# QUANTIFYING VALIDITY AND RELIABILITY OF GPS DERIVED DISTANCES DURING SIMULATED TENNIS MOVEMENTS

Edoardo Tessaro

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Jay H. Williams, Chair

David P. Tegarden

Kevin P. Davy

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**ABSTRACT**

Tennis is a competitive sport attracting millions of players and fans worldwide. During a competition, the physical component crucially affects the final result of a match. In field sports such as soccer physical demand data are collected using the global positioning system (GPS). There is question regarding the validity and reliability of using GPS technology for court sports such as tennis. The purpose of this study is to determine the validity and reliability of GPS to determine distances covered during simulated tennis movements. This was done by comparing GPS recorded distances to distances determined with a calibrated trundle wheel. Two SPI HPU units were attached to the wheel Four different trials were performed to assess accuracy and reliability: distance trial (DIST), shuttle run trial (SHUT), change of direction trial (COD) and random movement trial (RAND). The latter three trials are performed on a tennis court and designed to mimic movements during a tennis match. Bland-Altman analysis showed that during all trails, there were small differences in the trundle wheel and GPS derived distances. Bias for the DIST, SHUT, COD and RAND trails were -0.02±0.10, -0.51±0.15, -0.24±0.19 and 0.28±0.20%, respectively. Root mean squared (RMS) errors for the four trials were 0.41±0.10, 1.28±0.10, 1.70±0.10 and 1.55±0.13%. Analysis of paired units showed a good reliability with mean bias and RMS errors <2%%. These results suggest that SPI HPU units are both accurate and reliable for simulated tennis movements. They can be confidently used to determine the physical demands of court sports like tennis.

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**ABSTRACT**

Wearable technology, including global positioning system (GPS) devices, are becoming increasingly popular among athletes and sports teams. These devices offer a quick and simple method of determining distances covered, movement speeds and accelerations during training and competition. Such data are then used to determine match or training load and help the athlete maximize training benefits while minimizing injury risk. However, in order for these devices to be successfully used, their validity and reliability must be determined. GPS has been shown to be valid and reliable for field based sports, like soccer, but not for court based sports, such as tennis. In this study, the GPSports SPI HPU unit was found to be both valid and reliable for simulated tennis movements. The error between the unit distances and distances determined by a running wheel were less than 6% and typically within 2%. The results of this study indicate that the SPI HPU devices can be used to determine work load during tennis. Coaches and trainers can be confident that the data generated by these units are both reliable and valid.

# ACKNOWLEDGEMENTS

Today is the Day; writing this note is the last touch on my thesis. I would love to dedicate this page to all the people who helped and "carried" me during these two amazing years.

First, I must express my very profound gratitude to my family who gave me the possibility to have such a tremendous experience; they have always supported the decisions I had taken during the completion of my student's career; I know they would love to be here for my defense's day and even if they are not with me in this moment, I know they are proud of what I achieved so far.

"*Grazie di tutto! dal profondo del mio cuore. Vi voglio un mondo di bene*"

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# CHAPTER 1

# INTRODUCTION

## Statement to the Problem

To date, there is considerable question regarding the accuracy or validity and reliability of using GPS technology to determine the physical demands of tennis. Several studies have been conducted which compare GPS derived distances covered by players with criterion distances. These studies typically compare the distance covered by an athlete moving along a criterion pathway to that recorded by the GPS unit. This approach can be problematic if the athlete does not follow the criterion pathway accurately. For exa mple, the distance of the inside lane of a 400m running track is measured along a line 0.3m outside of the inside lane line. When an athlete's path wavers during running in this lane, the distance traveled by the GPS unit will vary. In this case, errors in distance between the GPS unit and the criterion distance reflect an inability of the athlete to accurately follow the designated course. Also, in sports such as tennis, movements of the torso are not always reflected in movements of the feet. For example, lateral swaying before receiving a serve may cause the GPS unit to record "distance" while the player's feet have not moved. Further, reaching for a shot by lateral leaning or forward bending can result in the torso moving a greater distance than the feet. As with track running, variability between the GPS unit and player distances can be introduced.

No study has compared distances covered by the GPS units to a "gold standard" measurement such as a calibrated trundle wheel. This is particularly true for the new 15 Hz GPS units and the GPSports SPI HPU device. This approach would remove much of the variability induced by trunk movements that are independent of foot movements. In addition, the validity and reliability of GPS technology has generally been determined using correlation approaches and not been evaluated using the more appropriate Bland-Altman analysis (Scott et al., 2015).

## Research Question

Is the SPI HPU GPS Sport unit a valid and reliable tool to measure distances during simulated tennis movements?

## Specific Aims

***Aim 1***: To determine the validity of the SPI HPU GPS units to determine distances covered during simulated tennis movements. This was done by comparing GPS recorded distances to distances determined with a calibrated trundle wheel using Bland-Altman analysis.

***Aim 2:*** To determine the reliability of the SPI HPU GPS units to determine distances covered during simulated tennis movements. Reliability was determined by comparing GPS distances between paired units simultaneously following the same path.

## Operational Definitions

***Validity:*** The extent to which an instrument measures what it is designed to measure. For this study, validity is the agreement between distances simultaneously determined by GPS units and the trundle wheel.

***Reliability:*** The extent to which similar instruments are consistent in their measurements. In this study, reliability is the agreement in recorded distances by two GPS units simultaneously attached to the trundle wheel.

***Bias:*** Determined from Bland-Altman analysis. It is the average difference between distances simultaneously measured by the trundle wheel and GPS units.

***LOA (Limits of Agreement):*** The LOA represents the 95% confidence interval of the mean difference between measures of the same variable ($\overline{X}$ ± 1.98*SD).

***Root Mean Square (RMS) Error:*** The RMS error is the root of the squared differences between two measures of the same variable:

$$\sum_{i=1}^{n} \sqrt[2]{(Trundle\ Wheel_i -\ GPS\ Unit_i)^2}$$

**Limitations**

The following limitations were intrinsic in this study:

- Trundle Wheel Movements: During the trials, the trundle wheel may have executed backward movements. This would result in distance being subtracted by the counter and underestimate the actual distance travelled by the wheel.
- Trundle Wheel Calibration: During use, calibration of the trundle wheel could vary, altering the recorded distances.
- GPS Unit Placement: The two SPI HPU GPS Units were placed one above each other, 7cm apart.
- GPS Unit Movement: Movement of the trundle wheel handle could cause medio-lateral and anterio-posterior movement of the GPS units that may not be reflected in wheel movements.
- Weather Conditions: Cloud cover and overcast sky can degrade GPS performance. All experiments were conducted on days with no or minimal cloud cover.
- Environmental Conditions: Buildings and trees can affect GPS signal quality. All experiments were conducted on tennis courts or a running track that is free of obstructions.

- Dilution of Precision (DOP): DOP reflects to orientation of GPS satellites with respect to the GPS unit. SPI HPU GPSports units do not generate DOP values.
- GPS distances were computed by proprietary software (TeamAMS) provided by GPSports.

**Delimitations:**

The following delimitations were set by the investigator:

- Criterion paths and distances were set by the investigator to simulate tennis movements.
- The GPSports SHI HPU GPS units were selected for use as was the Meter-Man MK45M trundle wheel.
- A total of 20 GPS units were utilized in the study.
- A hard surface tennis court was used in the study.

# CHAPTER 2

# LITERATURE REVIEW

## Introduction

Tennis is a very complex sport where, in order to become a successful player, one needs to develop different performance attributes. There are two main components in this sport: psychological and physiological. While the psychological abilities of a tennis player are the hardest part to train and develop, the physiological components are something that has been reported in several research papers. As a result, there are now some guidelines on how a tennis player must be trained to have the best performance possible during an official match. The game of tennis places unique demands on its players; tennis is an open loop sport where players have to adjust their strokes in any occasion (except for serve, the only close loop action), thus, they need to develop a different set of abilities and capacities that allow them to perform at their best. Over the past twentyfive years, tennis has radically changed: players are stronger, faster and fitter and the physical component is what can make a huge difference during a match and a tournament. Specific physical training that is well planned and implemented has become a key factor in being successful on the court or not. It is fundamental for coaches and trainers to be aware of these changes, recognizing what is important to implement during the preparation with the goal of optimizing fitness gains.

## Tennis Match Characteristics

There are many variables that can influence a tennis match. Tennis is actually one of the few sports without a finite time of duration. A match can last for an hour or, in some circumstances, more than three hours. Thus, a tennis player must be able to sprint, stop and recover really quickly and, at the same time, has to be fit enough to maintain a peak physical activity level throughout the whole match.

A single point in tennis usually lasts in between 6 – 10 seconds, followed by a short recovery (10 – 20 sec) with longer periods of rest during the changeover (90 – 120 sec). In his study, Kovacs (2007) suggested that high level matches have a work to rest ratio of 1:2 to 1:5 Points have an average length of three seconds on some of the faster surfaces (grass, carpet, and indoor) and close to 15 seconds on slower (clay). Figure 1, taken from Kovacs (2007) shows the average times of single points as reported by several studies. As can be seen, the time can vary considerably but on average a point lasts about 8 seconds.

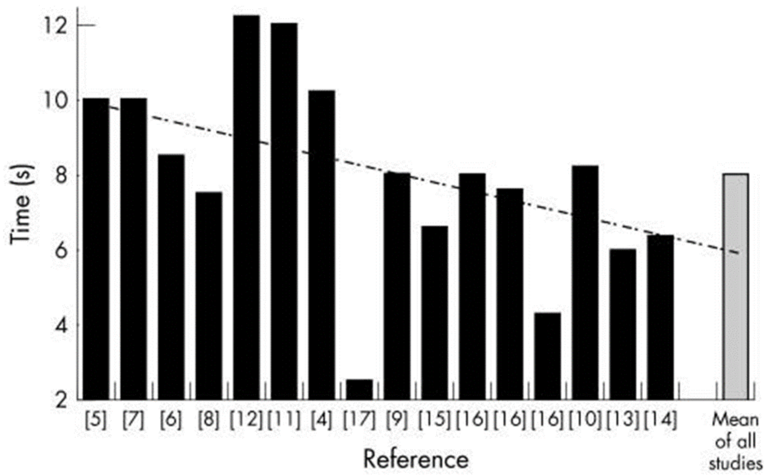



**Figure 1.** Average time in seconds per point during competitive tennis. From Kovacs (2007).

There are several important variables that can influence the duration of a tennis match: the surface of the court and the playing style. In Table 1, Schonborn (1999) shows how the average duration of a point is less on grass compared to both hard and clay courts. Unfortunately, there are few studies about tennis played on grass court because this surface is not common to most matches and tournaments and there are few opportunities to monitor player movements during grass court matches.

| Length | Men | Women |
|---|---|---|
| Average duration of a point on grass | 2.7s | 5.4s |
| Average duration of a point on hard | 6.5s | 6.6s |
| Average duration of a point on clay | 8.3s | 10.7s |
| Rest interval between points | 25.6s | 19.4s |

**Table 1.** Duration of a point and average rest interval between the points. From Schonborn (1999).

As shown in Table 1, there is a substantial and relevant difference between men and women in terms of point duration and rest period. Durations of points played by women are generally longer and the rest interval between points is shorter. The women's game tends to lasts more than men's because the velocity of each shot is "slower". Also, aces and ground stroke winners are less common in the women's game (Schonborn, 1999). These types of shots can markedly reduce the duration of a point.

Another parameter to take in consideration when evaluating the physiological demands of a tennis match is the player's game style. Bernardi et al. (1998) identified three different styles: attacking, whole court and baseline player. From their study it is clear that attacking players (players who prefer to go to the net) have shorter rallies or points (4.8s) than baseliners (players who prefer stay on the back) who average the longest rallies (15.7s). In this study, the researchers also found that the percentage of the playing time with respect to the total time of the match is approximately 21% for the attacking players, 28.6% for whole court players, and 38.5% for baseline players. Thus, the physical demand is influenced by playing styles and strokes used which ultimately how a long a player spends on the court in play. As each player has his own favorite style, coaches must be able to recognize which one is the best for his capacities and, then, program an optimal preparation to be more successful during a match.

## Physical Components

A tennis match is characterized by quick starts and stops, with many accelerations and decelerations and the involvement of many motor skills (e.g. power, speed and duration). From a physiological point of view, tennis is considered an intermittent sport, combining low – high intensity activity periods. The ATP – creatine phosphate and glycolytic systems are the main producer of energy over the oxidative system, with a major emphasis on glycolysis and glycogenolysis (Kovacs, 2007). However, players, considering the fact that a tennis match is never predictable from a duration point of view, must be aerobically fit enough to last for more than three hours. In fact, Banzer et al. (2009) states that focusing on incomplete physiological recovery between points, as well as between matches and tournaments, high cardiorespiratory capacity might be crucial, in order to avoid or postpone 'fatigue'.

In a review conducted by Kovacs (2007) two parameters have been analyzed: $VO_2max$ (marker of aerobic and cardiorespiratory fitness), and exercising heart rate (HR). $VO_2max$ is a parameter that measures the maximal oxygen consumption per minute. In tennis, as shown in Table 2, the average $VO_2max$ range is between 44ml/kg/min and 69ml/kg/min. These values demonstrate a good aerobic status but not as great as aerobic sports men like marathon runners or cyclists. Actually, even if a match can last for more than three hours, the effective time of playing is usually not over the 40% of the total time. Thus, the aerobic metabolism is not used as much as during a long distance sport. Moreover, Kovacs (2007) suggests that it is fascinating to understand that players who were considered to be aggressive (attacking players) had lower hear rates (HR) and lower $VO_2$ levels during a match than baseline players. A player's playing style is definitely a factor to take in consideration when evaluating training and physical performance. Every player has different tennis skills, and a coach need to plan practices that can help him to develop a good physiological level for how he will perform on the court.

| Study (year) | No. | $VO_2max$ (mL/kg/min) |
|---|---|---|
| Bergeron et al. (1991) | 10 | 58.5 ± 9.4 |
| Elliot et al. (1985) | 8 | 65.9 ± 6.3 |
| Bernardi et al. (1998) | 7 | 65 ± 4 |
| Christmass et al. (1994) | 8 | 54.25 ±1.9 |
| Smekal et al. (2001) | 20 | 57.3 ± 5.1 |
| Faff et al. (2000) | 72 | 62.3 ±4.8 |

**Table 2.** Comparison of maximal oxygen consumption ($VO_2max$) values in elite tennis players.

Heart Rate (HR) is one of the most common variables monitored and is useful when determining the physiological demands placed on a player. Since HR is a response to the movements executed during the match, it is considered an "internal" load (Halson, 2014). Kovacs (2006) states that during match play, the average HR of a collegiate tennis player is 144.6 ± 13.2 beats per minute. Kovacs (2006) also suggests that HR remains to a moderate level throughout the whole match, despite tennis is an intermittent sport with quite long recovery periods. Table 3 shows the percentage of maximal heart rate ($\%HR_{max}$) collected in several studies and the average is 86.2% ± 1.0%. However, HR by itself, cannot be used to establish tennis metabolism values. Maximal HR is determined by both age and training. And $\%HR_{max}$ is a function of fitness level. Exercising HR is also a parameter that can be influenced by many factors (such as weather, daily physical conditions, opponent skill, playing style). Thus, in order to have a full understanding of the physiological load in tennis, it is better to have other data to compare with it. For example, both internal and external loads (Halson, 2014)

| Study (year) | No. | Level | %$HR_{max}$ |
|---|---|---|---|
| Christmass et al. (1995) | 8 | Regional | 86 |
| Bernardi et al. (1998) | 7 | Regional | 63.6–82.5 |
| Therminarias et al. (1991) | 19 | Elite | 87 |
| Bergeron et al. (1991) | 10 | Elite | 86.2 |
| Elliott et al. (1985) | 8 | Elite | 79 |

**Table 3.** Mean %$HR_{max}$ in male tennis players.

As emphasized before, a player has to be able to adjust his game style and his tactic in order to have success at the same time on slower and faster surfaces. The type of surface a player is competing on plays a key role on physical demands as the surface represents one of the most important variables to take in consideration when determining the physiological load in tennis.

Clay court is considered the slowest surface because it slows down the speed of the ball and causes a high bounce of the ball. Moreover, in order to move correctly, players often slide to reach the ball. Due to these characteristics, clay reduces the speed of the whole game, and players have much more time to return each shot. Players who prefer to give a lot of spin to the ball and who prefer run side to side on the court, have the major benefits on playing on this surface. On the other hand, hard courts are usually made from asphalt or concrete and are the most commonly available courts. There are different types of hard courts but, usually, they provide a surface where the ball travels at a speed faster than clay, the bounce of the ball is very predictable as the surface is flat and easy to maintain. Players who are successful playing on hard surfaces are usually "aggressive" on the court. Thus, serve and volley or players with big shoots have a higher chance to win on hard courts. Given this, one would expect a clay court match to be characterized by longer movements and greater distance covered whereas a hard court match would be characterized by short movements, more changes in direction and less distance covered. As a result, HR responses could vary between play on these surfaces.

In a more specific study it is better explained how playing on hard court is less expensive from a metabolic point of view. Pereira et al. (2016) noted that total distance travelled and high intensity running distances were 24 and 30% greater on clay court than hard court matches.

| **Velocity Range** | **Clay** | **Hard** |
|---|---|---|
| 0 – 5.5 km/h | 2054.5 ± 139.9 m | 1651.3 ± 220.9 m* |
| 5.5 – 7 km/h | 244.6 ± 83.3 m | 156.6 ± 68.5 m* |
| 7 – 10 km/h | 211.1 ± 38.9 m | 117.8 ± 36.3 m* |
| 10 – 15 km/h | 122.3 ± 32.6 m | 66.3 ± 18.7 m* |
| 15 – 18 km/h | 18.6 ± 13.3 m | 13.0 ± 7.9 m* |
| >18 km/h | 5.8 ± 5.8 m | 7.2 ± 9.3 m |
| Total Distance | 2656.9 ± 220.2 m | 2012.3 ± 295.8 m* |

**Table 4.** Distances covered in different velocity ranges in clay and hard courts matches (Mean ± SD, *p<.05 vs clay). From Pereira et al. (2016).

Table 4 shows how the court characteristics influence a tennis match; total distance and distance covered at different speeds are the most influenced factors. At each speed, players who are on a clay court, must cover more distance during the whole match (the only inference not clear is the one above 18km/h). This is likely ascribable to the surface because, as explained before, ball speed is slower giving much more time to players to reach the ball. This could in turn, lead to loanger rallies. Reid et al. (2013) also point out that the hard and clay courts elicit different physiological and psychological responses. Hence, these data suggests that playing on a hard court, where the ball is faster and rallies shorter, influences the physical demand required from tennis players.

## College Tennis

College tennis is controlled by the Intercollegiate Tennis Association (ITA). Matches general have the same rules as pro tournaments. However, the ITA introduced two uniques rules. First, "No Let" for men's matches. Players continue the point when the service hits the net cord but lands in the service court. Second, "No Advantage" for both men and women. When the score is 40/40, only one point is needed to win the game rather than two. ITA decided to introduce these two rules to make a college match faster and more spectacular. Another important characteristic of college tennis is that matches are played only on hard courts. This has a huge impact on the physical demand of a player because different papers showed how playing on hard courts makes matches shorter, with less rallies. Kovacs et al (2004) note that a typical point during a collegiate tennis tournament lasts 6.36s. Thus, this suggests that there is a bigger contribution of the aerobic system compared to matches played on slower surfaces. Lastly, college players often play more than one match during a day's competition. Often a doubles match is immediately followed by a singles match. Given the above rule changes by the ITA, it is likely that college match play results in different total distances covered and different heart rate responses compared to professional matches.

## Global Positioning System

The global positioning system (GPS) is a tracking system originally introduced by the American Department of Defense for military use (www.gps.gov). This system works thanks to 27 satellites spread outside the atmosphere around the earth, which send signals to the GPS receiver allowing the unit to calculate the position of the user. To record a correct position, a GPS receiver must lock onto at least 4 satellites which can give accurate information on latitude, longitude and altitude. Scott et al. (2016) emphasizes the fact that satellites signals can be affected by weather conditions such a cloud cover which can negatively affect the GPS ability to track a position. Scott et al (2016) also notes that environmental conditions such as buildings, trees, etc can interfere with the GPS signal and can reduce the number of satellites used to determine position. While the total number of satellites is a fundamental parameter for a correct position measurement, another crucial aspect is the orientation or positioning of the satellites interacting with the receiver. This value is called the Dilution of Precision (DOP). Malone et al. (2016) state that DOP value is high with poor precision when satellites are bunched together, while, on the other hand, DOP value is low with great precision when satelittes are spread out across the horizon. This DOP variable can have a value from 0 to 50, with 1-2 considered very good and <1 considered excellent condition. In an ideal scenario, one satellite would be placed right above the receiver with the others equally spread across the horizon (see Figure 2).

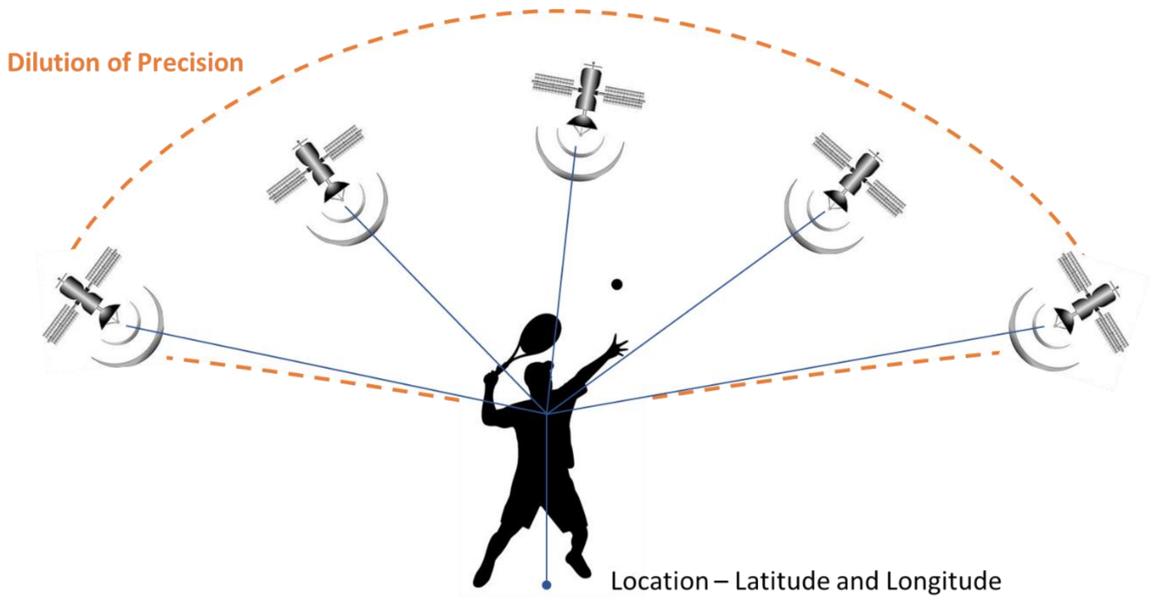



**Figure 2.** An example of GPS receiver and satellite distribution.

**GPS: A New Tool to Track Athlete Movements**

With the development of new technologies, coaches are able to have a better and more precise understanding of the physiological demands of training and competition. In the last decade, time motion analysis systems, video recording, new computer software and hardware have successfully used to increase the possibility of "creating" an athlete who can be possibly close to be considered perfect from a physical point of view. Unfortunately, these types of tracking systems are not easy to use and they have logistical problems. Thus, in the few last years, a solution for this problem, has been the introduction of trunk- mounted GPS. These units are typically small and placed in a "holder" secured to the back of the athlete. Thus, position of the athlete along with distances, velocities and accelerations can easily be recorded. Cummins et al. (2013) describe GPS as a satellite – based navigational technology that allows researchers to track movements over time in different kinds of environments. Nowadays, the successful development of this device has extended its application in different fields and sport is one of those.

