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**Section:** Original Investigation

**Article Title:** Comparing Global Positioning System (GPS) and Global Navigation Satellite System (GNSS) Measures of Team Sport Movements

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## Abstract

***Purpose:*** To compare data from conventional GPS and new GNSS-enabled tracking devices, and to examine the inter-unit reliability of GNSS devices. ***Methods:*** Inter-device differences between 10 Hz GPS and GNSS devices were examined during laps (n=40) of a simulated game circuit (SGC) and during elite hockey matches (n=21); GNSS inter-unit reliability was also examined during the SGC laps. Differences in distance values and measures in three velocity categories (low <3 $m.s^{-1}$; moderate 3-5 $m.s^{-1}$; high >5 $m.s^{-1}$) and acceleration/deceleration counts (>1.46 $m.s^{-2}$ and < -1.46 $m.s^{-2}$) were examined using one-way ANOVA. Inter-unit GNSS reliability was examined using the coefficient of variation (CV) and intra-class correlation coefficient (ICC). ***Results:*** Inter-device differences (P <0.05) were found for measures of peak deceleration, low-speed distance, % total distance at low speed, and deceleration count during the SGC, and for all measures except total distance and low-speed distance during hockey matches. Inter-unit (GNSS) differences (P <0.05) were not found. The CV was below 5% for total distance, average and peak speeds and distance and % total distance of low-speed running. The GNSS devices had a lower HDoP score than GPS devices in all conditions. ***Conclusions:*** These findings suggest that GNSS devices may be more sensitive than GPS in quantifying the physical demands of team sport movements, but further study into the accuracy of GNSS devices is required.

***Key Words:*** time-motion analysis; reliability; variability; accelerations; precision

## Introduction

Global Positioning System (GPS) devices are commonly used in elite-level team sports as a way of tracking player movements and quantifying workloads.[1-3] The data collected from GPS devices is important to coaches, athletes and scientists, as it provides details about the movement patterns performed within a given sport, and also allows for energy cost estimation throughout a period of competition or training.[4,5] GPS data has become useful for a number of purposes, including the design of sport-specific training drills and conditioning programs, workload management and injury prevention.[6]

While GPS devices have demonstrated a reasonable level of accuracy for measuring total distance covered during team sport competition,[7,8] some limitations remain.[9] Typically, distance measures become less reliable as running speed increases, whilst accuracy is reduced when movement occurs over a non-linear path.[7] Higher sampling rates (from 1 Hz through 5 Hz to 10 Hz) have led to improvements in both the accuracy and inter-unit reliability of GPS devices,[8,10,11] although units with higher sampling rates are still found to be unreliable when measuring movement at speeds >20 $km.h^{-1}$.[12] In team sports, rapid changes in speed and direction are common, and while changes in direction have been found to reduce the accuracy of GPS-derived distance measures,[13] accelerations >4 $m.s^{-2}$ have been found to reduce the reliability of GPS-derived speed measures.[14] Consequently, important player movements, which are meaningful in the determination of energy expenditure and physical workload, are potentially missed. Accordingly, the limitations of current GPS technology need to be taken into account when attempting to quantify player movements. Improvements in player-tracking technologies, which increase the resolution of devices so that they are more sensitive to rapid changes in speed or direction, are a potentially beneficial innovation in overcoming the current limitations of GPS technology.

One possible solution to improving the aforementioned shortcomings with existing GPS units might be the Global Navigation Satellite System (GNSS), a collective term used to encompass all satellite navigation systems providing geospatial positioning with global coverage. Currently, this includes both the United States-based GPS (n=24) and the Russian-based GLONASS (GLObal NAvigation Satellite System) systems (n=24), which together comprise a network of 48 satellites. Recently, a GNSS-enabled player tracking device (Optimeye S5, Catapult Innovations South Melbourne, Victoria, Australia), with access to the full array of 48 satellites (rather than just 24) was made commercially available. By doubling the number of satellites available during tracking, the resolution capabilities of the technology are potentially enhanced, and it is expected that the GNSS device will be more sensitive to changes in direction and speed in comparison to existing GPS devices.

