations (e.g. SD, CI, LoA) of primary results clearly reported – validity component / reliability component	0-1 / 0-1
10	Actual results (e.g. *xx % vs. < xx %*) clearly reported (e.g. table format) for primary statistics	0-1
16	Data dredging	0-1
18	Suitable form of statistical analysis employed (e.g. CV, SEE, SEM, RMSE) – validity component / reliability component	0-1 / 0-1
20	Appropriate criterion measure (validity studies)	0-1
	Total	***xx %***

SD = standard deviation; CI = confidence interval; LoA = limits of agreement; CV = co-efficient of variation; SEE = standard error of the estimate; SEM = standard error of measurement RMSE = root mean square error

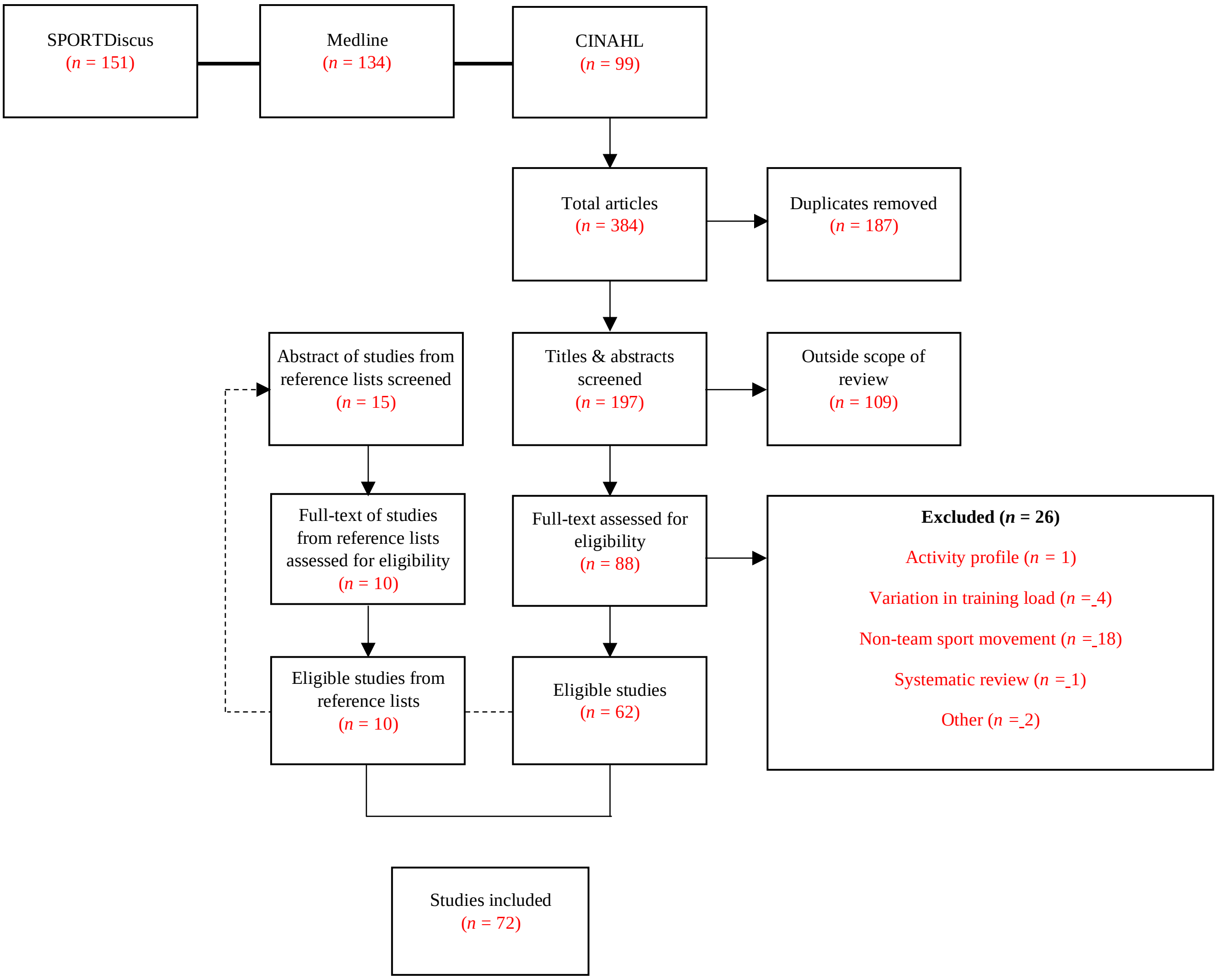

Figure 1 Systematic review selection process highlighting the inclusion and exclusion of studies.

Supplementary Table 1 Methodological quality of eligible studies used in the systematic review.

	Items assessed using modified Downs and Black checklist [31]											
	Reporting						Internal validity					
Study	**1**	**2**	**3**	**6**	**7**		**10**	**16**	**18**		**20**	
					V	R			V	R		
Akenhead et al. [78]	1	1	1	1	1	1	1	1	1	1	1	**100%**
Alexander et al. [91]	1	1	1	1	0	N/A	1	1	1	N/A	0.5	**83%**
Barbero-Alvarez et al. [70]	1	1	1	1	0	1	1	1	0	1	0	**73%**
Barr et al. [74]	1	1	1	1	0	1	1	1	1	1	0	**82%**
Barreira et al. [109]	1	1	1	1	N/A	0	1	1	N/A	0	N/A	**75%**
Barrett et al. [108]	1	1	1	1	N/A	0	1	1	N/A	1	N/A	**88%**
Bastida-Castillo et al. [41]	1	1	1	1	1	1	1	1	0	0	0	**73%**
Bataller et al. [79]	1	1	1	1	1	1	1	1	1	0	0	**82%**
Beato et al. [43]	1	1	1	1	1	N/A	1	1	0	N/A	0.5	**83%**
Beato & De Keijzer [102]	1	1	1	1	N/A	0	1	1	N/A	1	N/A	**88%**
Beato et al. [44]	1	1	1	1	1	1	1	1	0	1	0.5	**86%**
Boyd et al. [105]	1	1	1	1	N/A	1	1	1	N/A	1	N/A	**100%**
Buchheit et al. [100]	1	1	1	1	N/A	0	1	1	N/A	1	N/A	**88%**
Buchheit et al. [75]	1	1	1	1	1	1	0	1	1	1	0	**82%**
Buchheit et al. [95]	1	1	1	1	1	1	1	1	1	1	1	**100%**
Chambers et al. [16]	1	1	1	1	N/A	N/A	1	1	1	N/A	1	**100%**
Chambers et al. [14]	1	1	1	1	1	N/A	1	1	1	N/A	1	**100%**
Coutts and Duffield [49]	1	1	1	1	1	1	1	1	0	1	0	**82%**
Delaney et al. [103]	1	1	1	1	N/A	1	1	1	N/A	1	N/A	**100%**
Delaney et al. [81]	1	1	1	1	0	N/A	1	1	1	N/A	1	**89%**
Dogramaci et al. [50]	1	1	1	1	0	N/A	1	1	1	N/A	0	**78%**
Duffield et al. [58]	1	1	1	1	0	0	1	1	0	1	1	**73%**
Edgecomb and Norton [45]	1	1	1	1	1	N/A	1	1	0	N/A	0	**78%**
Fitzpatrick et al. [107]	1	1	1	1	N	1	1	1	N/A	1	N/A	**100%**
Fox et al. [46]	1	1	1	1	0	N/A	1	1	0	N/A	0	**67%**
Frencken et al. [60]	1	1	1	1	1	N/A	1	1	1	N/A	0	**89%**
Gabbett et al. [84]	1	1	1	1	0	N/A	1	1	0	N/A	1	**78%**
Gastin et al. [97]	1	1	1	1	0	N/A	1	1	1	N/A	1	**89%**
Gastin et al. [87]	1	1	1	1	0	N/A	1	1	0	N/A	1	**78%**
Gray et al. [47]	1	1	1	1	1	0	1	1	0	1	1	**82%**
Highton et al. [94]	1	1	1	1	1	N/A	1	1	0	N/A	1	**89%**
Hoppe et al. [51]	1	1	1	1	1	1	1	1	1	1	0	**91%**
Hulin et al. [15]	1	1	1	1	1	N/A	1	1	1	N/A	1	**100%**
Jackson et al. [101]	1	1	1	1	N/A	0	1	1	N/A	1	N/A	**88%**
Jennings et al. [52]	1	1	1	1	1	1	1	1	1	1	0	**91%**
Jennings et al. [99]	1	1	1	1	N/A	1	1	1	N/A	0	N/A	**88%**
Johnston et al. [54]	1	1	1	1	0	0	1	1	0	1	0.5	**68%**
Johnston et al. [55]	1	1	1	1	0	0	1	1	0	1	0	**64%**
Johnston et al. [53]	1	1	1	1	0	0	1	1	0	1	0	**64%**
Kelly et al. [85]	1	1	1	1	0	N/A	1	1	1	N/A	1	**89%**
Lacome et al. [71]	1	1	1	1	1	1	1	1	1	1	1	**100%**
Leser et al. [66]	1	1	1	1	1	N/A	1	1	0	N/A	0	**78%**
Linke et al. [34]	1	1	1	1	1	N/A	1	1	1	N/A	1	**100%**
Luteberget et al. [63]	1	1	1	1	1	N/A	1	1	0	N/A	1	**89%**
Luteberget et al. [104]	1	1	1	1	N/A	1	1	1	N/A	1	N/A	**100%**
MacLeod et al. [56]	1	1	1	1	1	N/A	1	1	0	N/A	0.5	**83%**
MacLeod et al. [86]	1	1	1	1	0	1	1	1	1	1	1	**91%**
McNamara et al. [17]	1	1	1	1	0	N/A	1	1	1	N/A	0.5	**83%**
Munoz-Lopez et al. [57]	1	1	1	1	1	1	1	1	0	0	0	**73%**

Supplementary Table 1 continued

	Items assessed using modified Downs and Black checklist [31]											
	Reporting							Internal validity				
Study	**1**	**2**	**3**	**6**	**7**		**10**	**16**	**18**		**20**	
					V	R			V	R		
Nagahara et al. [72]	1	1	1	1	1	N/A	1	1	1	N/A	1	**100%**
Nikolaidis et al. [35]	1	1	1	1	1	1	1	1	1	1	0	**91%**
Orgis et al. [77]	1	1	0	1	1	N/A	1	1	0	N/A	1	**78%**
Padulo et al. [36]	1	1	1	1	0	0	1	1	1	0	0.5	**68%**
Petersen et al. [37]	1	1	1	1	1	1	1	1	1	1	0	**91%**
Portas et al. [48]	1	1	1	1	1	1	1	1	1	1	0	**91%**
Rampinini et al. [38]	1	1	1	1	1	N/A	1	1	1	N/A	1	**100%**
Rawstorn et al. [39]	1	1	1	1	1	1	1	1	0	1	0	**82%**
Rhodes et al. [61]	1	1	1	1	1	0	1	1	1	1	1	**91%**
Roe et al. [73]	1	1	1	1	1	N/A	1	1	1	N/A	1	**100%**
Roell et al. [89]	1	1	1	1	0	N/A	1	1	1	N/A	1	**89%**
Sathyan et al. [64]	1	1	1	1	0	N/A	1	1	0	N/A	0	**67%**
Serpiello et al. [65]	1	1	1	1	1	N/A	1	1	1	N/A	1	**100%**
Stevens et al. [62]	1	1	1	1	0	N/A	1	1	0	N/A	1	**78%**
Thornton et al. [33]	1	1	1	1	N/A	1	1	1	N/A	1	N/A	**100%**
Van Iterson et al. [110]	1	1	1	1	N/A	1	1	1	N/A	1	N/A	**100%**
Varley et al. [80]	1	1	1	1	1	1	1	1	1	1	1	**100%**
Vickery et al. [40]	1	1	1	1	0	0	1	1	0	1	1	**73%**
Waldron et al. [59]	1	1	1	1	0	0	1	1	1	1	0	**73%**
Willmott et al. [42]	1	1	1	1	0	0	1	1	1	1	0	**73%**
Wundersitz et al. [88]	1	1	1	1	0	N/A	1	1	1	N/A	1	**89%**
Wundersitz et al. [90]	1	1	1	1	0	N/A	1	1	1	N/A	1	**89%**
Zanetti et al. [98]	1	1	1	1	1	N/A	1	1	1	N/A	1	**100%**

N/A = not applicable

Supplementary Table 2 Summary of studies that investigated the validity of wearable microtechnology to measure total distance

Device	Criterion	Movement/Protocol	Findings	Reference
Global positioning systems				
SPI-10 (1-Hz)	Measuring tape	Team sport circuit (128.5 m)	Bias = -4.1%	Coutts and Duffield [49]
	Trundle wheel	Running circuit (128 – 1386 m)	Bias = 4.8%	Edgecomb and Norton [45]
	Athletic track	Walk (< 2 m·s^{-1}) (8800 m)	SEE = 0.6%	Petersen et al. [37]
		Jog (2.0 – 3.5 m·s^{-1}) (2400 m)	SEE = 0.5%	
		Run (3.5 – 4.0 m·s^{-1}) (1200 m)	SEE = 2.1%	
		Stride (4.0 – 5.0 m·s^{-1}) (600 m)	SEE = 0.8%	
SPI-Elite (1-Hz)	Measuring tape	Team sport circuit (128.5 m)	Bias = -2.0%	Coutts and Duffield [49]
	Trundle wheel	Team sport circuit (487 m)	Bias = 2.5 m	MacLeod et al. [56]
	Measuring tape	Futsal circuit	CV = 2.2%	Dogramaci et al. [50]
	3D motion analysis	Jog – rectangular pattern (26 m)	No significant difference to criterion	Duffield et al. [58]
		Run – rectangular pattern (26 m)	2/2 devices significant difference to criterion	
		2-m tennis (side to side)	2/2 devices significant difference to criterion	
		4-m tennis (side to side)	2/2 devices significant difference to criterion	
		Random movement (6 seconds)	2/2 devices significant difference to criterion	
WiSpi (1-Hz)	Measuring tape	Team sport circuit (128.5 m)	Bias = 0.7%	Coutts and Duffield [49]
	Theodolite	Linear course (200 m);		Gray et al. [47]
		Walk (0 – 1.6 m·s^{-1})	Bias = 2.8%	
		Jog (1.6 – 3.5 m·s^{-1})	Bias = 0.8%	
		Run (3.5 – 5 m·s^{-1})	Bias = 1.5%	
		Sprint (> 5 m·s^{-1})	Bias = 2.5%	
		Non-linear course (200 m);		
		Walk (0 – 1.6 m·s^{-1})	Bias = -0.5%	
		Jog (1.6 – 3.5 m·s^{-1})	Bias = -5.8%	
		Run (3.5 – 5 m·s^{-1})	Bias = -7.7%	
		Sprint (> 5 m·s^{-1})	Bias = -9.8%	
MinimaxX 2.5 (1-Hz)	Measuring tape	Straight-line (10 m, 20 m, 40 m, 20 - 40 m);		Jennings et al. [52]
		Walk	SEE = 9.6 – 23.8%	
		Jog	SEE = 11.5 – 25.7%	
		Stride	SEE = 11.3 – 31.1%	
		Sprint	SEE = 12.2 – 32.4%	
		Gradual 90º change of direction (40 m);		
		Walk	SEE = 9.1%	
		Jog	SEE = 10.2%	
		Stride	SEE = 11.5%	
		Sprint	SEE = 12.7%	
		Tight 90º change of direction (40 m);		
		Walk	SEE = 12.6%	
		Jog	SEE = 9.0%	
		Stride	SEE = 10.4%	
		Sprint	SEE = 12.5%	
		Team sport circuit (140 m)	SEE = 3.6%	