GPS is even more useful if it is integrated with a tri-axial accelerometer that is able to collect data about movement in three different plans of movement (Aughey, 2011; Coutts & Duffield, 2008). Most GPS systems now utilize accelerometer data to augment or supplement the GPS signal, improving its accuracy. Thus, GPS has become the best way to track an athlete. Cummins et al. (2013) specifies that GPS can be used to quantify physical exertion and the physical demands placed on individual athletes, examine performance during competition, assess different workloads, establish training programs, and monitor changes in player physiological demands. GPS uses postion to track both distances and speed. However, it has allowed metrics to be developed that detect fatigue status, periods of high or low intensity, metabolic demand as well as differentiate physical loads between positions on within a team sport (Cummins et al, 2013). GPS has the unique ability to calculate and quantify the external training load during different practices and matches allowing a simultaneous tracking of several athletes. Along with all these factors, GPS is considered a great innovation to monitor physiological status of a player, thus, with the analysis of the data collected, it has an outstanding value to prevent or at least delay injuries.

**GPSports Technology**

GPSports is a sport technology company that is used worldwide. They provide wearable technology that is able to measure distance, speed and acceleration (via GPS), body load and impact (via accelerometry) and heart rate. These units allow coaches to monitor, collect and manage data in different sports and during different training sessions or matches. The GPSports devices are widely used in team sports because they give a better understanding of physiological demands of performance within a large space and can give more information about how to plan specific trainings. Unfortunately, the use of this technology has been limited in court-based sports such as tennis.

The GPSports system is composed of a custom designed vest which houses the unit (GPS and accelerometer) and contained a heart rate monitoring strap. The latest model (SPI HPU) contains a 15Hz GPS unit, a 100Hz-10G accelerometer and a 50Hz magnetometer. The device also utilizes a Polar HR monitor that is sampled at 100Hz. At the end of each session, data are provided that contain different variables generated by the GPSports analysis package (TeamAMS):

- ***Volume Indicators:*** distance, distance in speed zones, acceleration and deceleration count, body load and heart rate exertion.
- ***Intensity Indicators:*** speed, number of sprints, maximum speed, maximum

acceleration and maximum heart rate.

For many field based sports, these parameters have been widely reported. Much is known about distances covered, running speeds, heart rates and accelerations during sports such as soccer, rugby and Australian rules football (Cummins et al., 2013; Dellaserra et al., 2014; Gray & Jenkins, 2010).

**Validity and Reliability**

Given the wide use of GPS in the last decade, several studies have been conducted on the accuracy and the reliability of GPS devices. Being aware of the eventual error that a GPS measurement can imply is important for researchers, who have the responsibility of taking it in consideration during a study. Sports-specific GPS are manufactured to collect positional data at several frequencies (the speed at which the unit gathers data, expressed in samples per sec or Hz). Early units operated at a 1Hz sampling frequency while newer units collect data at 15Hz. It is important to note that the higher frequency units actually sample GPS position at lower frequencies, then utilize interpolation from a tri-axial accelerometer to increase sample frequency. For example, the GPSports SPI HPU unit collects GPS data at 5Hz then uses accelerometer data to interpolate that frequency to 15Hz. Many researchers agree that with higher frequency rate and accelerometer interpolation, the data collected are more precise with less errors (Aughey, 2011, Coutts & Duffield, 2008).

There have been numerous studies examining the validity and reliability of GPS for field-based sport movement distances and speeds (see Delleserra et al., 2014). Based on previous research, reliability is rated as good (<5%), moderate (5 – 10%) or poor (>10%) (Scott et al., 2016). In general, these studies show fairly good reliability and validity of lower speed, longer distance activities (Cummins et al., 2013). With shorter distances and higher speed movements, the GPS accuracy is thought to degrade. Johnston et al. (2014) and Rampinini et al. (2015) found that as speed increased the typical error of measurement using 10 and 15Hz GPS units increased from <1% to more than 15%. For example, in a recent study, Rawstorn et al (2014) asked subjects to perform change of direction and intermittent intensity tasks while wearing a 15Hz GPS device (GPSports SPI ProX). They found that accuracy degrades with rapid directional and speed changes. During curvilinear and shuttle running, the measurement biases were 2.2 and 3.0%, respectively while the limits of agreement were 1.7 and 3.4%. It is important to note that Rawstorn et al. (2014) as well as others used the track distance as the criterion measurement. Thus, any deviation from the criterion path by the subject would have resulted in excess distance travelled and be interpreted as error.

In 2010, Duffield et al. (2010) examined the accuracy of 1 and 5 Hz GPS units during simulated court-based (tennis) movements. These units were provided by two difference companies, GPSports and Catapult. In this study, players were asked to perform several fast and slow change of direction movements while positional data was collected by the GPS units and by video analysis using a VICON system as the criterion measurement. A reflective marker was placed on the GPS units and tracked by video. The advantage of this approach is that the VICON operates at 100Hz and has an error of 0.0008% (Duffield et al, 2010). They found that as the speed of movement increased, accuracy of the GPS system declined. The reported error for fast and slow movements ranged from 2 to 25%. By using the VICON system and a reflective marker placed over the GPS units, Duffield et al. (2010) eliminated any error that might be produced by errors in the subject following the criterion track and by body lean encountered during changes of direction.

Vickery et al. (2014) also used a VICON system to examine accuracy of 5, 10 and

15Hz GPS units in situations where tennis movements are involved as well as field based movements. A typical soccer field measures 110 x 70m whereas one side of a singles tennis court measures 8.23 x 6.40m. Vickery et al. (2014), using VICON as the criterion measurement, showed that 10 and 15Hz GPS units underestimated distances during 2 and 4m side to side shuttle runs by 10-14%. Underestimation of GPS distance measurements were smaller when performing longer efforts, 20 and 40m shuttle runs.

In tennis, these kinds of movements (changes of direction in a small space) are very common. Thus, researchers must consider the errors of GPS technology in this context. Another problem of GPS is that it tracks movement of the unit that do not necessarily correspond to actual distances traveld by the athlete. In tennis, there are trunk movements that are tracked by the GPS but do not reflect distances covered by the player. For instance, when a player is returning to a serve or reaching for a shot, it is not unusual to for the trunk to move more than the feet. This is not considered a movement or distance covered but as the GPS unit moves, it tracks the movement as distance covered. Thus, determining accuracy based on feet movements may introduce error. Clearly, there is a need to examine the accuracy and reliability of the GPS unit in the absence of player movements.

**Determining Accuracy and Reliability**

An important criticism of the previous studies is the statistical approach used to compare two methods of distance measurement or to assess the accuracy and reliability of a method versus a standard. The majority of studies examining GPS distance measurements utilized linear regression (Person Product-Moment correlation), intraclass correlation and/or coefficient of variation determination to assess validity (Atkinson & Neville, 1998) (Figure 3). Altman and Bland (1983) argued that these are not appropriate techniques for determining agreement or comparability between two methods. Correlation analyses determine the degree of association between two variables and do not quantify the extent of agreement (Altman & Bland, 1983; Bland & Altman, 1986). Further, while correlations can identify random errors, they do not provide information on systematic bias. Bland-Altman (1986) suggest that a more appropriate determination of agreement is to examine a plot of the difference between paired measurements versus the mean of the two methods (Figure 4). This approach, called Bland-Altman analysis yields two important variables that are related to agreement. The first is bias or the mean difference between the two methods. The second is the limits of agreement (LOA) which is the 95% confidence interval of the mean difference. In addition, the Bland-Altman plot shows whether or not the bias is consistent across a range of measurement values or if there are systematic patterns of bias (Giavarina, 2015). Giavarina (2015) further suggests that this approach can be extended by plotting the percent error between the two measurements versus their mean. This results in a relative expression of both bias and LOA. To date, no validation studies of GPS distances and speeds have used the Bland-Altman approach.

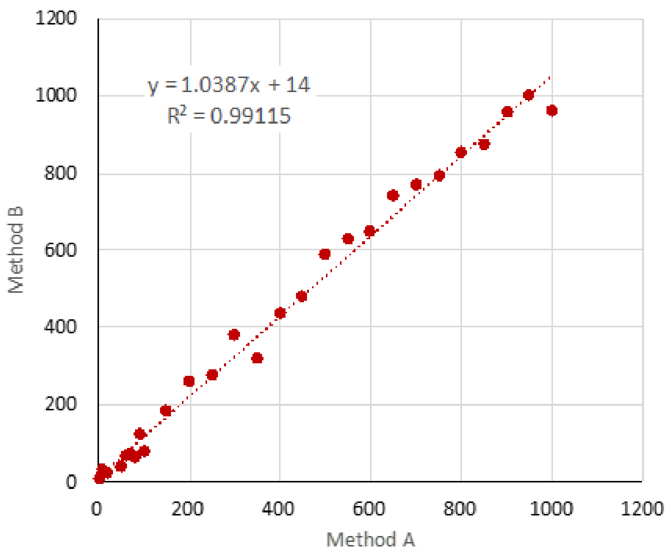



**Figure 3.** Person Product-Moment comparison of two methods used to measure the same variable. From Giavarina (2015)

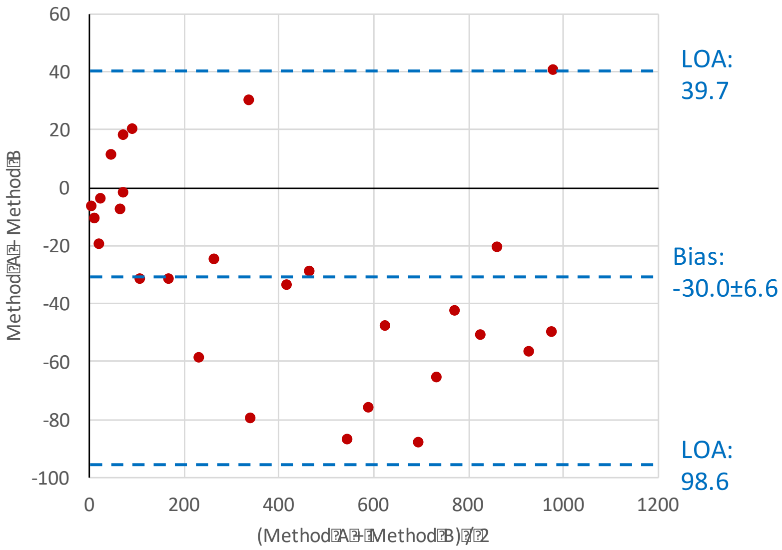



**Figure 4.** Bland – Altman comparison of two methods used to measure the same variable. From Giavarina (2015)

In order to understand the agreement between GPS measurements of distance and other measurements or a "gold standard", a Bland-Altman approach is needed. Also, establishment of a gold standard or criterion is needed. Traditionally, the gold standard distance traveled is the distance of a criterion path to be followed by an athlete. However, in many activities, athletes may waver from this path, particularly during high speed and change of direction movements. This is shown in Figure 5. During a "zig-zag" course, the criterion distance is measured between the change of direction point (typically cones placed on a field).

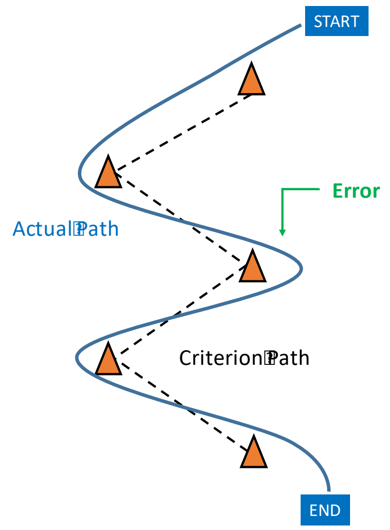



**Figure 5.** An example of an athlete running a "zig-zag" course: the dashed and red lines represent the player's path whereas the blue line represents to criterion path

However, players must run past the cone when executing a turn or they may not reach the cone. This is shown in Figure 6. The player is changing directions. While his foot reaches the criterion point (or cone), his torso does not. Depending on how the player executes the task, GPS recorded distances could vary considerably from the criterion distance.

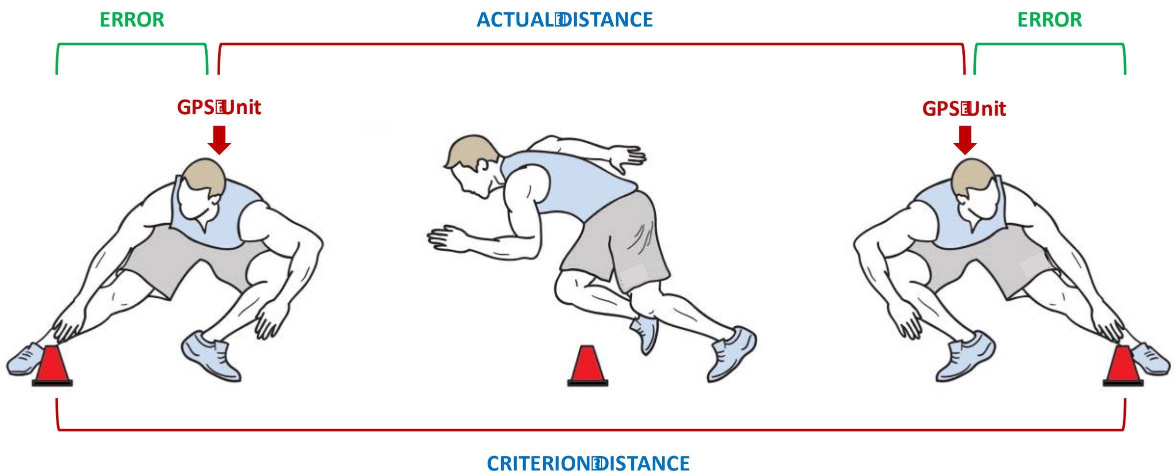



**Figure 6.** Athlete movement which can lead to a measurement error

Activities such as tennis require movements where the player's torso may move but the player's feet remain stationary. This is shown in Figure 7. As can be seen, when the two players reach for a ball, the torso moves while the feet do not. This would result in the trunk-mounted GPS unit recording distance traveled while the player's entire body did not. Thus, using player movements and criterion distances may not be the best approach to evaluating the validity of GPS derived distances.

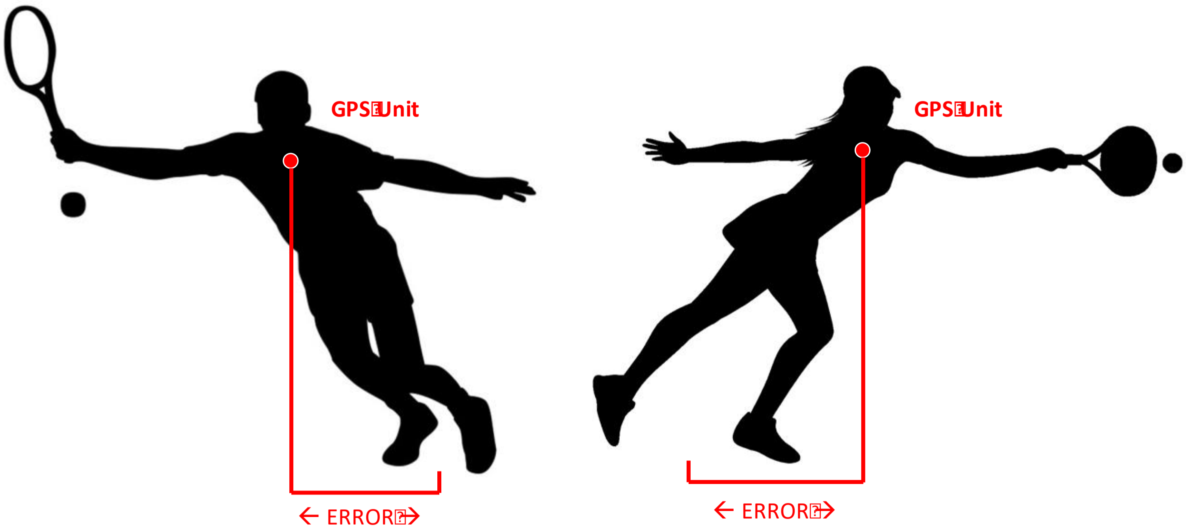



**Figure 7.** Examples of tennis movements where the GPS unit may record distance or displacement but the players' feet remain stationary.

**Summary**

Based on this review of literature, several conclusions can be drawn regarding the use of GPS in determining the physical demands of tennis:

- GPS has emerged as a standard for determining the physical demands of sport (distance, velocity and acceleration). Its use is widespread among field sports such as soccer and rugby.
- Court-based sports such as tennis require rapid bursts of activity within a confined space. This results in relatively short movements and numerous changes in direction.
- There is some concern as to the accuracy, validity and reliability of GPS to measure distances traveled during court-based sports such as tennis. Some of

this concern stems from the gold standard used to evaluate GPS data and the types of activities evaluated.

- Thus, the usefulness of GPS in monitoring the physical demands of sports such as tennis is questioned.

Given the above, future studies should be directed towards evaluating the validity and reliability of current GPS technology for use in court-based sports.

# CHAPTER 3

# METHODS

## General Methods

This study utilized 20 triaxial GPS units (SPI HPU, GPSports). These units contain a 15 Hz GPS receiver and a 100Hz, 16g accelerometer. Record positional data at 5 Hz which is then supplemented or augmented by accelerometer data to record interpolated position at 15 Hz. The triaxial accelerometer orientation is determined by a 50 Hz magnetometer (used to orient the axes of the accelerometer). Each unit measures 74mm x 42mm x 16mm and weighs 56g.

The study also used a calibrated trundle wheel (Meter-Man MK45M, Komelon). This wheel has a diameter of 363cm, a circumference of 1.141m and a resolution of 0.1m. At the beginning of each day's testing session, the trundle wheel was calibrated against a 100m distance (measured with a steel tape). A preliminary studing using this device revealed that day-to-day variation in the calibrated distance is within the resolution of the wheel (±0.1m and ±0.1%, n=6 days).

For each trial, two HPU SPI units (paired units) were secured to the handle of the wheel, directly above the axis of the wheel, 8 and 15 cm above the wheel axis and 2.5 cm lateral to the pivot point of the wheel (Figure 8). During use, the handle of the wheel rotates from vertical to approximately 20˚ from vertical. This results in a posterior displacement of the center of the upper and lower mounted GPS units of 4 and 7 cm, respectively and no lateral displacement. The paired unit arrangement allowed comparisons between the GPS units and the trundle wheel and between paired units (reliability).

**Figure 8.** Arrangement of the GPS units attached to the trundle wheel.

**Experimental Trials**

***Distance (DIST) Trial:*** The DIST trial was conducted on a 400m running track that conforms to International Association of Athletics Federations specifications. The GPS units and trundle wheel travelled along a 1600m path (four laps of a 400m track). The trial began with the wheel placed directly on the start/finish line and the distance meter reset to zero. The start time of each trial was recorded by a satellite-linked digital watch. During the DIST trial, the wheel travelled along a path approximately 0.3m from the inside of the lane. Standard running tracks are designed such that this imaginary line measures 400m. During each lap, the units travelled through 100m at alternating speeds similar to a jog, run and sprint (Figure 9). At the end of the final lap, the units were slowed and the wheel brought to a stop directly over the start/finish line. The finish time was recorded by the satellite-linked watch and the distance traveled by the wheel was recorded.

***Shuttle Run (SHUT) Trial:*** The SHUT trial was performed on a tennis court that meets International Tennis Federation specification. For this trial (Figure 10), the wheel followed an 8.2m straight line (along the baseline between the singles lines), pivoted

180˚, then returned to the starting point. In order to simulate a tennis match, this path was repeated using 5 "points" of three laps with 20 sec pause between points. The distance and number or points were used to simulate that of a singles tennis game. The pause time represents the maximal allowable time between points in an official Intercollegiate Tennis Association match. The SHUT trial had a total distance of 246.9m.

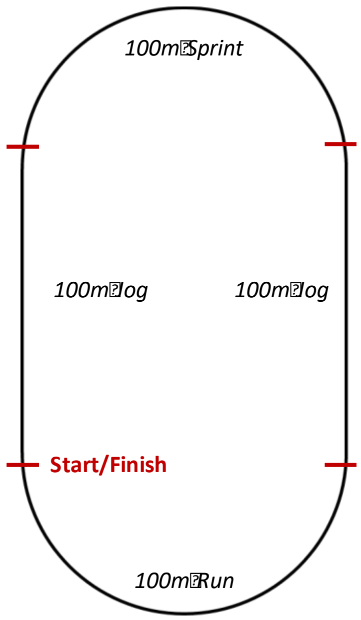



**Figure 9.** Criterion Path used for the DIST Trial

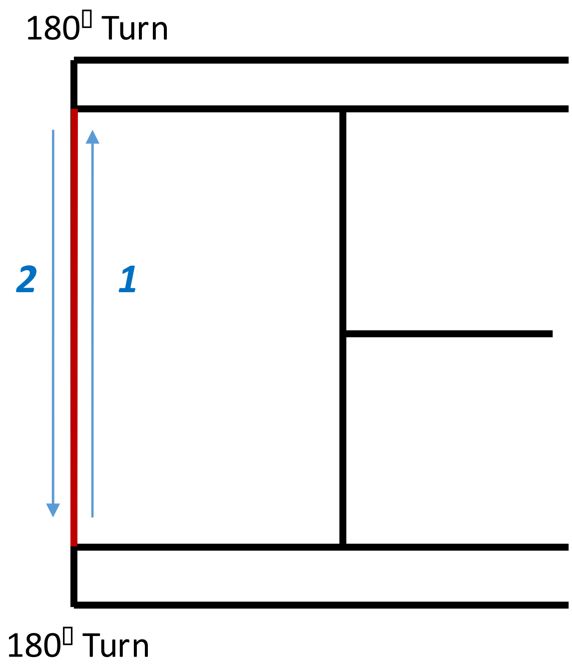



**Figure 10.** Criterion Path used for SHUT Trial

***Change of Direction (COD) Trial:*** For the COD trial, the wheel followed a course laid out on a regulation tennis court (Figure 11). The course consisted of five segments and four turns. For segment 1, the wheel was moved along the baseline between the doubles alley lines (10.8m). A 180° turn was executed and the segment 2 consisted of returning the wheel along the baseline. A 90° turn was executed and wheel moved along the doubles sideline to the service line (5.5m). The wheel was rotated 90° and followed the service line to the other doubles sideline (10.8m). For segment 5, a 153° turn was executed and the wheel moved along a straight line towards the intersection of the opposite doubles sideline and the baseline (12.1m). The second lap or point of the course began with a 153° turn and moving the wheel along the baseline (segment 1). The distance covered during a single lap of the course was 50.0m. In order to simulate a match, 5 points were executed for each COD trial with a 20s pause between points (250m, 24 turns).