Recent research has found GNSS tracking to be both accurate and reliable in slalom alpine skiing.[15,16] Given the high speeds and accelerations attained during this activity, along with continual and rapid changes in direction, these findings are promising with respect to team sport activity. However, the sensitivity and reliability of GNSS tracking in team sports remains to be investigated with a recent paper noting "there has yet to be a direct comparison study completed comparing the data quality of GPS versus GNSS in a sporting context, which lends to future research".[6] Therefore, the aim of this study was to determine whether any differences exist between the movement data collected from conventional GPS and the new GNSS-enabled tracking devices. A secondary aim was to examine the inter-unit reliability of the GNSS devices.

## Methods

### *Design*

Part 1 of the study investigated the inter-device differences between GNSS and GPS units, and the inter-unit reliability of GNSS devices, under controlled conditions. Participants completed a modified version of a previously validated simulated game circuit (SGC),[17] in an attempt to replicate the typical movement patterns observed during team sport activity. Part 2 investigated inter-device differences between GPS and GNSS units during hockey match play, in order to determine if any differences found in Part 1 were replicated in an elite competition-based setting, where more uncontrolled and spontaneous movements, at higher magnitudes, occur.

### *Participants*

In Part 1, five moderately trained participants (four females; one male) were recruited and written informed consent was gained. In Part 2, data output from five male hockey players (no goalkeepers) of the Australian National Hockey Squad was accessed from a de-identified match database, collected during the Australian Hockey League (AHL) for the Australian Institute of Sport (AIS) Hockey program. As part of their scholarship, AIS athletes provide signed informed consent acknowledging that any testing or competition data collected during their scholarship period may be de-identified and used for scientific analysis and published in scientific literature. Institutional ethics approval for both Part 1 and 2 was granted by the Human Ethics office of The University of Western Australia (RA/4/1/8536).

### *Methodology*

Part 1 was performed on playing fields at a large open space with minimal obstructions low on the horizon to minimise signal interference and maximise satellite reception. Weather conditions on the testing day were fine (23.5°C, 42% relative humidity, 11 km.h$^{-1}$ wind speed) with no cloud cover.[18] Prior to testing, participants were fitted with a custom-designed harness that could carry two tracking units, each in separate but adjacent pockets (see Figure 1). One GNSS unit was placed in the back pocket and either a GPS or second GNSS unit was placed in the front pocket. Such practice replicates previously published validation studies for these devices.[7,8] It is possible that the close proximity of the units may have interfered with signal quality, but the extent of this interference is unknown.[6] Although the manufacturers advise that no significant interference is evident between units placed immediately adjacent to each other, they suggest that if the current anecdotal issues of potential interference are of concern, users may consider a gap of 10cm to eliminate any possible obstruction (Catapult Sports, email communication, February 2018).

During the test, participants completed four sets of activity, each comprising four laps of the modified SGC (see Figure 2). Two sets of the protocol were completed for inter-device differences between GNSS and GPS and two sets for GNSS inter-unit reliability assessment. The SGC incorporates a series of walks, jogs, sprints and changes of direction. Each circuit took approximately 45-60 seconds to complete. Throughout all sets, the participants wore a GNSS tracking unit (Optimeye S5 10 Hz, Catapult Innovations, South Melbourne, Victoria, Australia, firmware version 7.12). During the inter-device difference sets, a conventional GPS unit (MinimaxX S4 10 Hz, Catapult Innovations, South Melbourne, Victoria, Australia, firmware version 6.72) was worn alongside the GNSS unit, whilst during the inter-unit reliability sets, a second GNSS unit was worn. These devices determine distance via positional differentiation and velocity based on the Doppler-shift measurement principle. Between each lap, participants had a 10 s pause at the marker cone to allow for clear lap identification, whilst a short break between sets allowed the units to be exchanged.

Match data for Part 2 was collected from athletes during six games of the AHL competition. Due to injuries and equipment malfunctions, a total of 21 matches were recorded.

Players were provided with the same type of harness as in Part 1, which did not restrict their movements. As such, the hockey players wore both a GNSS unit and a GPS unit simultaneously during match play. The devices used here were identical to those used in Part 1, with players assigned the same GNSS and GPS device for each match. As in Part 1, the GNSS and GPS units were placed in the same pocket for each match.

