Concurrent agreement and test-retest reliability of a global positioning system device for measuring maximal horizontal deceleration ability in elite youth academy soccer players.

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Keywords:	Braking, Profiling, Acceleration-deceleration ability test, Football, Validity

Abstract

Purpose: Investigate the concurrent agreement and test-retest reliability of 10 Hz global positioning system (GPS) device against a criterion measure (47 Hz radar device) to assess maximal horizontal deceleration ability (maximum deceleration [DEC_{Max}], average deceleration [DEC_{Ave}], time to stop [TTS], and distance to stop [DTS]). ***Methods:*** Thirty-two male elite youth academy soccer players (18.1 ± 1.6 yrs; 76.6 ± 7.9 kg) completed the acceleration-deceleration ability test with sixteen completing a second test to assess test-retest reliability. Maximal horizontal deceleration ability was measured concurrently using GPS_{Raw} (10 Hz data), GPS_{Export} (STATSports software), and a radar device. Bland-Altman method and equivalence testing assessed concurrent agreement and intra-class correlations (ICC) with coefficient of variation (CV%) was used to assess test-retest reliability. ***Results:*** Equivalence testing showed mean difference between the radar device and GPS-derived values of DEC_{Ave} and DEC_{Max} were within equivalence bounds. GPS_{Raw} and GPS_{Export} derived values of DEC_{Max} showed *good* overall (ICC = 0.84 to 0.86, CV% = 4.50 to 5.48) test-retest reliability. ***Conclusion:*** Practitioners can consider using deceleration variables (DEC_{Ave} and DEC_{Max}) obtained from GPS as a cost-effective, valid, and reliable alternative to radar technology to assess maximal horizontal deceleration ability in team sports players.

Key words: Braking, profiling, acceleration-deceleration ability test, football, validity

Introduction

Profiling horizontal deceleration ability can inform performance enhancement and injury-prevention strategies in team-sport environments[1]. However, there remains a paucity of valid and reliable methods to assess an athlete's horizontal deceleration ability in the field[1]. While radar or laser devices are considered the criterion measure of horizontal deceleration ability[1], not all high-level clubs have access to such technologies[2]. Moreover, these technologies only permit individual testing, making it difficult for practitioners to assess horizontal deceleration ability within time-constrained environments[3]. Instead, most clubs are now equipped with global positioning system (GPS) devices[2], which presents a viable alternative to assess horizontal deceleration capabilities without additional equipment and associated time demand.

Previous research has highlighted several variables to quantify horizontal deceleration ability[1]. The deceleration variables: maximum deceleration (DEC_{Max}), average deceleration (DEC_{Ave}), and time to stop (TTS) have all shown *moderate* inter-test reliability using radar technology during a maximal deceleration task[1]. However, the reliability for many of these variables obtained from GPS remains unclear. *Poor* to *moderate* inter-unit reliability for DEC_{Max} has been reported previously, with these mixed results likely due to differences in protocols used[4,5]. Furthermore, the concurrent agreement and test-retest reliability of these deceleration variables obtained from a GPS device during a maximal deceleration task remains unknown.

Therefore, the aims of this study were to examine 1) the concurrent agreement between deceleration variables obtained from GPS with a criterion measure and 2) the test-retest reliability of deceleration variables assessed using a GPS device in elite youth academy soccer players.

Methods

Subjects

Thirty-two male youth soccer players (age: 18.1 ± 1.6 years; body mass: 76.6 ± 7.9 kg) from an English Premier League academy were recruited and completed the concurrent agreement session. Due to congested fixtures, only sixteen players (age: 17.4 ± 1.3 years; body mass: 73.6 ± 8.0 kg) completed the test-retest reliability session. The research was approved by the University Ethics Committee and conducted in accordance with the Declaration of Helsinki. All participants provided voluntary informed consent prior to starting the study.

Design

Within-subject repeated measures.

Methodology

The study was conducted during an in-season competition phase, with testing completed at the same time of day on an artificial turf surface. Participants all wore studded footwear and completed a 20 m maximal sprint test followed by two testing sessions, each separated by a week (Figure 1). Before testing, participants completed a 10-minute standardised warm-up and two progressive deceleration test trials.

Maximal 20 m sprint times were recorded using timing gates (TC, Brower Timing Systems, UT, USA) positioned at 0 and 20 m. Participants started 1 m behind the first gate and initiated their sprint from a stationary split stance, completing two trials with at least 2-minutes recovery. The fastest 20 m split was used as a 'criterion' time in the maximal horizontal deceleration test[2].

During both testing sessions, participants completed two repetitions of the acceleration-deceleration ability (ADA) test following a similar protocol used by Harper and colleagues[1] (Figure 1). Trials were considered unsuccessful if the 20 m time was 5% greater than the 'criterion' time and repeated after a 3-minute recovery.

Raw velocity data was recorded concurrently during the ADA test using two methods: A radar device (Stalker Pro II, Applied Concepts, Inc., TX, USA) positioned 5 m behind the participants on a tripod 1 m off the ground (Figure 1), sampled data at 46.875 Hz and a 10 Hz GPS unit (APEX, STATSports, Ireland) worn in a fitted vest. The average horizontal dilution of precision was 0.55 ± 0.38 and number of satellites was 20.3 ± 1.4.

