The inter-unit reliability of global navigation satellite systems Apex (STATSports) metrics during a standardized intermittent running activity

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Abstract

This study aimed to evaluate the inter-unit reliability of global navigation satellite systems (GNSS) STATSports Apex metrics and to assess which metrics can be used by practitioners for the monitoring of short-distance intermittent running activities. Fifty-four male soccer players were enrolled (age = 20.7 ± 1.9 years, body mass = 73.2 ± 9.5 kg, and height = 1.76 ± 0.07 m) in this observational study. 10-Hz GNSS Apex (STATSports, Northern Ireland, Newry) units recorded total distance, high speed running (HSR), accelerations, decelerations, peak speed, average metabolic power, metabolic distance, dynamic stress load (DSL), relative distance, and speed intensity. The standardized intermitted running protocol used was a Yo-yo intermittent recovery level 1. This study reported that Apex inter-unit analysis did not show any significant difference (delta difference and 95% CIs) in total distance = 2.6 (-2.6; 7.9) m, HSR = 3.2 (-0.2; 6.8) m, accelerations = 0.09 (-0.9; 1.1), decelerations = 0.3 (-0.4; 1.1), peak speed = 0.02 (-0.03; 0.07) $m \cdot s^{-1}$, average metabolic power = 0.01 (-0.02; 0.04) $W \cdot kg^{-1}$, metabolic distance = 0.9 (-6.2; 8,0) m, DSL = 2.8 (-5.6; 10.7) au, relative distance = 0.14 (-0.19;0.47) $m \cdot min^{-1}$, and speed intensity = 0.21 (-0.21; 0.64) au. All metrics presented a delta *d* between *trivial* to *small.* The inter-unit intra-class correlation coefficient (ICC) was *good* or *excellent* for all metrics, with the exception of DSL, which was considered q*uestionable*. In conclusion, this study reports that all the metrics analysis in this study presents a low inter-unit bias and high reliability (ICC), with the exception of DSL.

Keywords: GNSS, GPS, team sports, sprint, performance, football

INTRODUCTION

Wearable technology is commonly used to assess amateur and professional team sport athletes' training and match load (2,32). Of the wearable devices available, global navigation satellite systems (GNSS) are the most commonly used (23,28). GNSS units allow for the analysis of external load metrics such as total distance, accelerations, decelerations, sprinting distance and so on (1,6,21,22). Such information is used to help coaches and sport scientists make informed decisions around modifying training sessions, evaluating the intensity of drills, and adapting training load at the individual level (22,26,37).

A multi-GNSS augmented unit acquires and tracks multiple satellite systems (e.g., global positioning system [GPS], GLONASS, Galileo, and BeiDou) concurrently and thus provides more accurate positional information compared with GPS alone (7). In fact, previous research reports that several activities can be accurately monitored using GNSS units (13,26,33). For example, when GNSS units were compared to a criterion measure for peak speed during linear activities, they reported only a negligible error and obtained high inter-unit reliability (7,10). Moreover, in different GNSS models, the total distance during linear and sport-specific activities was also found accurate (error <5%) and reliable (7,8,29). However, large variability in accuracy between manufacturers' models and units has been previously identified (8,36) and such differences may undermine practitioners' ability to monitor and plan training effectively

(34). To reduce possible inter-model biases, players should be monitored using the same GNSS technology, while to reduce inter-unit biases, the same GNSS unit should be utilized with the same player during each session (17,20) However, this is very unpractical, and this approach does not sort out the possible bias of the inter-players comparison, which is a core component of the training and match load analysis since coaches need to compare the training load among players during sessions (22). For such a reason, an inter-unit analysis should be performed for each GNSS manufacturer to verify its reliability (36). Previous research reported that GNSS Apex (STATSports) units have excellent inter-unit reliability and a coefficient of variation ranging from 1.64% to 2.91% for the analysis of peak speed during short sprints (between 5 and 30 m) (10). However, inter-unit reliability analysis of this GNSS model does not currently exist for the most common metrics used in team sports, which is a critical limitation for the use of this technology in the sport industry and for research purposes.

