Note. This article will be published in a forthcoming issue of the *International Journal of Sports Physiology and Performance*. The article appears here in its peer-reviewed and accepted form; it has not been copyedited, proofread, or formatted by the publisher.

**Section:** Original Investigation

**Article Title:** The reliability of MinimaxX accelerometers for measuring physical activity in Australian football

**Authors:** Luke J. Boyd 1,2 Kevin Ball 1 & Robert J. Aughey 1,2

**Affiliations:**
1 School of Sport and Exercise Science, Institute of Sport, Exercise and Active Living, Victoria University, Melbourne, Australia
2 Western Bulldogs Football Club, Melbourne, Australia

**Journal:** *International Journal of Sports Physiology and Performance*

©2011 Human Kinetics, Inc.
ABSTRACT

Purpose: To assess the reliability of tri-axial accelerometers as a measure of physical activity in team sports. Methods: Eight accelerometers (MinimaxX 2.0, Catapult, Australia) were attached to a hydraulic universal testing machine (Instron 8501) and oscillated over two protocols (0.5 G; and 3.0 G) to assess within- and between-device reliability. A static assessment was also conducted. Secondly, 10 players were instrumented with two accelerometers during Australian football matches. The vector magnitude was calculated, expressed as Player load™ and assessed for reliability using typical error (TE) ± 90% confidence intervals (CI), and expressed as a coefficient of variation (CV%). The smallest worthwhile difference (SWD) in Player load™ was calculated to determine if the device was capable of detecting differences in physical activity. Results: Laboratory: Within- (Dynamic: CV 0.91 to 1.05%; Static: CV 1.01%), and between-device (Dynamic: CV 1.02 to 1.04%; Static: CV 1.10%) reliability was acceptable across each test. Field: The between-device reliability of accelerometers during Australian football matches was also acceptable (CV 1.9%). The SWD was 5.88%. Conclusions: The reliability of the MinimaxX accelerometer is acceptable both within- and between-devices under controlled laboratory conditions, and between-devices during field testing. MinimaxX accelerometers can be confidently utilised as a reliable tool to measure physical activity in team sports across multiple players and repeated bouts of activity. The noise (CV%) of Player load™ was lower than the signal (SWD), suggesting that accelerometers can detect changes or differences in physical activity during Australian football.

Keywords: Reliability, Accelerometers, Contact-based team sports
Introduction

Measuring the physical demands experienced by the athlete in the training and competitive environment can provide valuable information to coaches and support staff to facilitate subsequent performance enhancement. Common methods used to measure physical demands include heart rate telemetry, and time-motion analysis through video and more recently, global positioning systems. These methods have been used in many team sports including Australian football, rugby codes and hockey. In particular, in Australian football, many elite and many sub-elite teams rely on time-motion analysis information for organising rotations (where players substitute on and off the field), measuring locomotive activity, and overall management of load from week to week.

Current systems used to quantify the physical demands of team sport competition are limited. The validity of heart rate information is questionable when activity levels are intermittent and at high intensities. Video time-motion analysis is labour intensive, typically observes only one player at a time, is prone to human error, and cannot function in real-time. Global positioning system (GPS) time-motion analysis can eliminate many of these issues, however poor reliability and validity (coefficient of variation (CV) ≤34%) in measuring distance especially at high speeds over short distances have been exposed in previous work. This method is also unavailable during indoor competition. Current practice also fails to account for the skill (passing, jumping, kicking, marking) and contact based (tackling, blocking) activities that occur up to 173 times per game, or every 45 seconds in Australian football.

These activities are currently analysed using only frequency statistics rather than assessing the acute and accumulated magnitude of the activity. Failure to adequately account for these activities may greatly underestimate the physical demands of Australian football.