Raw velocity data from the radar and GPS (GPS_{Raw}) was exported and processed in R statistical software (R v3.3.0. R Foundation for Statistical Computing) using a custom-made

R-script to calculate the deceleration variables (DEC_{Ave}, DEC_{Max}, TTS, and distance to stop [DTS]) based on methods in previous studies (see supplementary material)[1,6,7]. Maximum velocity (V_{Max}) and DEC_{Max} were also directly obtained from STATSports software (Sonra 4.0, STATSports, Ireland) (GPS_{Export}).

Insert Figure 1 here

Statistical Analysis

Concurrent agreement between the criterion (radar) and practical measures (10 Hz GPS_{Raw}/GPS_{Export}) was assessed with Bland-Altman method limits of agreement (LOA; 95%) and equivalence testing (two one-sided tests [TOST]). TOST lower and upper equivalent bounds were based on the smallest effect size in raw units and test-retest typical error of the criterion measure[1]: V_{Max} = ±0.15 m·s^{-1}, TTS = ±0.1 s, DTS = ±0.5 m, DEC_{Ave} = ±0.25 m·s^{-2}, and DEC_{Max} = ±0.50 m·s^{-2}. A secondary agreement analysis was also conducted (see supplementary material).

Test-retest reliability of the practical measures (10 Hz GPS_{Raw}/GPS_{Export}) was assessed by determining the intraclass correlation coefficient (ICC; two-way mixed model), coefficient of variation (CV%), and the standard error of measurement (SEM). CV% was calculated from the typical error, expressed as a percentage[1,2], and SEM was calculated using the formula: SD × √(1 – ICC), expressed in raw units. Overall reliability was interpreted as follows: ICC > 0.9 and CV% < 5 = excellent; ICC 0.75 to 0.9 and CV% < 10 = good; ICC < 0.75 or CV% < 10 = moderate; ICC < 0.75 and CV% > 10 = poor[9,10].

For information regarding the calculation of agreement and test-retest reliability measures (see supplementary material).

Results

Data related to the concurrent agreement and test-retest reliability are displayed in Table 1. Limits of agreement graphs from the Bland-Altman analysis are shown in Figure 2.

Insert Table 1 here

Insert Figure 2 here

Discussion

The main findings of this study suggest GPS as a potential valid and reliable device to assess DEC_{Ave} and DEC_{Max} variables. Therefore, opening-up the possibilities for practitioners assess maximal horizontal deceleration ability in the field.

Concurrent agreement and equivalence analysis showed the mean difference between the radar and GPS for DEC_{Ave} and DEC_{Max} were within the equivalence bounds, suggesting devices to be practically equivalent. However, the LOA were outside these bounds, indicating a potential lack of between-method agreement on an individual level. Crang et al.,[11] found similar mean difference (-0.07 $m \cdot s^{-2}$) between a 10 Hz GPS and laser device measuring DEC_{Max}, supporting the current results. However, the decelerations were not performed from high speeds (< 7 $m \cdot s^{-1}$)[11], which may explain the greater mean difference found in the current study. This suggests the ability of GPS devices to adequately detect deceleration may be compromised when movement velocity is increased[3,12]. In support of this, higher sampling devices (e.g., 16 Hz) still exhibited error (Typical error of estimate [TEE] = 1.59 ± 0.42%) in V_{Max} during high-velocity movements[3]. Therefore, practitioners may still wish to use GPS-derived values of DEC_{Max} and DEC_{Ave} to assess an athlete's horizontal deceleration ability. However, *poor* agreement (mean difference and LOA outside of equivalence bounds) was found between the radar and GPS for DTS and TTS. The origin of this difference is unclear but may be attributed to the higher sampling rate (47 Hz vs 10 Hz) of the radar compared to the GPS or data-processing methods. Therefore, their use in practice should be carefully considered.

The present study demonstrated *good* overall test-retest reliability for DEC_{Max}. In contrast, previous studies have shown *poor* to *moderate* inter-unit reliability in values of DEC_{Max}[4,5]. However, neither of these studies controlled the deceleration velocities (e.g., participants achieving ≥ 95% of 20 m split time), therefore, making it difficult to compare the current results. Nonetheless, the current findings suggest GPS_{Export} values of DEC_{Max} can be used as a time-efficient method (no additional data-processing) that could be easily implemented during in-situ pitch-based warmups to regularly monitor player horizontal deceleration ability. In addition, practitioners may wish to use GPS_{Raw} data to calculate novel variables such as DEC_{Ave}, TTS, and DTS. Although, all these variables showed *moderate* test-retest reliability, similar reliability (CV% = 6.0) in DEC_{Ave} measured using a 10 Hz GPS unit has been observed previously[12], potentially supporting its use in practice. However, using GPS_{Raw} data requires additional post-processing and a custom R-script to calculate these variables which may limit accessibility practitioners. In addition, when using radar technology, Harper et al.,[1] found similar test-retest reliability values for all deceleration variables compared to those found in the current study. This suggests error from the testing procedure (e.g., deceleration strategy) rather than the measurement technique itself.