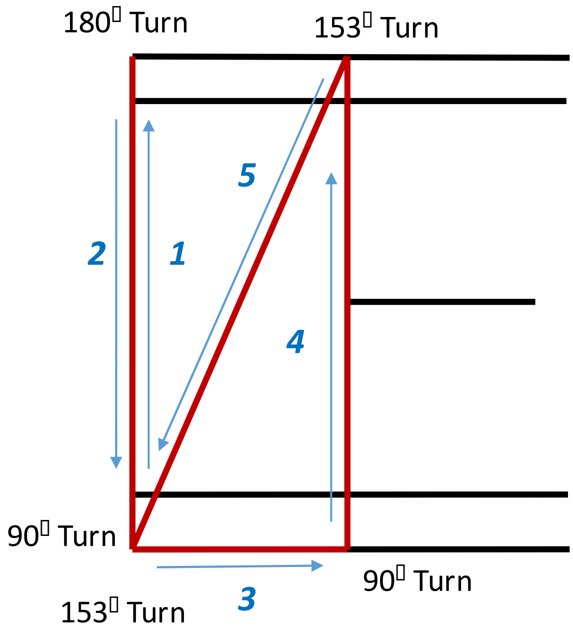



**Figure 11.** Criterion used for the COD Trial

***Random (RAND) Trial:*** The RAND Trial was performed on a tennis court which meets the International Tennis Federation specification. It consisted of 5 points of 10s of random movements within the single court, replicating movements that are common during a tennis match. At the beginning of each point, the wheel was placed directly on the middle of the baseline. In order to simulate a tennis match, this path was repeated 5 times or points with a 10s of pause between points. No criterion distance was established but 5 points covered ~135m. All movements were contained within one side of the singles court (8.23 x 11.89m). A stylized image of the RAND trial is shown in Figure 12.

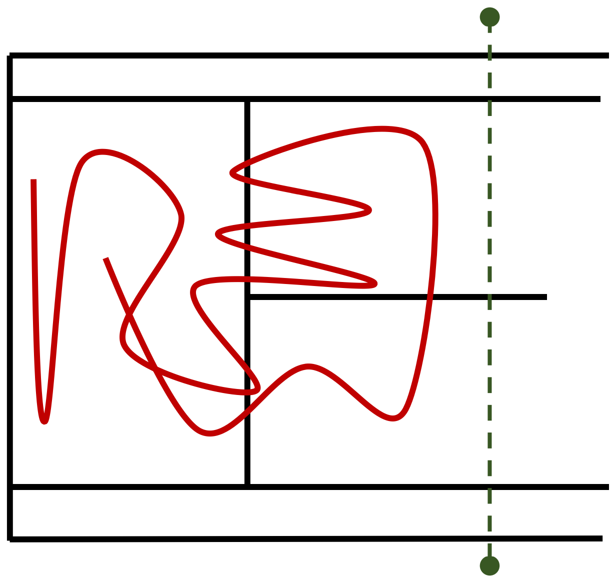


**Figure 12.** Typical stylizied path executed for the RAND Trial

**Data Analysis and Statistics**

After each day's session, data from the SPI HPU units were downloaded and analyzed by the manufacturers software package (Team AMS, GPSports). The trials were then "split" using the start and end times recorded for each trial. For each trial, total distance was determined. Paired t-tests and repeated measures ANOVA were used to determine difference between the trundle wheel and GPS recorded distances as well as the criterion distances. Significance was established *a priori* at $p<.05$

Bland-Altman plots were used to determine the bias between the GPS units and trundle wheel and between paired units attached to the wheel (Bland & Altman, 1983; Giavarina, 2015). For this analysis, absolute differences (m) between trundle wheel and GPS unit derived distances were used as were relative differences (%). In addition, absolute and relative differences were determined for paired units – the two units attached to the trundle wheel and following the same criterion path. Using the Bland-Altman approach, bias and limits of agreement (LOA) were determined.

In addition to Bland-Altman analysis, root mean square (RMS) errors were determined using absolute (m) and percent differences.

For data reduction and statistical analyses, Excel, Simga-Plot and JMP were used.

**Human Subjects**

Federal regulations (45 CFR 46) govern the use and consent of individuals involved in human research. This study does not involve obtaining data on or about living individuals. Further, it does not involve collecting individually identifiable information about living individuals. Therefore, it is not considered "research involving human subjects" and 45 CFR 46 does not apply to this study.

# CHAPTER 4

# RESULTS

***DIST Trial:***

During the distance trial, satellite acquisition was 10.2±0.3 satellites ($\overline{X}$±SEM). An example of the GPS determined location during the DIST trial is shown in Figure 13. Both graphs indicate small deviations from the criterion path (lower panel of Figure 13). This result from either error in the GPS measurement of error in tracking the exact path.

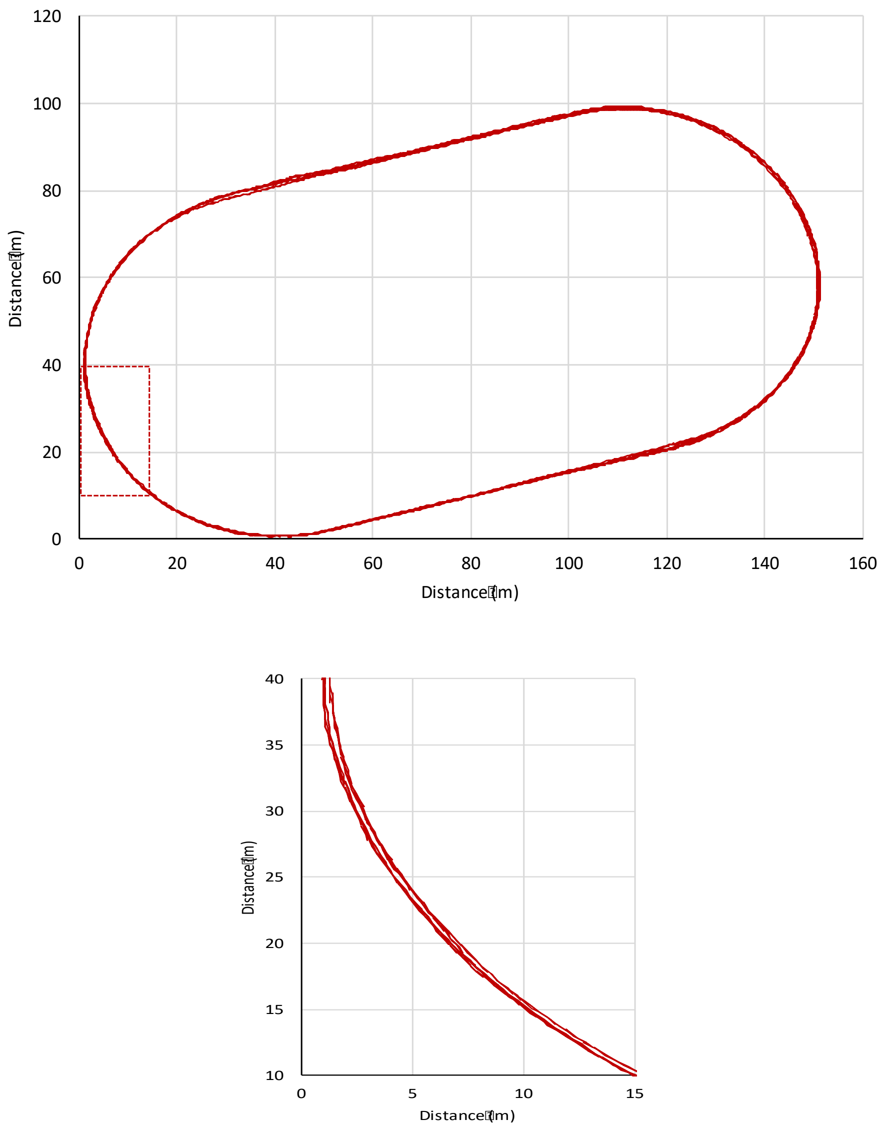



**Figure 13.** GPS determined position during DIST trial. The upper panel shows four laps around a 400m track. The lower panel is an expanded view of a segment of the path (box in the upper panel).

Distances recorded by the trundle wheel and GPS units are shown in Table 5. Both devices significantly overestimated the 1600m criterion distance slightly more than 1% or 17m. However, there was no significant difference between the distances recorded by both units (p>.05).

| DIST Trial | Mean | SEM |
|---|---|---|
| Criterion | 1600.00 | |
| Wheel (m) | 1617.30 | 2.49 |
| GPS (m) | 1617.70 | 3.13 |
| Bias (m) | -0.40 | 2.17 |
| U LOA (m) | 18.81 | |
| L LOA (m) | -19.61 | |
| RMS E (m) | 6.61 | 1.56 |
| Bias (%) | -0.02 | 0.60 |
| U LOA (%) | 1.15 | |
| L LOA (%) | -1.20 | |
| RMS E (%) | 0.41 | 0.10 |

**Table 5.** DIST Trial comparison between GPS and Trundle Wheel.

The Bland-Altman plot of the trundle wheel and GPS unit measurements are shown in Figure 14. This analysis yielded a bias of -0.40±2.17m ($p$>.05 versus 0.00) with the GPS units showing greater distances. The LOA were 18.81m and -19.61m with 19 of 20 (95%) measurements falling within the LOA. Similar results are seen when percent differences are used for the Bland-Altman analysis (Figure 14). The mean bias was -0.02±0.60 % ($p$>.05 versus 0.00) and the LOA were 1.15 and -1.20% with an absolute percent difference of 0.41± 0.10%.

Bland-Altman analysis of paired GPS units is shown in Figure 15. This analysis showed an absolute bias of 0.60±3.47m and LOA values of 31.31 and -30.11 m. The percent difference between paired units was 0.68±0.14% with LOA of 1.15 and -1.20%. For each analysis, 19 of 20 (95%) difference points fall within the upper and lowe--r LOA. RMS error values were 6.61±1.56% and 0.41±0.10%.

Reliability between paired units is shown in Table 6. For this experiment, distances were compared between the two units simultaneously mounted on the trundle wheel. Bland-Altman plot are shown in Figure 15. Each point represents the difference between the two units where the distance obtained by the upper unit was subtracted from that obtained by the lower mounted unit. Bias values were 0.60±3.47m and 0.04±0.21% All but one data point (90%) fell within the LOA. RMS error values were also small, 10.94±2.32m and 0.68±0.14%.

| DIST Trial | Mean | SEM |
|---|---|---|
| **Bias (m)** | 0.60 | 3.47 |
| **U LOA (m)** | 31.31 | |
| **L LOA (m)** | -30.11 | |
| **RMS E (m)** | 10.94 | 2.32 |
| **Bias (%)** | 0.04 | 0.21 |
| **U LOA (%)** | 1.90 | |
| **L LOA (%)** | -1.82 | |
| **RMS E (%)** | 0.68 | 0.14 |

**Table 6.** Distance values compared between paired units during the DIST trial.

The results of the distance trial show very good validity and reliability. Limits of agreement between the units and wheel were less than ±1.5% and between paired units less than ±2%.

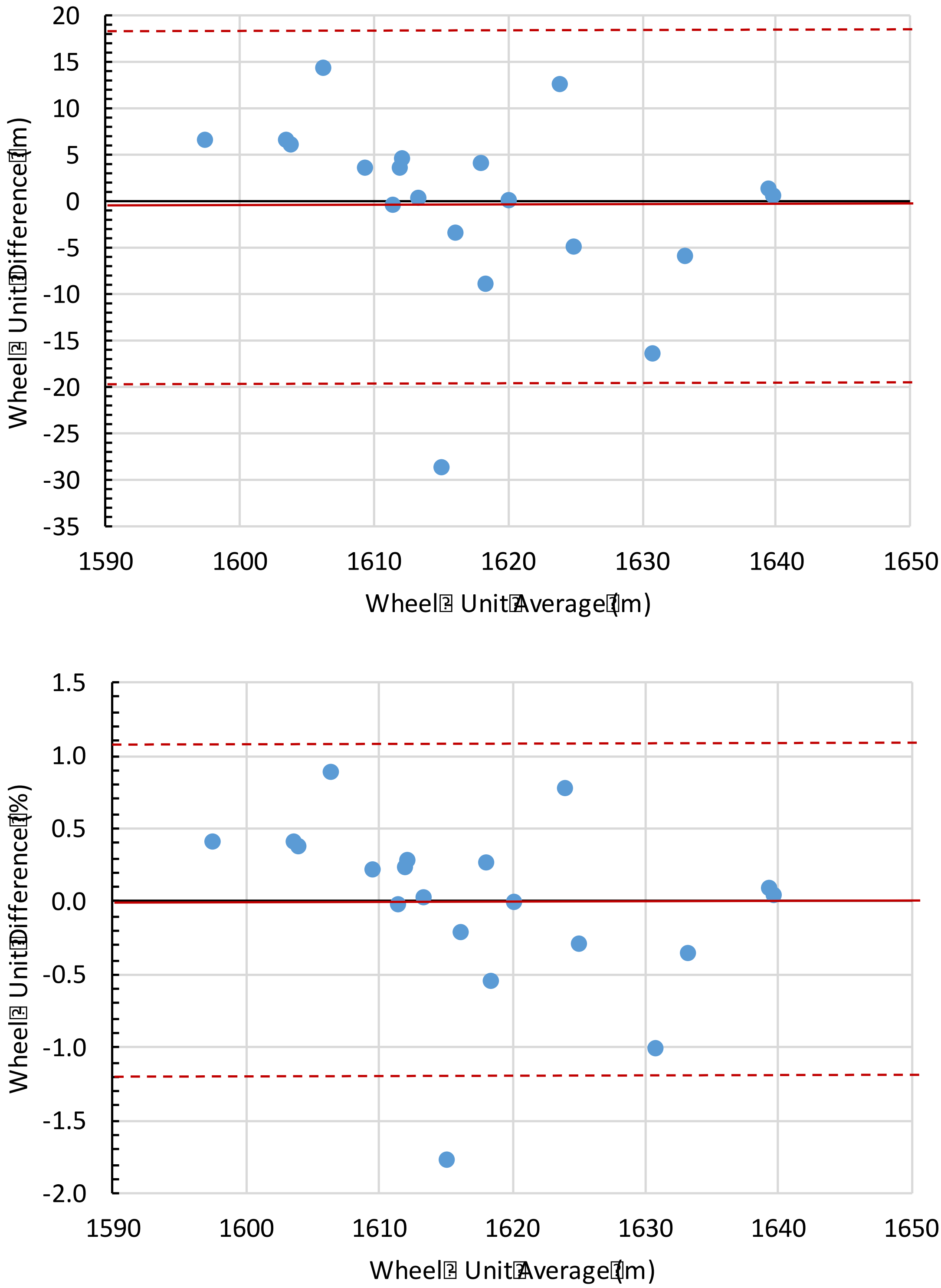



**Figure 14.** Bland-Altman plots of the GPS and trundle wheel distances during the DIST Trial using absolute differences (upper panel) and percent differences (lower panel). The solid red line indicates the bias and the two dashed lines represent the upper and lower LOA.

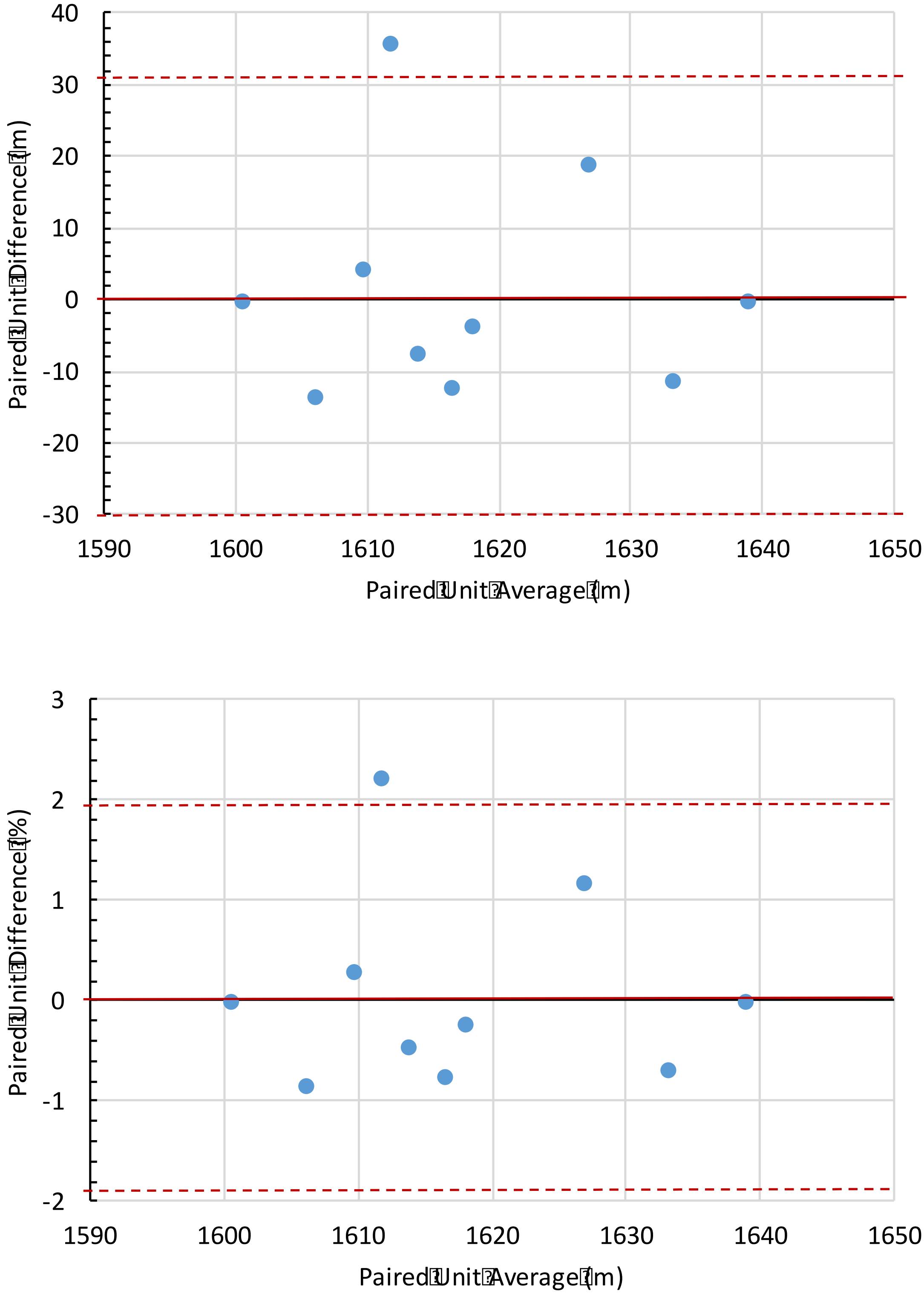



**Figure 15.** Bland-Altman plots of the paired unit distances during the DIST trial using absolute differences (upper panel) and percent differences (lower panel).

***SHUT Trial:***

For the SHUT trial, there were no significant differences between the criterion distance and distances recorded by the trundle wheel and GPS units ($p>.05$). Although the GPS units tended to overestimate distance by 1.3m or 0.5%.

The Bland-Altman plot of the trundle wheel and GPS unit measurements recorded in the SHUT trial are shown in Figure 16 and the results of the analysis are shown in Table 7. This analysis yields a bias of -1.29±0.86m ($p>0.5$) with the trundle wheel measurement recorded almost the exact same distance of the criterion path. The upper LOA was 6.33m, while the lower LOA was -8.91m. Figure 16 also shows that 19 of 20 measurements (95%) fall within the LOA. Similar results are shown when percent differences are used for the Bland-Altman plot (Figure 16). Mean bias was -0.51±0.35 % ($p>0.05$) and the LOA were 2.55 and -3.58% with an absolute percent difference of 1.26±0.22%. RMS errors for the SHUT trial were 10.94±2.32m and 0.68±0.14%.

Bland-Altman analysis of paired GPS units is shown in Figure 17. This analysis showed a 0.17±2.11m bias and LOA values of 13.41 and -13.07 m (Table 8). The absolute percent difference between paired units was 1.84±0.59%. RMS errors for the paired units were 3.79±1.00m and 1.84±0.59%.

| SHUT Trial | Mean | SEM |
|---|---|---|
| **Criterion** | 246.90 | |
| **Wheel (m)** | 246.89 | 0.50 |
| **GPS (m)** | 248.18 | 0.90 |
| **Bias (m)** | -1.29 | 0.86 |
| **U LOA (m)** | 6.33 | |
| **L LOA (m)** | -8.91 | |
| **RMS E (m)** | 3.13 | 0.56 |
| **Bias (%)** | -0.51 | 0.35 |
| **U LOA (%)** | 2.55 | |
| **L LOA (%)** | -3.58 | |
| **RMS E (%)** | 1.26 | 0.22 |

**Table 7.** SHUT Trial raw data GPS vs Trundle Wheel.

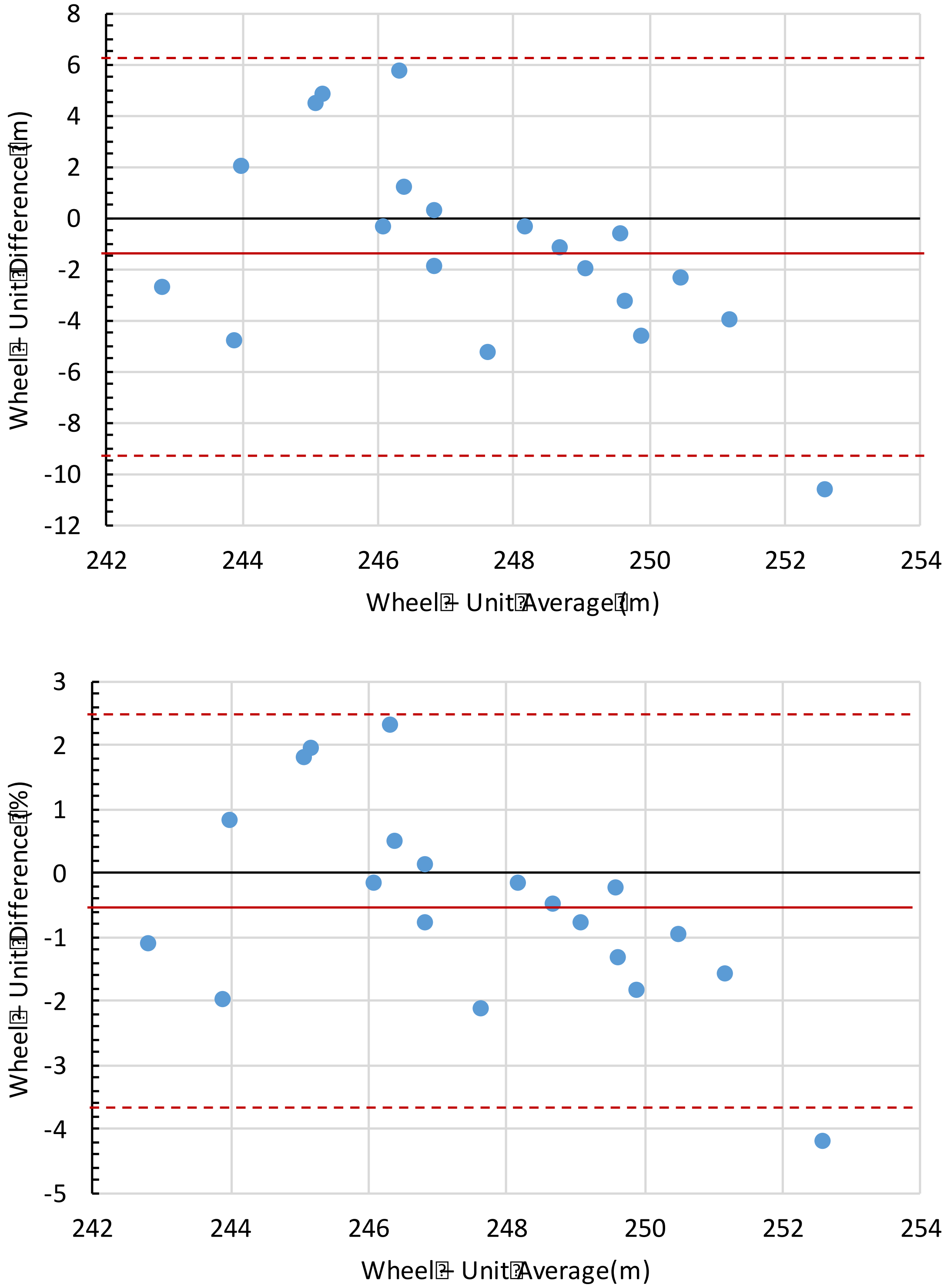



**Figure 16.** Bland-Altman plots of the GPS and trundle wheel distances during the SHUT Trial using absolute differences (upper panel) and percent differences (lower panel)