Supplementary Table 2 continued

Device	Criterion	Movement/Protocol	Findings	Reference
	Trundle wheel	Straight-line;		Portas et al. [48]
		Walk (1.79 m·s^{-1})	SEE = 2.7%	
		Run (3.58 m·s^{-1})	SEE = 2.6%	
		Multidirectional courses;		
		Walk (1.79 m·s^{-1})	SEE = 1.8 – 4.2%	
		Run (3.58 m·s^{-1})	SEE = 2.4 – 6.8%	
		Team sport circuit	SEE = 1.3 – 3.0%	
Wimu (5-Hz)	Measuring tape	Team sport circuit (146 m)	Bias = -1.9%	Munoz-Lopez et al. [57]
		Straight-line sprint (10 m)	Bias = -8.0%	
		Straight-line sprint (30 m)	Bias = 1.4%	
MinimaxX 2.5 (5-Hz)	Measuring tape	Straight-line (10 m, 20 m, 40 m, 20 - 40 m);		Jennings et al. [52]
		Walk	SEE = 9.8 – 21.3%	
		Jog	SEE = 10.7 – 23.2%	
		Stride	SEE = 9.0 – 27.4%	
		Sprint	SEE = 11.9 – 30.9%	
		Gradual 90º change of direction (40 m);		
		Walk	SEE = 8.9%	
		Jog	SEE = 9.7%	
		Stride	SEE = 11.0%	
		Sprint	SEE = 11.7%	
		Tight 90º change of direction (40 m);		
		Walk	SEE = 9.9%	
		Jog	SEE = 10.6%	
		Stride	SEE = 10.8%	
		Sprint	SEE = 11.5%	
		Team sport circuit (140 m)	SEE = 3.8%	
	Measuring tape	Team sport circuit (130.5 m)	No significant difference to criterion	Johnston et al. [54]
	Trundle wheel	Straight-line;		Portas et al. [48]
		Walk (1.79 m·s^{-1})	SEE = 3.1%	
		Run (3.58 m·s^{-1})	SEE = 2.9%	
		Multidirectional courses;		
		Walk (1.79 m·s^{-1})	SEE = 2.2 – 4.4%	
		Run (3.58 m·s^{-1})	SEE = 2.2 – 3.6%	
		Team sport circuit	SEE = 1.5 – 2.2%	
	3D motion analysis	Jog – rectangular pattern (26 m)	1/2 devices significant difference to criterion	Duffield et al. [58]
		Run – rectangular pattern (26 m)	2/2 devices significant difference to criterion	
		2-m tennis (side to side)	2/2 devices significant difference to criterion	
		4-m tennis (side to side)	2/2 devices significant difference to criterion	
		Random movement (6 seconds)	2/2 devices significant difference to criterion	

Supplementary Table 2 continued

Device	Criterion	Movement/Protocol	Findings	Reference
	3D motion analysis	Court-based team sport protocols;		Vickery et al. [40]
		2-m tennis	1/2 devices significant difference to criterion	
		4-m tennis	1/2 devices significant difference to criterion	
		Half-court	No significant difference to criterion	
		Random	1/2 devices significant difference to criterion	
		Field-based team sport protocols;		
		Run-a-three (16 m)	No significant difference to criterion	
		Fast bowling (15 m)	2/2 devices significant difference to criterion	
		Fielding (18 m)	No significant difference to criterion	
		Gradual 90º change of direction (24 m)	No significant difference to criterion	
		Tight 45º change of direction (20 m)	No significant difference to criterion	
		Random	No significant difference to criterion	
MinimaxX (5-Hz)	Athletic track	Walk (< 2 m·s^{-1}) (8800 m)	SEE = 2.0 – 3.8%	Petersen et al. [37]
		Jog (2.0 – 3.5 m·s^{-1}) (2400 m)	SEE = 1.8 – 2.6%	
		Run (3.5 – 4.0 m·s^{-1}) (1200 m)	SEE = 2.8 – 3.0%	
		Stride (4.0 – 5.0 m·s^{-1}) (600 m)	SEE = 1.7 – 1.8%	
		Straight-line sprint;		
		20 m	SEE = 15.2 – 23.8%	
		30 m	SEE = 14.4 – 19.7%	
		40 m	SEE = 14.9 – 16.1%	
		Run-a-three sprint (18 m)	SEE = 5.3 – 12.7%	
SPI-Pro (5-Hz)	Athletic track	Walk (< 2 m·s^{-1}) (8800 m)	SEE = 0.5 – 1.0%	Petersen et al. [37]
		Jog (2.0 – 3.5 m·s^{-1}) (2400 m)	SEE = 1.5 – 3.7%	
		Run (3.5 – 4.0 m·s^{-1}) (1200 m)	SEE = 0.7 – 2.4%	
		Stride (4.0 – 5.0 m·s^{-1}) (600 m)	SEE = 0.4 – 3.0%	
		Straight-line sprint;		
		20 m	SEE = 5.5 – 10.5%	
		30 m	SEE = 4.2 – 7.6%	
		40 m	SEE = 2.9 – 7.7%	
		Run-a-three sprint (18 m)	SEE = 2.6 – 6.7%	
	Radar	Straight-line shuttle runs (70 m)	CV = 2.8%	Rampinini et al. [38]
	Measuring tape	Straight-line sprint (30 m);		Waldron et al. [59]
		10 m	CV = 8.1%	
		20 m	CV = 8.1%	
		30 m	CV = 5.0%	
		Moving 10 m	CV = 4.8%	
FieldWiz (10-Hz)	Trundle wheel	Straight-line run (690 m)	CV = 3.9%	Willmott et al. [42]
		Tight and gradual change of direction course (570 m)	CV = 7.3%	
		Team sport circuit (128.5 m)	CV = 2.5%	

Supplementary Table 2 continued

Device	Criterion	Movement/Protocol	Findings	Reference
WimuPro (10-Hz)	Trundle wheel	Linear course (138 m);		Bastida-Castillo et al. [41]
		Walk (< 6 km·h^{-1})	Bias = 0.9 m	
		Sprint (> 16 km·h^{-1})	Bias = 1.7 m	
		Circular course (57 m);		
		Walk (< 6 km·h^{-1})	Bias = 1.0 m	
		Sprint (> 16 km·h^{-1})	Bias = 1.8 m	
		Zig-zag course (20 m);		
		Walk (< 6 km·h^{-1})	Bias = 0.5 m	
		Sprint (> 16 km·h^{-1})	Bias = 1.2 m	
Apex (10-Hz)	Athletic track/ground truth reference	Straight-line jog (20 m)	Bias = 1.1%	Beato et al. [43]
		Team sport circuit (128.5 m)	Bias = 2.3%	
		Track running (400 m)	Bias = 1.1%	
Viper (10-Hz)	Athletic track/ground truth reference	Straight-line jog (20 m)	Bias = 1.3%	Beato et al. [44]
		Team sport circuit (128.5 m)	Bias = 2.7%	
		Track running (400 m)	Bias = 2.0%	
MinimaxX S4 (10-Hz)	Trundle wheel and measuring tape	Team sport circuit (129.6 m)	SEE = 3.0%	Hoppe et al. [51]
	Measuring tape	Team sport circuit (165 m)	No significant difference to criterion; Bias = < 1%	Johnston et al. [55]
	Measuring tape	Team sport circuit (165 m)	No significant difference to criterion	Johnston et al. [53]
	Not specified	Cricket bowling action	SEE = 1.3 m; Bias = 0.8%	McNamara et al. [17]
	Radar	Straight-line shuttle runs (70 m)	CV = 1.9%	Rampinini et al. [38]
	3D motion analysis	Court-based team sport protocols;		Vickery et al. [40]
		2-m tennis	Significant difference to criterion	
		4-m tennis	Significant difference to criterion	
		Half-court	No significant difference to criterion	
		Random	No significant difference to criterion	
		Field-based team sport protocols;		
		Run-a-three (16 m)	No significant difference to criterion	
		Fast bowling (15 m)	No significant difference to criterion	
		Fielding (18 m)	No significant difference to criterion	
		Gradual 90º change of direction (24 m)	Significant difference to criterion	
		Tight 45º change of direction (20 m)	Significant difference to criterion	
		Random	Significant difference to criterion	
Polar team pro sensor (10-Hz)	Trundle wheel	Straight-line walk, jog, sprint (168.5 m)	Bias = 11.6 m (back-mounted sensor); 14.9 m (chest-mounted sensor)	Fox et al. [46]
		Agility t-test (40 m)	Bias = 1.0 m (back-mounted sensor); 0.19 m (chest-mounted sensor)	
Johan (10-Hz)	Athletic track	Running circuit (200 m)	SEE = -0.13 – 2.13 m	Nikolaidis et al. [35]
		Shuttle endurance test (20 m)	SEE = -1.33 – 9.0 m	
Apex (18-Hz)	Athletic track/ground truth reference	Straight-line jog (20 m)	Bias = 1.2%	Beato et al. [43]
		Team sport circuit (128.5 m)	Bias = 2.1%	
		Track running (400 m)	Bias = 1.2%	

Supplementary Table 2 continued

Device	Criterion	Movement/Protocol	Findings	Reference
GPEXE, Exelio (18-Hz)	Trundle wheel and measuring tape	Team sport circuit (129.6 m)	SEE = 1.6%	Hoppe et al. [51]
SPI-ProX (interpolated 15-Hz)	3D motion analysis	Team sport circuit	RMSE = 1.2%	Linke et al. [34]
		Shuttle runs (20 m)	RMSE = 4.4%	
		Small sided game	RMSE = 2.2%	
	Measuring tape	Team sport circuit (165 m)	No significant difference to criterion	Johnston et al. [53]
	Athletic track	LIST movement pattern (13,200 m);		Rawstorn et al. [39]
		Straight-line shuttle (20 m)’	Bias = -2.2%	
		Walk	Bias = -2.2%	
		Jog	Bias = -2.2%	
		Run	Bias = -2.2%	
		Sprint	Bias = -1.9%	
		Curvilinear (200 m);	Bias = 3.0%	
		Walk	Bias = 3.0%	
		Jog	Bias = 3.0%	
		Run	Bias = 3.0%	
		Sprint	Bias = 3.2%	
	3D motion analysis	Court-based team sport protocols;		Vickery et al. [40]
		2-m tennis	No significant difference to criterion	
		4-m tennis	1/2 devices significant difference to criterion	
		Half-court	1/2 devices significant difference to criterion	
		Random	1/2 devices significant difference to criterion	
		Field-based team sport protocols;		
		Run-a-three (16 m)	No significant difference to criterion	
		Fast bowling (15 m)	No significant difference to criterion	
		Fielding (18 m)	No significant difference to criterion	
		Gradual 90º change of direction (24 m)	2/2 devices significant difference to criterion	
		Tight 45º change of direction (20 m)	1/2 devices significant difference to criterion	
		Random	No significant difference to criterion	
Spin (50-Hz)	Measuring tape	Shuttle run;		Padulo et al. [36]
		20 m	CV = 0.24%	
		15 m	CV = 0.37%	
		10 m	CV = 0.39%	
		7.5 m	CV = 0.93%	
		5 m	CV = 1.1%	
		Square run (40 m)	CV = 1.1%	
		Zig-zag (60 m)	CV = 0.42%	
		Cross-path run (40 m)	CV = 0.79%	

Supplementary Table 2 continued

Device	Criterion	Movement/Protocol	Findings	Reference
Local positioning systems				
WASP	Measuring tape	Straight-line course;		Sathyan et al. [64]
		Outdoors (30 m);		
		Walk and jog	Bias = 1.3%	
		Run and sprint	Bias = 1.4%	
		Indoors (28 m);		
		Walk and jog	Bias = 2.4%	
		Run and sprint	Bias = 2.0%	
		Non-linear course;		
		Outdoors (27.6 m);		
		Walk and jog	Bias = 3.0%	
		Run and sprint	Bias = 3.9%	
		Indoors (27.6 m);		
		Walk and jog	Bias = 3.5%	
		Run and sprint	Bias = 2.0%	
WimuPro	Trundle wheel	Linear course (138 m);		Bastida-Castillo et al. [41]
		Walk (< 6 $km{\cdot}h^{-1}$)	Bias = 0.99 m	
		Sprint (> 16 $km{\cdot}h^{-1}$)	Bias = 0.74 m	
		Circular course (57 m);		
		Walk (< 6 $km{\cdot}h^{-1}$)	Bias = 0.55 m	
		Sprint (> 16 $km{\cdot}h^{-1}$)	Bias = 1.2 m	
		Zig-zag course (20 m);		
		Walk (< 6 $km{\cdot}h^{-1}$)	Bias = 0.57 m	
		Sprint (> 16 $km{\cdot}h^{-1}$)	Bias = 1.2 m	
Clearsky T6	3D motion analysis	Straight-line sprint to deceleration (10 m)	Bias = 1.5% (optimal set-up); 24.9% (sub-optimal set-up)	Luteberget et al. [63]
		Left and right 75º diagonal movements (5 m)	Bias = 1.8% (optimal set-up); 29.0% (sub-optimal set-up)	
		Straight-line sprint with 90º change of direction to deceleration (10 m)	Bias = 1.6% (optimal set-up); 20.9% (sub-optimal set-up)	
		Zig-zag (60º and 360º change of direction)	Bias = 1.5% (optimal set-up); 15.0% (sub-optimal set-up)	
		Zig-zag (60º change of direction)	Bias = 0.5% (optimal set-up); 29.5% (sub-optimal set-up)	
	3D motion analysis	Straight-line (12 m);		Serpiello et al. [65]
		Walk	CV = 1.7%	
		Jog	CV = 2.5%	
		Sprint	CV = 1.2%	
		45º change of direction (5.5 m)	CV = 2.2%	
Inmotio	3D motion analysis	Team sport circuit	RMSE = 2.3%	Linke et al. [34]
		Shuttle runs (20 m)	RMSE = 0.74%	
		Small sided game	RMSE = 4.0%	

Supplementary Table 2 continued

Device	Criterion	Movement/Protocol	Findings	Reference
	Measuring tape	Straight-line (5 m);		Frencken et al. [60]
		Walk	CV = 0.4%	
		Sprint	CV = 0.6%	
		45º change of direction (10 m);		
		Walk	CV = 0.6%	
		Sprint	CV = 0.9%	
		90º change of direction (10 m);		
		Walk	CV = 1.0%	
		Sprint	CV = 2.0%	
		Combined movement (25 m);		
		Walk	CV = 1.1%	
		Sprint	CV = 1.7%	
	3D motion analysis	Straight-line (jog, sub-maximal, maximal intensity)	Bias = -0.9 – 2.0%	Stevens et al. [62]
		Straight-line shuttle (jog, sub-maximal, maximal intensity)	Bias = -6.8 - -3.6%	
		90º change of direction (frequent and gradual – jog, sub-maximal, maximal intensity)	Bias = -2.6 - -0.6%	
Kinexon one	Trundle wheel and measuring tape	Team sport circuit (129.6 m)	SEE = 1.4%	Hoppe et al. [51]
Ubisense	Trundle wheel	Practice match (basketball)	Bias = 3.5%	Leser et al. [66]
	Laser total station	Figure 8 course (81 m);		Rhodes et al. [61]
		4 $km \cdot h^{-1}$	SEE = 1.9 – 2.1 m	
		6 $km \cdot h^{-1}$	SEE = 1.0 – 1.1 m	
		8 $km \cdot h^{-1}$	SEE = 0.98 – 1.1 m	
		Match-play replication (wheel-chair court sport)	Bias = 3.0 – 5.0 m	

SEE = standard error of the estimate; CV = co-efficient of variation; RMSE = root mean square error; LIST =Loughborough intermittent shuttle running test

Supplementary Table 3 Summary of studies that investigated the validity of wearable microtechnology to measure velocity-based threshold distance