Practical Applications

- DEC_{Ave} and DEC_{Max} variables obtained from GPS devices displayed equivalent mean difference compared with a radar device. Therefore, suggesting a cost-effective alternative to radar technology for assessing horizontal deceleration ability.
- DEC_{Max} obtained with GPS showed *good* overall test-retest reliability, confirming GPS can be used to accurately monitor maximal horizontal deceleration ability over time.

While GPS devices were shown to be reliable in measuring DEC_{Max} from a 20 m sprint distance. Future investigations are needed to confirm the practical application of GPS from other sprint distances. Additionally, as only test-retest reliability was assessed, further research is necessary to understand the sensitivity to changes (e.g. pre-post pre-season) of the deceleration variables obtained with GPS.

Conclusion

The present study indicates GPS-derived values of DEC_{Ave} and DEC_{Max} as a potential cost-effective alternative to radar technology to assess maximal horizontal deceleration ability in elite youth soccer players. Future studies need to examine the use of GPS devices in measuring deceleration variables from different sprint distances to help inform more advanced insights into athlete's deceleration capabilities.

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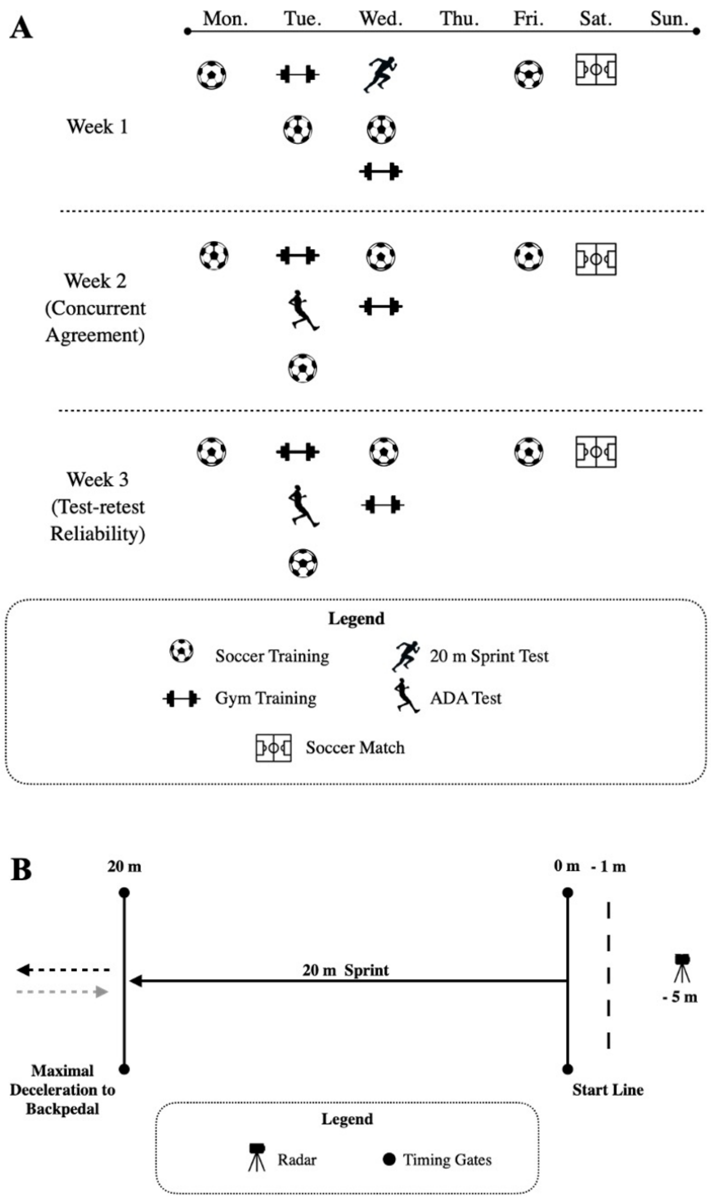
Legend