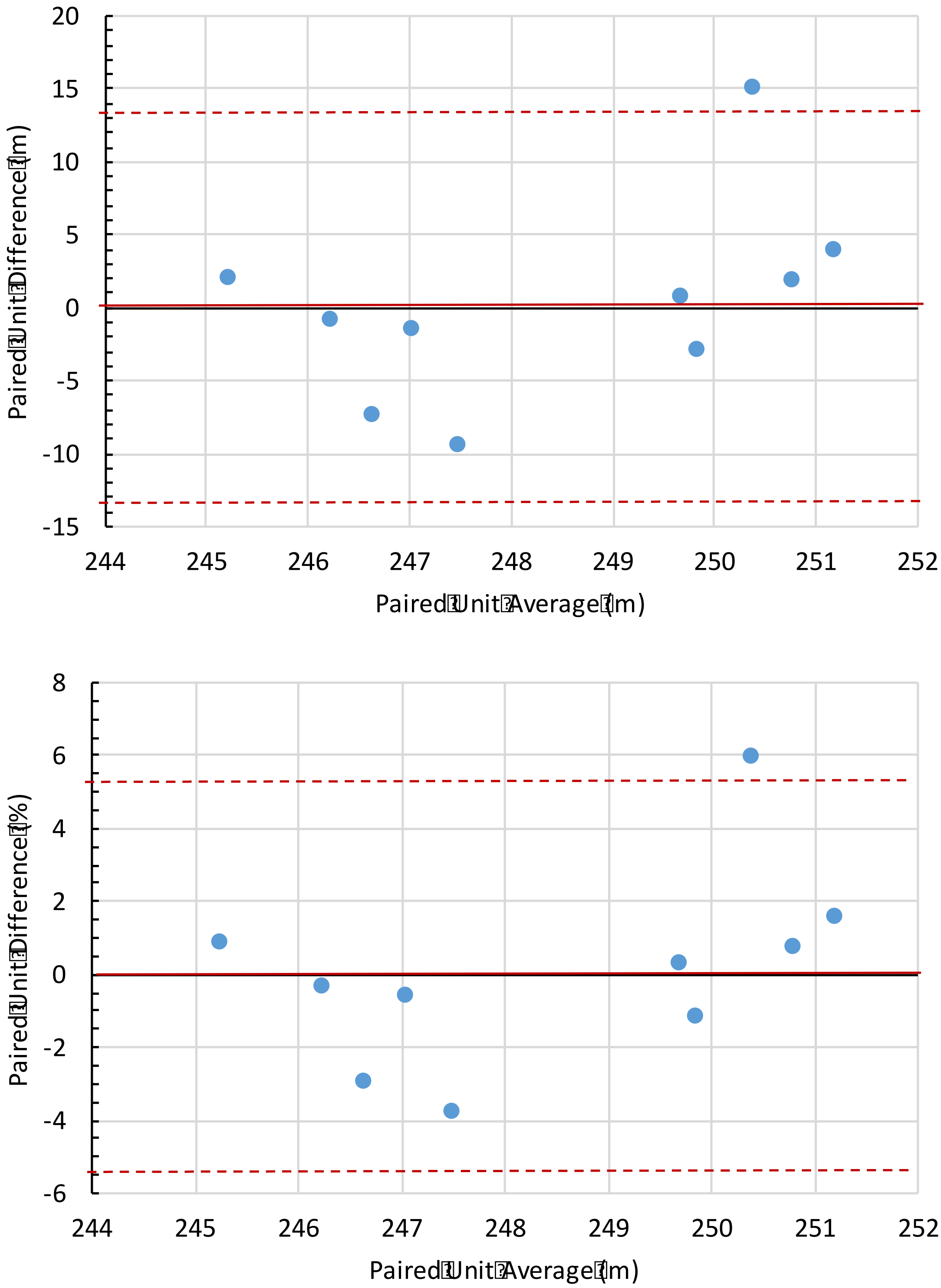



**Figure 17.** Bland-Altman plots of the paired units distances during the SHUT trial using absolute differences (upper panel) and percent differences (lower panel)

| SHUT Trial | Mean | SEM |
|---|---|---|
| Bias (m) | 0.17 | 2.11 |
| U LOA (m) | 13.41 | |
| L LOA (m) | -13.07 | |
| RMS E (m) | 4.57 | 1.47 |
| Bias (%) | 0.06 | 0.85 |
| U LOA (%) | 5.37 | |
| L LOA (%) | -5.25 | |
| RMS E (%) | 1.84 | 0.59 |

**Table 8.** SHUT Trial raw data GPS vs Trundle Wheel.

***COD Trial:***

The Bland – Altman plot of the trundle wheel and GPS unit measurements recorded in the COD trial are shown in Figure 18. This analysis yields a bias of -0.66m ± 1.12m ($p>0.5$) with both deviced recording a greater total distance, but with no significant difference between the distances recorded by the trundle wheel and the GPS units (254.28m vs 254.94m) (Table 9). The upper LOA was 9.28m and the lower LOA was -10.60m and all points fell within this range. The RMS error was 4.31 ± 0.55m. Looking at the Bland-Altman analysis from the percent differences, the mean bias was -0.25 ± 0.44% ($p>0.05$), the LOA values respectively 3.65 and -4.15%. The RMS error for the COD trial 1.69 ± 0.22%.

Bland-Altman analysis of paired GPS units is shown in Figure 19 and Table 10. This analysis showed a -0.63 ± 1.60m bias and LOA values of 9.38 and –10.64 m with 9 of 10 (90%) of points within the LOA. Average RMS errors for the paired units were 3.79±1.00m and 1.84±0.59%.

| COD Trial | Mean | SEM |
|---|---|---|
| Criterion | 249.00 | |
| Wheel (m) | 254.28 | 0.51 |
| GPS (m) | 254.94 | 0.91 |
| Bias (m) | -0.66 | 1.12 |
| U LOA (m) | 9.28 | |
| L LOA (m) | -10.60 | |
| RMS E (m) | 4.31 | 0.55 |
| Bias (%) | -0.25 | 0.44 |
| U LOA (%) | 3.65 | |
| L LOA (%) | -4.15 | |
| RMS E (%) | 1.69 | 0.22 |

**Table 9.** COD Trial raw data GPS vs Trundle Wheel**.**

| COD Trial | Mean | SEM |
|---|---|---|
| Bias (m) | -0.63 | 1.60 |
| U LOA (m) | 9.38 | |
| L LOA (m) | -10.64 | |
| RMS E (m) | 3.79 | 1.00 |
| Bias (%) | -0.24 | 0.63 |
| U LOA (%) | 4.18 | |
| L LOA (%) | -3.71 | |
| RMS E (%) | 1.49 | 0.40 |

**Table 10**. COD trial reliability data between paired units.

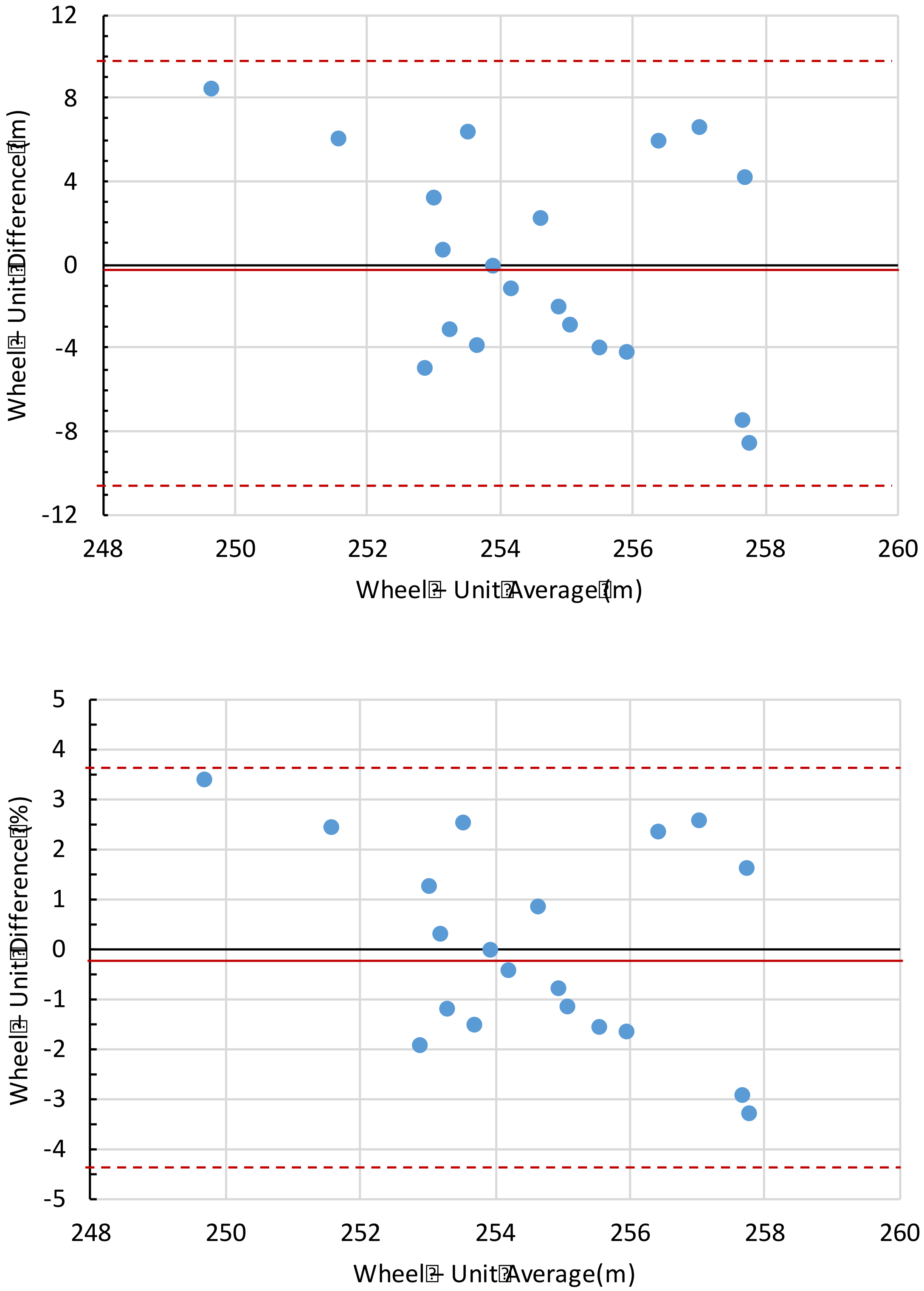
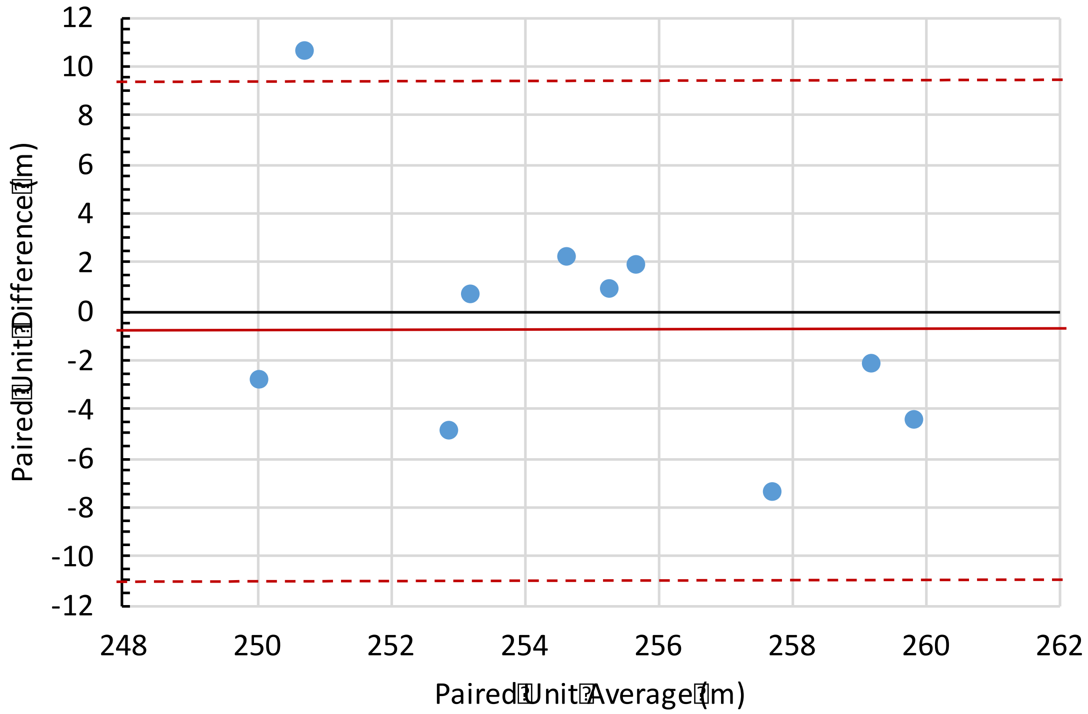



**Figure 18.** Bland-Altman plots of the GPS and trundle wheel distances during the COD Trial using absolute differences (upper panel) and percent differences (lower panel)



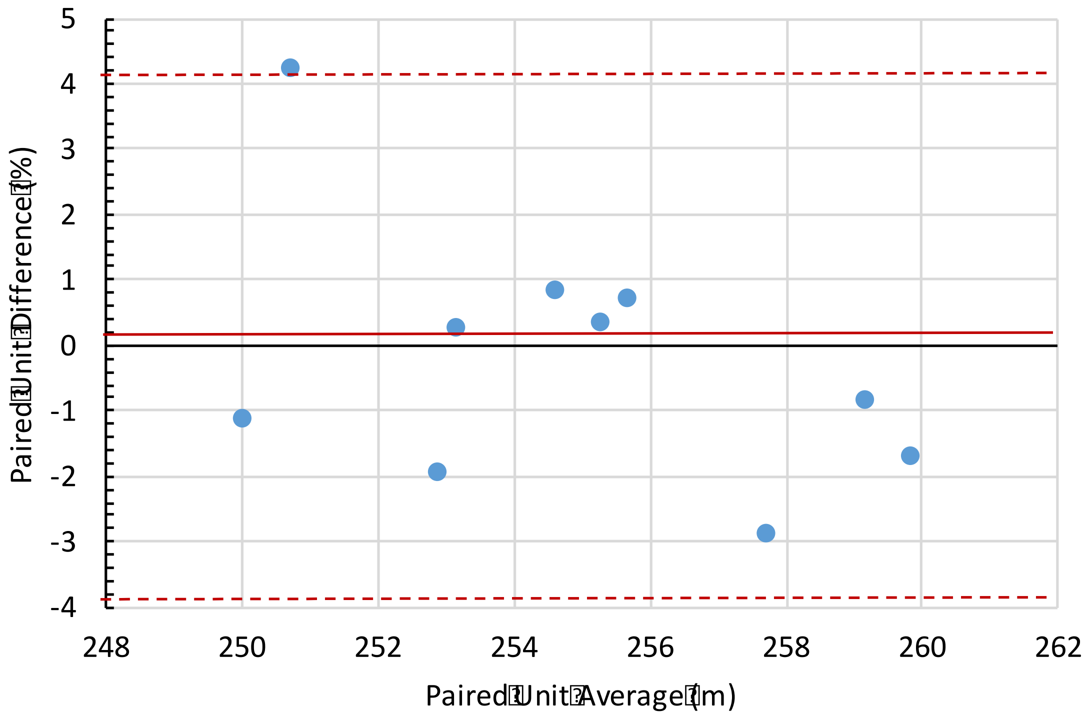




**Figure 19.** Bland-Altman plots of the paired units distances during the COD trial using absolute differences (upper panel) and percent differences (lower panel)

***RAND Trial:***

The RAND trial did not have a criterion distance because the movements were executed randomly. The average of the total distance recorded during each lap was ~135m. The Bland – Altman plot of the trundle wheel and GPS unit measurements recorded in the Random Trial are shown in Figure 20. This analysis yielded a bias of 2.38 ± 0.64m ($p$>.05) (Table 11). The LOA were 8.04m and -3.29m with 19 of 20 (95%) measurements falling within the LOA. Similar results are seen when percent differences are used for the Bland-Altman analysis (Figure 20). The mean bias was -1.75 ± 0.46 % ($p$>.05) and the LOA were 5.81 and -2.31% with an absolute percent difference of 2.29 ± 0.31%. It should be pointed out that there was a trend for the wheel – unit differences to increase from negative to positive as the average distance increased (Figure 20). This suggests a systematic error during this trial (Giavarina, 2015). However, the range of average distances was quite small, less than 20m. Thus, it is not clear if this trend would hold for longer distances travelled.

| RAND Trial | Mean | SEM |
|---|---|---|
| Criterion | | |
| Wheel (m) | 139.49 | 1.49 |
| GPS (m) | 141.87 | 1.01 |
| Bias (m) | 2.38 | 0.64 |
| U LOA (m) | 8.04 | |
| L LOA (m) | -3.29 | |
| RMS E (m) | 3.19 | 0.42 |
| Bias (%) | -1.75 | 0.46 |
| U LOA (%) | 5.81 | |
| L LOA (%) | -2.31 | |
| RMS E (%) | 2.29 | 0.31 |

**Table 11.** RAND Trial - GPS vs Trundle Wheel

Bland-Altman analyses of paired GPS units during the RND trial are shown in Table 12 and Figure 21. This analysis showed a 0.89±0.52m bias and LOA values of 4.11

and -2.33 m. The percent difference between paired units was 0.63±0.36%. Average RMS error values were 1.39±0.37m and 0.98±0.26%.

| RAND Trial | Mean | SEM |
| --- | --- | --- |
| Bias (m) | 0.89 | 0.52 |
| U LOA (m) | 4.11 | |
| L LOA (m) | -2.33 | |
| RMS E (m) | 1.39 | 0.37 |
| Bias (%) | 0.63 | 0.36 |
| U LOA (%) | 2.89 | |
| L LOA (%) | -1.62 | |
| RMS E (%) | 0.98 | 0.26 |

**Table 12.** RAND Trial raw data between paired units.

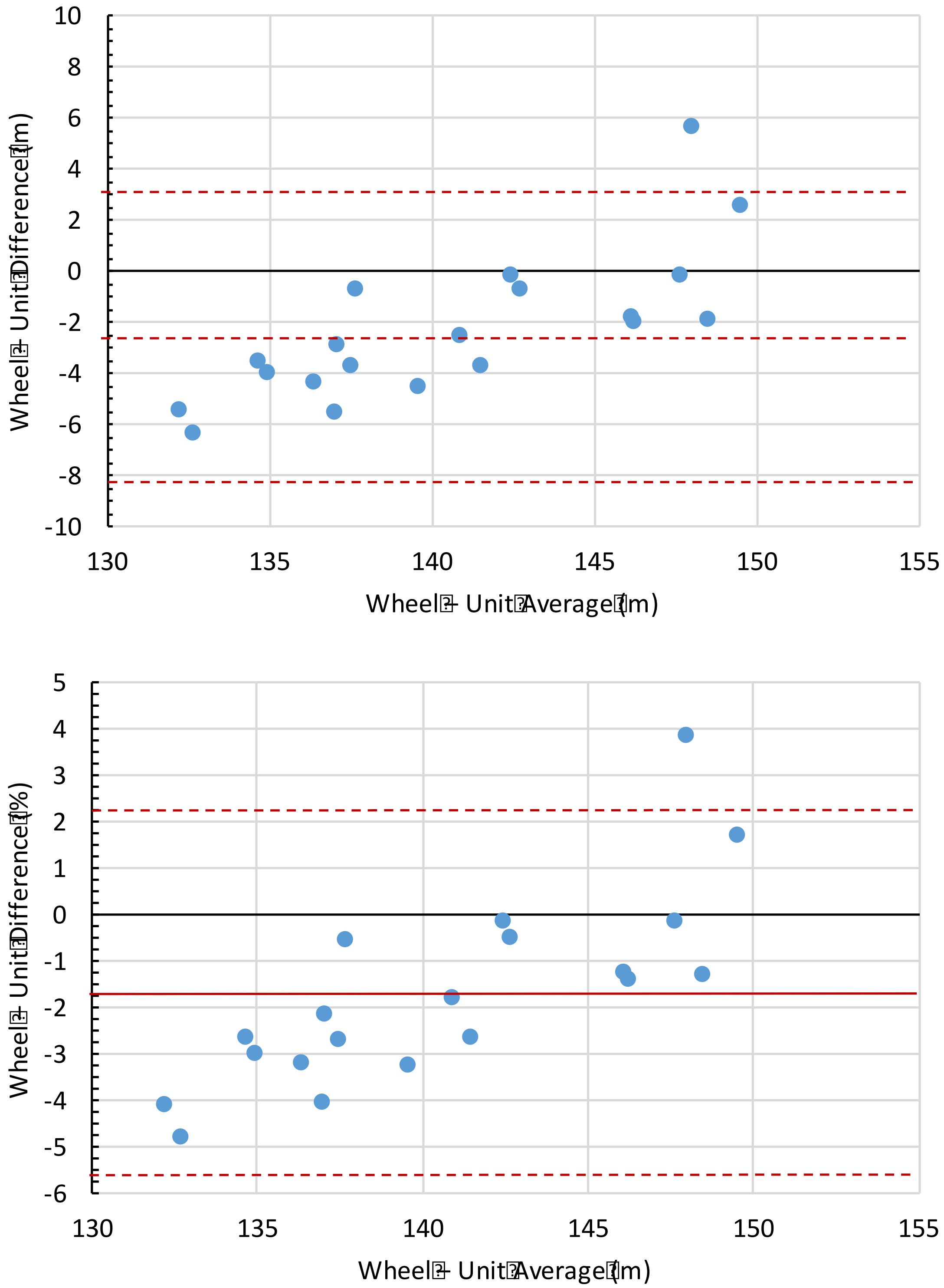



**Figure 20.** Bland-Altman plots of the GPS and trundle wheel distances during the RAND Trial using absolute differences (upper panel) and percent differences (lower panel).