Device	Criterion	Movement/Protocol	Threshold	Findings	Reference
Global positioning systems					
SPI-Pro (5-Hz)	Radar	Straight-line shuttle runs (70 m)	> 4.17 m·s^{-1}	CV = 7.5%	Rampinini et al. [38]
			> 5.56 m·s^{-1}	CV = 23.2%	
MinimaxX S4 (10-Hz)	Radar	Straight-line shuttle runs (70 m)	> 4.17 m·s^{-1}	CV = 4.7%	Rampinini et al. [38]
			> 5.56 m·s^{-1}	CV = 10.5%	
SPI-ProX (interpolated 15-Hz)	3D motion analysis	Team sport circuit	0.28 – 1.7 m·s^{-1}	RMSE = 7.7%	Linke et al. [34]
			1.7 – 4.2 m·s^{-1}	RMSE = 8.6%	
			4.2 – 5.6 m·s^{-1}	RMSE = 14.6%	
			5.6 – 6.9 m·s^{-1}	RMSE = 18.1%	
			> 6.9 m·s^{-1}	RMSE = 51.1%	
		Shuttle runs (20 m)	0.28 – 1.7 m·s^{-1}	RMSE = 57.2%	
			1.7 – 4.2 m·s^{-1}	RMSE = 6.3%	
			4.2 – 5.6 m·s^{-1}	RMSE = 77.5%	
		Small sided game	0.28 – 1.7 m·s^{-1}	RMSE = 18.4%	
			1.7 – 4.2 m·s^{-1}	RMSE = 3.7%	
			4.2 – 5.6 m·s^{-1}	RMSE = 38.7%	
			5.6 – 6.9 m·s^{-1}	RMSE = 97.4%	
Local positioning systems					
Inmotio	3D motion analysis	Team sport circuit	0.28 – 1.7 m·s^{-1}	RMSE = 5.2%	Linke et al. [34]
			1.7 – 4.2 m·s^{-1}	RMSE = 9.2%	
			4.2 – 5.6 m·s^{-1}	RMSE = 13.9%	
			5.6 – 6.9 m·s^{-1}	RMSE = 22.0%	
			> 6.9 m·s^{-1}	RMSE = 28.7%	
		Shuttle runs (20 m)	0.28 – 1.7 m·s^{-1}	RMSE = 5.0%	
			1.7 – 4.2 m·s^{-1}	RMSE = 1.1%	
			4.2 – 5.6 m·s^{-1}	RMSE = 207.1%	
		Small sided game	0.28 – 1.7 m·s^{-1}	RMSE = 8.0%	
			1.7 – 4.2 m·s^{-1}	RMSE = 6.2%	
			4.2 – 5.6 m·s^{-1}	RMSE = 21.7%	
			5.6 – 6.9 m·s^{-1}	RMSE = 43.8%	

CV = co-efficient of variation; RMSE = root mean square error

Supplementary Table 4 Summary of studies that investigated the validity of wearable microtechnology to measure peak velocity

Device	Criterion	Movement/Protocol	Findings	Reference
		Global positioning systems		
SPI-Elite (1-Hz)	Timing gates	Straight-line sprint (30 m)	Total sprint time = r^2 -0.96 Fastest time = r^2 -0.93	Barbero-Alvarez et al. [70]
	Timing gates	Team sport circuit (128.5 m)	Sprint time r = -0.40 - -0.53	Coutts and Duffield [49]
	3D motion analysis	Jog – rectangular pattern (26 m)	No significant difference to criterion	Duffield et al. [58]
		Run – rectangular pattern (26 m)	1/2 devices significant difference to criterion	
		2-m tennis (side to side)	2/2 devices significant difference to criterion	
		4-m tennis (side to side)	2/2 devices significant difference to criterion	
		Random movement (6 seconds)	2/2 devices significant difference to criterion	
SPI-10 (1-Hz)	Timing gates	Team sport circuit (128.5 m)	Sprint time = r -0.40 - -0.53	Coutts and Duffield [49]
WiSpi (1-Hz)	Timing gates	Team sport circuit (128.5 m)	Sprint time = r -0.40 - -0.53	Coutts and Duffield [49]
VX (4-Hz)	Timing gates	Straight-line sprint (40 m)	SEE = 3.4%	Buchheit et al. [75]
MinimaxX 2.5 (5-Hz)	Radar	Flying sprint (50 m)	No significant difference to criterion	Johnston et al. [54]
	Timing gates	Team sport circuit (130.5 m)	No significant difference to criterion	
	3D motion analysis	Court-based team sport protocols;		Vickery et al. [40]
		2-m tennis	No significant difference to criterion	
		4-m tennis	No significant difference to criterion	
		Half-court	No significant difference to criterion	
		Random	No significant difference to criterion	
		Field-based team sport protocols;		
		Run-a-three (16 m)	No significant difference to criterion	
		Fast bowling (15 m)	No significant difference to criterion	
		Fielding (18 m)	No significant difference to criterion	
		Gradual 90º change of direction (24 m)	No significant difference to criterion	
		Tight 45º change of direction (20 m)	No significant difference to criterion	
		Random	No significant difference to criterion	
	3D motion analysis	Jog – rectangular pattern (26 m)	1/2 devices significant difference to criterion	Duffield et al. [58]
		Run – rectangular pattern (26 m)	1/2 devices significant difference to criterion	
		2-m tennis (side to side)	No significant difference to criterion	
		4-m tennis (side to side)	1/2 devices significant difference to criterion	
		Random movement (6 seconds)	No significant difference to criterion	
SPI-ProXII (5-Hz)	Timing gates	Straight-line sprint (40 m)	SEE = 3.3%	Buchheit et al. [75]
Apex (10-Hz)	Radar	Straight-line sprint (20 m)	Bias = 2.4%	Beato et al. [43]
Viper (10-Hz)	Radar	Straight-line sprint (20 m)	Bias = 1.8%	Beato et al. [44]
MinimaxX S4 (10-Hz)	Timing gates	Team sport circuit (129.6 m)	SEE = 4.1%	Hoppe et al. [51]
	Timing gates	Team sport circuit (165 m)	2/2 devices significant difference to criterion Bias = < 2.5%	Johnston et al. [55]
	Timing gates	Team sport circuit (165 m)	2/2 devices significant difference to criterion	Johnston et al. [53]

Supplementary Table 4 continued

Device	Criterion	Movement/Protocol	Findings	Reference
	3D motion analysis	Court-based team sport protocols;		Vickery et al. [40]
		2-m tennis	No significant difference to criterion	
		4-m tennis	No significant difference to criterion	
		Half-court	No significant difference to criterion	
		Random	No significant difference to criterion	
		Field-based team sport protocols;		
		Run-a-three (16 m)	No significant difference to criterion	
		Fast bowling (15 m)	No significant difference to criterion	
		Fielding (18 m)	No significant difference to criterion	
		Gradual 90º change of direction (24 m)	No significant difference to criterion	
		Tight 45º change of direction (20 m)	No significant difference to criterion	
		Random	No significant difference to criterion	
Optimeye S5 (10-Hz)	Radar	Straight-line sprint (40 m)	SEE = 1.9% (Openfield software) SEE = 2.0% (Sprint software)	Roe et al. [73]
SPI-HPU (15-Hz)	Timing gates	Straight-line sprint (36.6 m)	CV = 0.9%; SEM = 0.07 $m{\cdot}s^{-1}$	Barr et al. [74]
SPI-ProX (interpolated 15-Hz)	Timing gates	Team sport circuit (165 m)	1/2 devices significant difference to criterion	Johnston et al. [53]
	3D motion analysis	Team sport circuit	RMSE = 4.0%	Linke et al. [34]
		Shuttle runs (20 m)	RMSE = 5.0%	
		Small sided game	RMSE = 6.1%	
	Laser	Straight-line sprint (> 30 m)	CV = 5.1%	Nagahara et al. [72]
	3D motion analysis	Court-based team sport protocols;		Vickery et al. [40]
		2-m tennis	No significant difference to criterion	
		4-m tennis	No significant difference to criterion	
		Half-court	No significant difference to criterion	
		Random	1/2 devices significant difference to criterion	
		Field-based team sport protocols;		
		Run-a-three (16 m)	No significant difference to criterion	
		Fast bowling (15 m)	No significant difference to criterion	
		Fielding (18 m)	No significant difference to criterion	
		Gradual 90º change of direction (24 m)	No significant difference to criterion	
		Tight 45º change of direction (20 m)	1/2 devices significant difference to criterion	
		Random	No significant difference to criterion	
Sensoreverywhere v2 (16-Hz)	Radar	Straight-line sprint (40 m)	SEE = 2.0%	Lacome et al. [71]
Apex (18-Hz)	Radar	Straight-line sprint (20 m)	Bias = 2.0%	Beato et al. [43]
GPEXE, Exelio (18-Hz)	Timing gates	Team sport circuit (129.6 m)	SEE = 4.5%	Hoppe et al. [51]
GPEXE, Exelio (20-Hz)	Radar	Straight-line sprint (> 30 m)	CV = 2.5%	Nagahara et al. [72]

Supplementary Table 4 continued

Device	Criterion	Movement/Protocol	Findings	Reference
		Local positioning systems		
Not specified	3D motion analysis	Straight-line (26.5 m);		Orgis et al. [77]
		Walk (2 – 6 km·h^{-1})	Bias = 6.9%	
		Jog (6.1 – 11 km·h^{-1})	Bias = 13.2%	
		Low-speed run (11.1 – 14 km·h^{-1})	Bias = 12.6%	
		Moderate speed run (14.1 – 19 km·h^{-1})	Bias = 11.6%	
		High-speed run (>19 km·h^{-1})	Bias = 11.8%	
		Sprint (as fast as possible)	Bias = 6.8%	
		45° change of direction;		
		Moderate speed run (14.1 – 19 km·h^{-1})	Bias = -1.5%	
		High-speed run (>19 km·h^{-1})	Bias = 2.7%	
		90° change of direction;		
		High-speed run (>19 km·h^{-1})	Bias = 1.3%	
		Small sided game;		
		2 v 2	Bias = 8.3%	
		2 v 3	Bias = 7.4%	
		3 v 3	Bias = 7.2%	
Kinexon one	Timing gates	Team sport circuit (129.6 m)	SEE = 2.1%	Hoppe et al. [51]
Ubisense	Wireless inertial sensor	Straight-line sprint (20 m)	Bias = 0.05 – 0.08 m·s^{-1}	Rhodes et al. [61]
Clearsky T6	3D motion analysis	Straight-line (12 m);		Serpiello et al. [65]
		Walk	CV = 2.8%	
		Jog	CV = 4.7%	
		Sprint	CV = 3.2%	
		45º change of direction (5.5 m)	CV = 2.1%	
Inmotio	3D motion analysis	Team sport circuit	RMSE = 4.5%	Linke et al. [34]
		Shuttle runs (20 m)	RMSE = 11.3%	
		Small sided game	RMSE = 7.1%	
	Timing gates	Straight-line sprint (40 m)	SEE = 1.2%	Buchheit et al. [75]
	3D motion analysis	Straight-line shuttle (jog, sub-maximal, maximal intensity)	Bias = -4.1 – 2.2%	Stevens et al. [62]
		90º change of direction (frequent and gradual – jog, sub-maximal, maximal intensity)	Bias = 0.1 – 3.4%	

SEE = standard error of the estimate; RMSE = root mean square error; CV =co-efficient of variation

Supplementary Table 5 Summary of studies that investigated the validity of wearable microtechnology to measure instantaneous velocity

Device	Criterion	Movement/Protocol	Findings	Reference
Global navigation satellite systems				
MinimaxX v2 (5-Hz)	Laser	Straight-line movement;		Varley et al. [80]
		Constant velocity;		
		1-3 $m{\cdot}s^{-1}$	CV = 11.1%	
		3-5 $m{\cdot}s^{-1}$	CV = 10.6%	
		5-8 $m{\cdot}s^{-1}$	CV = 3.6%	
		Acceleration - starting velocity;		
		1-3 $m{\cdot}s^{-1}$	CV = 14.9%	
		3-5 $m{\cdot}s^{-1}$	CV = 9.5%	
		5-8 $m{\cdot}s^{-1}$	CV = 7.1%	
		Deceleration - starting velocity;		
		5-8 $m{\cdot}s^{-1}$	CV = 33.2%	
MinimaxX S4 (10-Hz)	Laser	Straight-line sprint (10 m);	SEE = 0.19 $m{\cdot}s^{-1}$ (smooth); 0.29 $m{\cdot}s^{-1}$ (raw)	Akenhead et al. [78]
		Acceleration 0-1 $m{\cdot}s^{-2}$	SEE = 0.12 $m{\cdot}s^{-1}$ (smooth); 0.19 $m{\cdot}s^{-1}$ (raw)	
		Acceleration 1-2 $m{\cdot}s^{-2}$	SEE = 0.16 $m{\cdot}s^{-1}$ (smooth); 0.17 $m{\cdot}s^{-1}$ (raw)	
		Acceleration 2-3 $m{\cdot}s^{-2}$	SEE = 0.18 $m{\cdot}s^{-1}$ (smooth); 0.30 $m{\cdot}s^{-1}$ (raw)	
		Acceleration 3-4 $m{\cdot}s^{-2}$	SEE = 0.19 $m{\cdot}s^{-1}$ (smooth); 0.29 $m{\cdot}s^{-1}$ (raw)	
		Acceleration >4 $m{\cdot}s^{-2}$	SEE = 0.32 $m{\cdot}s^{-1}$ (smooth); 0.36 $m{\cdot}s^{-1}$ (raw)	
	Laser	Straight-line movement;		Varley et al. [80]
		Constant velocity;		
		1-3 $m{\cdot}s^{-1}$	CV = 8.3%	
		3-5 $m{\cdot}s^{-1}$	CV = 4.3%	
		5-8 $m{\cdot}s^{-1}$	CV = 3.1%	
		Acceleration - starting velocity;		
		1-3 $m{\cdot}s^{-1}$	CV = 5.9%	
		3-5 $m{\cdot}s^{-1}$	CV = 4.9%	
		5-8 $m{\cdot}s^{-1}$	CV = 3.6%	
		Deceleration - starting velocity;		
		5-8 $m{\cdot}s^{-1}$	CV = 11.3%	
Viper (10-Hz)	Radar	Straight-line sprint (40 m)	Bias = -0.13 $m{\cdot}s^{-1}$; STE = 0.22 (*small*)	Bataller et al. [79]
SPI-ProX (interpolated 15-Hz)	3D motion analysis	Team sport circuit	RMSE = 0.32 $m{\cdot}s^{-1}$	Linke et al. [34]
		Shuttle run	RMSE = 0.39 $m{\cdot}s^{-1}$	
		Small sided game	RMSE = 0.39 $m{\cdot}s^{-1}$	

Supplementary Table 5 continued

Device	Criterion	Movement/Protocol	Findings	Reference
SPI-HPU (15-Hz)	Timing gates	Straight-line sprint (36.6 m, 4.6 m splits);		Barr et al. [74]
		Split 1	CV = 13.1%; SEM = 0.70 m·s^{-1}	
		Split 2	CV = 3.3%; SEM = 0.15 m·s^{-1}	
		Split 3	CV = 2.6%; SEM = 0.13 m·s^{-1}	
		Split 4	CV = 0.9%; SEM = 0.14 m·s^{-1}	
		Split 5	CV = 0.9%; SEM = 0.06 m·s^{-1}	
		Local positioning systems		
Clearsky T6	3D motion analysis	Straight-line sprint to deceleration (10 m)	Bias = 34.8% (optimal set-up); 83.7% (sub-optimal set-up)	Luteberget et al. [63]
		Left and right 75º diagonal movements (5 m)	Bias = 33.5% (optimal set-up); 74.4% (sub-optimal set-up)	
		Straight-line sprint with 90º change of direction to deceleration (10 m)	Bias = 39.2% (optimal set-up); 87.7% (sub-optimal set-up)	
		Zig-zag (60º and 360º change of direction)	Bias = 35.3% (optimal set-up); 90.8% (sub-optimal set-up)	
		Zig-zag (60º change of direction)	Bias = 37.0% (optimal set-up); 75.4% (sub-optimal set-up)	
Inmotio	3D motion analysis	Team sport circuit	RMSE = 0.35 m·s^{-1}	Linke et al. [34]
		Shuttle run	RMSE = 0.31 m·s^{-1}	
		Small sided game	RMSE = 0.36 m·s^{-1}	