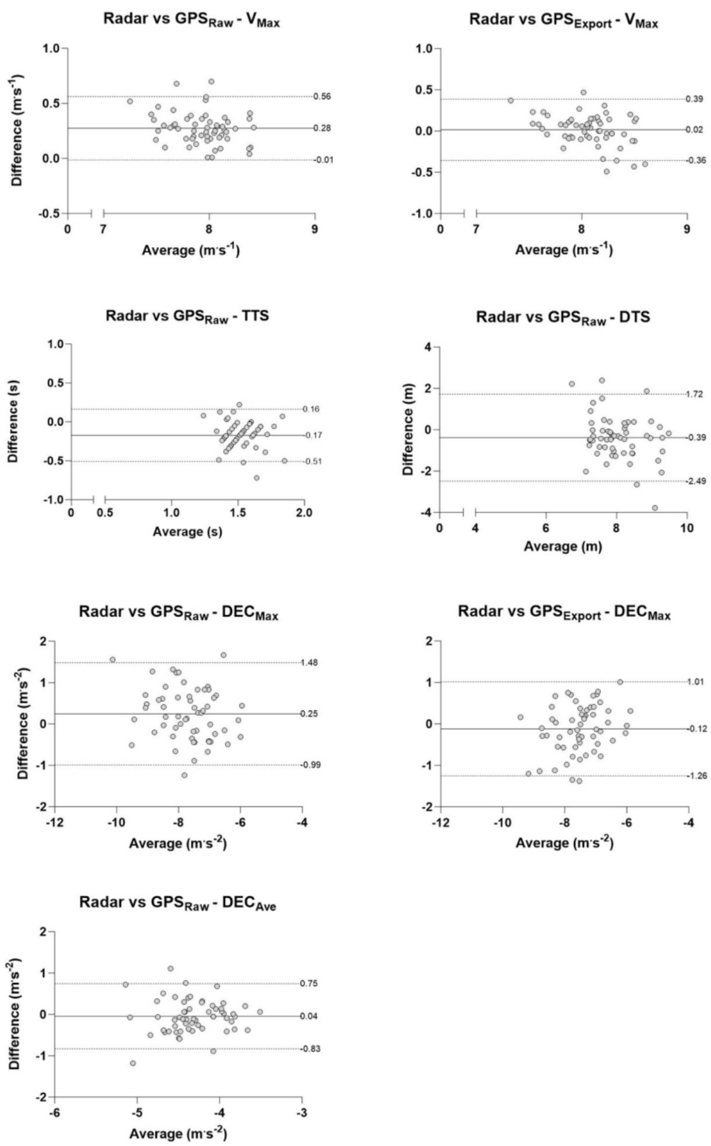
Figure 1. (A) Schematic representation of the study design. Testing was conducted within a three-week regular soccer training plan. Week one included a maximal 20 m linear sprint test and maximal horizontal deceleration ability was assessed using the global positioning system devices during week two and three. (B) Schematic representation of acceleration-deceleration ability (ADA) test layout. Timing gates were positioned at 0 and 20 metres (m). Participants were instructed to perform a maximal sprint over 20 m using the same starting procedure as the 20 m sprint test, followed by a maximal horizontal deceleration phase. The 20 m timing gate was used by the participants to initiate the deceleration phase. After the end of the deceleration, participants immediately backpedalled to the 20 m timing gate line.

Figure 2. Bland-Altman analyses. Black line represents the mean difference. Dashed lines represent 95% limits of agreements. V_{Max}: maximal velocity; TTS: time to stop; DTS: distance to stop; DEC_{Ave}: average deceleration and DEC_{Max}: maximum deceleration.

Table 1. Concurrent agreement and test-retest reliability analysis. Raw data for criterion (Radar) and practical (GPS_{Raw} and GPS_{Export}) are presented as mean ± SD. Mean difference, effect size, limits of agreement, and TOST equivalence testing. Mean difference and effect size are presented with 95% confidence intervals. TOST stands for Two One-Sided Tests and are presented as lower and upper *p*-values; LOA stands for Limits of Agreement and are presented as ± 95% bounds. Reliability statistics are presented with 95% confidence intervals. ICC stands for intra-class correlation. CV standards for coefficient of variation. SEM stands for standard error of measurement. V_{Max}: maximal velocity; TTS: time to stop; DTS: distance to stop; DEC_{Ave}: average deceleration and DEC_{Max}: maximum deceleration.



140x234mm (144 x 144 DPI)