The majority of the activities performed by team sport players are intermittent in nature, frequently requiring changes of direction and are usually performed over short distances (14,15,23). Such short distances and constantly changing running characteristics may indeed affect the reliability of the GNSS units (6). It is therefore paramount to verify the inter-unit reliability of the most commonly used GNSS Apex metrics (i.e., total distance, high-speed running distance (HSR), accelerations, decelerations, peak speed, average metabolic power, metabolic distance, dynamic stress load (DSL), relative distance, and speed intensity) during standardized intermittent exercise (i.e., Yo-yo intermittent recovery level 1 [YYIRL1]) (4). Such information is currently missing and could have very important practical applications for sport scientists and coaches working in amateur and professional team sports. Therefore, this study aims, firstly, to evaluate the inter-unit reliability of GNSS STATSports Apex metrics, and secondly, to assess which of those metrics can be used by practitioners for monitoring short-distance intermittent running activities.

METHODS

Subjects

Fifty-four male amateur soccer players were enrolled (age = 20.7 ± 1.9 years, body mass = 73.2 ± 9.5 kg, and height = 1.76 ± 0.07 m) in this observational study. The subjects had a soccer experience ranging from 11 to 16 years and they were regularly training 2-3 times a week (including matches). The sample size power was calculated *a priori* using G power (Düsseldorf, Germany) and indicated that a total sample of 26 subjects would be required to detect a *large* (r = 0.50) correlation with 80% beta and alpha 5%, resulting in a power of 0.806. However, this study enrolled a larger sample consisting of 54 subjects in order to reduce the chances of type 2 errors in the inter-unit analysis, which resulted in an actual power (1-beta error prob) of > 0.95 (5). The study was performed in accordance with the Declaration of Helsinki for studies on human subjects. The Institutional Ethics Board of the University of Suffolk (Ipswich, UK) approved the experimental protocol (SREC20023/RT). A written informed consent form was obtained from all subjects of the current investigation.

Procedures

GNSS Apex (STATSports, Northern Ireland, Newry) have the following characteristics: wide = 30 mm, high = 80 mm, and mass = 48 g. The 10 Hz GNSS device is equipped with a 100 Hz gyroscope, a 100 Hz tri-axial accelerometer, and a 10 Hz magnetometer (7). Apex data were collected on an outdoor soccer pitch in the absence of high buildings. Data collection was only performed in good meteorological conditions to enhance satellite reception, following the recommendations of recent investigations (7,8). Prior to each session, a standardized warm-up was led by an accredited strength and conditioning coach to reduce the risk of muscle injuries.

The Apex units were turned on 20 minutes prior to the beginning of the protocol; the satellites connected to each unit ranged between 18 and 21. Each player used two units, which were placed in a manufacturer-provided vest on the subject's back about 3 cm from each other, midway between the scapulas, to permit equal exposure to the embedded antenna (6,7). Prior to the protocol, subjects were required to stand still for 10 seconds at the starting point to facilitate data analysis, then they were required to follow the audio indications related to the standardized test used in this protocol. Apex data were downloaded and further analyzed by the respective software (Apex 10 Hz, Sonra v4.2.1.).

The inter-unit reliability between Apex vs. Apex was performed for several metrics such as total distance, HSR, accelerations, decelerations, peak speed, average metabolic power, metabolic distance, DSL, relative distance, and speed intensity (9,11,32,35), whose detailed explanation is given below. The standardized intermittent running protocol was performed using a YYIRL1, which is a commonly used and validated test in team sports (4). In brief, players performed a 20 m + 20 m course, with a change of direction of 180°, with a 10-second active break after each 40 m, with the speed increasing at set intervals until the players were unable to continue.

GNSS Metrics

Total distance was the overall distance covered by the subjects during the YYIRL1, HSR was the total distance covered at a speed of over 5.5 $m \cdot s^{-1}$ (19.8 $km \cdot h^{-1}$) (9), accelerations and decelerations were quantified as the number of events with intensity > 3 $m \cdot s^{-2}$ and < 3 $m \cdot s^{-2}$ for a minimum duration of 0.5 seconds, respectively (35). Peak speed ($m \cdot s^{-1}$) was the higher velocity recorded by each subject during the YYIRL1 protocol (10). Average metabolic power ($W \cdot kg^{-1}$) and metabolic distance (m) were calculated using di Prampero's model, further details about the used formula can be found in the following paper (30). DSL is an accelerometer-derived metric which aggregates the rates of accelerations on its three orthogonal axes (X, Y, and Z planes) to form a composite magnitude vector (expressed as *g* force) which this inputted to a curved weighted function to get a value in arbitrary units (au), further details about its formula can be found in the following paper (11). Relative distance is the total distance per unit of time ($m \cdot min^{-1}$), while speed intensity (au) is a measure of total exertion calculated as the sum of a convexly weighted measure of instantaneous speed (32).