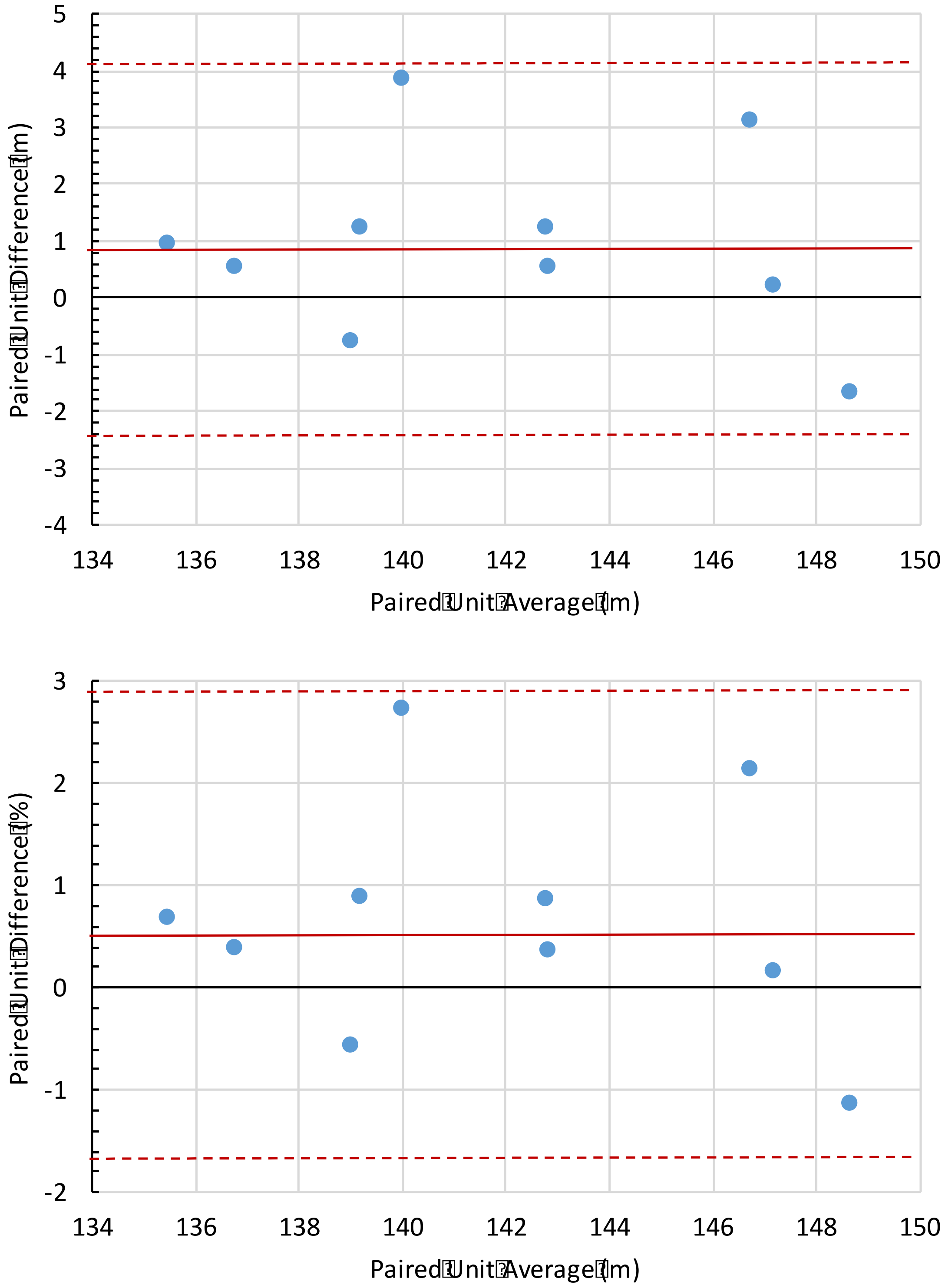



**Figure 21.** Bland-Altman plots of the paired units distances during the RAND trial using absolute differences (upper panel) and percent differences (lower panel)

***Point Distances:***

For the court-based trials (SHUT, COD and RAND), accumulated distances covered during each of the five intervals or simulated "points" were compared between the trundle wheel and GPS units and between paired units. Bias units (both absolute and percent differences) are shown in Table 13. In this table, accumulated distances are shown for each trial. For example, the criterion distances for SHUT trial were 49.4, 98.8, 148.1, 197.5, and 246.9m, respectively (n=20 for each point). As can be seen, absolute bias values increased as distance increased while the percent bias values remained fairly constant across points. This is shown graphically in Figure 22 and Bland-Altman plots of each point during each trial.

| | | Points | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | | 2 | | 3 | | 4 | | 5 | |
| Trial | Bias | Mean | SEM | Mean | SEM | Mean | SEM | Mean | SEM | Mean | SEM |
| SHUT | (m) | -0.29 | 0.17 | -0.49 | 0.35 | -0.73 | 0.52 | -0.96 | 0.70 | -1.29 | 0.86 |
| | (%) | -0.57 | 0.34 | -0.48 | 0.35 | -0.49 | 0.35 | -0.48 | 0.35 | -0.51 | 0.35 |
| COD | (m) | -0.10 | 0.23 | -0.27 | 0.46 | -3.84 | 0.68 | -0.54 | 0.90 | -0.66 | 1.12 |
| | (%) | -0.19 | 0.45 | -0.25 | 0.45 | -0.24 | 0.44 | -0.26 | 0.44 | -0.25 | 0.44 |
| RAND | (m) | -0.88 | 0.12 | -1.54 | 0.24 | 2.04 | 0.36 | 2.63 | 0.36 | -2.38 | 0.64 |
| | (%) | -2.99 | 0.41 | 2.74 | 0.43 | 2.41 | 0.43 | 2.35 | 0.33 | -1.75 | 0.46 |

**Table 13.** Bland-Altman bias values for the wheel - unit comparisons during each trial and point.

Bias values for paired units are shown in Table 14. As in the above table, absolute bias scores tend to increase in magnitude with increasing accumulated distance. On the other hand, percent differences remained relatively constant.

| | | Points | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | | 2 | | 3 | | 4 | | 5 | |
| Trial | Bias | Mean | SEM | Mean | SEM | Mean | SEM | Mean | SEM | Mean | SEM |
| SHUT | (m) | 0.09 | 0.41 | 0.22 | 0.85 | 0.34 | 1.25 | 0.42 | 1.71 | 0.17 | 2.11 |
| | (%) | 0.17 | 0.83 | 0.21 | 0.85 | 0.22 | 0.84 | 0.21 | 0.86 | 0.06 | 0.85 |
| COD | (m) | -0.12 | 0.32 | -0.30 | 0.64 | -0.43 | 0.92 | 0.95 | 1.29 | -0.63 | 1.60 |
| | (%) | -0.22 | 0.62 | -0.28 | 0.63 | 0.27 | 0.64 | 0.23 | 0.64 | 0.24 | 0.63 |
| RAND | (m) | 0.13 | 0.22 | -0.33 | 0.42 | 0.23 | 0.71 | 0.65 | 0.62 | 0.89 | 0.52 |
| | (%) | 0.47 | 0.75 | -0.58 | 0.72 | 0.28 | 0.82 | 0.58 | 0.53 | 0.63 | 0.36 |

**Table 14.** Bland-Altman bias values for paired unit comparisons during each trial and point.

RMS errors for the court trials and all points are shown in Figure 22. For comparison, RMS error for the DIST trial is also shown. As expected, the absolute error (m) tends to increase with increasing criterion distance, rising from <1m during the first point to nearly 11m for the 1600m trial. On the other hand, the percent error was somewhat consistent across points within each trial. For the court trials, the average RMS error ranged between1 and 2%. For the 1600m trial, it was less than 1%.

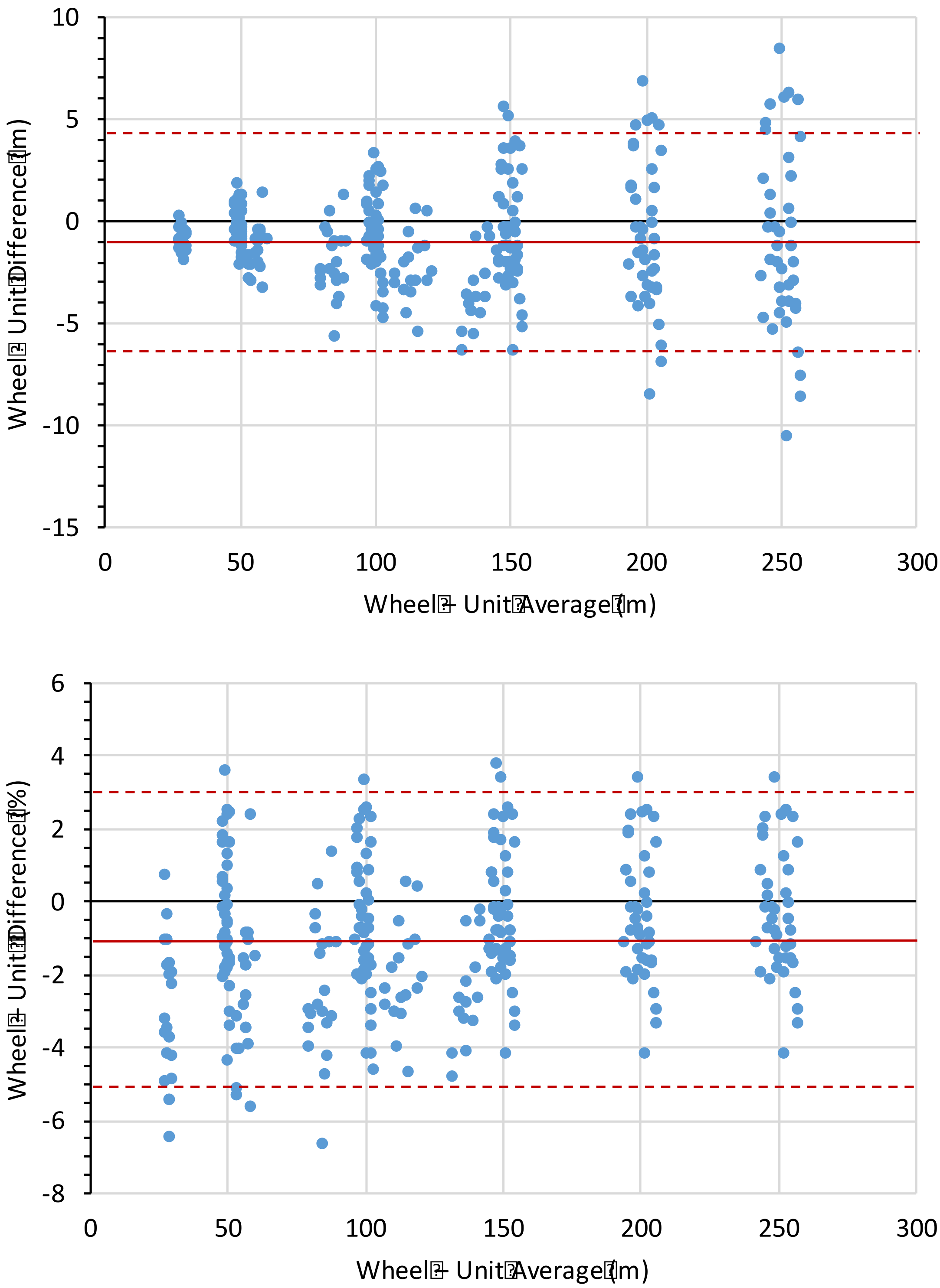



**Figure 22.** Bland-Altman plot of all three court trials and points. Absolute differences (m) are shown in the top panel and percent differences (%) are shown in the bottom panel.

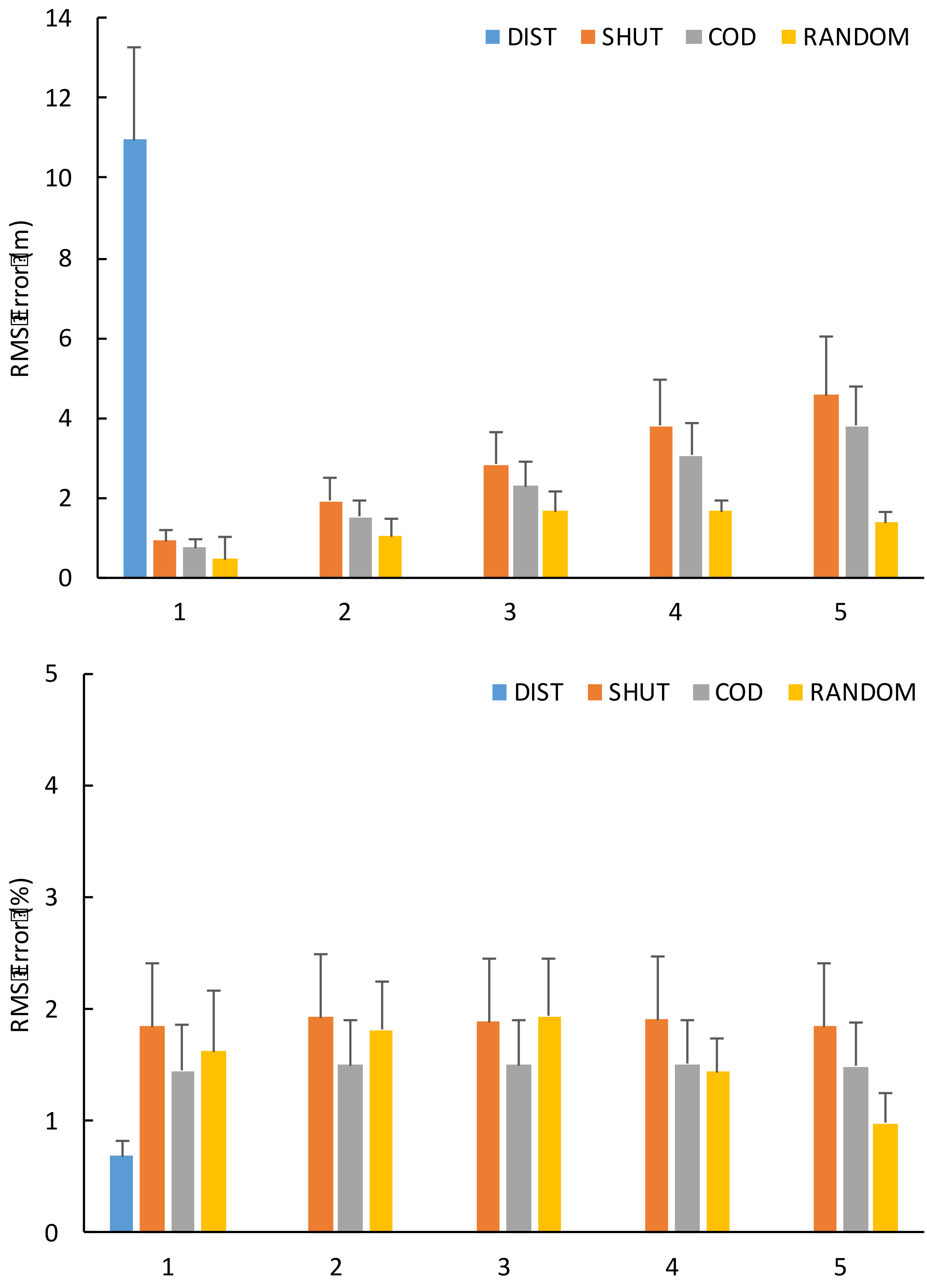



**Figure 23.** RMS errors for the four court trials and points along with the DIST trial. Absolute errors (m) are shown in the top panel and the percent errors are shown in the bottom panel.

### *All Trials and Points*

All trials and points are aggregated and analyzed (n=320). Since the trials differed in the total distance covered, this analysis used relative bias and RMS error values. Figure 24 shows the mean bias for each trial along with the 95% confidence interval (LOA). As can be seen, bias values were within ±1% and LOA within ±2.5%

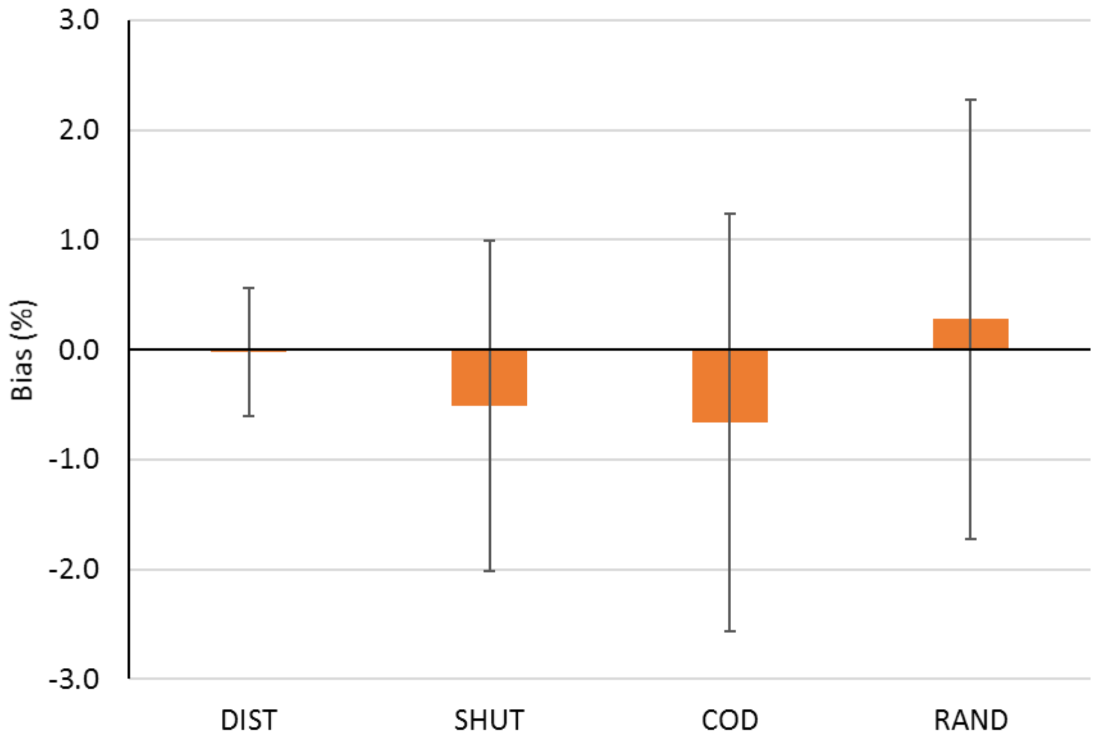



**Figure 24.** Bias values determined for each. Error bars indicate the 95% confidence interval for each (LOA).

Figure 25 shows all of the percent differences and RMS error values for each unit and point within each trial, ranked by magnitude. The range of percent differences was -6.67 to 3.78. The range of RMS errors was 0.01 to 6.67. Distributions of the percent differences and RMS error values are shown in the histograms included in Figure 26. The mean bias for the entire data set was -1.00±0.11% with upper and lower LOA of 2.95 and -4.94%, respectively. The mean RME error was 1.79±0.07%. Both the bias and RMS error values were significantly different from 0 ($p<.05$). Thus, the GPS units overestimate trundle wheel distances by about 1% of the total distance measured. In addition, the average error between the units and wheel is less than 2%.

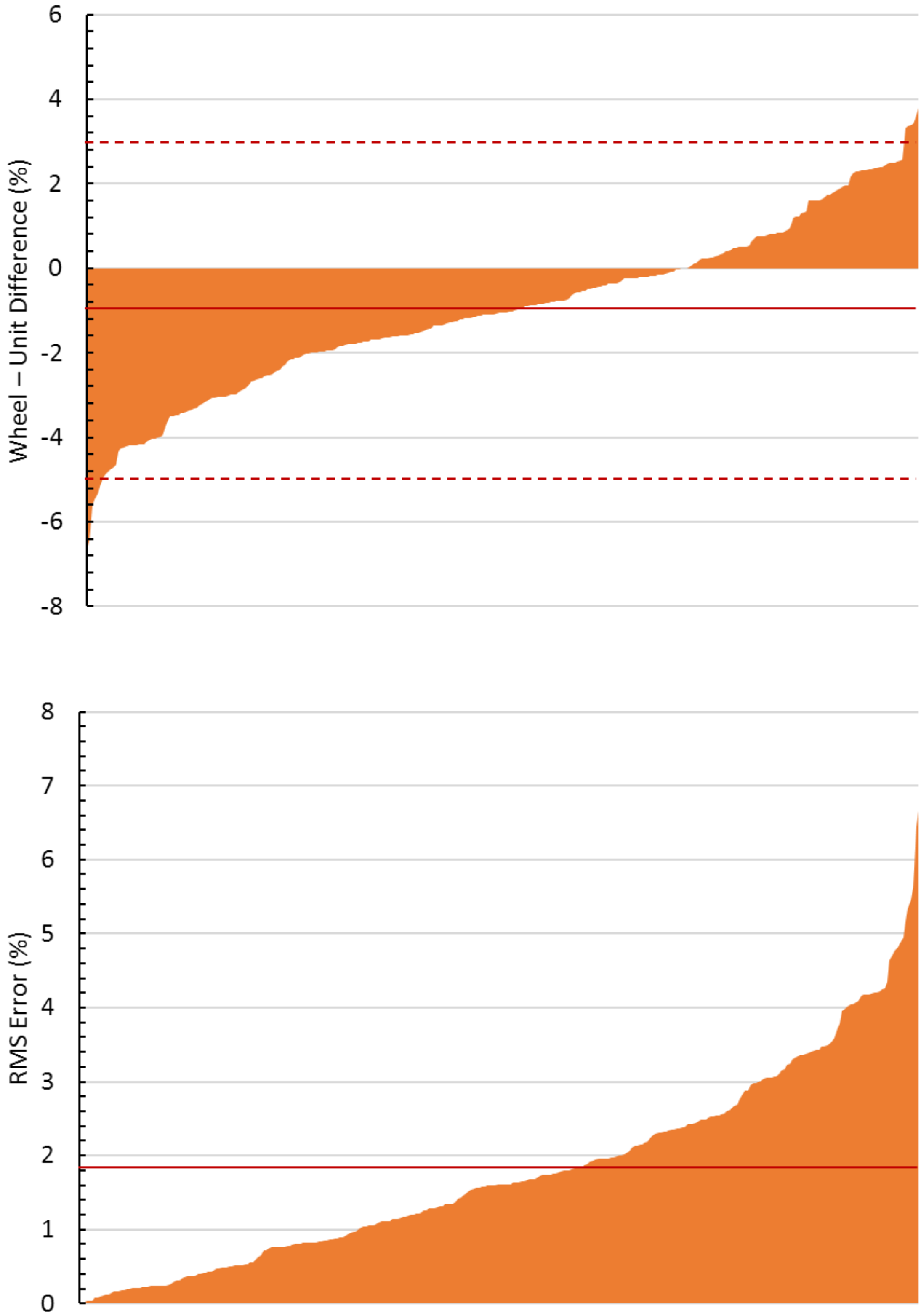



**Figure 25.** Percent difference (top panel) and RMS error (lower panel) values for all trials and points.

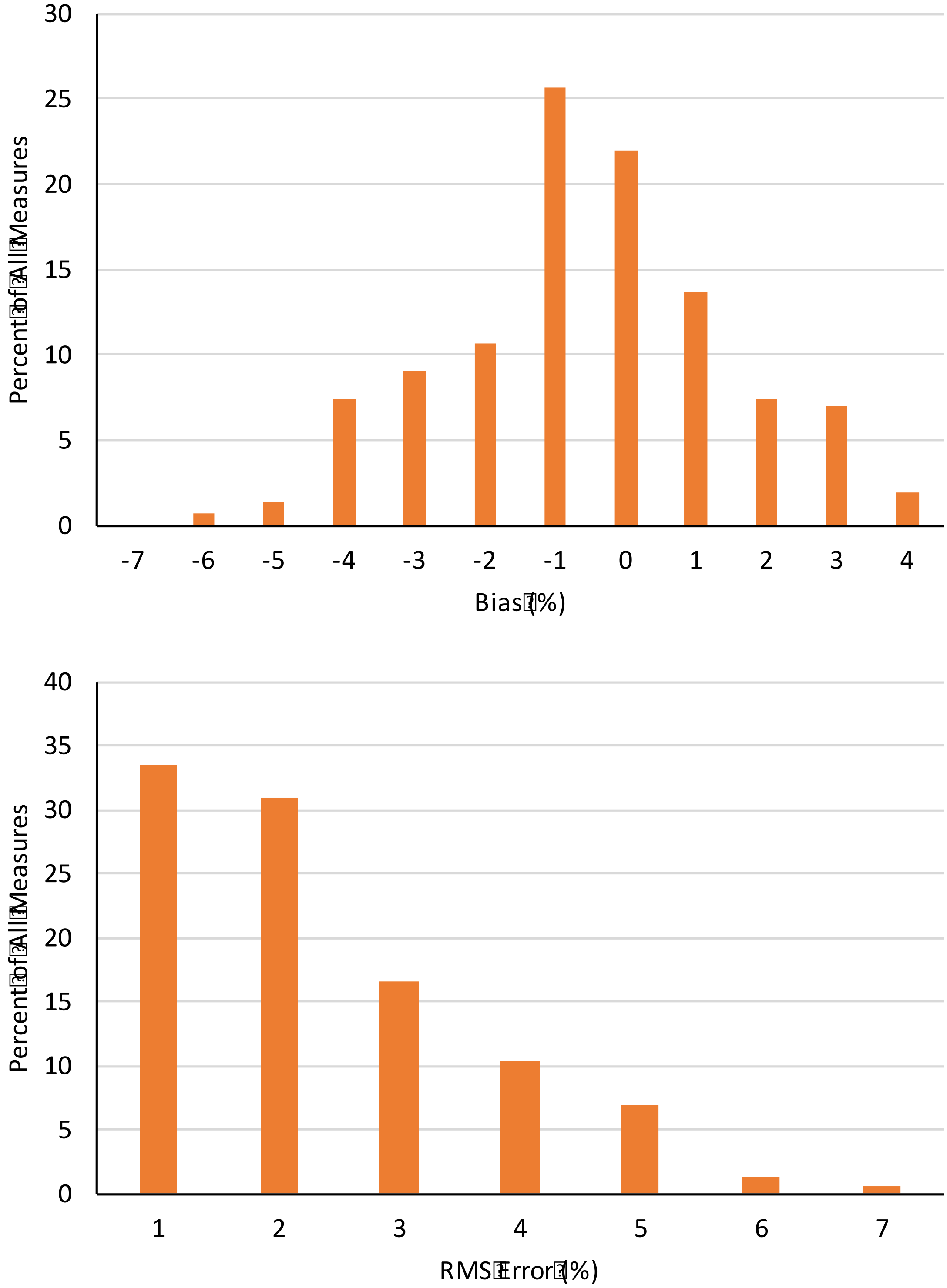



**Figure 26.** Histograms of the bias (upper panel) and RMS error (lower panel). Both graphs include all trial and point measurements (n=320).