*Data Processing*

For all trials across both Parts 1 and 2, data was downloaded into proprietary software (Catapult Sprint, Version 5.1.7, 2014) before being cropped and assigned into discrete periods. For Part 1, the in-built accelerometer trace was used to help identify the start and finish of each repetition (lap), which were treated as separate periods. For Part 2, data files were divided into periods of active play (i.e. when the player was on the field during the match) resulting in 136 distinct periods from all matches. The software applied a proprietary filter smoothing algorithm to the velocity data. The minimum effort duration was set at 1.0 s and 0.6 s for velocity and acceleration, respectively, and the interval over which acceleration was calculated from velocity (smoothing filter width) was set at 0.2 s.[19] The software provided summary values for total distance, peak and average speed, and peak acceleration and deceleration for each period. These variables were exported into an Excel spreadsheet for further analysis. Additionally, data was categorised into the following velocity bands; low-speed running (<3 $m.s^{-1}$), moderate-speed running (3-5 $m.s^{-1}$) and high-speed running (>5 $m.s^{-1}$). For each velocity band, the accumulated distance and number of efforts was recorded. Subsequently, the percentage of total distance covered in each velocity band was calculated for each period. For acceleration and deceleration, the number of efforts (>1.46 $m.s^{-2}$ and < -1.46 $m.s^{-2}$) was recorded. As well as these movement variables, the value for horizontal dilution of precision (HDoP) was extracted for all playing periods. The HDoP is a derived error term, which is dependent upon the number of satellites being used and their geometric distribution. A lower HDoP value indicates a better positional fix accuracy; the maximum value of 50 indicates the position fix is entirely unreliable.[6] The software did not provide output for an absolute count of number of satellites above 13, and therefore HDoP was the primary variable used to describe positional measurement precision.



*Statistical Analysis*

The Statistical Package for Social Sciences (version 22.0) and Microsoft Excel (2016) were used for statistical calculations. One-way analysis of variance (ANOVA) was used to examine differences in the selected variables for the inter-unit reliability of GNSS devices in Part 1, and for the inter-device differences between GNSS and GPS devices in Parts 1 and 2. Significance was set at $P < 0.05$. In addition, inter-unit reliability of the GNSS devices was assessed using the typical error (TE), expressed as a coefficient of variation (CV). For the current study, a CV of <5% was considered acceptable.[20] An intra-class correlation coefficient (ICC) was also calculated for the inter-unit GNSS reliability comparison. The ICC was categorised as poor (<0.4), fair to good (0.4-0.75) and excellent (>0.75).[21] For the current study, only excellent values were considered acceptable. Effect sizes (*d*) ± 95% confidence intervals (CI) were calculated to examine the magnitude of the mean difference between the units, in both the inter-device difference and inter-unit reliability trials. The *d* was categorised as trivial (<0.2), small (0.2-0.6), moderate (>0.6-1.2), large (>1.2-2.0) or very large (>2.0).[22] Confidence intervals were set with 95% precision of estimation. When the 95% confidence interval concurrently crossed the positive and negative thresholds for the smallest meaningful change or difference (0.2 x between-subject SD), the effect was deemed unclear.

## Results

*Part 1: Simulated Game Circuit*

Table 1 presents the values for measured and derived variables from the SGC.

*GNSS and GPS Inter-device Differences:* The GNSS device recorded more low-speed distance (*P* = 0.037, *d* = 0.46 ± 0.44) and less moderate-speed distance in absolute terms (*P* = 0.049, *d* = 0.44 ± 0.44) and as a percentage of total distance (*P* = 0.017, *d* = 0.50 ± 0.43) than the GPS device. The GNSS device also measured higher peak deceleration values (*P* = 0.001, *d* = 0.72 ± 0.42) and lower deceleration count (*P* = 0.012, *d* = 0.85 ± 0.64) than the GPS device. The mean ± SD (standard deviation) HDoP for the GNSS device (0.67 ± 0.05) was lower (*P* < 0.001, *d* = 1.85 ± 0.16) than the GPS device (0.89 ± 0.04).

*GNSS Inter-unit Reliability:* The two GNSS units were found not to differ in any variables. A CV value <5% was only found for total distance, average speed, peak speed and the absolute and percentage of total distance spent at low-speed. Excellent ICC values were found for all variables, except total distance, peak deceleration and counts for moderate speed running, accelerations and decelerations. The HDoP recorded by the two GNSS units (0.68 ± 0.06 and 0.60 ± 0.06) were different (P < 0.001, *d* = 1.14 ± 0.37).