CV = co-efficient of variation; SEE = standard error of the estimate; STE = standardised typical error; RMSE = root mean square error; SEM = standard error of measurement

Supplementary Table 6 Summary of studies that investigated the validity of wearable microtechnology to measure average speed

Device	Criterion	Movement/Protocol	Findings	Reference
		Global navigation satellite systems		
SPI-Elite (1-Hz)	Timing gates	Team sport circuit (487 m)	Bias = 0.0 km·h^{-1}	MacLeod et al. [56]
	3D motion analysis	Jog – rectangular pattern (26 m)	1/2 devices significant difference to criterion	Duffield et al. [58]
		Run – rectangular pattern (26 m)	2/2 devices significant difference to criterion	
		2-m tennis (side to side)	2/2 devices significant difference to criterion	
		4-m tennis (side to side)	2/2 devices significant difference to criterion	
		Random movement (6 seconds)	1/2 devices significant difference to criterion	
MinimaxX 2.5 (5-Hz)	3D motion analysis	Court-based team sport protocols;		Vickery et al. [40]
		2-m tennis	1/2 devices significant difference to criterion	
		4-m tennis	1/2 devices significant difference to criterion	
		Half-court	2/2 devices significant difference to criterion	
		Random	No significant difference to criterion	
		Field-based team sport protocols;		
		Run-a-three (16 m)	No significant difference to criterion	
		Fast bowling (15 m)	2/2 devices significant difference to criterion	
		Fielding (18 m)	No significant difference to criterion	
		Gradual 90º change of direction (24 m)	2/2 devices significant difference to criterion	
		Tight 45º change of direction (20 m)	2/2 devices significant difference to criterion	
		Random	1/2 devices significant difference to criterion	

Supplementary Table 6 continued

Device	Criterion	Movement/Protocol	Findings	Reference
	3D motion analysis	Jog – rectangular pattern (26 m)	No significant to criterion	Duffield et al. [58]
		Run – rectangular pattern (26 m)	2/2 devices significant difference to criterion	
		2-m tennis (side to side)	2/2 devices significant difference to criterion	
		4-m tennis (side to side)	1/2 devices significant difference to criterion	
		Random movement (6 seconds)	No significant difference to criterion	
SPI-Pro (5-Hz)	Timing gates	Straight-line sprint (30 m);		Waldron et al. [59]
		10 m	CV = 9.8%	
		20 m	CV = 8.5%	
		30 m	CV = 6.6%	
		Moving 10 m	CV = 5.7%	
Evo (10-Hz)	3D motion analysis	Team sport acceleration circuit;		Delaney et al. [81]
		Raw data	SEE = 0.01 $m{\cdot}s^{-1}$; Bias = 0.01 – 0.02 $m{\cdot}s^{-1}$	
		Exported software data	SEE = 0.02 $m{\cdot}s^{-1}$; Bias = 0.02 – 0.03 $m{\cdot}s^{-1}$	
MinimaxX S4 (10-Hz)	Timing gates	Cricket bowling action (5 m)	SEE = 0.24 $m{\cdot}s^{-1}$; Bias = -7.3%	McNamara et al. [17]
		Cricket bowling action (10 m)	SEE = 0.29 $m{\cdot}s^{-1}$; Bias = -8.9%	
	3D motion analysis	Court-based team sport protocols;		Vickery et al. [40]
		2-m tennis	Significant difference to criterion	
		4-m tennis	Significant difference to criterion	
		Half-court	No significant difference to criterion	
		Random	No significant difference to criterion	
		Field-based team sport protocols;		
		Run-a-three (16 m)	No significant difference to criterion	
		Fast bowling (15 m)	No significant difference to criterion	
		Fielding (18 m)	No significant difference to criterion	
		Gradual 90º change of direction (24 m)	Significant difference to criterion	
		Tight 45º change of direction (20 m)	Significant difference to criterion	
		Random	Significant difference to criterion	
Viper (10-Hz)	Timing gates	Straight-line sprint (40 m)	Bias = 0.61 $m{\cdot}s^{-1}$; STE = 0.17 (*small*)	Bataller et al. [79]
Polar team pro sensor (10-Hz)	Timing gates	Straight-line walk, jog, sprint (168.5 m)	Bias = 0.62 $km{\cdot}h^{-1}$ (back-mounted sensor); 1.0 $km{\cdot}h^{-1}$ (chest-mounted sensor)	Fox et al. [46]
		Agility t-test (40 m)	Bias = 0.58 $km{\cdot}h^{-1}$ (back-mounted sensor); 0.91 $km{\cdot}h^{-1}$ (chest-mounted sensor)	
WimuPro (10-Hz)	Timing gates	Linear course (138 m);		Bastida-Castillo et al. [41]
		Walk (< 6 $km{\cdot}h^{-1}$)	Bias = 0.01 $km{\cdot}h^{-1}$	
		Sprint (> 16 $km{\cdot}h^{-1}$)	Bias = 0.28 $km{\cdot}h^{-1}$	
		Circular course (57 m);		
		Walk (< 6 $km{\cdot}h^{-1}$)	Bias = 0.05 $km{\cdot}h^{-1}$	
		Sprint (> 16 $km{\cdot}h^{-1}$)	Bias = 0.31 $km{\cdot}h^{-1}$	
		Zig-zag course (20 m);		
		Walk (< 6 $km{\cdot}h^{-1}$)	Bias = 0.03 $km{\cdot}h^{-1}$	
		Sprint (> 16 $km{\cdot}h^{-1}$)	Bias = 0.41 $km{\cdot}h^{-1}$	

Supplementary Table 6 continued

Device	Criterion	Movement/Protocol	Findings	Reference
SPI-ProX (interpolated 15-Hz)	3D motion analysis	Court-based team sport protocols;		Vickery et al. [40]
		2-m tennis	No significant difference to criterion	
		4-m tennis	1/2 devices significant difference to criterion	
		Half-court	No significant difference to criterion	
		Random	No significant difference to criterion	
		Field-based team sport protocols;		
		Run-a-three (16 m)	No significant difference to criterion	
		Fast bowling (15 m)	No significant difference to criterion	
		Fielding (18 m)	No significant difference to criterion	
		Gradual 90º change of direction (24 m)	2/2 devices significant difference to criterion	
		Tight 45º change of direction (20 m)	1/2 devices significant difference to criterion	
		Random	No significant difference to criterion	
Spin (50-Hz)	Timing gate	Shuttle run;		Padulo et al. [36]
		20 m	CV = 0.24%	
		15 m	CV = 0.37%	
		10 m	CV = 0.38%	
		7.5 m	CV = 0.93%	
		5 m	CV = 1.1%	
		Square run (40 m)	CV = 1.0%	
		Zig-zag (60 m)	CV = 0.42%	
		Cross-path run (40 m)	CV = 0.79%	
		Local positioning systems		
Not specified	3D motion analysis	Straight-line (26.5 m);		Orgis et al. [77]
		Walk (2 – 6 $km \cdot h^{-1}$)	Bias = 3.5%	
		Jog (6.1 – 11 $km \cdot h^{-1}$)	Bias = 0.08%	
		Low-speed run (11.1 – 14 $km \cdot h^{-1}$)	Bias = -0.8%	
		Moderate speed run (14.1 – 19 $km \cdot h^{-1}$)	Bias = -0.03%	
		High-speed run (>19 $km \cdot h^{-1}$)	Bias = -0.9%	
		Sprint (as fast as possible)	Bias = -1.2%	
		45° change of direction;		
		Moderate speed run (14.1 – 19 $km \cdot h^{-1}$)	Bias = 0.4%	
		High-speed run (>19 $km \cdot h^{-1}$)	Bias = 0.5%	
		90° change of direction;		
		High-speed run (>19 $km \cdot h^{-1}$)	Bias = -3.5%	
		Small sided game;		
		2 v 2	Bias = 7.5%	
		2 v 3	Bias = 6.2%	
		3 v 3	Bias = 5.1%	

Supplementary Table 6 continued

Device	Criterion	Movement/Protocol	Findings	Reference
Ubisense	Timing gates	Figure 8 course (81 m);		Rhodes et al. [61]
		4 $km{\cdot}h^{-1}$	SEE = 0.01 $m{\cdot}s^{-1}$	
		6 $km{\cdot}h^{-1}$	SEE = 0.01 $m{\cdot}s^{-1}$	
		8 $km{\cdot}h^{-1}$	SEE = 0.01 $m{\cdot}s^{-1}$	
		Match-play replication (wheel-chair court sport)	Bias = 0.01 $m{\cdot}s^{-1}$	
WimuPro	Timing gates	Linear course (138 m);		Bastida-Castillo et al. [41]
		Walk (< 6 $km{\cdot}h^{-1}$)	Bias = 0.06 $km{\cdot}h^{-1}$	
		Sprint (> 16 $km{\cdot}h^{-1}$)	Bias = 0.22 $km{\cdot}h^{-1}$	
		Circular course (57 m);		
		Walk (< 6 $km{\cdot}h^{-1}$)	Bias = 0.06 $km{\cdot}h^{-1}$	
		Sprint (> 16 $km{\cdot}h^{-1}$)	Bias = 0.08 $km{\cdot}h^{-1}$	
		Zig-zag course (20 m);		
		Walk (< 6 $km{\cdot}h^{-1}$)	Bias = 0.05 $km{\cdot}h^{-1}$	
		Sprint (> 16 $km{\cdot}h^{-1}$)	Bias = 0.13 $km{\cdot}h^{-1}$	
Clearsky T6	3D motion analysis	Straight-line sprint to deceleration (10 m)	Bias = 2.2% (Optimal set up), 26.0% (Sub-optimal set up)	Luteberget et al. [63]
		Left and right 75º diagonal movements (5 m)	Bias = 1.4% (Optimal set up), 27.6% (Sub-optimal set up)	
		Straight-line sprint with 90º change of direction to deceleration (10 m)	Bias = 2.8% (Optimal set up), 20.2% (Sub-optimal set up)	
		Zig-zag (60º and 360º change of direction)	Bias = 2.3% (Optimal set up), 14.7% (Sub-optimal set up)	
		Zig-zag (60º change of direction)	Bias = 0.5% (Optimal set up), 29.1% (Sub-optimal set up)	
	3D motion analysis	Straight-line (12 m);		Serpiello et al. [65]
		Walk	CV = 3.3%	
		Jog	CV = 4.4%	
		Sprint	CV = 4.8%	
		45º change of direction (5.5 m)	CV = 3.5%	
Inmotio	Timing gates	Straight-line (5 m);		Frencken et al. [60]
		Walk	CV = 3.9%	
		Sprint	CV = 3.2%	
		45º change of direction (10 m);		
		Walk	CV = 1.6%	
		Sprint	CV = 2.2%	
		90º change of direction (10 m);		
		Walk	CV = 1.4%	
		Sprint	CV = 2.6%	
		Combined movement (25 m);		
		Walk	CV = 1.4%	
		Sprint	CV = 1.8%	

Supplementary Table 6 continued

Device	Criterion	Movement/Protocol	Findings	Reference
	3D motion analysis	Straight-line (jog, sub-maximal, maximal intensity) Straight-line shuttle (jog, sub-maximal, maximal intensity) 90º change of direction (frequent and gradual – jog, sub-maximal, maximal intensity)	Bias = -0.8 – 2.0% Bias = -3.6 - -1.5% Bias = -1.0 – 1.0%	Stevens et al. [62]

SEE = standard error of the estimate; STE = standardised typical error; CV = co-efficient of variation

Supplementary Table 7 Summary of studies that investigated the validity of wearable microtechnology to detect collision events

Device	Criterion	Movement/Protocol	Findings	Reference
		Inertial measurement units		
MinimaxX (100-Hz)	Manual video coding	Training and match-play (rugby league)	r = 0.96	Gabbett et al. [84]
SPI-Pro (100-Hz)	Manual video coding	Match-play (rugby union)	Recall = 0.93 Precision = 0.96	Kelly et al. [85]
Optimeye S5 (100-Hz)	Manual video coding	Match-play (rugby league)	Sensitivity = 97.6% Specificity = 87.6%	Hulin et al. [15]
Viper (100-Hz)	Manual video coding	Match-play (rugby union)	Sensitivity = 93.7% Specificity = 92.7%	MacLeod et al. [86]

r = Pearson's correlation co-efficient

Supplementary Table 8 Summary of studies that investigated the validity of wearable microtechnology to measure sport specific events

Device	Criterion	Movement/Protocol	Metric	Findings	Reference
			Inertial measurement units		
Optimeye S5 (100-Hz)	Manual video coding	Match-play (rugby union)	Ruck events Tackle events	Random forest agreement = 79.4% Random forest agreement = 81.0%	Chambers et al. [14]
	Manual video coding	Match-play (rugby union) Training	Scrum events	Accuracy = 93.6%; Sensitivity = .94; Specificity = .94 Accuracy = 87.6%; Sensitivity = .89; Specificity = .87	Chambers et al. [16]
MinimaxX S4 (100-Hz)	Manual video coding	Cricket bowling training	Bowling event	Sensitivity = 99.0% Specificity = 98.1%	McNamara et al. [17]
		Match-play (Cricket)		Sensitivity = 99.5% Specificity = 74.0%	
	Manual video coding	Match-play (Australian football)	Tackle events	Tackle events detected (criterion) = 352 Tackle events detected (by device) = 1510 True positive = 275 False positive = 1235 False negative = 77	Gastin et al. [87]

Supplementary Table 9 Summary of studies that investigated the validity of wearable microtechnology to measure acceleration/deceleration-based metrics

Device	Criterion	Movement/Protocol	Metric	Findings	Reference
Global navigation satellite systems					
Evo (10-Hz)	3D motion analysis (centre of motion & scapulae)	Team sport acceleration circuit	Average acceleration;		Delaney et al. [81]
			Raw data	Bias = -0.23 $m{\cdot}s^{-2}$; SEE = 0.05 – 0.07 $m{\cdot}s^{-2}$	
			Software exported data	Bias = -0.74 $m{\cdot}s^{-2}$; SEE = 0.03 – 0.05 $m{\cdot}s^{-2}$	
SPI-ProX (interpolated 15-Hz)	3D motion analysis	Team sport circuit	Instantaneous acceleration	RMSE = 1.2 $m{\cdot}s^{-2}$	Linke et al. [34]
		Shuttle run		RMSE = 0.56 $m{\cdot}s^{-2}$	
		Small sided game		RMSE = 0.69 $m{\cdot}s^{-2}$	
	3D motion analysis	Team sport circuit	Acceleration distance > 3 $m{\cdot}s^{-2}$	RMSE = 65.1%	Linke et al. [34]
			Deceleration distance < -3 $m{\cdot}s^{-2}$	RMSE = 46.5%	
		Shuttle runs (20 m)	Acceleration distance > 3 $m{\cdot}s^{-2}$	RMSE = 35.0%	
			Deceleration distance < -3 $m{\cdot}s^{-2}$	RMSE = 60.6%	
		Small sided game	Acceleration distance > 3 $m{\cdot}s^{-2}$	RMSE = 50.3%	
			Deceleration distance < -3 $m{\cdot}s^{-2}$	RMSE = 93.3%	
Inertial measurement units					
Optimeye S5 (100-Hz)	3D motion analysis	Low, moderate, high intensity;	Complementary filter (5-Hz);		Roell et al. [89]
		Straight-line to stop	Peak resultant acceleration	CV = 17.2%	
			Average resultant acceleration	CV = 8.9%	
		Diagonal – forward/back	Peak resultant acceleration	CV = 16.7%	
			Average resultant acceleration	CV = 8.9%	
		90° change of direction	Peak resultant acceleration	CV = 15.3%	
			Average resultant acceleration	CV = 8.6%	
		Zig-zag (with 360° COD)	Peak resultant acceleration	CV = 11.4%	
			Average resultant acceleration	CV = 7.3%	
		Zig-zag (5 laps)	Peak resultant acceleration	CV = 11.4%	
			Average resultant acceleration	CV = 5.9%	
MinimaxX S4 (100-Hz)	3D motion analysis	Team sport circuit;	Peak resultant acceleration (12-Hz filtered data)	CV = 5.6%	Wundersitz et al. [90]
		Walk		CV = 6.3%	
		Jog		CV = 3.7%	
		Sprint		CV = 6.9%	
		Change of direction		CV = 6.2%	
		Tackle		CV = 4.8%	
		Single leg jump		CV = 5.3%	
		Double leg jump		CV = 4.6%	
	3D motion analysis	Contact protocols;	Peak resultant impact acceleration (20-Hz filtered data)		Wundersitz et al. [88]
		Tackle bag		CV = 6.5%	
		Bump pad		CV = 11.3%	
		Tackle drill (human)		CV = 11.2%	
SPI-HPU (100-Hz)	Timing gates	Straight-line sprint (40 m)	Average acceleration (0 – 10 m);		Alexander et al. [91]
			Raw data	CV = 22.5%	
			3 point moving average filter	CV = 21.4%	