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	Agreement vs Radar					Test-retest Reliability					
	Mean ± SD	**Mean Difference (95% CI)**	**TOST (Lower and Upper *p*-value)**	**Effect Size (95% CI)**	**LOA (Lower and Upper Bounds)**	**Day 1**	**Day 2**	**ICC (95% CI)**	**CV% (95% CI)**	**Rating**	**SEM (95% CI)**
Radar (Criterion)											
V_{Max} ($m \cdot s^{-1}$)	8.07 ± 0.26	-		-	-	8.16 ± 0.21	8.09 ± 0.25	0.88 (0.69 to 0.96)	1.06 (0.78 to 1.65)	*Good*	0.08 (0.06 to 0.12)
TTS (s)	1.43 ± 0.14	-		-	-	1.40 ± 0.13	1.34 ± 0.12	0.67 (0.28 to 0.87)	5.45 (4.00 to 8.56)	*Moderate*	0.07 (0.05 to 0.11)
DTS (m)	7.86 ± 0.73	-		-	-	7.77 ± 0.65	7.58 ± 0.63	0.62 (0.20 to 0.85)	5.48 (4.02 to 8.61)	*Moderate*	0.39 (0.29 to 0.60)
DEC_{Ave} ($m \cdot s^{-2}$)	-4.33 ± 0.41	-		-	-	-4.41 ± 0.41	-4.39 ± 0.28	0.73 (0.39 to 0.88)	4.36 (3.20 to 6.3)	*Moderate*	0.18 (0.13 to 0.28)
DEC_{Max} ($m \cdot s^{-2}$)	-7.58 ± 0.89	-		-	-	-7.52 ± 0.97	-7.64 ± 0.77	0.78 (0.48 to 0.92)	6.04 (4.43 to 9.51)	*Good*	0.41 (0.30 to 0.63)
GPS_{Raw}											
V_{Max} ($m \cdot s^{-1}$)	7.80 ± 0.30	0.28 (0.24 to 0.31)	Lower: $p < 0.001$ Upper: $p = 1$	1.87 (1.62 to 2.18)	0.28 (-0.01 to 0.56)	7.90 ± 0.25	7.78 ± 0.23	0.81 (0.54 to 0.93)	1.41 (1.04 to 2.18)	*Good*	0.10 (0.07 to 0.15)
TTS (s)	1.61 ± 0.15	-0.17 (-0.22 to -0.13)	Lower: $p = 0.999$ Upper: $p < 0.001$	-1.01 (-1.36 to -0.70)	0.33 (-0.51 to 0.16)	1.59 ± 0.14	1.56 ± 0.09	0.48 (0.00 to 0.78)	5.77 (4.23 to 9.07)	*Moderate*	0.09 (0.07 to 0.14)
DTS (m)	8.25 ± 0.96	-0.39 (-0.67 to -0.10)	Lower: $p = 0.209$ Upper: $p < 0.001$	-0.36 (-0.70 to -0.04)	2.11 (-2.49 to 1.72)	8.21 ± 0.85	7.97 ± 0.57	0.53 (0.06 to 0.81)	6.63 (4.85 to 10.44)	*Moderate*	0.49 (0.36 to 0.76)
DEC_{Ave} ($m \cdot s^{-2}$)	-4.29 ± 0.40	-0.04 (-0.15 to 0.06)	Lower: $p < 0.001$ Upper: $p < 0.001$	-0.11 (-0.37 to 0.15)	0.79 (-0.83 to 0.75)	-4.37 ± 0.40	-4.38 ± 0.35	0.57 (0.13 to 0.83)	6.07 (4.45 to 9.56)	*Moderate*	0.25 (0.18 to 0.39)
DEC_{Max} ($m \cdot s^{-2}$)	-7.83 ± 1.01	0.25 (0.08 to 0.41)	Lower: $p < 0.001$ Upper: $p = 0.002$	0.39 (0.22 to 0.57)	1.23 (-0.99 to 1.48)	-7.91 ± 1.06	-8.05 ± 1.03	0.86 (0.64 to 0.95)	5.48 (4.03 to 8.63)	*Good*	0.39 (0.29 to 0.60)
GPS_{Export}											
V_{Max} ($m \cdot s^{-1}$)	8.06 + 0.33	0.02 (-0.03 to 0.07)	Lower: $p < 0.001$ Upper: $p < 0.001$	0.08 (-0.07 to 0.24)	0.37 (-0.36 to 0.39)	8.16 ± 0.26	8.03 ± 0.28	0.82 (0.56 to 0.93)	1.51 (1.11 to 2.35)	*Good*	0.11 (0.08 to 0.17)
DEC_{Max} ($m \cdot s^{-2}$)	-7.46 ± 0.74	-0.12 (-0.27 to 0.03)	Lower: $p < 0.001$ Upper: $p < 0.001$	-0.21 (-0.39 to -0.02)	1.13 (-1.25 to 1.01)	-7.51 ± 0.78	-7.61 ± 0.73	0.84 (0.59 to 0.94)	4.50 (3.31 to 7.05)	*Good*	0.30 (0.22 to 0.46)

<u>Supplementary Material:</u>

Data Processing:

Radar:

The radar device sampled instantaneous horizontal velocity at 46.875 Hz during the ADA test and was gathered using MookyStalker (version 3.0.15, MTraining, Ecole-Valentin, France). Raw velocity data was processed following a similar procedure outlined by Simperingham et al., (2016). This involved: (i) deleting all data recorded before the start of the sprint and following the end of the deceleration phase, (ii) manually removing unexpected high and low data points on the velocity-time curve that were likely caused by segmental movements of the participants while sprinting, (iii) applying a digital fourth order, zero lag Butterworth filter with a cut-off frequency of 1 Hz (*signal* package), A cut-off frequency of 1 Hz was selected following recommendations of alternative post-processing methods by Harper et al., (2023) and similar cut-off frequencies being used to filter laser device data (Hader et al., 2015).

References:

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GPS:

The raw instantaneous velocity was filtered by applying a digital fourth order, zero lag Butterworth filter with a cut-off frequency of 1 Hz. This cut-off frequency was shown to be most appropriate for filtering velocity data (Delves et al., 2022).

Reference:

Delves RIM, Duthie GM, Ball KA, Aughey RJ. Applying common filtering processes to Global Navigation Satellite System-derived acceleration during team sport locomotion. *J Sports Sci*. 2022;40(10):1116-1126. doi:10.1080/02640414.2022.2051332

Calculation of Deceleration Variables:

Kinematic deceleration variables (DECAve, DECMax, TTS, and DTS) during the deceleration phase were calculated from the processed velocity data using a custom-made script in R Studio (R v3.3.0. R Foundation for Statistical Computing). The deceleration phase was defined as the time point immediately following the maximal velocity (VMax) to the timepoint where the lowest velocity (VMin) was reached following Vmax (Harper et al., 2023). The table below shows the calculations for each deceleration variable.