*Part 2: Hockey Match GNSS and GPS Inter-device Differences*

Table 2 presents the values for measured and derived variables from the hockey match data. The GNSS device recorded greater values for average (*P* < 0.001, *d* = 0.52 ± 0.23) and peak speeds (*P* = 0.003, *d* = 0.36 ± 0.24), peak acceleration (*P* < 0.001, *d* = -0.67 ± 0.31), and peak deceleration (*P* < 0.001, *d* = 0.72 ± 0.27), compared to the GPS device. Further, moderate-speed absolute distance (*P* = 0.005, *d* = 0.30 ± 0.24), percentage of total distance (*P* <0.001, *d* = 0.54 ± 0.23) and count (*P* = 0.020, *d* = 0.24 ± 0.24), as well as high-speed absolute distance (*P* < 0.001, *d* = 0.38 ± 0.24), and percentage of total distance (*P* = 0.001, *d* = 0.45 ± 0.23) and count (*P* = 0.020, *d* = 0.39 ± 0.23) were higher for the GNSS device. Additionally, the GNSS device recorded lower values for low-speed running percentage of total distance (*P* <0.001, *d* = 0.83 ± 0.22) and acceleration (*P* = <0.001, *d* = 0.96 ± 0.18) and deceleration count (*P* = <0.001, *d* = 0.88 ± 0.17) than the GPS device. The mean ± SD HDoP for the GNSS device (0.63 ± 0.13) was lower (*P* < 0.001, *d* = 1.50 ± 0.16) than the GPS device (0.90 ± 0.14).



**Discussion**

This investigation demonstrates that differences exist between data collected from conventional GPS tracking devices and new GNSS-enabled devices for certain movement variables. As a result, it is important that data from the two devices is not considered interchangeably.

The HDoP values in this investigation are the primary evidence to suggest that GNSS offers improved measurement precision compared to GPS. The GNSS HDoP values were markedly lower than GPS values, suggesting GNSS was measuring with greater precision than GPS based on the underlying assumptions of improved HDoP values. [6] However, the magnitude of the difference was considerably lower than that recorded for inter-device differences. Nevertheless, the current study demonstrated that GNSS HDoP values are lower than corresponding GPS values, thus suggesting that GNSS may be able to quantify movement variables with more precision than their GPS counterparts. However, further investigation is required to fully elucidate this prospect.

For both SGC and hockey match data, the lack of difference between GPS and GNSS in terms of total distance covered may be explained by previous GPS-based studies, which found GPS to have reasonable accuracy in measuring total distance.[7,12,23] Therefore, GNSS may not provide a worthwhile improvement in measurement precision of total distance compared with GPS. Similarly, an earlier investigation found peak speeds were measured with reasonable accuracy by GPS,[7] and this could explain the lack of inter-device difference in SGC values for this variable; however, such findings are disputed in a more recent investigation in which GPS measures of peak speeds were found to be lower in validity.[12] These findings may explain the inter-device differences in peak speed during hockey matches, suggesting GNSS may be able to more precisely measure peak speed than GPS. Additionally, inter-device differences for average speed during hockey matches indicates that GNSS may measure speed with more precision than conventional GPS.

The examination of speed zone data highlights several differences between GPS and GNSS values. However, SGC and hockey match data each exhibit different findings. For low-speed running distance, the inter-device differences found in the SGC were not evident in the hockey matches, and similarly, inter-device differences in the SGC moderate-speed running variables were contrasted with trends in the hockey match data. In general, based on the differences found in both movement data and differential HDoP values, SGC data suggests that GNSS may not offer large improvements in measurement precision compared with GPS. However, it is possible that the movement in the SGC was neither erratic enough, nor performed over a sufficient distance and range of movement speeds, to expose differences between the devices. Numerous inter-device differences found in the hockey match data suggest this may be the case, with the data differentially distributed between the three speed zones. These findings however, are not fundamentally surprising if the movement demands of the two activities is considered. While the SGC is designed to replicate typical team sport movement patterns, each lap follows a predetermined course, with a relatively limited number of changes in direction and speed, and an average length of each period being <1 min. In comparison, hockey match periods lasted on average 7.6 min, and movements occurred in an unconstrained game setting. Combining these two factors, the hockey data exhibits a greater number of changes in speed and direction per period compared with SGC data, and these movements likely occurred at higher speeds. It has been well documented that high speeds,[7,8,11] accelerations[14] and changes in direction[13,24] decrease the accuracy of conventional GPS to assess distance, and consequently derived measures of velocity and acceleration as well. It has also been shown that high rates of change in velocity reduce the validity and reliability of the GPS unit evaluated in the current study to assess instantaneous velocity in comparison to a laser.[25] Together, these factors may potentially explain the inter-device differences demonstrated in the current study.