# CHAPTER 5

# DISCUSSION

## Summary of Results

The use of GPS to estimate work load during court-based sports such as tennis has aroused a lot of interest in coaches and trainers. However, a key concern is the accuracy and reliability of this technology for rapid change of direction movements within a confined space. In this study, the GPSports SPI HPU units were found to be very accurate and reliable for these types of activity. The GPS units overestimated criterion distances during the DIST, SHUT and COD trials by 1.1, 0.52 and 2.39%, respectively. However, the GPS units overestimated the trundle wheel distances during all four trials by less than 2.5%. Bland-Altman analysis showed bias values of less than 2% and LOA values of ±5%. Reliability, determined by comparing paired units used simultaneously, was also very good. Paired units differed by less than 2% across all trials. Bland-Altman bias values were less that 0.7% and the LOA were also ±5%. For both validity and reliability measurements, more than 95% of the points fell within the LOAs. Given this, it is concluded that the SPI HPU GPS units can be confidently used to determine distances ran during court-based sports such as tennis.

Overall, the SPI HPU GPSports technology showed a great accuracy in all four trials. These trails included both moderate speed movements with little change in direction (DIST) as well as high speed movements with numerous changes in direction (SHUT, COD, RAND). The percent error tended to be greatest for the RAND and smallest for the DIST trials. However, the differences were not statistically different. Nevertheless, this raises the possibility that as number of changes in direction increase and the area of movement decreases, the GPS error increases.

In addition, the reliability of the units was very good. Paired units showed considerable agreement in calculated distance as they were moved along the same path. And this held for all four trials. Also, there was no systematic bias between the upper- and lower-mounted units. Thus, one can be confident in using the GPSports SPI HPU units to determing distances covered by players during court-based sports like tennis

While this study suggests very good validity and reliability of the SPI HPU units, it is important to view these two parameters in the context of how they are being utilized. Giavarina (2015) emphasizes that Bland-Altman analysis only quantifies or defines the extent of agreement between two methods of measurement. This analysis as well as the present data do not imply that those limits are acceptable within a particular context. Giavarina (2015) suggests that acceptable limits should be defined a priori, based on research or practical considerations and goals. For example, if the intended use of the SPI HPU units is to provide a coach or medical staff with a sound estimate to distance traveled during a training session or competition for use in periodizing workouts, a 2% error may be more than acceptable. However, if the units are to be used in a research setting where an experimental intervention may evoke small (1-3%) changes in distance, then the use of the SPI HPU unit might be questionable. Thus, while this study shows very good validity and reliability of these units for distance measurement during sports such as tennis, the user is the ultimate evaluator of these devices.

**Comparison With Other Studies**

In other studies, such as Vickery et al. (2014) and Duffield et al. (2009), investigators compared distances recorded by the GPS units with video determination using VICON. The accuracy in these studies was found to be in between 4 to 10%. It's is not readily clear why the results of the present study show greater accuracy. It is well known that the VICON and similar video system have very high accuracy, much greater than the trundle wheel used in the present study. Thus, a more precise "gold standard" may explain the differences between GPS and video derived distances in these studies compared to the present study. Differences between studies could also reflect difference in the GPS unit used (GPSports SPI Elite and Catapult MinnimaX). Both units report GPS positions at 15Hz. And all utilize 100Hz accelerometry data to supplement 5Hz GPS data to obtain the 15Hz reported values. Further, the GPSports devices utilize a magnetometer to orient the triaxial accelerometer whereas the Catapult devices use a gyroscope. Manufacturers of these devices utilize proprietary algorithms to integrate GPS and accelerometer data. Chan et al (2006) demonstrate that the choice of algorithm can impact the calculated distances. While it is not clear if the units studies utilize different methods of computing distance, it is possible that such a difference could affect validity scores. Given this, future research into the validity of the SPI HPU units should include a video-based measurement system.

Other studies utilized a criterion distance as their gold standard with assessing validity of GPS units for distance measurements. However, this assumes that the individual wearing the GPS unit is capable of following the criterion path. Any deviation along this path introduces error into validity determination. Rawstorn et al. (2015) performed several measurements on the running track. Subjects had to follow movements pattern on a shuttle and curvilinear running track while wearing a 15Hz GPS device (SPI Pro X, GPSports Systems, Australia). During the curvilinear movements, they found a statistically significant overestimation of the path (2.6%). This error could reflect differences in the distance of the path (13,200m) and actual distance travels by the subjects wearing GPS units. The present data provide evidence to support this idea. As can be seen in Figure 13, there are noticeable deviations in the GPS signals between laps or points executed. During the trials, the goal was to follow the criterion path as closely as possible. It was evident during the study that this was done to differing degrees. For example, the trundle wheel often deviated several inches away from baseline during the SHUT trial and the turns were not always executed on the singles line. Also, during the DIST trial, the goal was to follow an imaginary line positioned 0.3m from the inside of lane one. It is very likely that there was considerable error in tracking this path. However, in the present study, the GPS units were secured to the trundle wheel. Thus, any errors or deviations in following the criterion path would be detected by the wheel. In fact, both the wheel and units recorded more distance than the criterion in each trial. Thus, the use of a calibrated trundle wheel as the gold standard is preferable to a criterion distance.

**Limitations**

In this research, there are several limitations that must be taken into consideration when interpreting the results. In terms of the quality of the GPS signals, the SPI HPU units provide a count of the number of satellites used in the calculation of position. However, they do not provide dilution of precision information (HDOP, VDOP, etc). Low DOP values indicate limited satellite signal interference, proper satellite location and high quality of location determination. High DOP values could affect some of the results by introducing error into the GPS position determination. As noted, SPI HPU DOP values could not be recorded. All data were collected on days with minimal cloud cover and in areas where there is limited buildings and trees. Thus, minimal interference would be expected. Also, a separate GPS tracking device using during data collection reported DOP signals less than 1.0 in most cases and less than 2.0 in all cases. This suggests an exceptional or excellent GPS signal quality. However, it is important to note that DOP values can differ between receiving devices, even when located at or near the same position. Thus, while there is no evidence to suggests that the present results were impacted by poor signal quality, no data are available to verify this.

Another deficiency, is that the trundle wheel cannot measure both forward and backward movements. When the wheel moves backwards, distance is subtracted by the mechanical counter. Thus, in order to mimic backwards movements during the SHUT and RAND trials, the wheel had to rotate or pivot on its ground contact point before being moved straight forward. If the wheel was accidentally moved backwards during any of the trials, the distance meter would underestimate the actual distance travelled. Further, if the wheel lost contact with the ground or "slipped" sideways, the distance recorded by the wheel could be affected. For this study, considerable care was taken to insure constant contact with the ground during the trial. Also, considerable care was taken to avoid reversing the wheel. As the wheel distance served as the gold standard, "overrunning" the criterion stopping point then backing up was not needed to validate the GPS units.

For this study, the units were positioned over the trundle wheel and away from the wheel's point of contact with the ground. As the handle of the wheel rotates forwards and backwards, in the absence of wheel movement, the units would record these as distance travelled (4 and 7cm degrees of rotation). In addition, any sideway lean of the wheel would similarly introduce error. Care was taken to maintain the handle in the same position through each of the trials. However, it is possible that the handle and units were not always positioned over the wheel ground contact point, especially during the RAND trial where movements and changes in direction varied considerably.

Despite these limitations, the present results suggest that GPSports SPI HPU units are both accurate and reliable. Comparing trundle wheel distance measurements with the distances determined by the GPS units very little absolute and relative bias, no consistent bias and small RMS error.

## Applications

Given that the SPI HPU unit can be used successfully to measure distances traveled during court-based sports, these devices should prove useful in monitoring the physiological demands of training and competition. Gabbett and colleagues (Black et al., 2016; Gabbett & Jenkins, 2011; Gabbett, 2016; Malone et al., 2016) have produced a series of elegant studies and review articles designed to quantify "player load" and to use that information to minimize injury risk. For these studies, this group has utilized ratings of perceived exertion as well as distances traveled as load metrics. They argue that acute changes in load (increase or decrease) raise the risk of injury. Although, these studies were conducted in field based sports such as rugby, soccer and cricket, they have implications for tennis. Using GPS units, coaches and trainers could easily monitor distances covers, speeds and accelerations during training and matches. These data could then be monitored or tracked over the course of a season in an effort to limit acute changes in load and reduce injury risk. Thus, future research should also focus on investigating the links between player load during tennis and injury risk.

Further, these devices have the ability to generate other metrics of load such as heart rate, acceleration, and impact. These variables provide indices of both volume and intensity of activity. While no study has addressed the combination of these or other variable to quantify training load, future studies should attempt to do so. Additional data on both external load and the athlete's physiological responses could prove very powerful in monitoring training with a eye towards maximizing performance and minimizing injury risk.

An important issue that is not addressed in this study is what constitutes "distance traveled" during an activity such as tennis and hence, energy expenditure. GPS units record distances traveled by the unit, not necessarily by the player. For example, when a player is receiving a serve, he/she often sways from side to side. With a trunk mounted GPS unit, this would be recorded as distance traveled despite the feet remaining stationary on the ground. A similar situation arises as players extend and reach for shots. Accordingly, energy may be expended moving the trunk even while the feet are planted. Thus, there is a need to define what is meant by distance traveled during specific activities. At the very least a proper use of terminology is needed. For example, the concept of distance covered during a tennis match might be expressed as GPS unit distance covered rather than player distance.

New technologies are also emerging that could be coupled with GPS units to monitor both player load and technical performance. PlaySight is a new tool that uses a video system to track both player and ball movements during tennis (www.playsight.com). This system provides data on distances traveled by the player as well as shot type, location, speed and spin. To date, the validity and reliability of the distance calculations has not been done by independent investigators. Further, the combination of physical demands (e.g. distance, heart rate, etc) and technical data (shot and service location and speed) could b very powerful in analyzing match performance. In addition, how player fitness and the development of fatigue impact performance could be determined.

**Conclusions**

GPSports SPI HPU units showed a considerable accuracy and reliability in all the trials performed. Its utilization on a tennis court could be useful during the examination of player's physical demands. Coaches looking for a tool that could help them in planning specific trainings and analyzing matches can confidently use these devices. In addition, the high validity and reliability of these devices make them very useful to the researcher looking to determined distances traveled during court-based sports.