			10 point moving average filter	CV = 20.2%	

Supplementary Table 9 continued

Device	Criterion	Movement/Protocol	Metric	Findings	Reference
		Local positioning systems			
Clearsky T6	3D motion analysis	Straight-line (12 m);			Serpiello et al. [65]
		Walk	Average acceleration	CV = 6.1%	
			Average deceleration	CV = 15.0%	
			Peak acceleration	CV = 5.2%	
			Peak deceleration	CV = 17.0%	
		Jog	Average acceleration	CV = 9.3%	
			Average deceleration	CV = 21.0%	
			Peak acceleration	CV = 7.9%	
			Peak deceleration	CV = 14.0%	
		Sprint	Average acceleration	CV = 4.2%	
			Average deceleration	CV = 18.0%	
			Peak acceleration	CV = 3.5%	
			Peak deceleration	CV = 10.0%	
		45º change of direction (5.5 m)	Average acceleration	CV = 2.2%	
			Average deceleration	CV = 6.2%	
			Peak acceleration	CV = 5.1%	
			Peak deceleration	CV = 5.3%	
Inmotio	3D motion analysis	Straight-line (jog, sub-maximal, maximal intensity)	Average acceleration	Bias = -1.6 – 9.8%	Stevens et al. [62]
			Average deceleration	Bias = -3.8 - 10.7%	
			Peak acceleration	Bias = 22.1 – 35.7%	
			Peak deceleration	Bias = -3.5 – 6.9%	
		Straight-line shuttle (jog, sub-maximal, maximal intensity)	Average acceleration	Bias = -8.5 - 5.8%	
			Average deceleration	Bias = -7.0 – 4.8%	
			Peak acceleration	Bias = -3.3 – 10.1%	
			Peak deceleration	Bias = -14.9 - -4.7%	
		90º change of direction (frequent and gradual – jog, sub-maximal, maximal intensity)	Average acceleration	Bias = 3.5 – 13.8%	
			Average deceleration	Bias = -0.9 – 16.1%	
			Peak acceleration	Bias = 15.1 – 41.1%	
			Peak deceleration	Bias = -12.3 – 3.4%	
	3D motion analysis	Team sport circuit	Acceleration distance > 3 $m \cdot s^{-2}$	RMSE = 37.6%	Linke et al. [34]
			Deceleration distance < -3 $m \cdot s^{-2}$	RMSE = 15.8%	
		Shuttle runs (20 m)	Acceleration distance > 3 $m \cdot s^{-2}$	RMSE = 71.9%	
			Deceleration distance < -3 $m \cdot s^{-2}$	RMSE = 103.7%	
		Small sided game	Acceleration distance > 3 $m \cdot s^{-2}$	RMSE = 82.9%	
			Deceleration distance < -3 $m \cdot s^{-2}$	RMSE = 71.9%	
	3D motion analysis	Team sport circuit	Instantaneous acceleration	RMSE = 0.69 $m \cdot s^{-2}$	Linke et al. [34]
		Shuttle run		RMSE = 0.58 $m \cdot s^{-2}$	
		Small sided game		RMSE = 0.69 $m \cdot s^{-2}$	

CV = co-efficient of variation; RMSE = root mean square error

Supplementary Table 10 Summary of studies that investigated the validity of wearable microtechnology to measure other metrics

Device	Criterion	Movement/Protocol	Metric	Findings	Reference
			Global navigation satellite systems		
VX (4-Hz)	Gas analyser (VO_2)	Team sport circuit (soccer)	Average metabolic power	SEE = 19.8%	Buchheit et al. [75]
SPI-Pro (5-Hz)	Radar	Straight-line shuttle (70 m)	Average metabolic power	CV = 4.5%	Rampinini et al. [38]
			Metabolic power > 20 $W{\cdot}kg^{-1}$	CV = 9.0%	
			Metabolic power > 25 $W{\cdot}kg^{-1}$	CV = 11.6%	
MinimaxX S4 (10-Hz)	Timing gates	Team sport circuit (129.6 m)	Theoretical peak power	SEE = 20.7%	Hoppe et al. [51]
			Theoretical peak force	SEE = 23.1%	
	Radar	Straight-line shuttle (70 m)	Average metabolic power	CV = 2.4%	Rampinini et al. [38]
			Metabolic power > 20 $W{\cdot}kg^{-1}$	CV = 4.5%	
			Metabolic power > 25 $W{\cdot}kg^{-1}$	CV = 6.2%	
Optimeye S5 (10-Hz)	Open circuit spirometry	Repeat-effort protocol (8 m run and collision)	Energy expenditure	Bias = -5.94 $kcal{\cdot}min^{-1}$	Highton et al. [94]
GPEXE, Exelio (18-Hz)	Timing gates	Team sport circuit (129.6 m)	Theoretical peak power	SEE = 12.5%	Hoppe et al. [51]
			Theoretical peak force	SEE = 14.3%	
SPI-ProX (interpolated 15-Hz)	Laser	Straight-line sprint (> 30 m)	Peak power	CV = 15.8%	Nagahara et al. [72]
			Theoretical peak force	CV = 19.2%	
GPEXE, Exelio (20-Hz)	Radar	Straight-line sprint (> 30 m)	Peak power	CV = 4.5%	Nagahara et al. [72]
			Theoretical peak force	CV = 5.6%	
			Local positioning systems		
Kinexon One	Timing gates	Team sport circuit (129.6 m)	Theoretical peak power	SEE = 7.4%	Hoppe et al. [51]
			Theoretical peak force	SEE = 9.2%	
			Inertial measurement units		
ActiGraph GT3X+ (100-Hz)	Indirect calorimetry	Continuous;	Energy expenditure		Gastin et al. [97]
		Walk (333 m - 4 $km{\cdot}h^{-1}$)		RMSE = 40.8 kJ; Bias = 25.3%	
		Jog (667 m - 8 $km{\cdot}h^{-1}$)		RMSE = 48.1 kJ; Bias = 16.8%	
		Run (1000 m - 12 $km{\cdot}h^{-1}$)		RMSE = 47.9 kJ; Bias = -14.0%	
		Team sport circuit (460 m)		RMSE = 133.6 – 143.0 kJ; Bias = -61.3 - -56.9%	
BodyMedia SenseWear Armband (30-Hz)	Indirect calorimetry	Continuous;	Energy expenditure		Gastin et al. [97]
		Walk (333 m - 4 $km{\cdot}h^{-1}$)		RMSE = 35.5 kJ; Bias = 36.7%	
		Jog (667 m - 8 $km{\cdot}h^{-1}$)		RMSE = 46.4 kJ; Bias = 15.4%	
		Run (1000 m - 12 $km{\cdot}h^{-1}$)		RMSE = 54.8 kJ; Bias = -14.9%	
		Team sport circuit (460 m)		RMSE = 94.7 – 102.0 kJ; Bias = -37.3 - -35.3%	
	Indirect calorimetry	Team sport circuit (42 minutes)	Energy expenditure	CV = 10%	Zanetti et al. [98]

CV = co-efficient of variation; SEE = standard error of the estimate; RMSE = root mean square error

Supplementary Table 11 Summary of studies that investigated the inter-device reliability of wearable microtechnology to measure total distance

Device	Movement/Protocol	Findings	Reference
Global navigation satellite systems			
WiSpi (1-Hz)	Linear course (200 m);		Gray et al. [47]
	Walk (0 – 1.6 m·s^{-1})	CV = 2.0%	
	Jog (1.6 – 3.5 m·s^{-1})	CV = 2.3%	
	Run (3.5 – 5 m·s^{-1})	CV = 1.5%	
	Sprint (> 5 m·s^{-1})	CV = 3.4%	
	Non-linear course (200 m);		
	Walk (0 – 1.6 m·s^{-1})	CV = 3.4%	
	Jog (1.6 – 3.5 m·s^{-1})	CV = 1.6%	
	Run (3.5 – 5 m·s^{-1})	CV = 2.8%	
	Sprint (> 5 m·s^{-1})	CV = 6.0%	
SPI-Elite (1-Hz)	Jog – rectangular pattern (26 m)	CV = 3.6%	Duffield et al. [58]
	Run – rectangular pattern (26 m)	CV = 9.5%	
	2-m tennis (side to side)	CV = 3.6%	
	4-m tennis (side to side)	CV = 5.8%	
	Random movement (6 seconds)	CV = 7.6%	
MinimaxX 2.5 (1-Hz)	Straight-line (10 m);		Jennings et al. [52]
	Walk	CV = 30.8%	
	Jog	CV = 34.7%	
	Stride	CV = 58.8%	
	Sprint	CV = 77.2%	
	Straight-line (20 m);		
	Walk	CV = 20.4%	
	Jog	CV = 20.9%	
	Stride	CV = 33.3%	
	Sprint	CV = 44.9%	
	Straight-line (40 m);		
	Walk	CV = 7.0%	
	Jog	CV = 9.4%	
	Stride	CV = 10.5%	
	Sprint	CV = 11.5%	
	Straight-line (moving 20-40 m);		
	Walk	CV = 17.5%	
	Jog	CV = 21.0%	
	Stride	CV = 14.0%	
	Sprint	CV = 14.0%	
	Gradual 90º change of direction (40 m);		
	Walk	CV = 11.6%	
	Jog	CV = 9.0%	
	Stride	CV = 12.2%	
	Sprint	CV = 10.7%	
	Tight 90º change of direction (40 m);		
	Walk	CV = 17.5%	
	Jog	CV = 8.6%	
	Stride	CV = 10.8%	
	Sprint	CV = 12.0%	
	Team sport circuit (140 m)	CV = 3.6%	

Supplementary Table 11 continued

Device	Movement/Protocol	Findings	Reference
MinimaxX 2.5 (5-Hz)	Straight-line (10 m);		Jennings et al. [52]
	Walk	CV = 23.3%	
	Jog	CV = 22.8%	
	Stride	CV = 33.4%	
	Sprint	CV = 39.5%	
	Straight-line (20 m);		
	Walk	CV = 21.2%	
	Jog	CV = 15.6%	
	Stride	CV = 17.5%	
	Sprint	CV = 23.0%	
	Straight-line (40 m);		
	Walk	CV = 6.6%	
	Jog	CV = 9.1%	
	Stride	CV = 9.1%	
	Sprint	CV = 9.2%	
	Straight-line (moving 20-40 m);		
	Walk	CV = 12.1%	
	Jog	CV = 12.3%	
	Stride	CV = 8.0%	
	Sprint	CV = 9.8%	
	Gradual 90º change of direction (40 m);		
	Walk	CV = 11.5%	
	Jog	CV = 10.0%	
	Stride	CV = 9.9%	
	Sprint	CV = 7.9%	
	Tight 90º change of direction (40 m);		
	Walk	CV = 15.2%	
	Jog	CV = 8.6%	
	Stride	CV = 9.7%	
	Sprint	CV = 9.2%	
	Team sport circuit (140 m)	CV = 3.6%	
	Court-based team sport protocols;		Vickery et al. [40]
	2-m tennis	CV = 12.0%	
	4-m tennis	CV = 9.1%	
	Half-court	CV = 29.0%	
	Random tennis	CV = 18.4%	
	Field-based team sport protocols;		
	Run-a-three (16 m)	CV = 22.1%	
	Fast bowling (15 m)	CV = 21.2%	
	Fielding (18 m)	CV = 20.6%	
	Gradual 90º change of direction (24 m)	CV = 17.7%	
	Tight 45º change of direction (20 m)	CV = 22.7%	
	Random	CV = 22.8%	

Supplementary Table 11 continued

Device	Movement/Protocol	Findings	Reference
	Straight-line (10 m);		Jennings et al. [99]
	Walk	Bias = 10.7%	
	Jog	Bias = 10.9%	
	Stride	Bias = 11.1%	
	Sprint	Bias = 11.9%	
	Straight-line (20 m);		
	Walk	Bias = 11.1%	
	Jog	Bias = 11.1%	
	Stride	Bias = 10.3%	
	Sprint	Bias = 10.3%	
	Straight-line (40 m);		
	Walk	Bias = 10.1%	
	Jog	Bias = 10.2%	
	Stride	Bias = 10.2%	
	Sprint	Bias = 10.7%	
	Straight-line (moving 20-40 m);		
	Walk	Bias = 9.9%	
	Jog	Bias = 10.3%	
	Stride	Bias = 10.4%	
	Sprint	Bias = 10.5%	
	Tight change of direction;		
	Walk	Bias = 10.8%	
	Jog	Bias = 9.5%	
	Stride	Bias = 10.6%	
	Sprint	Bias = 10.7%	
	Gradual change of direction;		
	Walk	Bias = 10.4%	
	Jog	Bias = 10.4%	
	Stride	Bias = 9.7%	
	Sprint	Bias = 10.0%	
	Team sport circuit (140 m)	Bias = 11.1%	
	Match-play (Hockey)	Bias = 10.3%	
	Jog – rectangular pattern (26 m)	CV = 9.8%	Duffield et al. [58]
	Run – rectangular pattern (26 m)	CV = 17.8%	
	2-m tennis (side to side)	CV = 3.5%	
	4-m tennis (side to side)	CV = 11.0%	
	Random movement (6 seconds)	CV = 16.8%	
	Team sport circuit (130.5 m)	CV = 2.0%	Johnston et al. [54]
MinimaxX S3 (5-Hz)	Team sport circuit (165 m)	CV = 1.2%	Johnston et al. [55]

Supplementary Table 11 continued

Device	Movement/Protocol	Findings	Reference
WimuPro (10-Hz)	Linear course (138 m);		Bastida-Castillo et al. [41]
	Walk (< 6 km·h^{-1})	Bias = 0.03 m	
	Sprint (> 16 km·h^{-1})	Bias = 0.02 m	
	Circular course (57 m);		
	Walk (< 6 km·h^{-1})	Bias = 0.78 m	
	Sprint (> 16 km·h^{-1})	Bias = 0.41 m	
	Zig-zag course (20 m);		
	Walk (< 6 km·h^{-1})	Bias = 0.18 m	
	Sprint (> 16 km·h^{-1})	Bias = 0.13 m	
MinimaxX S4 (10-Hz)	Team sport circuit (129.6 m)	CV = 2.5%	Hoppe et al. [51]
	Team sport circuit (165 m)	CV = 1.3%	Johnston et al. [55]
	Team sport circuit (165 m)	CV = 1.3%	Johnston et al. [53]
Optimeye S5 (10-Hz)	Team sport circuit (129 m)	CV = 2.1%	Jackson et al. [101]
	Team sport circuit (40 minutes)	CV = 0.9% (raw); 1.5% (software-derived)	Thornton et al. [33]
Apex (10-Hz)	Team sport circuit (40 minutes)	CV = 0.3% (raw); 0.3% (software-derived)	Thornton et al. [33]
Evo (10-Hz)	Team sport circuit (40 minutes)	CV = 0.2% (raw); 1.5% (software-derived)	Thornton et al. [33]
Johan (10-Hz)	Running circuit (200 m)	CV = 1.3 – 2.2%	Nikolaidis et al. [35]
	Shuttle endurance test (20 m)	CV = 2.1 – 3.9%	
SPI-HPU (15-Hz)	Training session	CV = 1.4%; SEM = 34 m	Barr et al. [74]
SPI-ProX (interpolated 15-Hz)	Running routine (30 minutes)	CV = 3.0 – 5.0%	Buchheit et al. [100]
	Team sport circuit (165 m)	CV = 1.9%	Johnston et al. [53]
	Court-based team sport protocols;		Vickery et al. [40]
	2-m tennis	CV = 5.4%	
	4-m tennis	CV = 8.5%	
	Half-court	CV = 6.9%	
	Random tennis	CV = 12.1%	
	Field-based team sport protocols;		
	Run-a-three (16 m)	CV = 17.9%	
	Fast bowling (15 m)	CV = 5.5%	
	Fielding (18 m)	CV = 17.0%	
	Gradual 90º change of direction (24 m)	CV = 6.2%	
	Tight 45º change of direction (20 m)	CV = 12.4%	
	Random	CV = 8.2%	
SPI-ProX2A (chip version 2.6.1)	Running routine (30 minutes)	CV = 1.0%	Buchheit et al. [100]
SPI-ProX2B (chip version 2.6.4)	Running routine (30 minutes)	CV = 1.0%	Buchheit et al. [100]
GPEXE, Exelio (18-Hz)	Team sport circuit (129.6 m)	CV = 1.1%	Hoppe et al. [51]