Unsurprisingly, when acceleration variables were examined, numerous inter-device differences were found. Similar to speed zone data, there were few differences for SGC data, while the hockey data displayed inter-device differences for all acceleration variables measured. However, in contrast to speed zone variables, inter-device differences for acceleration variables displayed the same directionality for both SGC and hockey match data; that is, GNSS recorded higher values for peak acceleration and deceleration, and lower acceleration count values where inter-device differences were found. As stated previously, the hockey match periods included a number of accelerations, changes in direction and high-speed efforts, therefore it is expected that the accuracy of GPS is somewhat reduced. Lower acceleration counts by GNSS may possibly be explained by these devices being able to more precisely quantify accelerations than GPS. The overall low number of accelerations in the present study may be due to the minimum effort duration (0.6 s) adopted here. Recent research demonstrated that changes in minimum effort duration criteria can have a substantial impact on the number of efforts detected.[19] Future research should determine an appropriate minimum effort duration for accelerations based on biomechanical and data sampling considerations.

In addition to inter-device differences between GPS and GNSS, inter-unit reliability of GNSS was assessed. Consistent with work using GPS,[7] the current study found GNSS reported an acceptable CV for total distance and peak speed. Of note, the ICC for total distance was reported as being poor. Nevertheless, the reported CV indicates marginal improvements when compared with previously reported CV for GPS variables.[7,24] Acceptable CV values were also reported for peak speed, and both distance and percentage of low-speed running. Both moderate and high-speed running zones exhibited a CV >5%, which were higher than found with low-speed running. This is consistent with previous GPS studies showing that increases in running speed decrease the reliability of devices.[7,8,12] Therefore, despite improvements in technology, GNSS is still not able to measure high-speed running variables reliably. Additionally, the GNSS was found to be extremely unreliable in measuring accelerations, producing a CV of >100% while decelerations produced a very large CV of >50%. However, this is not completely surprising, as accelerations have previously shown low reliability in GPS data.[14]

While inter-unit reliability of GNSS units was measured, intra-unit reliability was unable to be determined here. Future research is recommended in this regard, due to the high importance of tracking within-athlete changes in sport. In addition, future research should examine the accuracy of GNSS directly against gold-standard, criterion measures of distance, speed and acceleration. Although the GPS and GNSS units were not alternated between front and back pockets of the harness between trials or matches to ensure consistency, this may have introduced bias with respect to signal interference.

**Practical Applications**

This investigation provides an insight into recent developments in athlete tracking technology. Compared with conventional GPS, GNSS potentially offers small improvements in inter-unit reliability, and potential improvements in movement tracking precision. However, this idea is based on the underlying assumption of improved HDoP values alone, since GNSS was not compared against a criterion measure in the current study. Regardless, GNSS is potentially more reliable and might be preferred over GPS when measuring total distance, peak and average speed, and low-speed running variables. Of note, GNSS remains unreliable when measuring higher-speed running and acceleration variables, and therefore, care should be taken when interpreting these results. Perhaps most importantly, however, it should be noted that data from the two devices is not interchangeable.

## Conclusions

Limitations of GPS player tracking devices have led to on-going technological developments, which have recently culminated in GNSS-enabled devices. In comparing variables measured during SGC trials and hockey matches between the new GNSS and existing GPS devices, numerous inter-device differences were found. These findings suggest GNSS has the potential to measure movement patterns with more precision, based on lower recorded HDoP values for GNSS compared with GPS. In addition to this potential improvement in precision, GNSS was found to have reasonable levels of inter-unit reliability for most measures, except higher-speed and acceleration variables.