Statistical analysis

All descriptive data were presented as means ± SDs. Between-units analysis was performed using a paired t-test. Normality assumption was checked using a Shapiro-Wilk test and if violated t-test results were compared with a non-parametric Wilcoxon signed-rank test. Statistical significance was set at $p < 0.05$ and confidence intervals (CIs) at 95% were reported (5). Cohen's *d* effect size was reported and interpreted with the following scale of magnitudes: $d < 0.20$ = *trivial*, 0.20 to 0.59 = small, 0.60 to 1.19 = *moderate*, 1.20 to 1.99 = *large*, and $d > 2.00$ = *very large* (24). The inter-unit reliability was calculated using a two-way mixed model intra-class correlation coefficient (ICC), which was interpreted accordingly: $ICC \geq 0.9$ = *excellent*; $0.9 > ICC \geq 0.8$ = *good*; $0.8 > ICC \geq 0.7$ = *acceptable*; $0.7 > ICC \geq 0.6$ = *questionable*; $0.6 > ICC \geq 0.5$ = *poor*; $ICC < 0.5$ = *unacceptable* (3). Technical error of measurement (TE) was calculated using the following formula: $TE = SD \cdot \sqrt{(1-ICC)}$ (3,25). Statistical analysis was performed using JASP (Amsterdam, Netherlands) software version 0.16.3.

RESULTS

A total of 1050 individual data points were analyzed in the current investigation to test Apex inter-unit reliability, which was divided into 10 metrics, 54 subjects and 2 GNSS units per subject. Each parameter had 54 data points except for HSR and Speed intensity that had 46 and 47, respectively. Descriptive analysis and test-retest analysis were reported in Table 1.

*****Please, add here Table 1 *****

Inter-unit reliability analysis was reported in Table 2. Inter-unit reliability was rated as *good* or *excellent* for most of the metrics analyzed except for DSL, which was rated as *questionable.*

*****Please, add here Table 2*****

Between units did not report any significant difference (delta difference, 95% CIs) in total distance = 2.6 (-2.6; 7.9) m, HSR = 3.2 (-0.2; 6.8) m, accelerations = 0.09 (-0.9; 1.1) number, decelerations = 0.3 (-0.4; 1.1) number, peak speed = 0.02 (-0.03; 0.07) $m \cdot s^{-1}$, average metabolic power = 0.01 (-0.02; 0.04) $W \cdot kg^{-1}$, metabolic distance = 0.9 (-6.2; 8,0) m, DSL = 2.8 (-5.6; 10.7) au, relative distance = 0.14 (-0.19;0.47) $m \cdot min^{-1}$, and speed intensity = 0.21 (-0.21; 0.64) au. A graphical representation of the between units' analysis for each subject and for each metric was reported in Figure 1, Figure 2, and Figure 3.

Please, add here Figure 1, Figure 2, and Figure 3

DISCUSSION

This study aimed to evaluate the inter-unit reliability of GNSS STATSports Apex metrics and to assess which metrics can be used by practitioners to monitor short-distance intermittent running activities. A total of 1050 individual data points were analyzed in the current investigation to test Apex inter-unit reliability. No significant between unit difference were found ($p>0.05$), with a *d* ranging from *trivial* to *small*. Additionally, the inter-unit reliability was *excellent* for the following metrics: total distance, HSR, accelerations, decelerations, average metabolic power, metabolic distance, relative distance, and speed intensity, with the exception for peak speed that was *good* and DSL which was considered q*uestionable*.