Tri-axial accelerometers are highly responsive motion sensors used to measure the frequency and magnitude of movement in 3 dimensions (anterior-posterior, medio-lateral, and longitudinal). These devices have been used to quantify physical activity in a variety of populations such as the ageing, sedentary, diseased, and youth. Accelerometers may offer a measurement system that circumvents some of the limitations that exist with heart rate and time-motion analysis, including a higher sample rate compared to GPS, the ability to monitor multiple players indoor as well as outdoor, reduced labour, and the inclusion of skill and contact based aspects of team sports that can contribute to player demands. These devices have the potential to represent gross fatiguing movements, not just locomotive activity.

Published research using accelerometers has focussed largely on the relationship between accelerometers and other measures such as heart rate, energy expenditure and oxygen uptake during various types of physical activity. Small quantities of team sport research have explored the activity levels of basketball in junior high school students, and elite junior players. Gait patterns in runners, and head impacts in various contact sports have also been assessed. However, an assessment of the reliability of accelerometer data in the team sports environment is notably absent from the literature. Existing assessments of the reliability of accelerometers have been limited to mechanical tests and basic physical activity tasks, the results of which have been somewhat mixed (between device CV 1.79 to 14.4%; within device CV 1.13 to 34.7%). Currently, literature-based evidence of accelerometer reliability in the sporting environment does not exist. Given the recent introduction of accelerometers such as the MinimaxX (Catapult Innovations, Scoresby, Australia) this research is critical to understanding the information that is extracted from these devices.

On this basis, a full evaluation of the reliability of accelerometers in a laboratory, and field setting was required to determine if a change in performance is evident, and if that change is meaningful. Devices will typically be instrumented on multiple players, therefore both the within- and between-device reliability needs to be established. Therefore, the aim of this
investigation was to assess the reliability of MinimaxX accelerometers within- and between-devices in the laboratory, and between-devices in the field. In addition, this investigation assessed the ‘signal’ to ‘noise’ ratio of the MinimaxX accelerometers which determined the sensitivity of the devices to detect real differences in performance between individuals and groups of athletes.
Methods

MinimaxX 2.0 Accelerometer:
The MinimaxX 2.0 (Catapult Innovations, Scoresby, Victoria) contains a triaxial piezoelectric linear accelerometer (Kionix: KXP94) that detects and measures movement using a micro-electro-mechanical system at 100 Hz. The full-scale output range is ±6 G. Each device has its own microprocessor, 1 GB flash memory and high-speed USB interface, to record, store and upload data. The device is powered by an internal battery with 5 hours of life, weighs 67 grams and is 88x50x19 mm in dimension.

Temperature regulation:
Manufacturers specify temperature regulation ranges from -40 to 85 °Celsius for the MinimaxX accelerometers. To verify these figures, stability testing was performed on two MinimaxX accelerometers in an environmental chamber (Tabai build-in chamber, model No. TBL-4RS-5) to assess any drift from the baseline gravity measure. Over a three-hour period the temperature was gradually increased from 15° to 35° C then decreased to 15° C. Changes of 0.1 Player load™ units were found which is considered negligible as Player load™ values of 1500+ are regularly seen in team sports matches and training (Boyd and Aughey unpublished observations).

Design:
Player load™ is a modified vector magnitude developed by Catapult using the MinimaxX accelerometer data. It is expressed as the square root of the sum of the squared instantaneous rate of change in acceleration in each of the three vectors (X, Y and Z axis) and divided by 100 (equation 1). Data was expressed in arbitrary units (AU). This variable was used in both sections of analysis. Device calibration is carried out prior to all reliability testing.

Reliability was established in two ways. The first utilised mechanical equipment in a laboratory to assess technical reliability. The second utilised AF players, this time to determine the technical reliability in a field setting.