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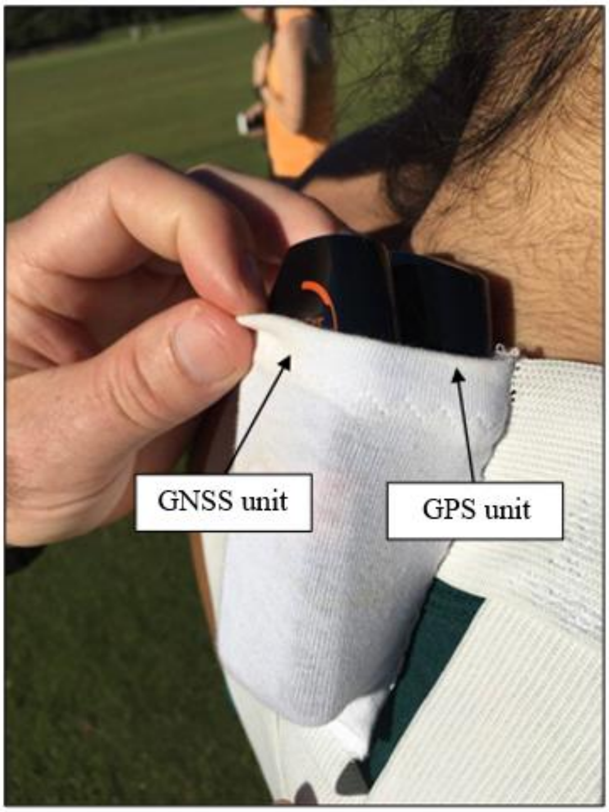


**Figure 1.** Custom-designed harness to carry two tracking units

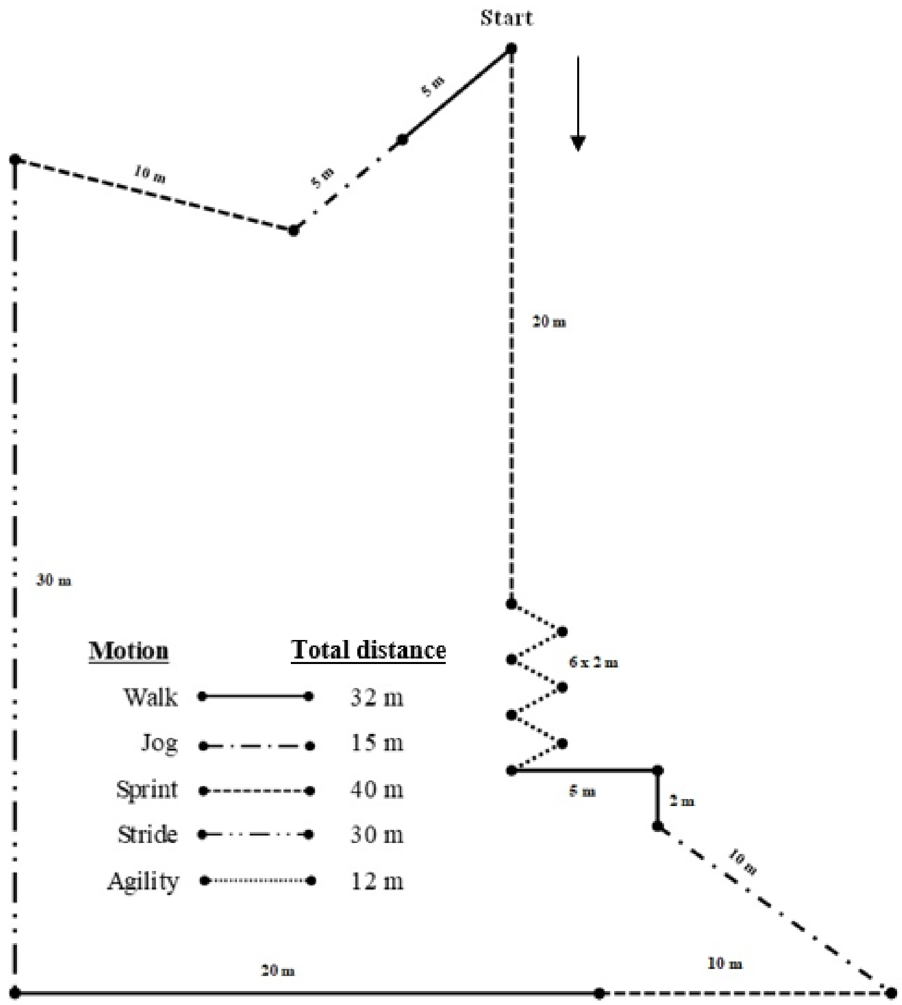


**Figure 2.** Modified Simulated Game Circuit: Adapted from Bishop, Spencer, Duffield & Lawrence (2001)

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**Table 1.** Inter-device and inter-unit comparisons in simulated game circuit data. Data presented as mean ± SD.