Reference:

Harper DJ, Morin JB, Carling C, Kiely J. Measuring maximal horizontal deceleration ability using radar technology: reliability and sensitivity of kinematic and kinetic variables. *Sports Biomech*. 2023;22(9):1192-1208. doi:10.1080/14763141.2020.1792968

Horizontal Deceleration Variable (Unit)	**Definition**	**Equation**
Time to Stop (s)	Time taken to stop during the deceleration phase	$tf - ti$
Distance to Stop (m)	Distance travelled during the deceleration phase	$\sum_{V_{Min}}^{V_{Max}} \frac{1}{2}(vf - vi) * (tf - ti)$
Instantaneous Deceleration ($m \cdot s^{-2}$)	Deceleration value for a given time point	$\frac{(vf - vi)}{(tf - ti)}$
Average Deceleration ($m \cdot s^{-2}$)	Average of all the instantaneous deceleration values across deceleration phase	$\sum_{V_{Min}}^{V_{Max}} \frac{(vf - vi)}{(tf - ti)}$
Maximum Deceleration ($m \cdot s^{-2}$)	Highest instantaneous deceleration value across the deceleration phase	$Max\ \frac{(vf - vi)}{(tf - ti)}$

vf: final velocity, vi: initial velocity, tf: final time, ti: initial time, $\sum_{V_{Min}}^{V_{Max}}$: sum across deceleration phase (V_{Max} to V_{Min}) and Max: maximum value.

Custom R-Script for GPS Raw Data:

```
library(signal)

library(zoo)


# Define filter specifications
```

```
cutoff_freq <- 1 # Hz

sampling_rate <- 10 # Hz

order <- 4


# Calculate filter coefficients

nyquist_freq <- sampling_rate/2

cutoff_norm <- cutoff_freq/nyquist_freq

filter_coef <- butter(order, cutoff_norm, type = "low", zero.phase = TRUE)


# Create an empty data frame to store the results

result_df <- data.frame(Player = character(), TTS = numeric(), DTS = numeric(), DECmax =
numeric(), DECave = numeric(), Vmax = numeric(), early_decel = numeric (),

late_decel = numeric())


# Loop over files, apply filter, and save filtered data to new file

for (ADA_file in ADA_file_list) {

  # Read in the original data

  gpsdata <- read.csv(ADA_file, header = TRUE, skip = 1)

  # Update column names

  colnames(gpsdata) <- c("Name", "Time", "Lat", "Lon","Speed", "Heart Rate", "Acceleration
Impulse")


  # Create a new column "new_time" that starts at 0 and increases by 0.1 seconds

  gpsdata$new_time <- seq(0, length.out = nrow(gpsdata)) * 0.1


  # Apply the Butterworth filter to the speed data
```

```
  x <- gpsdata[, 5]

  x <- na.approx(x)  # Interpolate missing values

  filteredspeed <- filter(filter_coef$b, filter_coef$a, x)


  # Combine the original data with the filtered and rolling average data

  new_gpsdata <- cbind(gpsdata, "filtered_speed" = filteredspeed)


  # Find the time point after max speed and the lowest speed after that

  fvmax <- max(filteredspeed)

  fvmax_time <- new_gpsdata$new_time[which.max(filteredspeed)]

  fvlow <- min(filteredspeed[which(new_gpsdata$new_time > fvmax_time)])

  fvlow_time <- new_gpsdata$new_time[which(filteredspeed == fvlow &
new_gpsdata$new_time > fvmax_time)]


  # Create vectors of NAs with the same length as new_gpsdata

  deceleration <- rep(NA, nrow(new_gpsdata))


  # Calculate the deceleration between fvmax_time and fvlow_time

  for (i in seq(which(new_gpsdata$new_time == fvmax_time)[1] + 1,
which(new_gpsdata$new_time == fvlow_time)[1])) {

    dv <- filteredspeed[i] - filteredspeed[i-1]

    dt <- new_gpsdata$new_time[i] - new_gpsdata$new_time[i-1]

    decel <- dv/dt

    deceleration[i] <- decel

  }
```

```
# Add the filtered speed deceleration values to new_gpsdata
new_gpsdata$deceleration <- deceleration

# Find the indices of filtered speed values within the range from Vmax to Vlow
valid_speed_indices <- which(new_gpsdata$new_time > fvmax_time &
new_gpsdata$new_time <= fvlow_time)

# Find the time point after max speed and the lowest speed after that
fvmax <- max(filteredspeed)
fvmax_time <- new_gpsdata$new_time[which.max(filteredspeed)]
fvlow <- min(filteredspeed[which(new_gpsdata$new_time > fvmax_time)])
fvlow_time <- new_gpsdata$new_time[which(filteredspeed == fvlow &
new_gpsdata$new_time > fvmax_time)]

# Calculate distance traveled at each time point during deceleration
distance <- numeric(length(filteredspeed))
start_index <- which(new_gpsdata$new_time == fvmax_time) + 1
end_index <- which(new_gpsdata$new_time == fvlow_time)
for (i in start_index:end_index) {
  distance[i] <- 0.5 * (filteredspeed[i] + filteredspeed[i-1]) * (new_gpsdata$new_time[i] -
new_gpsdata$new_time[i-1])
}
distance[1:(start_index-1)] <- NA
distance[(end_index+1):length(distance)] <- NA

# Add distance traveled column to new_gpsdata dataframe
new_gpsdata$Distance_Traveled <- distance
```

```
# Calculate TTS (time to stop)
tts <- sum(!is.na(deceleration)) * 0.1

# Calculate DTS (distance to stop) and round to 2 decimal places
dts <- round(sum(distance[!is.na(distance)]), 2)

# Calculate DECmax (maximum deceleration) and round to 2 decimal places
decmax <- round(min(deceleration, na.rm = TRUE), 2)

# Calculate DECave (average deceleration) and round to 2 decimal places
decave <- round(mean(deceleration, na.rm = TRUE),2)

# Calculate Vmax (maximum speed) and round to 2 decimal places
vmax <- round(fvmax, 2)

# Store these values in your result data frame
result <- data.frame(Player = gsub("^\\d{4}-\\d{2}-\\d{2}-|\\.csv$", "", ADA_file),
            TTS = tts,
            DTS = dts,
            DECmax = decmax,
            DECave = decave,
            Vmax = vmax,

# Append the result to the main result data frame
```

```
    result_df <- rbind(result_df, result)


    # Create a new folder within the working directory
    new_folder_name <- "GPS_Filtered_Data"
    dir.create(new_folder_name)


    # Write the filtered data to a new file with a new name in the new folder
    new_file_name <- paste0("filtered_", basename(ADA_file))
    write.csv(new_gpsdata, file = file.path(new_folder_name, new_file_name), row.names =
FALSE)


}


# Write the results to a new CSV file
write.csv(result_df, file = "result.csv", row.names = FALSE)
```