Laboratory assessment:
Methodology:
Static Reliability:
Ten MinimaxX accelerometers were positioned statically with the Z axis aligned to the vertical using a custom-designed cradle on a levelled surface. Given the units were static, the accelerometers should only have detecting acceleration due to gravity (constant value). Each device was subjected to six 30-second trials with a 2 minute interim between. Following each trial the devices were detached from the cradle and subsequently reattached for the next trial. After three static trials, the devices were attached to 10 athletes who performed a 180-minute team sport skills training session (volleyball) involving large volumes of high intensity short duration activities such as jumping and changing direction. Each device was mounted in a customised vest, which was fitted tightly to the body of each athlete. Following the skills training session, units were re-secured to the cradle and another three 30 s static trials were conducted. This was to determine if high intensity activity affected the stability of the device, and if re-calibration was required regularly. Each static trial was downloaded using the manufacturer’s software (Logan Plus 4.2), to obtain the Player load™ value.

Dynamic Reliability:
To perform a standardized and repeatable movement test for the MinimaxX accelerometers, an Instron 8501 hydraulic shaker was used. The Instron 8501 is a servo-hydraulic universal testing machine with an arm that oscillates in a single plane of movement (vertical). The machine had a stroke of 50 cm, and adjustable frequency to simulate various acceleration
ranges. A certified calibrated accelerometer (Brüel & Kjaer, 4370) was attached to the Instron to determine the reliability of the oscillations for each test. The CV was 0.26% over ten 10-second trials, confirming that the hydraulic testing machine is capable of producing highly repeatable dynamic movements. Previous research has utilised mechanical equipment with high repeatability to assess the reliability both within and between devices.16,23 Eight MinimaxX accelerometers were rigidly attached to the Instron 8501 shaker using hot melt adhesive. A metal plate was attached to the hydraulic arm so that all of the MinimaxX devices could be attached simultaneously. The devices aligned identically, lying flat on the metal plate attached to the hydraulic arm (Y axis - anterior-posterior). For protocol 1 the frequency was set at 3 Hz and the amplitude adjusted to represent a wave form of 0.5 G; protocol 2 was set at 8 Hz and had the amplitude adjusted to represent a 3 G wave form. The selected range of acceleration was based on typical values obtained during AF activity (Unpublished observations). Each unit was subjected to 10 trials of 10 s, for each protocol. Between each trial the shaker was stopped and restarted. Each trial was downloaded using the manufacturer’s software (Logan Plus 4.2), to obtain the Player loadTM value.

Field assessment:

Subjects:

Ten male semi-professional Australian football players currently playing in the Victorian Football League were recruited to participate in the study (Age, 23.2±2.3 yrs; Height, 181.6±5.4 cm; Body mass, 83.0±4.8 kg; Mean ± SD). Subjects were informed of the procedures verbally, and in a plain language statement and signed consent forms prior to participation. At the time of testing, participants were training a minimum of three times per week, and participating in one match per week. The research was approved by the University Human Research Ethics Committee.

Methodology:

Accelerometer data was collected during nine Victorian football league matches over the 2009 pre- and premiership-seasons. The venue changed from week to week depending on the club’s fixture. Five different venues were used in the analysis. For each game, participants were instrumented with two MinimaxX accelerometers. The two units were taped together so that their accelerometer axes were aligned. The device placed distally to the body recorded slightly higher Player loadTM values (CV= 1.6%; r = 0.999). This was accounted for by swapping the device position for the second match so that each device pairing produced data in both the proximal and distal position. Both units were inserted into a custom vest located on the posterior side of the upper torso fitted tightly to the body as is typically used in games. The participants were familiar with the procedure as the devices are a regular part of training and match analysis.

Player loadTM obtained from matches was cropped (Logan Plus 4.2) to remove rest breaks (e.g. half time) so that only data during time on the field was included in the analysis. The start and end time points for each period of time spent on the ground were aligned to the 0.001 seconds to ensure that the data obtained from both units had equal epochs. Player loadTM values from each device for the corresponding playing periods were compared to assess the difference in accelerometer output between devices.