| | **Inter-device differences (n=40)** | | | | **Inter-unit reliability (n=40)** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | GNSS | GPS | *P* | ES ± 95% CI | GNSS 1 | GNSS 2 | *P* | ES ± 95% CI | TE | CV (%) | ICC |
| **Totals** | | | | | | | | | | | |
| Total distance (m) | 129 ± 5 | 127 ± 3 | 0.076 | 0.38 ± 0.44 | 129 ± 3 | 130 ± 2 | 0.057 | 0.43 ± 0.44 | 2.77 | 2.1 | 0.20 |
| Average speed ($m.s^{-1}$) | 2.2 ± 0.2 | 2.2 ± 0.2 | 0.407 | 0.16 ± 0.45 | 2.2 ± 0.2 | 2.2 ± 0.2 | 0.627 | 0.13 ± 0.45 | 0.04 | 1.9 | 0.95 |
| Peak speed ($m.s^{-1}$) | 5.1 ± 0.8 | 5.0 ± 0.8 | 0.644 | 0.10 ± 0.45 | 5.1 ± 0.8 | 5.0 ± 0.8 | 0.763 | 0.07 ± 0.45 | 0.09 | 1.8 | 0.99 |
| Peak acceleration ($m.s^{-2}$) | 6.26 ± 1.76 | 6.25 ± 1.61 | 0.976 | 0.02 ± 0.47 | 7.01 ± 1.72 | 6.88 ± 1.84 | 0.757 | 0.08 ± 0.45 | 0.71 | 10.2 | 0.82 |
| Peak deceleration ($m.s^{-2}$) | -5.71 ± 1.49 | -4.70 ± 1.19 | 0.001 | 0.72 ± 0.42 | -5.89 ± 1.52 | -5.82 ± 1.54 | 0.850 | 0.04 ± 0.45 | 0.72 | 12.3 | 0.71 |
| **Velocity bands** | | | | | | | | | | | |
| < 3 $m.s^{-1}$ | | | | | | | | | | | |
| Distance (m) | 81 ± 12 | 75 ± 13 | 0.037 | 0.46 ± 0.44 | 78 ± 11 | 76 ± 10 | 0.250 | 0.24 ± 0.44 | 3.17 | 4.1 | 0.96 |
| % of total distance | 63 ± 10 | 59 ± 10 | 0.077 | 0.38 ± 0.44 | 61 ± 9 | 58 ± 8 | 0.133 | 0.30 ± 0.44 | 2.81 | 4.7 | 0.92 |
| 3 to 5 $m.s^{-1}$ | | | | | | | | | | | |
| Distance (m) | 43 ± 12 | 48 ± 10 | 0.049 | 0.44 ± 0.44 | 46 ± 12 | 50 ± 10 | 0.076 | 0.39 ± 0.44 | 4.51 | 9.4 | 0.86 |
| Count | 4.0 ± 0.7 | 4.1 ± 0.6 | 0.498 | 0.18 ± 0.45 | 4.3 ± 0.7 | 4.2 ± 0.6 | 0.867 | 0.01 ± 0.45 | 0.44 | 10.3 | 0.42 |
| % of total distance | 33 ± 9 | 38 ± 8 | 0.017 | 0.50 ± 0.43 | 36 ± 9 | 39 ± 7 | 0.096 | 0.37 ± 0.44 | 3.02 | 8.1 | 0.90 |
| >5 $m.s^{-1}$ | | | | | | | | | | | |
| Distance (m) | 12 ± 3 | 10 ± 4 | 0.201 | 0.52 ± 0.73 | 11 ± 4 | 11 ± 4 | 0.678 | 0.20 ± 0.73 | 1.50 | 13.5 | 0.90 |
| Count | 1.0 ± 0 | 0.8 ± 0.4 | 0.073 | 0.53 ± 0.78 | 1.1 ± 0.3 | 1.0 ± 0.4 | 0.576 | 0.32 ± 0.75 | 0.18 | 17.1 | 1.00 |