Custom R-Script for Radar Raw Data:

```
library(signal)
library(zoo)


# Define filter specifications
cutoff_freq <- 1 # Hz
sampling_rate <- 46.875 # Hz
```

```
order <- 4

# Calculate filter coefficients
nyquist_freq <- sampling_rate/2
cutoff_norm <- cutoff_freq/nyquist_freq
filter_coef <- butter(order, cutoff_norm, type = "low", zero.phase = TRUE)

# Create an empty data frame to store the results
result_df <- data.frame(Player = character(), TTS = numeric(), DTS = numeric(), DECmax =
numeric(), DECave = numeric(), Vmax = numeric())

 # Loop over files, apply filter, and save filtered data to new file
 for (radar_file in radar_file_list) {
  # Read in the original data
  radardata <- read.csv(radar_file, header = TRUE, skip = 0)
  # Update column names
  colnames(radardata) <- c("Time", "Speed", "Radar")

  # Convert time to milliseconds
  radardata$Time <- radardata$Time/1000

  # Apply the Butterworth filter to the speed data
  x <- radardata[, 2]
  x <- na.approx(x) # Interpolate missing values
  filteredspeed <- filter(filter_coef$b, filter_coef$a, x)
```

```
new_radardata <- cbind(radardata, "filtered_speed" = filteredspeed)

# Find the time point after max speed and the lowest speed after that

vmax <- max(filteredspeed)

vmax_time <- new_radardata$Time[which.max(filteredspeed)]

vlow <- min(filteredspeed[which(new_radardata$Time > vmax_time)])

vlow_time <- new_radardata$Time[which(filteredspeed == vlow & new_radardata$Time
> vmax_time)][1]

# Create a vector of NAs with the same length as new_radardata

deceleration <- rep(NA, nrow(new_radardata))

# Calculate the deceleration between vmax_time and vlow_time

for (i in seq(which(new_radardata$Time == vmax_time)[1] + 1,
which(new_radardata$Time == vlow_time)[1])) {

  if (i > 1) {

    dv <- filteredspeed[i] - filteredspeed[i-1]

    dt <- new_radardata$Time[i] - new_radardata$Time[i-1]

    decel <- dv/dt

    deceleration[i] <- decel

  }

}

# Add the deceleration values to new_radardata

new_radardata$deceleration <- deceleration
```

```
# Find the time point after max speed and the lowest speed after that

fvmax <- max(filteredspeed)

fvmax_time <- new_radardata$Time[which.max(filteredspeed)]

fvlow <- min(filteredspeed[which(new_radardata$Time > fvmax_time)])

fvlow_time <- new_radardata$Time[which(filteredspeed == fvlow & new_radardata$Time >
fvmax_time)]


# Calculate distance traveled at each time point during deceleration

distance <- numeric(length(filteredspeed))

start_index <- which(new_radardata$Time == fvmax_time) + 1

end_index <- which(new_radardata$Time == fvlow_time)

for (i in start_index:end_index) {

  distance[i] <- 0.5 * (filteredspeed[i] + filteredspeed[i-1]) * (new_radardata$Time[i] -
new_radardata$Time[i-1])

}

distance[1:(start_index-1)] <- NA

distance[(end_index+1):length(distance)] <- NA


# Add distance traveled column to new_gpsdata dataframe

new_radardata$Distance_Traveled <- distance


# Calculate TTS (time to stop)

tts <- sum(!is.na(deceleration)) * 0.021


# Calculate DTS (distance to stop) and round to 2 decimal places

dts <- round(sum(distance[!is.na(distance)]), 2)
```

```
  }

# Calculate DECmax (maximum deceleration) and round to 2 decimal places
decmax <- round(min(deceleration, na.rm = TRUE), 2)

# Calculate DECave (average deceleration) and round to 2 decimal places
decave <- round(mean(deceleration, na.rm = TRUE),2)

# Calculate Vmax (maximum speed) and round to 2 decimal places
vmax <- round(fvmax, 2)

# Store the results in a data frame
result <- data.frame(Player = gsub("Session 1_(.*)_([1-3]).csv", "\\1_\\2", radar_file),
                     TTS = tts,
                     DTS = dts,
                     DECmax = decmax,
                     DECave = decave,
                     Vmax = vmax)
# Append the result to the main result data frame
result_df <- rbind(result_df, result)

# Write the filtered data to a new file with a new name in the new folder
new_file_name <- paste0("filtered_", basename(radar_file))
write.csv(new_radardata, file = file.path(new_folder_name, new_file_name), row.names =
FALSE)
  }
# Write the results to a new CSV file
```

```
write.csv(result_df, file = "result.csv", row.names = FALSE
```