Statistical Analysis:

The Player loadTM values were log transformed to reduce bias due to non-uniformity of error and analysed using a customised spreadsheet (Hopkins 2009 – Analysis of Reliability [Microsoft Excel spreadsheet]). Within device reliability was calculated as the mean difference between laboratory trials for each device. Between device reliability was calculated as the mean difference between the devices across all laboratory trials. Reliability
during the laboratory assessment was expressed as an absolute using Typical Error (TE) with upper and lower 90% confidence intervals (CI). The magnitude of difference was expressed as a coefficient of variation (CV%). Similarly for the field assessment, the TE±90%CI was again used to display absolute differences and the CV% to determine the magnitude of differences displayed between units. Pearson’s product moment correlation coefficient (r) was also calculated to express the relationship between devices during the field assessment. The smallest worthwhile difference (SWD) was calculated as 0.2 x between-subject SD from the match data collected during the field assessment section of the study. Previous work has suggested that the SWD represents the smallest ‘real’ difference of practical importance. This investigation used the term ‘noise’ to represent the technical reliability, and the term ‘signal’ to represent the SWD. When the ‘noise (CV%) was ≤ ‘signal’ (SWD), the accelerometer was considered capable of detecting differences.
Results

All reliability results are displayed in table 1.

**Laboratory assessment:**
Static assessments for within- and between-device reliability were CV 1.0% and CV 1.0%, respectively.
The dynamic assessment of between device reliability was CV 1.04% for the 0.5 G trial and CV 1.02 for the 3.0 G trial (Figure 1). Similarly, within devices dynamic assessments were CV 0.91% for the 0.5 G trial and CV 1.05% for the 3.0 G trial (Figure 2).

**Field assessment:**
The between-device reliability of accelerometers during Australian football matches was 1.9% (CV) (Table 1). The results from individual player data indicated that all differences between units were ≤2.80%. Relationships between data from devices on the same individual ranged from r =0.996 - 0.999 (Figure 3).
Both the laboratory (CV% 0.91 to 1.05%) and field testing (CV 1.9%) measurement error or noise were less than the signal (SWD 5.88%).
Discussion

MinimaxX accelerometers demonstrated an acceptable level of technical reliability both within- and between-devices for measuring physical activity in team sports. The noise (technical reliability $CV\%$) for both the laboratory and field testing was below 2%. These values were well below the signal (SWD) which was 5.88%, suggesting that MinimaxX accelerometers are suitable for detecting differences in Australian football physical activity.

Laboratory assessment:
Both within- and between-device reliability was superior for the MinimaxX compared to other accelerometers reported in the literature during dynamic testing. The within device reliability ($CV$ 0.9 to 1.05%) of the MinimaxX accelerometer was equal or superior to both the RT3, 16 and DynaPort devices 23 trialled on mechanical testing machines. The between-device reliability ($CV$ 1.02 to 1.04%) of the MinimaxX was also superior to the Tritrac-R3D, RT3 and Dynaport using similar testing methods. 16,22,23 The MinimaxX therefore has acceptable levels of reliability compared to equivalent devices already in regular use.

It is important to note that in the current investigation the MinimaxX accelerometers were exposed to much higher rates of acceleration compared to previous literature during mechanical testing. If these previously employed ranges (0.35-0.64 G) were used, only approximately 21% of the data collected during team Australian football matches would be accounted for in the reliability trials. The greater range (0.5-3.0 G) used here would account for 96% of the values obtained during Australian football match activity. Thus, we can be confident that our testing is representative of the likely range of accelerations regularly imposed on these devices in competition.

The acceptable level of reliability indicated from the static testing ($CV$ 1.01 to 1.10%) we undertook is an important finding. The devices used in this study remained stable over a long period without drifting from the baseline measurement. Static periods are frequent in team-sport activity, such as when the ball is not in proximity to players, or during natural breaks in play. 5 During periods of negligible-motion the devices should not contribute to the total Player loadTM value obtained for a given activity bout. Assuming that the athlete is motionless during these periods, then the player load values obtained should be close to zero, and any recorded values during this static period may lead to overestimation of the Player loadTM. The drift in Player loadTM reported here is trivial compared to the values typically obtained for training and matches of 1500 or more Player loadTM units.