Although GNSS Apex units are amongst the most common wearables used to monitor training and competition for team sports (12,19,27), this is the first study to evaluate the inter-unit reliability of typically used GNSS and accelerometer metrics. Total distance reported a non-significant ($p = 0.327$) *trivial* difference, with a delta difference of only 2.6 m in the inter-unit analysis, HSR reported a non-significant ($p = 0.068$) *small* difference, with a delta difference of only 3.2 m in the inter-unit analysis (Figure 1). Furthermore, accelerations, decelerations and peak speed reported non-significant ($p = 0.862$, $p = 0.375$, and 0.471, respectively) *trivial* differences (see Table 1). These results show that these GNSS metrics are consistent and can be used to monitor team sport athletes during intermittent running activities. The peak speed results reported in this study are supported by previous research that compared peak speed reliability during maximal linear sprints from 5 m to 30 m. Specifically, Beato and de Keijzer (2019) did not find any statistically significant difference during sprinting activities at any distance interval such as 5-10 m ($p = 0.162$), 10-15 m ($p = 0.793$), 15-20 m ($p = 0.998$), 20-30 m ($p = 0.207$) (10). These results highlight that peak speed assessed with Apex units can be used for the analysis of speed data in team sports, as recently suggested to practitioners (9).

However, practitioners should avoid using interchangeably different GNSS manufacturers (or models) because statistically significant differences were previously found (10,36).

The analysis of derived metabolic metrics from GNSS such as Average metabolic power and Metabolic distance reported non-significant *trivial* differences (d = 0.076 and 0.034, respectively). These metrics have been used in several papers to assess metabolic power and energy cost indirectly (18,31,32), therefore, because of their common use for both sport and research purposes, the assessment of the inter-unit analysis of those parameters was needed. This study demonstrates for the first time that the inter-unit error between GNSS units is extremely small and cannot undermine the analysis of these metrics in such contexts (Figure 2). DSL, an accelerometer derived metric, is calculated by the aggregation of the rates of acceleration on its three orthogonal axes to form a composite magnitude vector, which is inputted to a curved weighted function and provide a value in arbitrary units (au) (11). DSL can be used to assess variation in running style and the acute or chronic fatigue effect on running pattern (11). DSL was also used to compare players of different levels, reporting greater DSL values for first team players compared to U23 and U18 players (32). In the present study, DSL obtained a non-significant ($p = 0.472$) *trivial* difference between units at group level, which highlight the potential use of this metric for between-group comparisons. Finally, relative intensity and speed intensity reported non-significant ($p = 0.407$ and $p = 0.323$, respectively) *trivial* differences, which highlights that inter-unit error of those metrics is low and they can be used to assess intensity in team sports (Figure 3).

The inter-unit analysis performed in this study found that the total distance has a negligible TE (2.76 m) and an *excellent* reliability, HSR also presented an *excellent* ICC of 0.974 95%CIs (0.955, 0.985). These reliability scores are much higher than previously reported for other GPS devices such as Catapult 10 Hz minimax, which reported an ICC = 0.51 and ICC = 0.88, for total distance and HSR, respectively (29). Moreover, GPSports 15 Hz reported a lower reliability for total distance than both STATSports Apex and Catapult 10 Hz minimax. Instead, GPSports 15 Hz reported a higher inter-unit reliability for HSR (ICC = 0.94) than Catapult 10 Hz minimax but lower than STATSports Apex (29).

In this study, STATSports Apex showed a negligible inter-unit bias for the accelerations and decelerations, with a TE of 2.67 and 2.03, respectively, and an *excellent* reliability (see Table 2). These results are in contrast with what was previously reported by other GPS manufacturers about accelerations and decelerations inter-unit reliability, which ranged from *poor* to *good* (13). The differences found between previous GPS units and the current GNSS STATSports could be due to recent technological advances, which consist of units with higher acquisition frequency (*i.e.,* from 1 or 5 Hz to 10 Hz) and the use of multi satellites systems (*i.e.*, from GPS to GNSS) (7). This point is particularly relevant for accelerations and decelerations, which are calculated using the 10 Hz-GNSS data, instead of using tri-axial accelerometer data, which is a common misconception. Finally, previous research reported that because of the inadequate inter-unit reliability found between devices, accelerations inter-unit (therefore inter-subject) comparisons should not be recommended (34). However, this recommendation was made based on studies published before 2016, and although correct at that time, such recommendations are not suitable anymore. The current study clearly demonstrated that Apex inter-unit reliability for accelerations and decelerations is suitable for such a comparison (Table 1 and Figure 1).