Supplementary Table 11 continued

Device	Movement	Findings	Reference
Local positioning systems			
WimuPro	Linear course (138 m);		Bastida-Castillo et al. [41]
	Walk (< 6 km·h^{-1})	Bias = 0.41 m	
	Sprint (> 16 km·h^{-1})	Bias = 0.19 m	
	Circular course (57 m);		
	Walk (< 6 km·h^{-1})	Bias = 0.03 m	
	Sprint (> 16 km·h^{-1})	Bias = 0.29 m	
	Zig-zag course (20 m);		
	Walk (< 6 km·h^{-1})	Bias = 0.18 m	
	Sprint (> 16 km·h^{-1})	Bias = 0.02 m	
Kinexon One	Team sport circuit (129.6 m)	CV = 1.3%	Hoppe et al. [51]

CV = co-efficient of variation; SEM = standard error of measurement

Supplementary Table 12 Summary of studies that investigated the inter-device reliability of wearable microtechnology to measure velocity-based threshold distance

Device	Movement/Protocol	Threshold	Findings	Reference
		Global navigation satellite systems		
MinimaxX 2.5 (5-Hz)	Flying sprint (50 m)	> 5.6 m·s^{-1}	CV = 20.1%	Johnston et al. [54]
		> 6.9 m·s^{-1}	CV = 59.3%	
	Team sport circuit (130.5 m)	0.0 – 1.6 m·s^{-1}	CV = 7.5%	
		1.6 – 3.3 m·s^{-1}	CV = 8.2%	
		3.3 – 5.0 m·s^{-1}	CV = 5.6%	
		5.0 – 6.9 m·s^{-1}	CV = 10.8%	
		> 6.9 m·s^{-1}	CV = 112.0%	
		0.0 – 3.9 m·s^{-1}	CV = 4.3%	
		3.9 – 5.6 m·s^{-1}	CV = 7.9%	
		> 5.6 m·s^{-1}	CV = 12.7%	
	Team sport circuit (140 m)	>4.17 m.s^{-1}	Bias = 11.6%	Jennings et al. [99]
	Match-play (Hockey)		Bias = 10.3%	
MinimaxX S3 (5-Hz)	Team sport circuit (165 m)	0.0 – 3.9 m·s^{-1}	CV = 2.4%	Johnston et al. [55]
		3.9 – 5.6 m·s^{-1}	CV = 7.9%	
		> 5.6 m·s^{-1}	CV = 6.0%	
MinimaxX S4 (10-Hz)	Team sport circuit (165 m)	0.0 – 3.9 m·s^{-1}	CV = 1.7%	Johnston et al. [55]
		3.9 – 5.6 m·s^{-1}	CV = 4.8%	
		> 5.6 m·s^{-1}	CV = 11.5%	
	Team sport circuit (165 m)	0.0 – 3.9 m·s^{-1}	CV = 1.7%	Johnston et al. [53]
		3.9 – 5.6 m·s^{-1}	CV = 4.8%	
		> 5.6 m·s^{-1}	CV = 11.5%	
Optimeye S5 (10-Hz)	Team sport circuit (129 m)	< 3 m·s^{-1}	CV = 4.1%	Jackson et al. [101]
		3 – 5 m·s^{-1}	CV = 9.4%	
		> 5 m·s^{-1}	CV = 13.5%	
	Team sport circuit (40 minutes)	< 3 m·s^{-1}	CV = 4.4% (raw); 5.5% (software-derived)	Thornton et al. [33]
		3 – 5 m·s^{-1}	CV = 0.3% (raw); 0.6% (software-derived)	
		> 5 m·s^{-1}	CV = 0.8% (raw); 1.0% (software-derived)	
Apex (10-Hz)	Team sport circuit (40 minutes)	< 3 m·s^{-1}	CV = 0.7% (raw); 0.7% (software-derived)	Thornton et al. [33]
		3 – 5 m·s^{-1}	CV = 0.4% (raw); 0.4% (software-derived)	
		> 5 m·s^{-1}	CV = 1.3% (raw); 1.3% (software-derived)	
Evo (10-Hz)	Team sport circuit (40 minutes)	< 3 m·s^{-1}	CV = 0.4% (raw); 0.8% (software-derived)	Thornton et al. [33]
		3 – 5 m·s^{-1}	CV = 0.4% (raw); 0.4% (software-derived)	
		> 5 m·s^{-1}	CV = 0.5% (raw); 0.5% (software-derived)	
SPI-HPU (15-Hz)	Training session	0 - 2 m·s^{-1}	CV = 3.2%; SEM = 96 m	Barr et al. [74]
		2 - 6 m·s^{-1}	CV = 7.8%; SEM = 111 m	
		> 6 m·s^{-1}	CV = 4.8%; SEM = 18 m	

Supplementary Table 12 continued

Device	Movement	Threshold	Findings	Reference
SPI-ProX (interpolated 15-Hz)	Running routine (30 minutes)	> 4.0 $m{\cdot}s^{-1}$	CV = 1.0 – 2.0%	Buchheit et al. [100]
		> 7.0 $m{\cdot}s^{-1}$	CV = 5.0 – 9.0%	
	Team sport circuit (165 m)	0.0 – 3.9 $m{\cdot}s^{-1}$	CV = 2.0%	Johnston et al. [53]
		3.9 – 5.6 $m{\cdot}s^{-1}$	CV = 7.6%	
		> 5.6 $m{\cdot}s^{-1}$	CV = 12.1%	
SPI-ProX2A (chip version 2.6.1)	Running routine (30 minutes)	> 4.0 $m{\cdot}s^{-1}$	CV = 1.0 %	Buchheit et al. [100]
		> 7.0 $m{\cdot}s^{-1}$	CV = 3.0 – 6.0%	
SPI-ProX2B (chip version 2.6.4)	Running routine (30 minutes)	> 4.0 $m{\cdot}s^{-1}$	CV = 1.0 %	Buchheit et al. [100]
		> 7.0 $m{\cdot}s^{-1}$	CV = 4.0 – 6.0%	

SEM = standard error of measurement; CV = co-efficient of variation

Supplementary Table 13 Summary of studies that investigated the inter-device reliability of wearable microtechnology to measure peak velocity

Device	Movement/Protocol	Findings	Reference
Global navigation satellite systems			
SPI -Elite (1-Hz)	Jog – rectangular pattern (26 m)	CV = 2.3%	Duffield et al. [58]
	Run – rectangular pattern (26 m)	CV = 15.3%	
	2-m tennis (side to side)	CV = 5.8%	
	4-m tennis (side to side)	CV = 12.6%	
	Random movement (6 seconds)	CV = 26.7%	
MinimaxX 2.5 (5-Hz)	Flying sprint (50 m)	CV = 9.2%	Johnston et al. [54]
	Team sport circuit (130.5 m)	CV = 7.5%	
	Court-based team sport protocols;		Vickery et al. [40]
	2-m tennis	CV = 22.5%	
	4-m tennis	CV = 22.9%	
	Half-court	CV = 32.9%	
	Random tennis	CV = 20.0%	
	Field-based team sport protocols;		
	Run-a-three (16 m)	CV = 14.2%	
	Fast bowling (15 m)	CV = 23.6%	
	Fielding (18 m)	CV = 16.2%	
	Gradual 90º change of direction (24 m)	CV = 26.3%	
	Tight 45º change of direction (20 m)	CV = 20.9%	
	Random	CV = 31.5%	
	Jog – rectangular pattern (26 m)	CV = 17.6%	Duffield et al. [58]
	Run – rectangular pattern (26 m)	CV = 31.7%	
	2-m tennis (side to side)	CV = 20.3%	
	4-m tennis (side to side)	CV = 24.5%	
	Random movement (6 seconds)	CV = 35.3%	
MinimaxX S4 (10-Hz)	Team sport circuit (129.6 m)	CV = 3.3%	Hoppe et al. [51]
	Team sport circuit (165 m)	CV = 1.6%	Johnston et al. [53]
Optimeye S5 (10-Hz)	Team sport circuit (129 m)	CV = 1.8%	Jackson et al. [101]
	Team sport circuit (40 minutes)	CV = 0.3% (raw); 0.3% (software-derived)	Thornton et al. [33]
Apex (10-Hz)	Team sport circuit (40 minutes)	CV = 1.9% (raw); 1.9% (software-derived)	Thornton et al. [33]
	Straight-line sprint;		Beato & De Keijzer [102]
	5 – 10 m	CV = 2.9%	
	10 – 15 m	CV = 2.2%	
	15 – 20 m	CV = 2.0%	
	20 – 30 m	CV = 1.6%	
	Overall (5 – 30 m)	CV = 1.9%	

Supplementary Table 13 continued

Device	Movement/Protocol	Findings	Reference
Viper (10-Hz)	Straight-line sprint;		Beato & De Keijzer [102]
	5 – 10 m	CV = 4.9%	
	10 – 15 m	CV = 4.4%	
	15 – 20 m	CV = 3.1%	
	20 – 30 m	CV = 2.6%	
	Overall (5 – 30 m)	CV = 3.3%	
Evo (10-Hz)	Team sport circuit (40 minutes)	CV = 0.2% (raw); 0.2% (software-derived)	Thornton et al. [33]
SPI-HPU (15-Hz)	Training session	CV = 1.0%; SEM = 0.11 $m{\cdot}s^{-1}$	Barr et al. [74]
SPI-ProX (interpolated 15-Hz)	Running routine (30 minutes)	CV = 1.0 – 2.0%	Buchheit et al. [100]
	Team sport circuit (165 m)	CV = 8.1%	Johnston et al. [53]
	Court-based team sport protocols;		Vickery et al. [40]
	2-m tennis	CV = 6.4%	
	4-m tennis	CV = 20.6%	
	Half-court	CV = 8.2%	
	Random tennis	CV = 5.4%	
	Field-based team sport protocols;		
	Run-a-three (16 m)	CV = 14.1%	
	Fast bowling (15 m)	CV = 8.4%	
	Fielding (18 m)	CV = 16.9%	
	Gradual 90º change of direction (24 m)	CV = 14.5%	
	Tight 45º change of direction (20 m)	CV = 20.0%	
	Random	CV = 11.9%	
SPI-ProX2A (chip version 2.6.1)	Running routine (30 minutes)	CV = 1.0%	Buchheit et al. [100]
SPI-ProX2B (chip version 2.6.4)	Running routine (30 minutes)	CV = 1.0%	Buchheit et al. [100]
Sensoreverywhere v2 (16-Hz)	Straight-line sprint (40 m)	CV = 0.5%	Lacome et al. [71]
GPEXE, Exelio (18-Hz)	Team sport circuit (129.6 m)	CV = 3.1%	Hoppe et al. [51]
Local positioning systems			
Kinexon One	Team sport circuit (129.6 m)	CV = 1.6%	Hoppe et al. [51]

CV = co-efficient of variation; SEM = standard error of measurement

Supplementary Table 14 Summary of studies that investigated the inter-device reliability of wearable microtechnology to measure instantaneous velocity

Device	Movement/Protocol	Findings	Reference
	Global navigation satellite systems		
MinimaxX v2 (5-Hz)	Straight-line movement;		Varley et al. [80]
	Constant velocity;		
	1-3 $m{\cdot}s^{-1}$	CV = 12.4%	
	3-5 $m{\cdot}s^{-1}$	CV = 6.7%	
	5-8 $m{\cdot}s^{-1}$	CV = 6.3%	
	Acceleration - starting velocity;		
	1-3 $m{\cdot}s^{-1}$	CV = 16.2%	
	3-5 $m{\cdot}s^{-1}$	CV = 9.5%	
	5-8 $m{\cdot}s^{-1}$	CV = 11.0%	
	Deceleration - starting velocity;		
	5-8 $m{\cdot}s^{-1}$	CV = 31.8%	
Viper (10-Hz)	Straight-line sprint (20 m + 20 m) with 180° change of direction	Bias = 0.05 $m{\cdot}s^{-1}$; ICC = 0.99	Bataller et al. [79]
MinimaxX S4 (10-Hz)	Straight-line sprint (10 m);	CV = 3.1% (smooth); 15.6% (raw)	Akenhead et al. [78]
	Acceleration 0-1 $m{\cdot}s^{-2}$	CV = 0.7% (smooth); 1.8% (raw)	
	Acceleration 1-2 $m{\cdot}s^{-2}$	CV = 1.1% (smooth); 3.5% (raw)	
	Acceleration 2-3 $m{\cdot}s^{-2}$	CV = 2.2% (smooth); 3.7% (raw)	
	Acceleration 3-4 $m{\cdot}s^{-2}$	CV = 3.9% (smooth); 31.2% (raw)	
	Acceleration >4 $m{\cdot}s^{-2}$	CV = 9.1% (smooth); 47.4% (raw)	
	Straight-line movement;		Varley et al. [80]
	Constant velocity;		
	1-3 $m{\cdot}s^{-1}$	CV = 5.3%	
	3-5 $m{\cdot}s^{-1}$	CV = 3.5%	
	5-8 $m{\cdot}s^{-1}$	CV = 2.0%	
	Acceleration - starting velocity;		
	1-3 $m{\cdot}s^{-1}$	CV = 4.3%	
	3-5 $m{\cdot}s^{-1}$	CV = 4.2%	
	5-8 $m{\cdot}s^{-1}$	CV = 1.9%	
	Deceleration - starting velocity;		
	5-8 $m{\cdot}s^{-1}$	CV = 6.0%	

CV = co-efficient of variation; ICC = intra-class correlation

Supplementary Table 15 Summary of studies that investigated the inter-device reliability of wearable microtechnology to measure average speed