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## APPENDIX

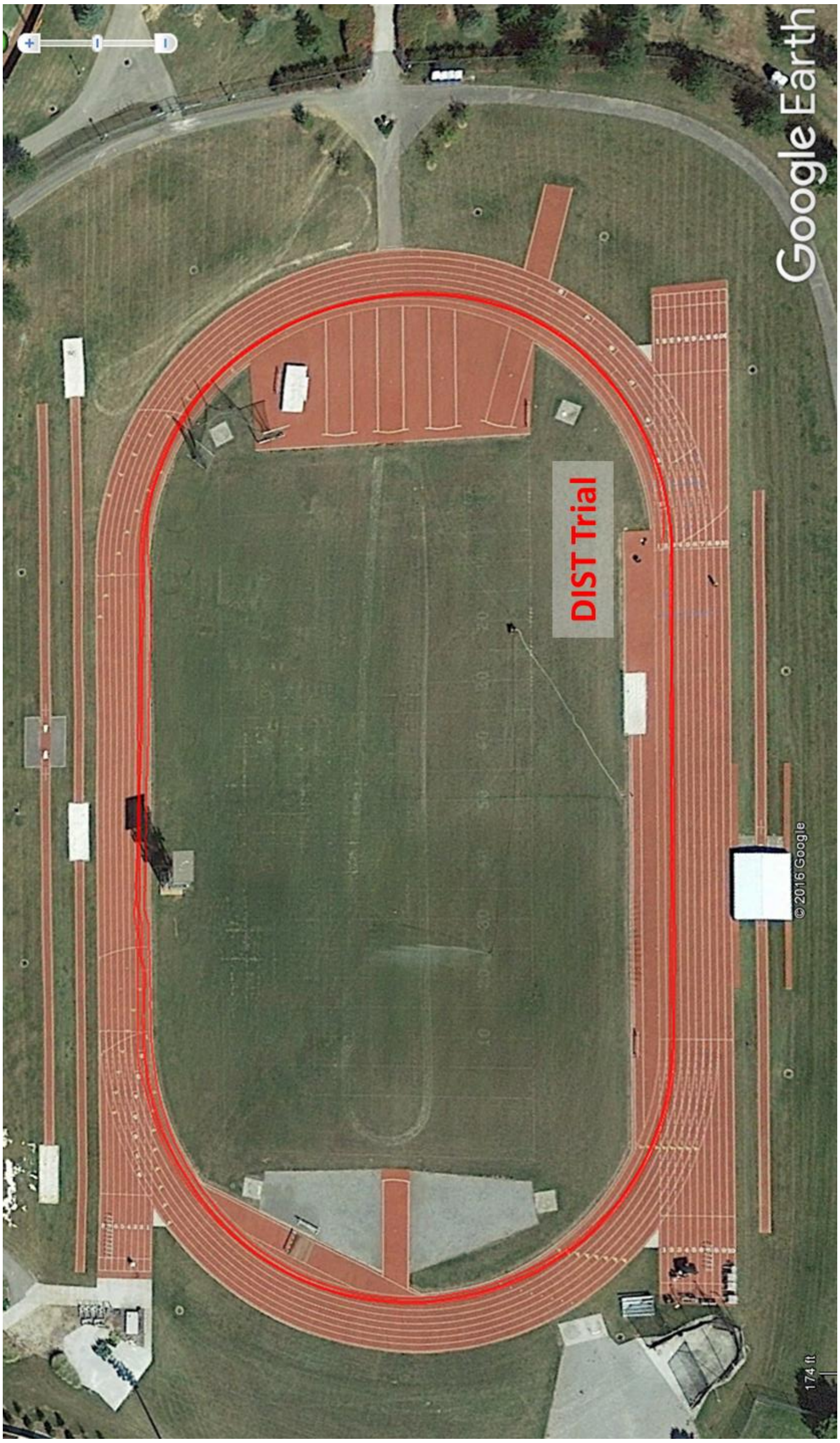


**Figure 27.** Sample GPS data recorded during a DIST trial


**Figure 28.** Sample of Raw GPS Data Recorded During the SHUT, COD and RAND Trials.

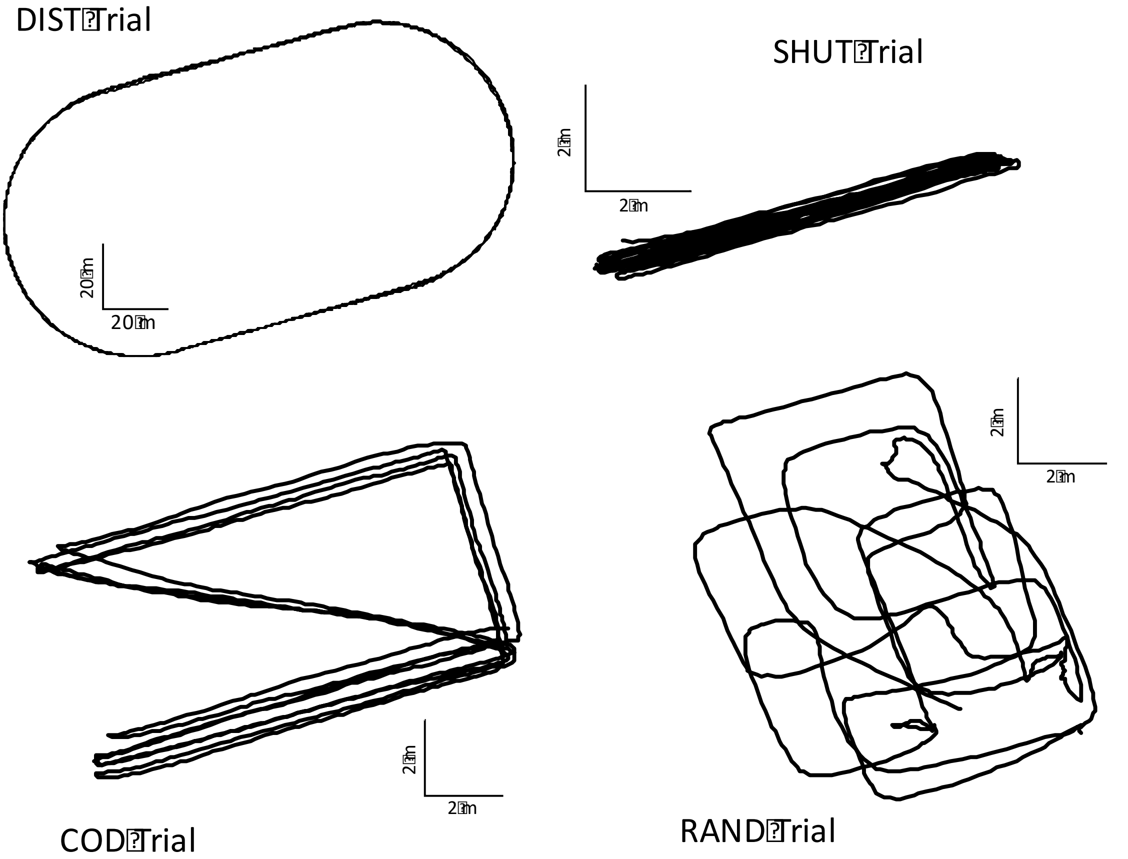


**Figure 29**. Sample of raw GPS data recorded during the DIST, SHUT, COD and RAND trials.

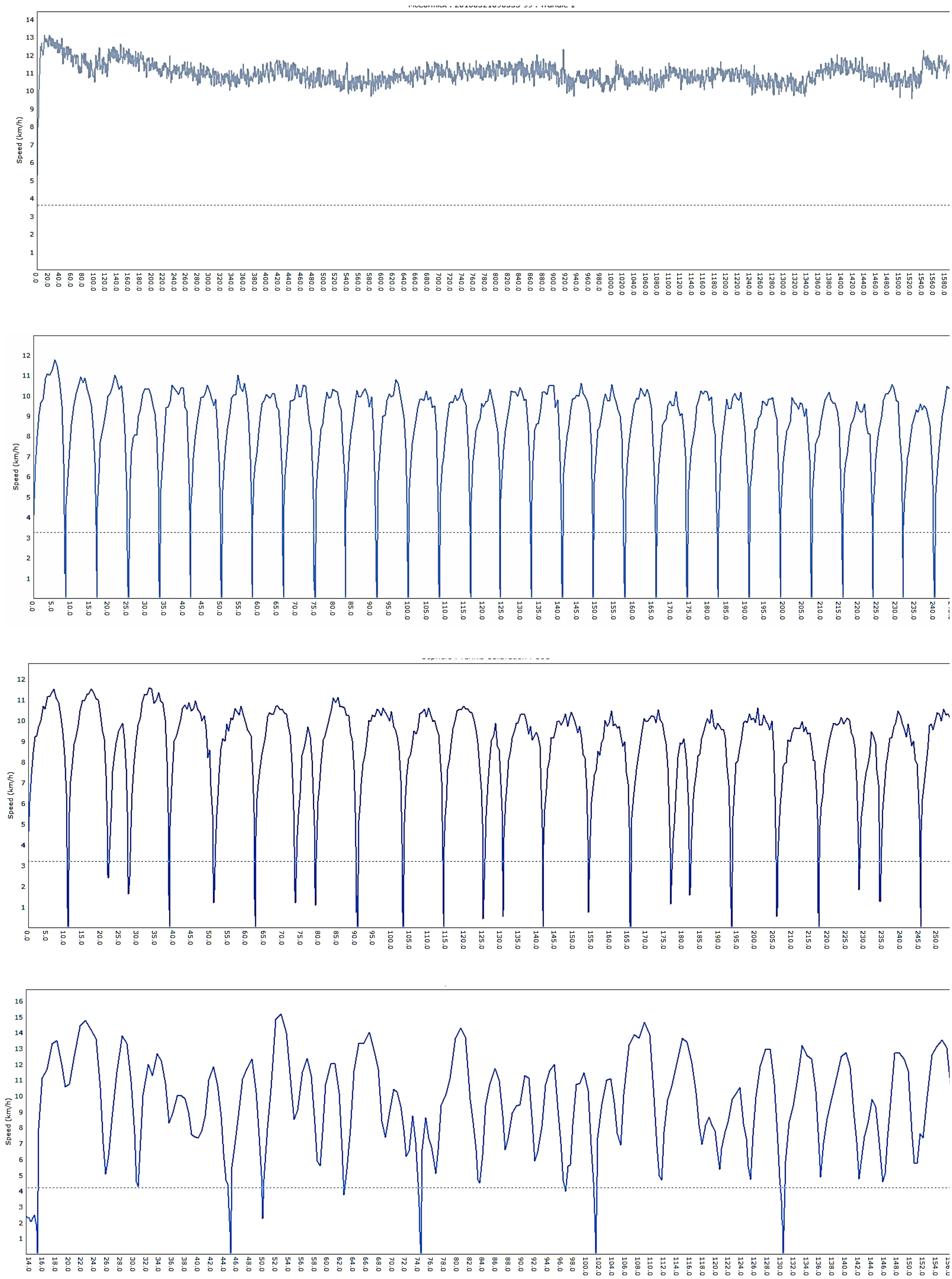


**Figure 30.** Sample distances and speeds during a DIST, SHUT, COD and RAND trial.

**Table 15.** Raw data.

| Unit | Trial | Point | Criterion (m) | Trundle Wheel (m) | GPS Unit (m) | Average (m) | Unit-Wheel (m) | Unit-Wheel (%) | RMS Error (m) | RMS Error (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | SHUT | 1 | 49.4 | 49.8 | 50.7 | 50 | -0.87 | -1.730 | 0.870 | 1.730 |
| 1 | SHUT | 2 | 98.8 | 99.7 | 101.3 | 101 | -1.66 | -1.652 | 1.660 | 1.652 |
| 1 | SHUT | 3 | 148.1 | 149.5 | 151.9 | 151 | -2.38 | -1.579 | 2.380 | 1.579 |
| 1 | SHUT | 4 | 197.5 | 199.4 | 202.5 | 201 | -3.14 | -1.563 | 3.140 | 1.563 |
| 1 | SHUT | 5 | 246.9 | 249.2 | 253.2 | 251 | -4.00 | -1.592 | 4.000 | 1.592 |
| 2 | SHUT | 1 | 49.4 | 49.8 | 48.8 | 49 | 1.07 | 2.170 | 1.070 | 2.170 |
| 2 | SHUT | 2 | 98.8 | 99.7 | 97.5 | 99 | 2.20 | 2.232 | 2.200 | 2.232 |
| 2 | SHUT | 3 | 148.1 | 149.5 | 146.0 | 148 | 3.52 | 2.382 | 3.520 | 2.382 |
| 2 | SHUT | 4 | 197.5 | 199.4 | 194.7 | 197 | 4.63 | 2.350 | 4.630 | 2.350 |
| 2 | SHUT | 5 | 246.9 | 249.2 | 243.5 | 246 | 5.70 | 2.314 | 5.700 | 2.314 |
| 3 | SHUT | 1 | 49.4 | 48.3 | 49.3 | 49 | -1.03 | -2.110 | 1.030 | 2.110 |
| 3 | SHUT | 2 | 98.8 | 96.6 | 98.6 | 98 | -1.95 | -1.998 | 1.950 | 1.998 |
| 3 | SHUT | 3 | 148.1 | 144.9 | 147.8 | 146 | -2.86 | -1.954 | 2.860 | 1.954 |
| 3 | SHUT | 4 | 197.5 | 193.2 | 197.0 | 195 | -3.80 | -1.948 | 3.800 | 1.948 |
| 3 | SHUT | 5 | 246.9 | 241.5 | 246.3 | 244 | -4.80 | -1.968 | 4.800 | 1.968 |
| 4 | SHUT | 1 | 49.4 | 48.3 | 48.8 | 49 | -0.48 | -0.989 | 0.480 | 0.989 |
| 4 | SHUT | 2 | 98.8 | 96.6 | 97.6 | 97 | -1.02 | -1.050 | 1.020 | 1.050 |
| 4 | SHUT | 3 | 148.1 | 144.9 | 146.4 | 146 | -1.52 | -1.044 | 1.520 | 1.044 |
| 4 | SHUT | 4 | 197.5 | 193.2 | 195.4 | 194 | -2.16 | -1.112 | 2.160 | 1.112 |
| 4 | SHUT | 5 | 246.9 | 241.5 | 244.2 | 243 | -2.70 | -1.112 | 2.700 | 1.112 |
| 5 | SHUT | 1 | 49.4 | 49.0 | 48.7 | 49 | 0.31 | 0.635 | 0.310 | 0.635 |
| 5 | SHUT | 2 | 98.8 | 98.0 | 97.2 | 98 | 0.77 | 0.789 | 0.770 | 0.789 |
| 5 | SHUT | 3 | 148.1 | 147.0 | 145.9 | 146 | 1.10 | 0.751 | 1.100 | 0.751 |
| 5 | SHUT | 4 | 197.5 | 196.0 | 194.4 | 195 | 1.59 | 0.815 | 1.590 | 0.815 |
| 5 | SHUT | 5 | 246.9 | 245.0 | 243.0 | 244 | 2.00 | 0.820 | 2.000 | 0.820 |
| 6 | SHUT | 1 | 49.4 | 49.0 | 50.0 | 49 | -0.97 | -1.960 | 0.970 | 1.960 |
| 6 | SHUT | 2 | 98.8 | 98.0 | 100.1 | 99 | -2.13 | -2.150 | 2.130 | 2.150 |
| 6 | SHUT | 3 | 148.1 | 147.0 | 150.2 | 149 | -3.17 | -2.133 | 3.170 | 2.133 |
| 6 | SHUT | 4 | 197.5 | 196.0 | 200.2 | 198 | -4.23 | -2.135 | 4.230 | 2.135 |
| 6 | SHUT | 5 | 246.9 | 245.0 | 250.3 | 248 | -5.30 | -2.140 | 5.300 | 2.140 |
| 7 | SHUT | 1 | 49.4 | 49.9 | 50.4 | 50 | -0.57 | -1.137 | 0.570 | 1.137 |
| 7 | SHUT | 2 | 98.8 | 99.7 | 100.6 | 100 | -0.89 | -0.889 | 0.890 | 0.889 |
| 7 | SHUT | 3 | 148.1 | 149.6 | 150.9 | 150 | -1.34 | -0.892 | 1.340 | 0.892 |
| 7 | SHUT | 4 | 197.5 | 199.4 | 201.3 | 200 | -1.89 | -0.943 | 1.890 | 0.943 |
| 7 | SHUT | 5 | 246.9 | 249.3 | 251.7 | 251 | -2.40 | -0.958 | 2.400 | 0.958 |
| 8 | SHUT | 1 | 49.4 | 49.9 | 50.0 | 50 | -0.18 | -0.360 | 0.180 | 0.360 |
| 8 | SHUT | 2 | 98.8 | 99.7 | 100.0 | 100 | -0.24 | -0.240 | 0.240 | 0.240 |
| 8 | SHUT | 3 | 148.1 | 149.6 | 149.9 | 150 | -0.36 | -0.240 | 0.360 | 0.240 |
| 8 | SHUT | 4 | 197.5 | 199.4 | 199.9 | 200 | -0.48 | -0.240 | 0.480 | 0.240 |
| 8 | SHUT | 5 | 246.9 | 249.3 | 249.9 | 250 | -0.60 | -0.240 | 0.600 | 0.240 |
| 9 | SHUT | 1 | 49.4 | 49.6 | 49.7 | 50 | -0.09 | -0.181 | 0.090 | 0.181 |
| 9 | SHUT | 2 | 98.8 | 99.2 | 99.4 | 99 | -0.24 | -0.242 | 0.240 | 0.242 |
| 9 | SHUT | 3 | 148.1 | 148.8 | 149.1 | 149 | -0.30 | -0.201 | 0.300 | 0.201 |
| 9 | SHUT | 4 | 197.5 | 198.4 | 198.7 | 199 | -0.34 | -0.171 | 0.340 | 0.171 |
| 9 | SHUT | 5 | 246.9 | 248.0 | 248.4 | 248 | -0.40 | -0.161 | 0.400 | 0.161 |
| 10 | SHUT | 1 | 49.4 | 49.6 | 50.2 | 50 | -0.63 | -1.262 | 0.630 | 1.262 |
| 10 | SHUT | 2 | 98.8 | 99.2 | 100.6 | 100 | -1.35 | -1.352 | 1.350 | 1.352 |
| 10 | SHUT | 3 | 148.1 | 148.8 | 150.9 | 150 | -2.05 | -1.368 | 2.050 | 1.368 |

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|---|---|---|---|---|---|---|---|---|---|---|
| 10 | SHUT | 4 | 197.5 | 198.4 | 201.1 | 200 | -2.69 | -1.347 | 2.690 | 1.347 |
| 10 | SHUT | 5 | 246.9 | 248.0 | 251.3 | 250 | -3.30 | -1.322 | 3.300 | 1.322 |
| 11 | SHUT | 1 | 49.4 | 49.5 | 48.7 | 49 | 0.87 | 1.772 | 0.870 | 1.772 |
| 11 | SHUT | 2 | 98.8 | 99.0 | 97.1 | 98 | 1.92 | 1.958 | 1.920 | 1.958 |
| 11 | SHUT | 3 | 148.1 | 148.6 | 145.8 | 147 | 2.78 | 1.889 | 2.780 | 1.889 |
| 11 | SHUT | 4 | 197.5 | 198.1 | 194.3 | 196 | 3.79 | 1.932 | 3.790 | 1.932 |
| 11 | SHUT | 5 | 246.9 | 247.6 | 242.8 | 245 | 4.80 | 1.958 | 4.800 | 1.958 |
| 12 | SHUT | 1 | 49.4 | 49.5 | 50.4 | 50 | -0.91 | -1.821 | 0.910 | 1.821 |
| 12 | SHUT | 2 | 98.8 | 99.0 | 101.0 | 100 | -1.92 | -1.920 | 1.920 | 1.920 |
| 12 | SHUT | 3 | 148.1 | 148.6 | 151.3 | 150 | -2.70 | -1.801 | 2.700 | 1.801 |
| 12 | SHUT | 4 | 197.5 | 198.1 | 201.8 | 200 | -3.74 | -1.870 | 3.740 | 1.870 |
| 12 | SHUT | 5 | 246.9 | 247.6 | 252.2 | 250 | -4.60 | -1.841 | 4.600 | 1.841 |
| 13 | SHUT | 1 | 49.4 | 49.5 | 51.7 | 51 | -2.20 | -4.351 | 2.200 | 4.351 |
| 13 | SHUT | 2 | 98.8 | 98.9 | 103.2 | 101 | -4.24 | -4.196 | 4.240 | 4.196 |
| 13 | SHUT | 3 | 148.1 | 148.4 | 154.7 | 152 | -6.33 | -4.177 | 6.330 | 4.177 |
| 13 | SHUT | 4 | 197.5 | 197.8 | 206.4 | 202 | -8.51 | -4.211 | 8.510 | 4.211 |
| 13 | SHUT | 5 | 246.9 | 247.3 | 257.9 | 253 | -10.60 | -4.196 | 10.600 | 4.196 |
| 14 | SHUT | 1 | 49.4 | 49.5 | 48.7 | 49 | 0.79 | 1.610 | 0.790 | 1.610 |
| 14 | SHUT | 2 | 98.8 | 98.9 | 97.2 | 98 | 1.70 | 1.733 | 1.700 | 1.733 |
| 14 | SHUT | 3 | 148.1 | 148.4 | 145.8 | 147 | 2.55 | 1.733 | 2.550 | 1.733 |
| 14 | SHUT | 4 | 197.5 | 197.8 | 194.2 | 196 | 3.62 | 1.847 | 3.620 | 1.847 |
| 14 | SHUT | 5 | 246.9 | 247.3 | 242.9 | 245 | 4.40 | 1.795 | 4.400 | 1.795 |
| 15 | SHUT | 1 | 49.4 | 49.4 | 49.2 | 49 | 0.25 | 0.507 | 0.250 | 0.507 |
| 15 | SHUT | 2 | 98.8 | 98.8 | 98.3 | 99 | 0.50 | 0.507 | 0.500 | 0.507 |
| 15 | SHUT | 3 | 148.1 | 148.2 | 147.5 | 148 | 0.74 | 0.501 | 0.740 | 0.501 |
| 15 | SHUT | 4 | 197.5 | 197.6 | 196.6 | 197 | 1.00 | 0.507 | 1.000 | 0.507 |
| 15 | SHUT | 5 | 246.9 | 247.0 | 245.8 | 246 | 1.20 | 0.487 | 1.200 | 0.487 |
| 16 | SHUT | 1 | 49.4 | 49.4 | 49.3 | 49 | 0.06 | 0.122 | 0.060 | 0.122 |
| 16 | SHUT | 2 | 98.8 | 98.0 | 97.1 | 98 | 0.89 | 0.912 | 0.890 | 0.912 |
| 16 | SHUT | 3 | 148.1 | 147.0 | 145.9 | 146 | 1.12 | 0.765 | 1.120 | 0.765 |
| 16 | SHUT | 4 | 197.5 | 196.0 | 194.4 | 195 | 1.65 | 0.845 | 1.650 | 0.845 |
| 16 | SHUT | 5 | 246.9 | 247.0 | 246.7 | 247 | 0.30 | 0.122 | 0.300 | 0.122 |
| 17 | SHUT | 1 | 49.4 | 49.2 | 49.3 | 49 | -0.09 | -0.183 | 0.090 | 0.183 |
| 17 | SHUT | 2 | 98.8 | 98.4 | 98.5 | 98 | -0.10 | -0.102 | 0.100 | 0.102 |
| 17 | SHUT | 3 | 148.1 | 147.5 | 147.9 | 148 | -0.34 | -0.230 | 0.340 | 0.230 |
| 17 | SHUT | 4 | 197.5 | 196.7 | 197.1 | 197 | -0.38 | -0.193 | 0.380 | 0.193 |
| 17 | SHUT | 5 | 246.9 | 245.9 | 246.3 | 246 | -0.40 | -0.163 | 0.400 | 0.163 |
| 18 | SHUT | 1 | 49.4 | 49.2 | 49.7 | 49 | -0.48 | -0.971 | 0.480 | 0.971 |
| 18 | SHUT | 2 | 98.8 | 98.4 | 99.1 | 99 | -0.76 | -0.770 | 0.760 | 0.770 |
| 18 | SHUT | 3 | 148.1 | 147.5 | 148.8 | 148 | -1.24 | -0.837 | 1.240 | 0.837 |
| 18 | SHUT | 4 | 197.5 | 196.7 | 198.3 | 198 | -1.60 | -0.810 | 1.600 | 0.810 |
| 18 | SHUT | 5 | 246.9 | 245.9 | 247.8 | 247 | -1.90 | -0.770 | 1.900 | 0.770 |
| 19 | SHUT | 1 | 49.4 | 49.6 | 50.1 | 50 | -0.43 | -0.863 | 0.430 | 0.863 |
| 19 | SHUT | 2 | 98.8 | 99.2 | 100.0 | 100 | -0.76 | -0.763 | 0.760 | 0.763 |
| 19 | SHUT | 3 | 148.1 | 148.9 | 150.1 | 149 | -1.25 | -0.836 | 1.250 | 0.836 |
| 19 | SHUT | 4 | 197.5 | 198.5 | 200.0 | 199 | -1.53 | -0.768 | 1.530 | 0.768 |
| 19 | SHUT | 5 | 246.9 | 248.1 | 250.1 | 249 | -2.00 | -0.803 | 2.000 | 0.803 |
| 20 | SHUT | 1 | 49.4 | 49.6 | 49.8 | 50 | -0.18 | -0.362 | 0.180 | 0.362 |
| 20 | SHUT | 2 | 98.8 | 99.2 | 99.7 | 99 | -0.43 | -0.432 | 0.430 | 0.432 |
| 20 | SHUT | 3 | 148.1 | 148.9 | 149.5 | 149 | -0.63 | -0.422 | 0.630 | 0.422 |
| 20 | SHUT | 4 | 197.5 | 198.5 | 199.4 | 199 | -0.95 | -0.477 | 0.950 | 0.477 |
| 20 | SHUT | 5 | 246.9 | 248.1 | 249.3 | 249 | -1.20 | -0.483 | 1.200 | 0.483 |
| 1 | COD | 1 | 49.8 | 50.8 | 51.6 | 51 | -0.79 | -1.544 | 0.790 | 1.544 |
| 1 | COD | 2 | 99.6 | 101.5 | 103.3 | 102 | -1.80 | -1.757 | 1.800 | 1.757 |

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|---|---|---|---|---|---|---|---|---|---|---|
| 1 | COD | 3 | 149.4 | 152.3 | 154.8 | 154 | -2.51 | -1.635 | 2.510 | 1.635 |
| 1 | COD | 4 | 199.2 | 203.0 | 206.5 | 205 | -3.45 | -1.685 | 3.450 | 1.685 |
| 1 | COD | 5 | 249.0 | 253.8 | 258.1 | 256 | -4.30 | -1.680 | 4.300 | 1.680 |
| 2 | COD | 1 | 49.8 | 50.8 | 52.0 | 51 | -1.20 | -2.336 | 1.200 | 2.336 |
| 2 | COD | 2 | 99.6 | 101.5 | 104.2 | 103 | -2.63 | -2.557 | 2.630 | 2.557 |
| 2 | COD | 3 | 149.4 | 152.3 | 156.2 | 154 | -3.92 | -2.541 | 3.920 | 2.541 |
| 2 | COD | 4 | 199.2 | 203.0 | 208.2 | 206 | -5.16 | -2.509 | 5.160 | 2.509 |
| 2 | COD | 5 | 249.0 | 253.8 | 260.3 | 257 | -6.50 | -2.529 | 6.500 | 2.529 |
| 3 | COD | 1 | 49.8 | 50.7 | 51.6 | 51 | -0.87 | -1.701 | 0.870 | 1.701 |
| 3 | COD | 2 | 99.6 | 101.4 | 103.0 | 102 | -1.60 | -1.566 | 1.600 | 1.566 |
| 3 | COD | 3 | 149.4 | 152.1 | 154.5 | 153 | -2.36 | -1.540 | 2.360 | 1.540 |
| 3 | COD | 4 | 199.2 | 202.8 | 206.2 | 204 | -3.35 | -1.638 | 3.350 | 1.638 |
| 3 | COD | 5 | 249.0 | 253.5 | 257.6 | 256 | -4.10 | -1.604 | 4.100 | 1.604 |
| 4 | COD | 1 | 49.8 | 50.7 | 52.5 | 52 | -1.77 | -3.431 | 1.770 | 3.431 |
| 4 | COD | 2 | 99.6 | 101.4 | 104.9 | 103 | -3.54 | -3.431 | 3.540 | 3.431 |
| 4 | COD | 3 | 149.4 | 152.1 | 157.4 | 155 | -5.25 | -3.393 | 5.250 | 3.393 |
| 4 | COD | 4 | 199.2 | 202.8 | 209.8 | 206 | -6.95 | -3.369 | 6.950 | 3.369 |
| 4 | COD | 5 | 249.0 | 253.5 | 262.1 | 258 | -8.60 | -3.336 | 8.600 | 3.336 |
| 5 | COD | 1 | 49.8 | 50.8 | 50.9 | 51 | -0.07 | -0.138 | 0.070 | 0.138 |
| 5 | COD | 2 | 99.6 | 101.6 | 101.6 | 102 | -0.01 | -0.010 | 0.010 | 0.010 |
| 5 | COD | 3 | 149.4 | 152.3 | 152.5 | 152 | -0.14 | -0.092 | 0.140 | 0.092 |
| 5 | COD | 4 | 199.2 | 203.1 | 203.3 | 203 | -0.15 | -0.074 | 0.150 | 0.074 |
| 5 | COD | 5 | 249.0 | 253.9 | 254.0 | 254 | -0.10 | -0.039 | 0.100 | 0.039 |
| 6 | COD | 1 | 49.8 | 50.8 | 52.4 | 52 | -1.58 | -3.064 | 1.580 | 3.064 |
| 6 | COD | 2 | 99.6 | 101.6 | 104.7 | 103 | -3.09 | -2.997 | 3.090 | 2.997 |
| 6 | COD | 3 | 149.4 | 152.3 | 157.0 | 155 | -4.66 | -3.013 | 4.660 | 3.013 |
| 6 | COD | 4 | 199.2 | 203.1 | 209.3 | 206 | -6.15 | -2.983 | 6.150 | 2.983 |
| 6 | COD | 5 | 249.0 | 253.9 | 261.5 | 258 | -7.60 | -2.949 | 7.600 | 2.949 |
| 7 | COD | 1 | 49.8 | 51.9 | 50.6 | 51 | 1.26 | 2.459 | 1.260 | 2.459 |
| 7 | COD | 2 | 99.6 | 103.8 | 101.4 | 103 | 2.38 | 2.320 | 2.380 | 2.320 |
| 7 | COD | 3 | 149.4 | 155.6 | 152.0 | 154 | 3.64 | 2.366 | 3.640 | 2.366 |
| 7 | COD | 4 | 199.2 | 207.5 | 202.8 | 205 | 4.70 | 2.291 | 4.700 | 2.291 |
| 7 | COD | 5 | 249.0 | 259.4 | 253.5 | 256 | 5.90 | 2.301 | 5.900 | 2.301 |
| 8 | COD | 1 | 49.8 | 50.7 | 50.5 | 51 | 0.16 | 0.316 | 0.160 | 0.316 |
| 8 | COD | 2 | 99.6 | 101.4 | 101.2 | 101 | 0.19 | 0.188 | 0.190 | 0.188 |
| 8 | COD | 3 | 149.4 | 152.1 | 151.7 | 152 | 0.44 | 0.290 | 0.440 | 0.290 |
| 8 | COD | 4 | 199.2 | 202.8 | 202.4 | 203 | 0.45 | 0.222 | 0.450 | 0.222 |
| 8 | COD | 5 | 249.0 | 253.5 | 252.9 | 253 | 0.60 | 0.237 | 0.600 | 0.237 |
| 9 | COD | 1 | 49.8 | 50.8 | 51.1 | 51 | -0.33 | -0.648 | 0.330 | 0.648 |
| 9 | COD | 2 | 99.6 | 101.6 | 102.3 | 102 | -0.77 | -0.755 | 0.770 | 0.755 |
| 9 | COD | 3 | 149.4 | 152.3 | 153.6 | 153 | -1.26 | -0.824 | 1.260 | 0.824 |
| 9 | COD | 4 | 199.2 | 203.1 | 204.9 | 204 | -1.73 | -0.848 | 1.730 | 0.848 |
| 9 | COD | 5 | 249.0 | 253.9 | 256.0 | 255 | -2.10 | -0.824 | 2.100 | 0.824 |
| 10 | COD | 1 | 49.8 | 50.8 | 49.0 | 50 | 1.77 | 3.547 | 1.770 | 3.547 |
| 10 | COD | 2 | 99.6 | 101.6 | 98.2 | 100 | 3.32 | 3.323 | 3.320 | 3.323 |
| 10 | COD | 3 | 149.4 | 152.3 | 147.2 | 150 | 5.12 | 3.418 | 5.120 | 3.418 |
| 10 | COD | 4 | 199.2 | 203.1 | 196.3 | 200 | 6.79 | 3.400 | 6.790 | 3.400 |
| 10 | COD | 5 | 249.0 | 253.9 | 245.5 | 250 | 8.40 | 3.364 | 8.400 | 3.364 |
| 11 | COD | 1 | 49.8 | 50.9 | 49.7 | 50 | 1.18 | 2.345 | 1.180 | 2.345 |
| 11 | COD | 2 | 99.6 | 101.8 | 99.3 | 101 | 2.50 | 2.485 | 2.500 | 2.485 |
| 11 | COD | 3 | 149.4 | 152.8 | 149.3 | 151 | 3.50 | 2.318 | 3.500 | 2.318 |
| 11 | COD | 4 | 199.2 | 203.7 | 198.8 | 201 | 4.87 | 2.420 | 4.870 | 2.420 |
| 11 | COD | 5 | 249.0 | 254.6 | 248.6 | 252 | 6.00 | 2.385 | 6.000 | 2.385 |
| 12 | COD | 1 | 49.8 | 50.9 | 50.3 | 51 | 0.65 | 1.285 | 0.650 | 1.285 |