The peak speed recorded during the YYIRL1 test was considered *good* to *excellent*, with an ICC of 0.898 95%CIs (0.831, 0.939), which is similar to the *excellent* inter-unit reliability obtained during maximal linear sprints from 5 m to 30 m previously reported (10). Additionally, the TE of the present (TE = 0.14 [see Table 2]) and the previous study, when compared for a similar distance such as 15 and 20 meters (TE = 0.14 [0.12 to 0.15]) was equivalent, which highlights the consistency of this inter-unit reliability between studies. The STATSports Apex units analyzed in the present study report a very high reliability when compared to Catapult S5 OptimEye GNSS system evaluated in previous research (16). Chahal et al. 2022, reported that these units have an ICC of 0.131 and 0.323 for total distance and peak speed, respectively (16). They conclude that the tested GNSS units (n=8) are not sufficiently consistent among themselves during straight-line sprint running (16).

The inter-unit analysis for average metabolic power and metabolic distance was *nearly perfect*, with ICC of 0.999 for both metrics (see Table 2). The DSL was the only parameter to report an ICC below expectation, with a score of 0.681, 95%CIs (0.510, 0.801), which is interpreted as *questionable.* This result is in contrast with previous research on the same topic, which reported that this metric could be consistently used to assess running activities (11). Because of these contrasting results, it is necessary to perform further investigations before making final conclusions. Finally, relative distance and speed intensity reported an *excellent* reliability score, with a *nearly perfect* ICC = 0.999 (0.999,1.000), which highlight the consistency between units.

This study is not without limitation, firstly, we have used a single GNSS manufacturer (STATSports Apex) in this research, therefore the current evidence reported cannot be translated to other GNSS devices, which need to be independently analyzed. Secondly, this study analyzed a sample of metrics that are commonly recorded with the GNSS Apex model, however, other less commonly used metrics should be analyzed in future studies. Thirdly, to perform the inter-unit reliability, units were placed in a manufacturer-provided vest on the subject's back about 3 cm from each other, midway between the scapulas, to permit equal exposure to the embedded antenna. For such a reason, the units were not placed exactly one above the other, therefore, some difference between units could be related to this. However, it is very important to highlight that the positioning of one unit above the other can decrease the quality of the signal and therefore decrease their inter-unit reliability; this is the motivation because the researchers involved in this study placed the units on the subject's in this way, as suggested in previous studies (7,10). Lastly, the inter-unit reliability of this study was performed during a standardized YYIRL1 test, which consists of short shuttle running activities (20 m) where changes of direction were present. Previous research reported that GPS technology presents a greater bias during such activities (6), so the protocol used in this study could be considered as a worst-case scenario. Considering this, future studies could assess the inter-unit reliability in ecological scenarios (e.g., during matches or standardized training sessions) to further verify their consistency.

This study evaluated the inter-unit reliability of GNSS STATSports Apex metrics and assessed which of those metrics can be used by practitioners for the monitoring of short-distance intermittent running activities. Apex units did not show any significant between unit difference ($p>0.05$), with a *d* between *trivial* to *small*. The inter-unit reliability was interpreted as *excellent* for total distance, HSR, accelerations, decelerations, average metabolic power, metabolic distance, relative distance, and speed intensity, while it was interpreted as *good* for peak speed. However, this study found a *questionable* ICC score for DSL, requiring further research to verify if its use is appropriate for the monitoring of team sport activities. In conclusion, coaches and sport scientists can confidently use GNSS Apex (STATSports) units for training load monitoring and they can perform inter-unit (inter-players) comparisons using the parameters assessed in this study.

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Table 1. Reliability data recorded during Yo-yo intermittent recovery level (54 players).