Device	Movement/Protocol	Findings	Reference
	Global navigation satellite systems		
SPI -Elite (1-Hz)	Jog – rectangular pattern (26 m)	CV = 2.1%	Duffield et al. [58]
	Run – rectangular pattern (26 m)	CV = 11.1%	
	2-m tennis (side to side)	CV = 3.9%	
	4-m tennis (side to side)	CV = 5.6%	
	Random movement (6 seconds)	CV = 19.3%	
Wimu (5-Hz)	Team sport circuit (277 m)	ICC = 0.98	Munoz-Lopez et al. [57]
	Straight-line motorised sprints	ICC = 0.99	
MinimaxX 2.5 (5-Hz)	Court-based team sport protocols;		Vickery et al. [40]
	2-m tennis	CV = 19.7%	
	4-m tennis	CV = 14.9%	
	Half-court	CV = 26.2%	
	Random tennis	CV = 21.0%	
	Field-based team sport protocols;		
	Run-a-three (16 m)	CV = 27.1%	
	Fast bowling (15 m)	CV = 20.2%	
	Fielding (18 m)	CV = 21.3%	
	Gradual 90º change of direction (24 m)	CV = 19.8%	
	Tight 45º change of direction (20 m)	CV = 28.1%	
	Random	CV = 33.4%	
	Jog – rectangular pattern (26 m)	CV = 9.1%	Duffield et al. [58]
	Run – rectangular pattern (26 m)	CV = 17.1%	
	2-m tennis (side to side)	CV = 3.4%	
	4-m tennis (side to side)	CV = 15.6%	
	Random movement (6 seconds)	CV = 16.9%	
Optimeye S5 (10-Hz)	Team sport circuit (129 m)	CV = 1.9%	Jackson et al. [101]
WimuPro (10-Hz)	Linear course (138 m);		Bastida-Castillo et al. [41]
	Walk (< 6 $km \cdot h^{-1}$)	Bias = 0.03 $km \cdot h^{-1}$	
	Sprint (> 16 $km \cdot h^{-1}$)	Bias = 0.01 $km \cdot h^{-1}$	
	Circular course (57 m);		
	Walk (< 6 $km \cdot h^{-1}$)	Bias = 0.01 $km \cdot h^{-1}$	
	Sprint (> 16 $km \cdot h^{-1}$)	Bias = 0.02 $km \cdot h^{-1}$	
	Zig-zag course (20 m);		
	Walk (< 6 $km \cdot h^{-1}$)	Bias = 0.01 $km \cdot h^{-1}$	
	Sprint (> 16 $km \cdot h^{-1}$)	Bias = 0.01 $km \cdot h^{-1}$	

Supplementary Table 15 continued

Device	Movement/Protocol	Findings	Reference
SPI-ProX (interpolated 15-Hz)	Court-based team sport protocols;		Vickery et al. [40]
	2-m tennis	CV = 3.5%	
	4-m tennis	CV = 8.6%	
	Half-court	CV = 7.4%	
	Random tennis	CV = 22.8%	
	Field-based team sport protocols;		
	Run-a-three (16 m)	CV = 16.3%	
	Fast bowling (15 m)	CV = 8.8%	
	Fielding (18 m)	CV = 15.2%	
	Gradual 90º change of direction (24 m)	CV = 7.8%	
	Tight 45º change of direction (20 m)	CV = 10.9%	
	Random	CV = 7.5%	
Local positioning systems			
WimuPro	Linear course (138 m);		Bastida-Castillo et al. [41]
	Walk (< 6 $km \cdot h^{-1}$)	Bias = 0.01 $km \cdot h^{-1}$	
	Sprint (> 16 $km \cdot h^{-1}$)	Bias = 0.01 $km \cdot h^{-1}$	
	Circular course (57 m);		
	Walk (< 6 $km \cdot h^{-1}$)	Bias = 0.03 $km \cdot h^{-1}$	
	Sprint (> 16 $km \cdot h^{-1}$)	Bias = 0.01 $km \cdot h^{-1}$	
	Zig-zag course (20 m);		
	Walk (< 6 $km \cdot h^{-1}$)	Bias = 0.01 $km \cdot h^{-1}$	
	Sprint (> 16 $km \cdot h^{-1}$)	Bias = 0.01 $km \cdot h^{-1}$	

CV = co-efficient of variation; ICC = intra-class correlation

Supplementary Table 16 Summary of studies that investigated the inter-device reliability of wearable microtechnology to measure acceleration/deceleration-based metrics

Device	Movement/Protocol	Metric	Findings	Reference
		Global navigation satellite systems		
SPI-HPU (5-Hz)	Team sport circuit (40 minutes)	Acceleration count;		Delaney et al. [103]
		1 – 2 m·s^{-2}	CV = 5.1%	
		2 – 3 m·s^{-2}	CV = 3.7 %	
		> 3 m·s^{-2}	CV = 13.2%	
		Deceleration count;		
		-1 – -2 m·s^{-2}	CV = 4.6%	
		-2 – -3 m·s^{-2}	CV = 4.8%	
		< -3 m·s^{-2}	CV = 6.5%	
		Acceleration distance;		
		1 – 2 m·s^{-2}	CV = 4.5%	
		2 – 3 m·s^{-2}	CV = 13.4%	
		> 3 m·s^{-2}	CV = 27.1%	
		Deceleration distance;		
		-1 – -2 m·s^{-2}	CV = 7.4%	
		-2 – -3 m·s^{-2}	CV = 17.3%	
		< -3 m·s^{-2}	CV = 23.0%	
		Average acceleration/deceleration	CV = 5.7%	
		Average acceleration	CV = 6.5%	
		Average deceleration	CV = 4.9%	
Optimeye S5 (10-Hz)	Team sport circuit (40 minutes)	Acceleration count;		Delaney et al. [103]
		1 – 2 m·s^{-2}	CV = 4.4 %	
		2 – 3 m·s^{-2}	CV = 5.3%	
		> 3 m·s^{-2}	CV = 5.9%	
		Deceleration count;		
		-1 – -2 m·s^{-2}	CV = 3.3%	
		-2 – -3 m·s^{-2}	CV = 5.2%	
		< -3 m·s^{-2}	CV = 4.8%	
		Acceleration distance;		
		1 – 2 m·s^{-2}	CV = 1.7%	
		2 – 3 m·s^{-2}	CV = 4.4%	
		> 3 m·s^{-2}	CV = 6.9%	
		Deceleration distance;		
		-1 – -2 m·s^{-2}	CV = 1.8%	
		-2 – -3 m·s^{-2}	CV = 5.7%	
		< -3 m·s^{-2}	CV = 11.1%	
		Average acceleration/deceleration	CV = 1.2%	
		Average acceleration	CV = 2.8%	
		Average deceleration	CV = 2.2%	

Supplementary Table 16 continued

Device	Movement/Protocol	Metric	Findings	Reference
	Team sport circuit (129 m)	Peak acceleration	CV = 10.2%	Jackson et al. [101]
		Acceleration count > 1.46 m·s^{-2}	CV = 118.2%	
		Peak deceleration	CV = 12.3%	
		Deceleration count < -1.46 m·s^{-2}	CV = 67.1%	
	Team sport circuit (40 minutes)	Acceleration distance;		Thornton et al. [33]
		1– 2 m·s^{-2}	CV = 3.2% (raw); 3.4% (software-derived)	
		2– 3 m·s^{-2}	CV = 2.3% (raw); 3.1% (software-derived)	
		> 3 m·s^{-2}	CV = 5.9% (raw); 2.1% (software-derived)	
		Deceleration distance;		
		-1 – -2 m·s^{-2}	CV = 1.7% (raw); 4.4% (software-derived)	
		-2 – -3 m·s^{-2}	CV = 3.9% (raw); 5.0% (software-derived)	
		< -3 m·s^{-2}	CV = 4.1% (raw); 12.8% (software-derived)	
		Average acceleration/deceleration	CV = 1.3% (raw)	
Apex (10-Hz)	Team sport circuit (40 minutes)	Acceleration distance;		Thornton et al. [33]
		1– 2 m·s^{-2}	CV = 2.6% (raw); 18.6% (software-derived)	
		2– 3 m·s^{-2}	CV = 2.9% (raw); 19.7% (software-derived)	
		> 3 m·s^{-2}	CV = 5.6% (raw); 6.6% (software-derived)	
		Deceleration distance;		
		-1 – -2 m·s^{-2}	CV = 1.8% (raw); 12.2% (software-derived)	
		-2 – -3 m·s^{-2}	CV = 7.8% (raw); 72.8% (software-derived)	
		< -3 m·s^{-2}	CV = 6.1% (raw); 26.0% (software-derived)	
		Average acceleration/deceleration	CV = 1.3% (raw); 3.6% (software-derived)	
Evo (10-Hz)	Team sport circuit (40 minutes)	Acceleration distance;		Thornton et al. [33]
		1– 2 m·s^{-2}	CV = 4.2% (raw); 4.2% (software-derived)	
		2– 3 m·s^{-2}	CV = 2.7% (raw); 2.7% (software-derived)	
		> 3 m·s^{-2}	CV = 1.4% (raw); 1.4% (software-derived)	
		Deceleration distance;		
		-1 – -2 m·s^{-2}	CV = 2.5% (raw); 2.5% (software-derived)	
		-2 – -3 m·s^{-2}	CV = 6.4% (raw); 6.4% (software-derived)	
		< -3 m·s^{-2}	CV = 10.9% (raw); 10.9% (software-derived)	
		Average acceleration/deceleration	CV = 1.2% (raw); 1.2% (software-derived)	

Supplementary Table 16 continued

Device	Movement/Protocol	Metric	Findings	Reference
SPI-ProX (interpolated 15-Hz)	Running routine (30 minutes)	Acceleration count > 3 $m{\cdot}s^{-2}$	CV = 25.0 – 41.0%	Buchheit et al. [100]
		Acceleration count > 4 $m{\cdot}s^{-2}$	CV = 33.0 – 52.0%	
		Peak acceleration	CV = 5.0 – 8.0%	
		Deceleration count < -3 $m{\cdot}s^{-2}$	CV = 18.0 – 53.0%	
		Deceleration count < -4 $m{\cdot}s^{-2}$	CV = 37.0 – 82.0%	
Sensoreverywhere v2 (16-Hz)	Straight-line sprint (40 m)	Peak acceleration	CV = 6.4%	Lacome et al. [71]
SPI-ProX2A (chip version 2.6.1)	Running routine (30 minutes)	Acceleration count > 3 $m{\cdot}s^{-2}$	CV = 7.0 – 10.0%	Buchheit et al. [100]
		Acceleration count > 4 $m{\cdot}s^{-2}$	CV = 15.0 – 17.0%	
		Peak acceleration	CV = 6.0 – 14.0%	
		Deceleration count < -3 $m{\cdot}s^{-2}$	CV = 9.0 – 11.0%	
		Deceleration count < -4 $m{\cdot}s^{-2}$	CV = 30.0 – 36.0%	
SPI-ProX2B (chip version 2.6.4)	Running routine (30 minutes)	Acceleration count > 3 $m{\cdot}s^{-2}$	CV = 5.0 – 8.0%	Buchheit et al. [100]
		Acceleration count > 4 $m{\cdot}s^{-2}$	CV = 15.0 – 22.0%	
		Peak acceleration	CV = 4.0 – 12.0%	
		Deceleration count < -3 $m{\cdot}s^{-2}$	CV = 10.0 – 12.0%	
		Deceleration count < -4 $m{\cdot}s^{-2}$	CV = 31.0 – 45.0%	
		Inertial measurement units		
Optimeye S5 (100-Hz)	One step side to side action	Inertial movement acceleration magnitude	CV = 3.1%	Luteberget et al. [104]
	Zig-zag change of direction		CV = 4.4 %	
	Start-stop action		CV = 6.7%	
	Multi change of direction		CV = 5.9%	
	Training session (handball)	Inertial movement acceleration frequency; > 1.5 $m{\cdot}s^{-1}$	CV = 1.8%	

CV = co-efficient of variation

Supplementary Table 17 Summary of studies that investigated the inter-device reliability of wearable microtechnology to measure PlayerLoad

Device	Movement/Protocol	Findings	Reference
Inertial Measurement Units			
MinimaxX v2.0 (100-Hz)	Australian football match	CV = 1.9%	Boyd et al. [105]
MinimaxX 2.5 (100-Hz)	Flying sprint (50 m)	CV = 4.9%	Johnston et al. [54]
MinimaxX S3 (100-Hz)	Team sport circuit (165 m)	CV = 1.1%	Johnston et al. [55]
Optimeye S5 (100-Hz)	Training session (handball)	CV = 0.9%	Luteberget et al. [104]
MinimaxX S4 (100-Hz)	Team sport circuit (165 m)	CV = 5.9%	Johnston et al. [55]

CV = co-efficient of variation

Supplementary Table 18 Summary of studies that investigated the inter-device reliability of wearable microtechnology to measure other metrics

Device	Movement/Protocol	Metric	Findings	Reference
Global navigation satellite systems				
MinimaxX S3 (5-Hz, 100-Hz accelerometer)	Team sport circuit (165 m)	Exertion index	CV = 2.2%	Johnston et al. [55]
		Repeated high intensity efforts ***	CV = 83.4%	
Viper (10-Hz)	Contact-based training session	Collision load ***	ICC = 0.82; CV = 10.1%	MacLeod et al. [86]
		Collision velocity	ICC = 0.89; CV = 13.2%	
		Momentum	ICC = 0.92; CV = 13.2%	
MinimaxX S4 (10-Hz, 100-Hz accelerometer)	Team sport circuit (165 m)	Exertion index	CV = 1.0%	Johnston et al. [55]
		Repeated high intensity efforts ***	CV = 79.0%	
MinimaxX S4 (10-Hz)	Team sport circuit (129.6 m)	Theoretical peak power	CV = 18.8%	Hoppe et al. [51]
		Theoretical peak force	CV = 20.9%	
GPEXE, Exelio (18-Hz)	Team sport circuit (129.6 m)	Theoretical peak power	CV = 7.4%	Hoppe et al. [51]
		Theoretical peak force	CV = 7.5%	
Inertial measurement units				
Viper (100-Hz)	Contact-based training session	Impact force	ICC = 0.70; CV = 19%	MacLeod et al. [86]
Local positioning systems				
Kinexon one	Team sport circuit (129.6 m)	Theoretical peak power	CV = 5.9%	Hoppe et al. [51]
		Theoretical peak force	CV = 7.3%	

CV = co-efficient of variation; ICC = intra-class correlation; *** indicates a metric that is calculated using data extracted from the GNSS chip and accelerometer of the wearable device

Supplementary Table 19 Summary of studies that investigated the intra-device reliability of wearable microtechnology to measure total distance

Device	Movement/Protocol	Findings	Reference
Global navigation satellite systems			
SPI-10 (1-Hz)	Team sport circuit (128.5 m)	CV = 4.5%	Coutts and Duffield [49]
	Running circuit (128 – 1386 m)	CV = 5.5%	Edgecomb & Norton [45]
	Athletic track;		Petersen et al. [37]
	Walking (<2 m·s^{-1}) (8800 m)	CV = 0.4%	
	Jogging (2.0 – 3.5 m·s^{-1}) (2400 m)	CV = 0.4%	
	Running (3.5 – 4.0 m·s^{-1}) (1200 m)	CV = 1.5%	
	Striding (4.0 – 5.0 m·s^{-1}) (600 m)	CV = 0.5%	
SPI-Elite (1-Hz)	Team sport circuit (128.5 m)	CV = 3.6%	Coutts and Duffield [49]
WiSpi (1-Hz)	Team sport circuit (128.5 m)	CV = 7.1%	Coutts and Duffield [49]
	Linear course (200 m);		Gray et al. [47]
	Walk (0 – 1.6 m·s^{-1})	CV = 1.9%	
	Jog (1.6 – 3.5 m·s^{-1})	CV = 2.5%	
	Run (3.5 – 5 m·s^{-1})	CV = 2.0%	
	Sprint (> 5 m·s^{-1})	CV = 2.7%	
	Non-linear course (200 m);		
	Walk (0 – 1.6 m·s^{-1})	CV = 2.8%	
	Jog (1.6 – 3.5 m·s^{-1})	CV = 2.0%	
	Run (3.5 – 5 m·s^{-1})	CV = 2.6%	
	Sprint (> 5 m·s^{-1})	CV = 4.8%	
MinimaxX 2.5 (1-Hz)	Straight-line;		Portas et al. [48]
	Walk (1.79 m·s^{-1})	CV = 4.4%	
	Run (3.58 m·s^{-1})	CV = 4.5%	
	Multidirectional courses;		
	Walk (1.79 m·s^{-1})	CV = 3.1 – 5.7%	
	Run (3.58 m·s^{-1})	CV = 4.1 – 7.7%	
	Team sport circuit	CV = 2.0 – 4.9%	
VX (4-Hz)	Straight-line run (19.8 km·h^{-1})	ICC = -0.31	Buchheit et al. [75]
	Team sport circuit (soccer)	CV = 5.8%	Buchheit et al. [95]
SPI-Pro (5-Hz)	Athletic track;		Petersen et al. [37]
	Walking (<2 m·s^{-1}) (8800 m)	CV = 0.3 - 0.7%	
	Jogging (2.0 – 3.5 m·s^{-1}) (2400 m)	CV = 1.1 - 2.9%	
	Running (3.5 – 4.0 m·s^{-1}) (1200 m)	CV = 0.5 - 1.8%	
	Striding (4.0 – 5.0 m·s^{-1}) (600 m)	CV = 0.3 - 2.3%	
	Straight-line;		
	Sprint (20 m)	CV = 4.8 - 9.3%	
	Sprint (30 m)	CV = 3.4 – 6.3%	
	Sprint (40 m)	CV = 2.3 - 5.8%	
	Run-a-three sprint (18 m)	CV = 2.0 – 6.3%	