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| 12 | COD | 2 | 99.6 | 101.8 | 100.5 | 101 | 1.33 | 1.315 | 1.330 | 1.315 |
| 12 | COD | 3 | 149.4 | 152.8 | 150.9 | 152 | 1.83 | 1.205 | 1.830 | 1.205 |
| 12 | COD | 4 | 199.2 | 203.7 | 201.2 | 202 | 2.46 | 1.215 | 2.460 | 1.215 |
| 12 | COD | 5 | 249.0 | 254.6 | 251.5 | 253 | 3.10 | 1.225 | 3.100 | 1.225 |
| 13 | COD | 1 | 49.8 | 50.3 | 51.1 | 51 | -0.74 | -1.459 | 0.740 | 1.459 |
| 13 | COD | 2 | 99.6 | 100.7 | 102.4 | 102 | -1.68 | -1.655 | 1.680 | 1.655 |
| 13 | COD | 3 | 149.4 | 151.0 | 153.3 | 152 | -2.31 | -1.518 | 2.310 | 1.518 |
| 13 | COD | 4 | 199.2 | 201.4 | 204.6 | 203 | -3.27 | -1.611 | 3.270 | 1.611 |
| 13 | COD | 5 | 249.0 | 251.7 | 255.7 | 254 | -4.00 | -1.577 | 4.000 | 1.577 |
| 14 | COD | 1 | 49.8 | 50.3 | 50.9 | 51 | -0.58 | -1.146 | 0.580 | 1.146 |
| 14 | COD | 2 | 99.6 | 100.7 | 102.0 | 101 | -1.30 | -1.283 | 1.300 | 1.283 |
| 14 | COD | 3 | 149.4 | 151.0 | 153.0 | 152 | -1.96 | -1.289 | 1.960 | 1.289 |
| 14 | COD | 4 | 199.2 | 201.4 | 203.8 | 203 | -2.46 | -1.214 | 2.460 | 1.214 |
| 14 | COD | 5 | 249.0 | 251.7 | 254.9 | 253 | -3.20 | -1.263 | 3.200 | 1.263 |
| 15 | COD | 1 | 49.8 | 52.0 | 51.1 | 52 | 0.83 | 1.610 | 0.830 | 1.610 |
| 15 | COD | 2 | 99.6 | 103.9 | 102.3 | 103 | 1.65 | 1.600 | 1.650 | 1.600 |
| 15 | COD | 3 | 149.4 | 155.9 | 153.4 | 155 | 2.48 | 1.604 | 2.480 | 1.604 |
| 15 | COD | 4 | 199.2 | 207.8 | 204.5 | 206 | 3.36 | 1.630 | 3.360 | 1.630 |
| 15 | COD | 5 | 249.0 | 259.8 | 255.7 | 258 | 4.10 | 1.591 | 4.100 | 1.591 |
| 16 | COD | 1 | 49.8 | 51.1 | 50.7 | 51 | 0.49 | 0.963 | 0.490 | 0.963 |
| 16 | COD | 2 | 99.6 | 102.3 | 101.4 | 102 | 0.84 | 0.825 | 0.840 | 0.825 |
| 16 | COD | 3 | 149.4 | 153.4 | 152.3 | 153 | 1.16 | 0.759 | 1.160 | 0.759 |
| 16 | COD | 4 | 199.2 | 204.6 | 202.9 | 204 | 1.63 | 0.800 | 1.630 | 0.800 |
| 16 | COD | 5 | 249.0 | 255.7 | 253.6 | 255 | 2.10 | 0.825 | 2.100 | 0.825 |
| 17 | COD | 1 | 49.8 | 50.7 | 51.3 | 51 | -0.54 | -1.059 | 0.540 | 1.059 |
| 17 | COD | 2 | 99.6 | 101.4 | 102.7 | 102 | -1.21 | -1.186 | 1.210 | 1.186 |
| 17 | COD | 3 | 149.4 | 152.2 | 153.9 | 153 | -1.70 | -1.111 | 1.700 | 1.111 |
| 17 | COD | 4 | 199.2 | 202.9 | 205.2 | 204 | -2.36 | -1.157 | 2.360 | 1.157 |
| 17 | COD | 5 | 249.0 | 253.6 | 256.6 | 255 | -3.00 | -1.176 | 3.000 | 1.176 |
| 18 | COD | 1 | 49.8 | 50.7 | 51.0 | 51 | -0.27 | -0.531 | 0.270 | 0.531 |
| 18 | COD | 2 | 99.6 | 101.4 | 102.0 | 102 | -0.51 | -0.501 | 0.510 | 0.501 |
| 18 | COD | 3 | 149.4 | 152.2 | 152.8 | 152 | -0.62 | -0.407 | 0.620 | 0.407 |
| 18 | COD | 4 | 199.2 | 202.9 | 203.8 | 203 | -0.90 | -0.443 | 0.900 | 0.443 |
| 18 | COD | 5 | 249.0 | 253.6 | 254.8 | 254 | -1.20 | -0.472 | 1.200 | 0.472 |
| 19 | COD | 1 | 49.8 | 51.3 | 50.1 | 51 | 1.28 | 2.525 | 1.280 | 2.525 |
| 19 | COD | 2 | 99.6 | 102.7 | 100.1 | 101 | 2.60 | 2.565 | 2.600 | 2.565 |
| 19 | COD | 3 | 149.4 | 154.0 | 150.2 | 152 | 3.87 | 2.545 | 3.870 | 2.545 |
| 19 | COD | 4 | 199.2 | 205.4 | 200.3 | 203 | 5.04 | 2.485 | 5.040 | 2.485 |
| 19 | COD | 5 | 249.0 | 256.7 | 250.4 | 254 | 6.30 | 2.485 | 6.300 | 2.485 |
| 20 | COD | 1 | 49.8 | 50.1 | 51.0 | 51 | -0.91 | -1.801 | 0.910 | 1.801 |
| 20 | COD | 2 | 99.6 | 100.2 | 102.2 | 101 | -2.03 | -2.006 | 2.030 | 2.006 |
| 20 | COD | 3 | 149.4 | 150.2 | 153.3 | 152 | -3.02 | -1.990 | 3.020 | 1.990 |
| 20 | COD | 4 | 199.2 | 200.3 | 204.4 | 202 | -4.10 | -2.026 | 4.100 | 2.026 |
| 20 | COD | 5 | 249.0 | 250.4 | 255.4 | 253 | -5.00 | -1.977 | 5.000 | 1.977 |
| 1 | RAND | 1 | | 27.6 | 29.0 | 28 | -1.40 | -4.947 | 1.400 | 4.947 |
| 1 | RAND | 2 | | 57.1 | 60.4 | 59 | -3.30 | -5.617 | 3.300 | 5.617 |
| 1 | RAND | 3 | | 82.6 | 88.3 | 85 | -5.70 | -6.671 | 5.700 | 6.671 |
| 1 | RAND | 4 | | 109.6 | 113.0 | 111 | -3.40 | -3.055 | 3.400 | 3.055 |
| 1 | RAND | 5 | | 135.6 | 138.6 | 137 | -3.00 | -2.188 | 3.000 | 2.188 |
| 2 | RAND | 1 | | 27.6 | 27.9 | 28 | -0.30 | -1.081 | 0.300 | 1.081 |
| 2 | RAND | 2 | | 57.1 | 58.1 | 58 | -1.00 | -1.736 | 1.000 | 1.736 |
| 2 | RAND | 3 | | 82.6 | 83.2 | 83 | -0.60 | -0.724 | 0.600 | 0.724 |
| 2 | RAND | 4 | | 109.6 | 113.0 | 111 | -3.40 | -3.055 | 3.400 | 3.055 |
| 2 | RAND | 5 | | 135.6 | 139.4 | 138 | -3.80 | -2.764 | 3.800 | 2.764 |

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|---|---|---|---|---|---|---|---|---|---|---|
| 3 | RAND | 1 | | 27.3 | 28.2 | 28 | -0.90 | -3.243 | 0.900 | 3.243 |
| 3 | RAND | 2 | | 52.9 | 55.1 | 54 | -2.20 | -4.074 | 2.200 | 4.074 |
| 3 | RAND | 3 | | 85.0 | 88.7 | 87 | -3.70 | -4.260 | 3.700 | 4.260 |
| 3 | RAND | 4 | | 109.8 | 114.3 | 112 | -4.50 | -4.016 | 4.500 | 4.016 |
| 3 | RAND | 5 | | 134.2 | 139.8 | 137 | -5.60 | -4.088 | 5.600 | 4.088 |
| 4 | RAND | 1 | | 27.3 | 28.3 | 28 | -1.00 | -3.597 | 1.000 | 3.597 |
| 4 | RAND | 2 | | 52.9 | 55.8 | 54 | -2.90 | -5.336 | 2.900 | 5.336 |
| 4 | RAND | 3 | | 85.0 | 87.9 | 86 | -2.90 | -3.355 | 2.900 | 3.355 |
| 4 | RAND | 4 | | 109.8 | 111.8 | 111 | -2.00 | -1.805 | 2.000 | 1.805 |
| 4 | RAND | 5 | | 134.2 | 138.6 | 136 | -4.40 | -3.226 | 4.400 | 3.226 |
| 5 | RAND | 1 | | 28.4 | 28.7 | 29 | -0.30 | -1.051 | 0.300 | 1.051 |
| 5 | RAND | 2 | | 56.5 | 57.5 | 57 | -1.00 | -1.754 | 1.000 | 1.754 |
| 5 | RAND | 3 | | 84.9 | 85.9 | 85 | -1.00 | -1.171 | 1.000 | 1.171 |
| 5 | RAND | 4 | | 115.8 | 117.2 | 117 | -1.40 | -1.202 | 1.400 | 1.202 |
| 5 | RAND | 5 | | 142.3 | 143.1 | 143 | -0.80 | -0.561 | 0.800 | 0.561 |
| 6 | RAND | 1 | | 28.4 | 28.9 | 29 | -0.50 | -1.745 | 0.500 | 1.745 |
| 6 | RAND | 2 | | 56.5 | 58.5 | 58 | -2.00 | -3.478 | 2.000 | 3.478 |
| 6 | RAND | 3 | | 84.9 | 87.0 | 86 | -2.10 | -2.443 | 2.100 | 2.443 |
| 6 | RAND | 4 | | 115.8 | 115.2 | 116 | 0.60 | 0.519 | 0.600 | 0.519 |
| 6 | RAND | 5 | | 142.3 | 142.6 | 142 | -0.30 | -0.211 | 0.300 | 0.211 |
| 7 | RAND | 1 | | 28.1 | 29.3 | 29 | -1.20 | -4.181 | 1.200 | 4.181 |
| 7 | RAND | 2 | | 55.7 | 57.3 | 57 | -1.60 | -2.832 | 1.600 | 2.832 |
| 7 | RAND | 3 | | 82.3 | 84.7 | 84 | -2.40 | -2.874 | 2.400 | 2.874 |
| 7 | RAND | 4 | | 112.3 | 115.8 | 114 | -3.50 | -3.069 | 3.500 | 3.069 |
| 7 | RAND | 5 | | 137.3 | 141.9 | 140 | -4.60 | -3.295 | 4.600 | 3.295 |
| 8 | RAND | 1 | | 28.1 | 29.1 | 29 | -1.00 | -3.497 | 1.000 | 3.497 |
| 8 | RAND | 2 | | 55.7 | 56.6 | 56 | -0.90 | -1.603 | 0.900 | 1.603 |
| 8 | RAND | 3 | | 82.3 | 82.6 | 82 | -0.30 | -0.364 | 0.300 | 0.364 |
| 8 | RAND | 4 | | 112.3 | 112.9 | 113 | -0.60 | -0.533 | 0.600 | 0.533 |
| 8 | RAND | 5 | | 137.3 | 138.1 | 138 | -0.80 | -0.581 | 0.800 | 0.581 |
| 9 | RAND | 1 | | 29.4 | 29.9 | 30 | -0.50 | -1.686 | 0.500 | 1.686 |
| 9 | RAND | 2 | | 57.7 | 58.3 | 58 | -0.60 | -1.034 | 0.600 | 1.034 |
| 9 | RAND | 3 | | 83.7 | 83.3 | 84 | 0.40 | 0.479 | 0.400 | 0.479 |
| 9 | RAND | 4 | | 112.2 | 115.2 | 114 | -3.00 | -2.639 | 3.000 | 2.639 |
| 9 | RAND | 5 | | 139.6 | 143.4 | 142 | -3.80 | -2.686 | 3.800 | 2.686 |
| 10 | RAND | 1 | | 29.4 | 30.0 | 30 | -0.60 | -2.020 | 0.600 | 2.020 |
| 10 | RAND | 2 | | 57.7 | 58.2 | 58 | -0.50 | -0.863 | 0.500 | 0.863 |
| 10 | RAND | 3 | | 83.7 | 84.9 | 84 | -1.20 | -1.423 | 1.200 | 1.423 |
| 10 | RAND | 4 | | 112.2 | 114.0 | 113 | -1.80 | -1.592 | 1.800 | 1.592 |
| 10 | RAND | 5 | | 139.6 | 142.2 | 141 | -2.60 | -1.845 | 2.600 | 1.845 |
| 11 | RAND | 1 | | 30.0 | 31.5 | 31 | -1.50 | -4.878 | 1.500 | 4.878 |
| 11 | RAND | 2 | | 53.4 | 55.6 | 55 | -2.20 | -4.037 | 2.200 | 4.037 |
| 11 | RAND | 3 | | 78.7 | 81.5 | 80 | -2.80 | -3.496 | 2.800 | 3.496 |
| 11 | RAND | 4 | | 101.0 | 105.3 | 103 | -4.30 | -4.169 | 4.300 | 4.169 |
| 11 | RAND | 5 | | 129.5 | 135.9 | 133 | -6.40 | -4.823 | 6.400 | 4.823 |
| 12 | RAND | 1 | | 30.0 | 31.3 | 31 | -1.30 | -4.241 | 1.300 | 4.241 |
| 12 | RAND | 2 | | 53.4 | 55.6 | 55 | -2.20 | -4.037 | 2.200 | 4.037 |
| 12 | RAND | 3 | | 78.7 | 81.9 | 80 | -3.20 | -3.985 | 3.200 | 3.985 |
| 12 | RAND | 4 | | 101.0 | 105.8 | 103 | -4.80 | -4.642 | 4.800 | 4.642 |
| 12 | RAND | 5 | | 129.5 | 135.0 | 132 | -5.50 | -4.159 | 5.500 | 4.159 |
| 13 | RAND | 1 | | 28.5 | 30.1 | 29 | -1.60 | -5.461 | 1.600 | 5.461 |
| 13 | RAND | 2 | | 52.8 | 54.5 | 54 | -1.70 | -3.169 | 1.700 | 3.169 |
| 13 | RAND | 3 | | 79.3 | 81.7 | 81 | -2.40 | -2.981 | 2.400 | 2.981 |
| 13 | RAND | 4 | | 106.2 | 109.3 | 108 | -3.10 | -2.877 | 3.100 | 2.877 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 13 | RAND | 5 | | 132.9 | 137.0 | 135 | -4.10 | -3.038 | 4.100 | 3.038 |
| 14 | RAND | 1 | | 28.5 | 30.4 | 29 | -1.90 | -6.452 | 1.900 | 6.452 |
| 14 | RAND | 2 | | 52.8 | 55.6 | 54 | -2.80 | -5.166 | 2.800 | 5.166 |
| 14 | RAND | 3 | | 79.3 | 81.8 | 81 | -2.50 | -3.104 | 2.500 | 3.104 |
| 14 | RAND | 4 | | 106.2 | 108.8 | 108 | -2.60 | -2.419 | 2.600 | 2.419 |
| 14 | RAND | 5 | | 132.9 | 136.5 | 135 | -3.60 | -2.673 | 3.600 | 2.673 |
| 15 | RAND | 1 | | 29.0 | 29.1 | 29 | -0.10 | -0.344 | 0.100 | 0.344 |
| 15 | RAND | 2 | | 57.0 | 57.5 | 57 | -0.50 | -0.873 | 0.500 | 0.873 |
| 15 | RAND | 3 | | 87.3 | 88.3 | 88 | -1.00 | -1.139 | 1.000 | 1.139 |
| 15 | RAND | 4 | | 118.5 | 119.8 | 119 | -1.30 | -1.091 | 1.300 | 1.091 |
| 15 | RAND | 5 | | 145.2 | 147.3 | 146 | -2.10 | -1.436 | 2.100 | 1.436 |
| 16 | RAND | 1 | | 29.0 | 30.1 | 30 | -1.10 | -3.723 | 1.100 | 3.723 |
| 16 | RAND | 2 | | 57.0 | 59.3 | 58 | -2.30 | -3.955 | 2.300 | 3.955 |
| 16 | RAND | 3 | | 87.3 | 90.1 | 89 | -2.80 | -3.157 | 2.800 | 3.157 |
| 16 | RAND | 4 | | 118.5 | 121.4 | 120 | -2.90 | -2.418 | 2.900 | 2.418 |
| 16 | RAND | 5 | | 145.2 | 147.1 | 146 | -1.90 | -1.300 | 1.900 | 1.300 |
| 17 | RAND | 1 | | 30.4 | 31.1 | 31 | -0.70 | -2.276 | 0.700 | 2.276 |
| 17 | RAND | 2 | | 59.9 | 58.5 | 59 | 1.40 | 2.365 | 1.400 | 2.365 |
| 17 | RAND | 3 | | 89.5 | 88.3 | 89 | 1.20 | 1.350 | 1.200 | 1.350 |
| 17 | RAND | 4 | | 120.3 | 119.8 | 120 | 0.50 | 0.416 | 0.500 | 0.416 |
| 17 | RAND | 5 | | 147.5 | 147.8 | 148 | -0.30 | -0.203 | 0.300 | 0.203 |
| 18 | RAND | 1 | | 30.4 | 31.0 | 31 | -0.60 | -1.954 | 0.600 | 1.954 |
| 18 | RAND | 2 | | 59.9 | 60.8 | 60 | -0.90 | -1.491 | 0.900 | 1.491 |
| 18 | RAND | 3 | | 89.5 | 90.5 | 90 | -1.00 | -1.111 | 1.000 | 1.111 |
| 18 | RAND | 4 | | 120.3 | 122.8 | 122 | -2.50 | -2.057 | 2.500 | 2.057 |
| 18 | RAND | 5 | | 147.5 | 149.5 | 149 | -2.00 | -1.347 | 2.000 | 1.347 |
| 19 | RAND | 1 | | 28.0 | 29.2 | 29 | -1.20 | -4.196 | 1.200 | 4.196 |
| 19 | RAND | 2 | | 56.5 | 58.5 | 58 | -2.00 | -3.478 | 2.000 | 3.478 |
| 19 | RAND | 3 | | 84.0 | 88.1 | 86 | -4.10 | -4.765 | 4.100 | 4.765 |
| 19 | RAND | 4 | | 113.8 | 119.3 | 117 | -5.50 | -4.719 | 5.500 | 4.719 |
| 19 | RAND | 5 | | 150.8 | 148.3 | 150 | 2.50 | 1.672 | 2.500 | 1.672 |
| 20 | RAND | 1 | | 28.0 | 27.8 | 28 | 0.20 | 0.717 | 0.200 | 0.717 |
| 20 | RAND | 2 | | 56.5 | 58.0 | 57 | -1.50 | -2.620 | 1.500 | 2.620 |
| 20 | RAND | 3 | | 84.0 | 86.6 | 85 | -2.60 | -3.048 | 2.600 | 3.048 |
| 20 | RAND | 4 | | 113.8 | 116.8 | 115 | -3.00 | -2.602 | 3.000 | 2.602 |
| 20 | RAND | 5 | | 150.8 | 145.2 | 148 | 5.60 | 3.784 | 5.600 | 3.784 |
| 1 | DIST | | 1600 | 1630 | 1636 | 1633.3 | 3.0 | -0.37 | 3.050 | 0.373 |
| 2 | DIST | | 1600 | 1630 | 1618 | 1624.0 | -6.2 | 0.76 | 6.200 | 0.764 |
| 3 | DIST | | 1600 | 1640 | 1639 | 1639.4 | -0.6 | 0.07 | 0.600 | 0.073 |
| 4 | DIST | | 1600 | 1640 | 1640 | 1639.8 | -0.3 | 0.03 | 0.250 | 0.030 |
| 5 | DIST | | 1600 | 1611 | 1612 | 1611.5 | 0.3 | -0.04 | 0.300 | 0.037 |
| 6 | DIST | | 1600 | 1611 | 1608 | 1609.5 | -1.7 | 0.21 | 1.700 | 0.211 |
| 7 | DIST | | 1600 | 1623 | 1628 | 1625.0 | 2.5 | -0.31 | 2.500 | 0.308 |
| 8 | DIST | | 1600 | 1623 | 1639 | 1630.8 | 8.3 | -1.02 | 8.300 | 1.018 |
| 9 | DIST | | 1600 | 1620 | 1616 | 1618.1 | -2.0 | 0.25 | 2.000 | 0.247 |
| 10 | DIST | | 1600 | 1620 | 1620 | 1620.2 | 0.1 | -0.01 | 0.100 | 0.012 |
| 11 | DIST | | 1600 | 1601 | 1630 | 1615.1 | 14.5 | -1.79 | 14.450 | 1.789 |
| 12 | DIST | | 1600 | 1601 | 1594 | 1597.5 | -3.1 | 0.39 | 3.150 | 0.394 |
| 13 | DIST | | 1600 | 1613 | 1599 | 1606.4 | -7.0 | 0.88 | 7.050 | 0.878 |
| 14 | DIST | | 1600 | 1613 | 1613 | 1613.4 | 0.0 | 0.01 | 0.050 | 0.006 |
| 15 | DIST | | 1600 | 1614 | 1610 | 1612.2 | -2.2 | 0.27 | 2.200 | 0.273 |
| 16 | DIST | | 1600 | 1614 | 1618 | 1616.2 | 1.8 | -0.22 | 1.800 | 0.223 |
| 17 | DIST | | 1600 | 1607 | 1600 | 1603.6 | -3.2 | 0.40 | 3.200 | 0.399 |
| 18 | DIST | | 1600 | 1607 | 1601 | 1603.9 | -2.9 | 0.36 | 2.900 | 0.362 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 19 | DIST | | 1600 | 1614 | 1610 | 1612.1 | -1.8 | 0.22 | 1.750 | 0.217 |
| 20 | DIST | | 1600 | 1614 | 1623 | 1618.4 | 4.6 | -0.56 | 4.550 | 0.562 |