Variables	Apex units	Apex units 2	Delta difference (CIs)	P-values	*d* (Interpretation)
Total distance (m)	1794.6 ± 874.9	1792.0 ± 870.9	2.6 (-2.6; 7.9)	0.327	0.135 (Trivial)
High speed running (m)	46.9 ± 55.2	43.6 ± 51.4	3.2 (-0.2; 6.8)	0.068	0.276 (Small)
Accelerations (n)	59.6 ± 31.9	59.5 ± 31.7	0.09 (-0.9; 1.1)	0.862	0.024 (Trivial)
Decelerations (n)	37.7 ± 21.4	37.4 ± 21.6	0.3 (-0.4; 1.1)	0.375	0.122 (Trivial)
Peak speed ($m·s^{-1}$)	5.98 ± 0.43	5.97 ± 0.41	0.02 (-0.03; 0.07)	0.471	0.099 (Trivial)
Average metabolic power ($W·kg^{-1}$)	13.62 ± 3.5	13.61 ± 3.5	0.01 (-0.02; 0.04)	0.579	0.076 (Trivial)
Metabolic distance (m)	1142.6 ± 556.7	1141.7 ± 553.2	0.9 (-6.2; 8,0)	0.804	0.034 (Trivial)
Dynamic stress load (au)	58.2 ± 39.7	55.3 ± 32.2	2.8 (-5.6; 10.7)	0.472	0.098 (Trivial)
Relative distance ($m·min^{-1}$)	125.4 ± 30.3	125.3 ± 30.2	0.14 (-0.19;0.47)	0.407	0.114 (Trivial)
Speed intensity (au)	102.0 ± 48.5	101.7 ± 28.2	0.21 (-0.21; 0.64)	0.323	0.146 (Trivial)

d = Cohen’s *d*, CIs = Confidence intervals, m = Meters, s = Seconds, Au = Arbitrary units.

Table 2. Reliability data recorded during Yo-yo intermittent recovery level (54 players).

Variables	**Apex inter-unit reliability ICC (95% CI)**	**Reliability qualitative interpretation**	**Technical error of measurement**
Total distance (m)	0.999 (0.999, 1.00)	*Excellent*	2.76
High speed running (m)	0.974 (0.955, 0.985)	*Excellent*	8.90
Accelerations (n)	0.993 (0.987, 0.996)	*Excellent*	2.67
Decelerations (n)	0.991 (0.985, 0.995)	*Excellent*	2.03
Peak speed ($m \cdot s^{-1}$)	0.898 (0.831, 0.939)	Good	0.14
Average metabolic power ($W \cdot kg^{-1}$)	0.999 (0.999,1.000)	*Excellent*	0.11
Metabolic distance (m)	0.999 (0.998, 0.999)	*Excellent*	17.58
Dynamic stress load (au)	0.681 (0.510, 0.801)	*Questionable*	22.4
Relative distance ($m \cdot min^{-1}$)	0.999 (0.999,1.000)	*Excellent*	0.96
Speed Intensity (au)	0.999 (0.999,1.000)	*Excellent*	1.50

ICC = intra-class correlation coefficient, CIs = Confidence Intervals, m = Meters, s = Seconds, Au = Arbitrary units.

Figure 1. A graphical representation of the between units' analysis for each participant. The global navigation satellite systems metrics are total distance, high-speed running distance, accelerations, and decelerations.