Supplementary Table 19 continued

Device	Movement/Protocol	Findings	Reference
	Straight-line sprint (30 m);		Waldron et al. [59]
	10 m	CV = 2.0%	
	20 m	CV = 2.1%	
	30 m	CV = 1.8%	
	Moving 10 m	CV = 2.3%	
SPI-ProXII (5-Hz)	Straight-line run (19.8 km·h^{-1})	ICC = 0.20	Buchheit et al. [75]
Wimu (5-Hz)	Team sport circuit (146 m)	Bias = 0.00 m	Munoz-Lopez et al. [57]
	Straight-line sprint (10 m)	Bias = 0.00 m	
	Straight-line sprint (30 m)	Bias = 0.00 m	
MinimaxX 2.5 (5-Hz)	Straight-line;		Portas et al. [48]
	Walk (1.79 m·s^{-1})	CV = 5.3%	
	Run (3.58 m·s^{-1})	CV = 4.6%	
	Multidirectional courses;		
	Walk (1.79 m·s^{-1})	CV = 3.4 – 6.7%	
	Run (3.58 m·s^{-1})	CV = 3.7 – 6.1%	
	Team sport circuit	CV = 2.2 – 4.5%	
MinimaxX (5-Hz)	Athletic track;		Petersen et al. [37]
	Walking (<2 m·s^{-1}) (8800 m)	CV = 1.4 - 2.6%	
	Jogging (2.0 – 3.5 m·s^{-1}) (2400 m)	CV = 1.3 - 1.8%	
	Running (3.5 – 4.0 m·s^{-1}) (1200 m)	CV = 2.0%	
	Striding (4.0 – 5.0 m·s^{-1}) (600 m)	CV = 1.2 - 1.3%	
	Straight-line;		
	Sprint (20 m)	CV = 19.7 - 30.0%	
	Sprint (30 m)	CV = 15.8 – 21.3%	
	Sprint (40 m)	CV = 16.1 - 17.1%	
	Run-a-three sprint (18 m)	CV = 5.3 – 13.6%	
Viper (10-Hz)	Straight-line jog (20 m)	CV = 0.4%	Beato et al. [44]
	Team sport circuit (128.5 m)	CV = 0.8%	
	Track running (400 m)	CV = 1.6%	
Johan (10-Hz)	Running circuit (200 m)	ICC = 0.83	Nikolaidis et al. [35]
	Shuttle endurance test (20 m)	ICC = 0.72 – 0.83	
WimuPro (10-Hz)	Linear course (138 m);		Bastida-Castillo et al. [41]
	Walk (< 6 km·h^{-1})	CV = 1.4%	
	Sprint (> 16 km·h^{-1})	CV = 1.1%	
	Circular course (57 m);		
	Walk (< 6 km·h^{-1})	CV = 1.8%	
	Sprint (> 16 km·h^{-1})	CV = 2.0%	
	Zig-zag course (20 m);		
	Walk (< 6 km·h^{-1})	CV = 1.4%	
	Sprint (> 16 km·h^{-1})	CV = 1.1%	

Supplementary Table 19 continued

Device	Movement/Protocol	Findings	Reference
FieldWiz (10-Hz)	Straight-line run (690 m)	CV = 1.3%	Willmott et al. [42]
	Tight and gradual change of direction course (570 m)	CV = 2.2%	
	Team sport circuit (128.5 m)	CV = 1.1%	
SPI-ProX (interpolated 15-Hz)	LIST movement pattern (13,200 m);		Rawstorn et al. [39]
	Straight-line shuttle (20 m)	CV = 2.4%	
	Curvilinear (200 m)	CV = 2.2%	
Spin (50-Hz)	Change of direction courses	ICC = 0.99	Padulo et al. [36]
Local positioning systems			
Ubisense	Figure 8 course (81 m)	CV = 0.1 – 0.6%	Rhodes et al. [61]
	Match-play replication (wheel-chair court sport)	CV = 0.2 – 0.5%	
Inmotio	Straight-line run (19.8 $km{\cdot}h^{-1}$)	ICC = 0.28	Buchheit et al. [75]
WimuPro	Linear course (138 m);		Bastida-Castillo et al. [41]
	Walk (< 6 $km{\cdot}h^{-1}$)	CV = 1.2%	
	Sprint (> 16 $km{\cdot}h^{-1}$)	CV = 1.2%	
	Circular course (57 m);		
	Walk (< 6 $km{\cdot}h^{-1}$)	CV = 1.3%	
	Sprint (> 16 $km{\cdot}h^{-1}$)	CV = 1.4%	
	Zig-zag course (20 m);		
	Walk (< 6 $km{\cdot}h^{-1}$)	CV = 1.2%	
	Sprint (> 16 $km{\cdot}h^{-1}$)	CV = 1.3%	

CV = co-efficient of variation; ICC = intra-class correlation

Supplementary Table 20 Summary of studies that investigated the intra-device reliability of wearable microtechnology to measure velocity-based threshold distance

Device	Movement/Protocol	Threshold	Findings	Reference
		Global navigation satellite systems		
SPI-10 (1-Hz)	Team sport circuit (128.5 m)	< 4 $m{\cdot}s^{-1}$	CV = 5.3%	Coutts and Duffield [49]
		> 4 $m{\cdot}s^{-1}$	CV = 32.4%	
		> 5.6 $m{\cdot}s^{-1}$	CV = 30.4%	
SPI-Elite (1-Hz)	Team sport circuit (128.5 m)	< 4 $m{\cdot}s^{-1}$	CV = 4.3%	Coutts and Duffield [49]
		> 4 $m{\cdot}s^{-1}$	CV = 11.2%	
		> 5.6 $m{\cdot}s^{-1}$	CV = 15.4%	
WiSpi (1-Hz)	Team sport circuit (128.5 m)	< 4 $m{\cdot}s^{-1}$	CV = 12.5%	Coutts and Duffield [49]
		> 4 $m{\cdot}s^{-1}$	CV = 20.4%	
		> 5.6 $m{\cdot}s^{-1}$	CV = 11.5%	
VX (4-Hz)	Team sport circuit (soccer)	> 2 $m{\cdot}s^{-1}$	CV = 22.3%	Buchheit et al. [95]
FieldWiz (10-Hz)	Straight-line run (690 m)	0.3 – 1.4 $m{\cdot}s^{-1}$	CV = 9.5%	Willmott et al. [42]
		1.4 – 2.8 $m{\cdot}s^{-1}$	CV = 9.6%	
		2.8 – 4.2 $m{\cdot}s^{-1}$	CV = 9.1%	
		4.2 – 5.6 $m{\cdot}s^{-1}$	CV = 8.1%	
		5.6 – 6.9 $m{\cdot}s^{-1}$	CV = 8.2%	
		> 6.9 $m{\cdot}s^{-1}$	CV = 5.3%	
	Tight & gradual change of direction (570 m)	0.3 – 1.4 $m{\cdot}s^{-1}$	CV = 6.5%	
		1.4 – 2.8 $m{\cdot}s^{-1}$	CV = 5.5%	
		2.8 – 4.2 $m{\cdot}s^{-1}$	CV = 6.9%	
		4.2 – 5.6 $m{\cdot}s^{-1}$	CV = 9.7%	
	Team sport circuit (128.5 m)			
		< 4.0 $m{\cdot}s^{-1}$	CV = 3.3%	
		4.0 – 5.6 $m{\cdot}s^{-1}$	CV = 2.2%	
		> 5.6 $m{\cdot}s^{-1}$	CV = 7.2%	

CV = co-efficient of variation

Supplementary Table 21 Summary of studies that investigated the intra-device reliability of wearable microtechnology to measure peak velocity

Device	Movement/Protocol	Findings	Reference
Global navigation satellite systems			
SPI-Elite (1-Hz)	Straight-line sprint (30 m)	CV = 1.2%	Barbero-Alvarez et al. [70]
	Team sport circuit (128.5 m)	CV = 2.3%	Coutts and Duffield [49]
SPI-10 (1-Hz)	Team sport circuit (128.5 m)	CV = 5.8%	Coutts and Duffield [49]
WiSpi (1-Hz)	Team sport circuit (128.5 m)	CV = 4.9%	Coutts and Duffield [49]
VX (4-Hz)	Straight-line sprint (40 m)	ICC = 0.97	Buchheit et al. [75]
	90° change of direction sprint	ICC = 0.66	
	Zig-zag sprint	ICC = 0.41	
Wimu (5-Hz)	Team sport circuit (146 m)	Bias = 0.00 $km{\cdot}h^{-1}$	Munoz-Lopez et al. [57]
	Straight-line sprints (10 m)	Bias = 0.00 $km{\cdot}h^{-1}$	
	Straight-line sprints (30 m)	Bias = 0.00 $km{\cdot}h^{-1}$	
SPI Pro (5-Hz)	Straight-line sprint (30 m);	CV = 0.8%	Waldron et al. [59]
SPI-ProXII (5-Hz)	Straight-line sprint (40 m)	ICC = 0.92	Buchheit et al. [75]
	90° change of direction sprint	ICC = 0.07	
	Zig-zag sprint	ICC = 0.61	
Viper (10-Hz)	Straight-line sprint (20 m)	CV = 0.7%	Beato et al. [44]
FieldWiz (10-Hz)	Straight-line run (690 m)	CV = 0.9%	Willmott et al. [42]
	Tight and gradual change of direction course (570 m)	CV = 0.8%	
	Team sport circuit (128.5 m)	CV = 2.3%	
Local positioning systems			
Ubisense	Figure 8 course (81 m)	CV = 1.6 – 2.7%	Rhodes et al. [61]
Inmotio	Straight-line sprint (40 m)	ICC = 0.97	Buchheit et al. [75]
	90° change of direction sprint	ICC = 0.32	
	Zig-zag sprint	ICC = -0.09	

CV = co-efficient of variation; ICC = intra-class correlation

Supplementary Table 22 Summary of studies that investigated the intra-device reliability of wearable microtechnology to measure average speed

Device	Movement/Protocol	Findings	Reference
Global navigation satellite systems			
Wimu (5-Hz)	Team sport circuit (146 m)	Bias = 0.00 $km{\cdot}h^{-1}$	Munoz-Lopez et al. [57]
	Straight-line sprints (10 m)	Bias = 0.00 $km{\cdot}h^{-1}$	
	Straight-line sprints (30 m)	Bias = 0.00 $km{\cdot}h^{-1}$	
SPI-Pro (5-Hz)	Straight-line sprint (30 m);		Waldron et al. [59]
	10 m	CV = 2.1%	
	20 m	CV = 1.9%	
	30 m	CV = 2.0%	
	Moving 10 m	CV = 1.6%	
WimuPro (10-Hz)	Linear course (138 m);		Bastida-Castillo et al. [41]
	Walk (< 6 $km{\cdot}h^{-1}$)	ICC = 0.97	
	Sprint (> 16 $km{\cdot}h^{-1}$)	ICC = 0.94	
	Circular course (57 m);		
	Walk (< 6 $km{\cdot}h^{-1}$)	ICC = 0.99	
	Sprint (> 16 $km{\cdot}h^{-1}$)	ICC = 0.98	
	Zig-zag course (20 m);		
	Walk (< 6 $km{\cdot}h^{-1}$)	ICC = 0.95	
	Sprint (> 16 $km{\cdot}h^{-1}$)	ICC = 0.96	
Spin (50-Hz)	Change of direction courses	ICC = 0.99	Padulo et al. [36]
Local positioning systems			
Ubisense	Straight-line sprint (20 m)	CV = 0.4 – 0.5%	Rhodes et al. [61]
WimuPro	Linear course (138 m);		Bastida-Castillo et al. [41]
	Walk (< 6 $km{\cdot}h^{-1}$)	ICC = 0.97	
	Sprint (> 16 $km{\cdot}h^{-1}$)	ICC = 0.94	
	Circular course (57 m);		
	Walk (< 6 $km{\cdot}h^{-1}$)	ICC = 0.99	
	Sprint (> 16 $km{\cdot}h^{-1}$)	ICC = 0.98	
	Zig-zag course (20 m);		
	Walk (< 6 $km{\cdot}h^{-1}$)	ICC = 0.99	
	Sprint (> 16 $km{\cdot}h^{-1}$)	ICC = 0.98	

CV = co-efficient of variation; ICC = intra-class correlation

Supplementary Table 23 Summary of studies that investigated the intra-device reliability of wearable microtechnology to measure acceleration/deceleration-based metrics

Device	Movement/Protocol	Metric	Findings	Reference
		Global navigation satellite systems		
VX (4-Hz)	Straight-line sprint (40 m)	Peak acceleration	ICC = 0.04	Buchheit et al. [75]
	90° change of direction sprint		ICC = -0.05	
	Zig-zag sprint		ICC = -0.07	
	Team sport circuit (soccer)	Acceleration distance > 3 $m{\cdot}s^{-2}$	CV = 84.7%	Buchheit et al. [95]
		Deceleration distance < - 3 $m{\cdot}s^{-2}$	CV = 58.1%	
SPI-ProXII (5-Hz)	Straight-line sprint (40 m)	Peak acceleration	ICC = -0.07	Buchheit et al. [75]
	90° change of direction sprint		ICC = 0.27	
	Zig-zag sprint		ICC = 0.36	
		Local positioning systems		
Inmotio	Straight-line sprint (40 m)	Peak acceleration	ICC = 0.49	Buchheit et al. [75]
	90° change of direction sprint		ICC = 0.38	
	Zig-zag sprint		ICC = 0.21	
		Inertial measurement units		
SPI-Pro (100-Hz)	Straight-line sprint (10 m)	Peak acceleration magnitude	CV = 5.0%	Waldron et al. [59]
		Acceleration magnitude count > 5 *g*	CV = 4.7%	
	Straight-line sprint (30 m)	Peak acceleration magnitude	CV = 5.2%	
		Acceleration magnitude count > 5 *g*	CV = 14.1%	

ICC = intra-class correlation; CV = co-efficient of variation

Supplementary Table 24 Summary of studies that investigated the intra-device reliability of wearable microtechnology to measure PlayerLoad

Device	Movement/Protocol	Findings	Reference
	Inertial measurement units		
MinimaxX S4 (100-Hz)	Straight-line shuttle (20 m);		Fitzpatrick et al. [107]
	2-minute duration	CV = 2.4%	
	3-minute duration	CV = 2.5%	
	4-minute duration	CV = 2.1%	
	Incremental treadmill test	CV = 5.9% (scapulae)	Barrett et al. [108]
		CV = 5.2% (centre of mass)	
Optimeye S5 (100-Hz)	Ice hockey specific movements	CV = 8.6%	Van Iterson et al. [110]
Viper (100-Hz)	Team sport circuit	*r* = 0.83 – 0.95	Barreira et al. [109]

CV = co-efficient of variation; *r* = Pearson's correlation co-efficient

Supplementary Table 25 Summary of studies that investigated the intra-device reliability of wearable microtechnology to measure other metrics

Device	Movement/Protocol	Metric	Findings	Reference
Global navigation satellite systems				
VX (4-Hz)	Team sport circuit (soccer)	Average metabolic power Metabolic power > 20 W·kg^{-1}	CV = 8.0% CV = 73.6%	Buchheit et al. [95]

CV = co-efficient of variation