| | **Inter-device differences (n=40)** | | | | **Inter-unit reliability (n=40)** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | GNSS | GPS | *P* | ES ± 95% CI | GNSS 1 | GNSS 2 | *P* | ES ± 95% CI | TE | CV (%) | ICC |
| % of total distance | 4 ± 5 | 3 ± 5 | 0.677 | 0.08 ± 0.45 | 4 ± 5 | 3 ± 5 | 0.830 | 0.23 ± 0.73 | 0.75 | 21.6 | 0.99 |
| **Acceleration count >1.46 m.s$^{-2}$** | 0.7 ± 0.6 | 0.6 ± 0.5 | 0.341 | 0.31 ± 0.66 | 1.1 ± 0.8 | 0.3 ± 0.5 | 0.180 | 0.52 ± 0.80 | 0.79 | 118.2 | -0.53 |
| **Deceleration count < -1.46 m.s$^{-2}$** | 0.5 ± 0.7 | 1.0 ± 0.6 | 0.012 | 0.85 ± 0.64 | 0.8 ± 0.6 | 0.9 ± 0.7 | 0.744 | 0.11 ± 0.70 | 0.59 | 67.1 | 0.18 |

GNSS: Global Navigation Satellite System; GPS: Global Positioning System; ES: effect size CI: confidence interval; TE: typical error; CV: coefficient of variation; ICC: intraclass correlation coefficient

**Table 2.** Inter-device comparisons in hockey match data (n=136). Data presented as mean ± SD.

| | GNSS | GPS | *P* | ES ± 95% CI |
|---|---|---|---|---|
| **Totals** | | | | |
| Total distance (m) | 997 ± 533 | 925 ± 499 | 0.252 | 0.12 ± 0.24 |
| Average speed ($m.s^{-1}$) | 2.2 ± 0.3 | 2.0 ± 0.3 | <0.001 | 0.52 ± 0.23 |
| Peak speed ($m.s^{-1}$) | 7.1 ± 0.7 | 6.9 ± 0.7 | 0.003 | 0.36 ± 0.24 |
| Peak acceleration ($m.s^{-2}$) | 7.96 ± 1.23 | 7.02 ±1.40 | <0.001 | 0.67 ± 0.31 |
| Peak deceleration ($m.s^{-2}$) | -7.79 ± 1.29 | -6.70 ± 1.50 | <0.001 | 0.72 ± 0.27 |
| **Velocity bands** | | | | |
| < 3 $m.s^{-1}$ | | | | |
| Distance (m) | 507 ± 262 | 535 ± 283 | 0.392 | 0.08 ± 0.24 |
| % of total distance | 51 ± 7 | 58 ± 8 | <0.001 | 0.83 ± 0.22 |
| 3 to 5 $m.s^{-1}$ | | | | |
| Distance (m) | 364 ± 225 | 294 ± 185 | 0.005 | 0.30 ± 0.24 |
| Count | 24.5 ± 13.9 | 20.8 ± 12.0 | 0.020 | 0.24 ± 0.24 |
| % of total distance | 36 ± 7 | 31 ± 7 | <0.001 | 0.54 ± 0.23 |
| >5 $m.s^{-1}$ | | | | |
| Distance (m) | 125 ± 73 | 96 ± 61 | <0.001 | 0.38 ± 0.24 |
| Count | 6.3 ± 3.6 | 5.1 ± 3.2 | 0.002 | 0.39 ± 0.23 |
| % of total distance | 13 ± 6 | 11 ± 5 | 0.001 | 0.45 ± 0.23 |
| **Acceleration count >1.46 $m.s^{-2}$** | 0.7 ± 1.0 | 3.3 ± 2.6 | <0.001 | 0.96 ± 0.18 |
| **Deceleration count < -1.46 $m.s^{-2}$** | 1.2 ± 1.2 | 3.4 ± 2.6 | <0.001 | 0.88 ± 0.17 |

GNSS: Global Navigation Satellite System; GPS: Global Positioning System; ES: effect size; CI: confidence interval