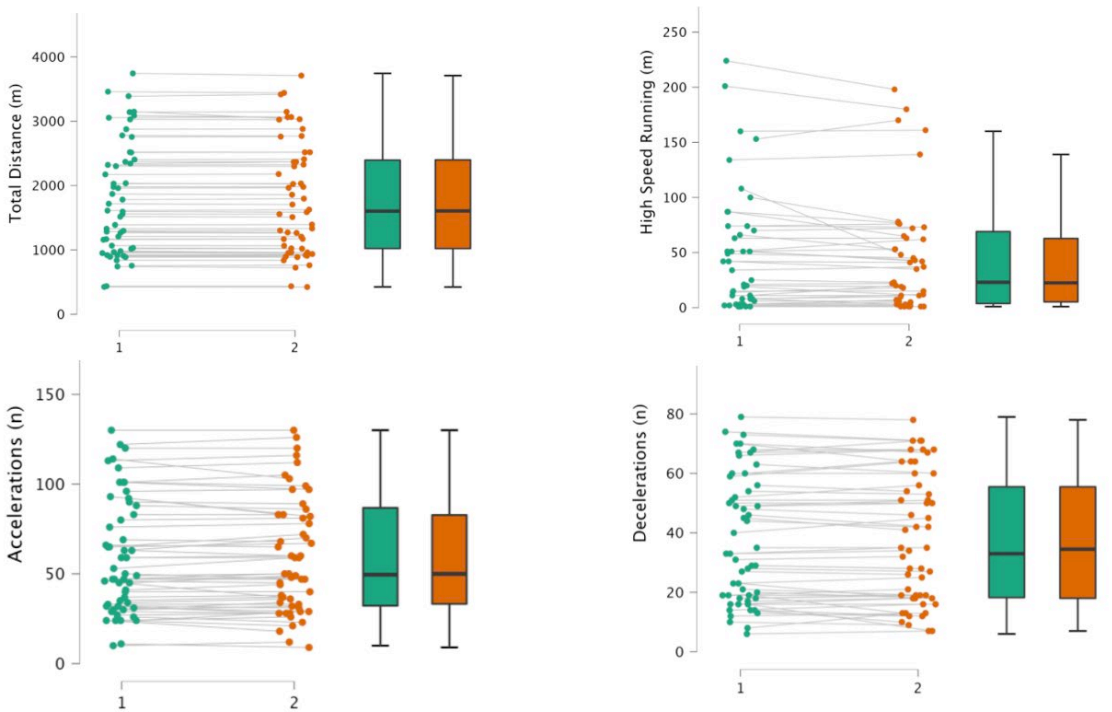

Figure 2. A graphical representation of the between units' analysis for each participant. The global navigation satellite systems metrics are average metabolic power, metabolic distance, and peak speed.

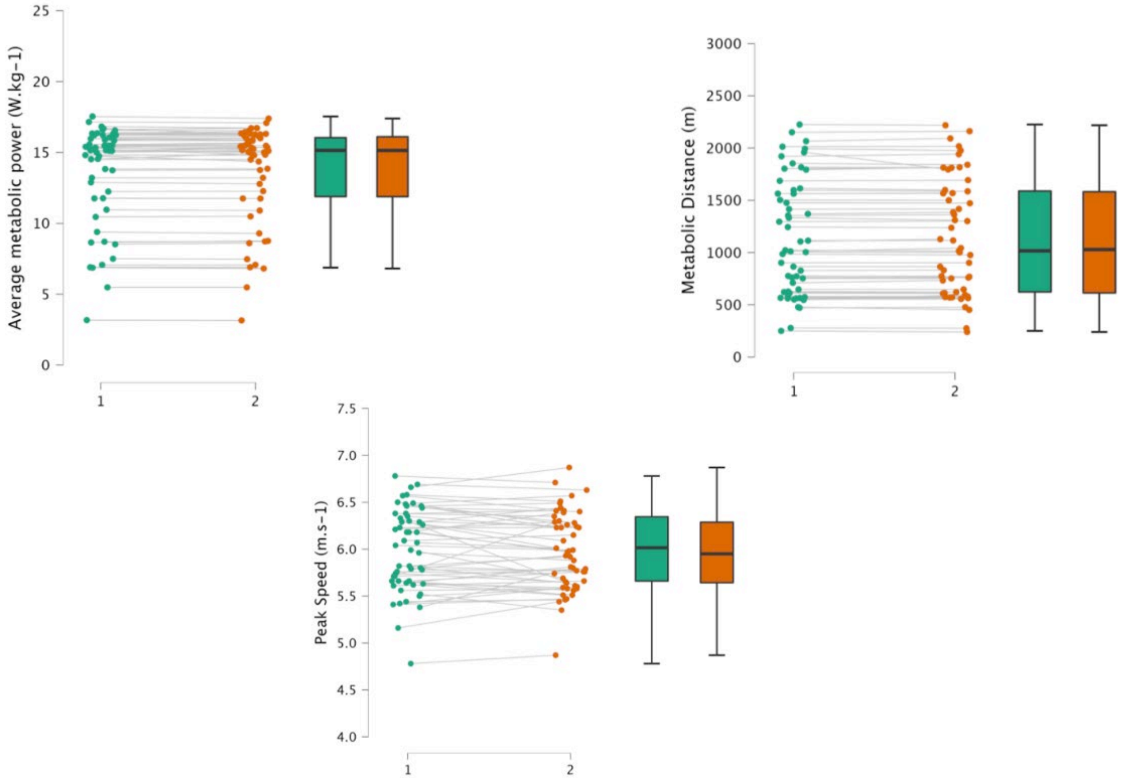

Figure 3. A graphical representation of the between units' analysis for each participant. The global navigation satellite systems metrics are dynamic stress load (DSL), relative distance, and speed intensity.