Statistical Analysis:

Concurrent Agreement:

Bland-Altman limits of agreement (95%) analysis was performed using Hopkins (2015) validity excel spreadsheet.

Reference:

Hopkins WG. Spreadsheets for analysis of validity and reliability. *Sportscience*. 2015;19,36–4

Equivalence testing:

Two one-sided tests were performed using the TOSTER (version 0.4.1) module in jamovi (jamovi Project, version 2.6.19, https://www.jamovi.org/). Mean difference (95% confidence intervals) between criterion and practical measures were taken from these tests.

Reference:

Lakens D. Equivalence Tests: A Practical Primer for *t* Tests, Correlations, and Meta-Analyses. *Soc Psychol Personal Sci*. 2017;8(4):355-362. doi:10.1177/1948550617697177

Secondary Agreement Analysis:

Secondary agreement analysis was performed using Hopkins (2015) validity excel spreadsheet which assessed mean bias, typical error of estimate in standardised units, and Pearson correlation coefficients, interpreted by thresholds proposed by Hopkins (2015).

Reference:

Hopkins WG. Spreadsheets for analysis of validity and reliability. *Sportscience*. 2015;19,36–4

Reliability Analysis:

ICC and CV%:

ICC and CV% (95%) were calculated using Hopkins (2015) reliability excel spreadsheet.

SEM:

As mentioned in the manuscript, SEM was calculated using the formula: SD × √(1 – ICC), using the ICC value was taken from that obtained from the Hopkins spreadsheet analysis mentioned above.

Each value of SEM was calculated manually using the formula and confidence intervals were obtained by inputting the SEM value into the Hopkin’s spreadsheet and using the formula: =SQRT(df * SEM^2 / CHIINV((1 - CI% / 100) / 2, df))

Where: df = degrees of freedom (n-1), CI% = 0.95 (95%), and SEM = standard error of measurement.

Reference:

Hopkins WG. Spreadsheets for analysis of validity and reliability. *Sportscience*. 2015;19,36–4

Data Table for Secondary Agreement Analysis:

	Mean ± SD	**Standardised Mean Bias (95% CI)**	**Standardised TEE (95% CI)**	**Pearson *r* Correlation (95% CI)**
Radar (Criterion)				
V_{Max} (m·s^{-1})	8.07 ± 0.26	-	-	-
TTS (s)	1.43 ± 0.14	-	-	-
DTS (m)	7.86 ± 0.73	-	-	-
DEC_{Ave} (m·s^{-2})	-4.33 ± 0.41	-	-	-
DEC_{Max} (m·s^{-2})	-7.58 ± 0.89	-	-	-
GPS_{Raw}				
V_{Max} (m·s^{-1})	7.80 ± 0.30	-1.01 (-1.17 to -0.85)	0.58 (0.43 to 0.79)	0.87 (0.78 to 0.92)
TTS (s)	1.61 ± 0.15	1.15 (0.84 to 1.46)	2.80 (1.53 to 11.66)	0.34 (0.09 to 0.55)
DTS (m)	8.25 ± 0.96	0.51 (0.12 to 0.89)	4.50 (1.98 to 22.74)	0.22 (-0.04 to 0.45)
DEC_{Ave} (m·s^{-2})	-4.29 ± 0.40	0.10 (-0.15 to 0.35)	1.69 (1.08 to 3.30)	0.51 (0.29 to 0.68)
DEC_{Max} (m·s^{-2})	-7.83 ± 1.01	-0.26 (-0.45 to -0.08)	0.79 (0.57 to 1.14)	0.78 (0.66 to 0.87)
GPS_{Export}				
V_{Max} (m·s^{-1})	8.06 + 0.33	-0.06 (-0.25 to 0.13)	0.70 (0.52 to 0.99)	0.82 (0.71 to 0.89)
DEC_{Max} (m·s^{-2})	-7.46 ± 0.74	0.13 (-0.04 to 0.30)	0.85 (0.62 to 1.25)	0.76 (0.63 to 0.85)