Field assessment:
Previous assessment of the vector magnitude of various accelerometer models has commonly used mechanical or carefully controlled physical activity trials rather than in actual sports activity. Thus, if applied in a sports setting, the actual reliability of these accelerometers may be lower than in carefully controlled settings. Withstanding the chaotic nature of collision team sports, the field testing carried out in this investigation resulted in superior between-device reliability ($CV$ 1.94%) than previously reported for other accelerometers tested on mechanical devices. 16 The MinimaxX also displayed far greater reliability than reported for low intensity physical activity ($CV$ 6 to 25%). 27 Indeed, strong relationships also existed between-devices ($r = 0.996 - 0.999$) during high intensity Australian football activity, indicating that Player loadTM results are consistent regardless of the unit used. The between-device reliability is important given multiple devices are typically used to measure Player loadTM across numerous players and from one match to another. The relationships displayed in the current investigation were much stronger than those reported for physical activity trials such as treadmill walking and running ($r = 0.73-0.87$). 22 It might have been expected that controlled physical activity trials such as walking and running would be more reliable
compared to the variable activity displayed in team sports match performance. In the current investigation this was not the case. This may be a reflection of the superiority of the MinimaxX sensors.

The signal (SWD) for Player load™ during matches was 5.88%. These results revealed that the noise (CV <2%) was much less than the signal, which supports the ability of the MinimaxX to detect differences in physical activity during Australian football. Best practice would require the determination of this value for discrete data sets and populations, as this study is only representative of a small cohort of Australian football players. Further investigation of MinimaxX accelerometers requires laboratory based reliability analysis at higher accelerations (Eg. 3 - 6 G) to match the full range of activity patterns likely in AF matches. In the current investigation, the mechanical shaker was unable to meet these specifications, however only 4% of typical values obtained during Australian football matches are between 3.0 - 6.0 G. An assessment within devices in random dynamic field settings would also be of interest however, this appears to be challenging. Physical activity trials would not service these needs, as repeated trials are difficult to conduct. Laboratory testing using mechanical devices, may be the only plausible way to test the devices, however random protocols may need to be generated. Finally, research assessing the relationship between accelerometers and other common measures of physical activity is still required in team sports.

Practical Applications

The MinimaxX accelerometers can be confidently applied to assess changes or differences over multiple periods of activity, or between players. Although low, the variation displayed should be taken into account when making inferences about the meaningfulness of differences. Further, for these activities, players can be equipped with any device rather than needing to use the same one at all times.

Conclusion

MinimaxX accelerometers vary by <2% during laboratory and field testing indicating acceptable reliability. The noise (CV%) was less than the signal (SWD 5.88%), suggesting that they are capable of detecting differences in physical activity levels. In addition, these values were below the 5% suggested in the literature as an acceptable level of reliability for sports analysis technology. Technological variation must be considered in determining the appropriateness of a device for use in testing and analysis. MinimaxX accelerometers are suitable for use in Australian football and in team sports where the signal (SWD) is greater than 2%.
REFERENCES


\[ PLAYERLOAD = \sqrt{\frac{\left( a_y - a_{y-1} \right)^2 + \left( a_x - a_{x-1} \right)^2 + \left( a_z - a_{z-1} \right)^2}{100}} \]

Where:
- \( a_y \) = Forwards accelerometer
- \( a_x \) = Sideways accelerometer
- \( a_z \) = Vertical accelerometer
- \( SF \) = Scaling factor

**Equation 1:** Player load equation (Catapult Innovations, Scoresby, Victoria)
<table>
<thead>
<tr>
<th>Description</th>
<th>Mean</th>
<th>SD</th>
<th>TE</th>
<th>Lower 90% CI</th>
<th>Upper 90% CI</th>
<th>CV%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static (within device)</td>
<td>0.062</td>
<td>0.07</td>
<td>0.055</td>
<td>0.046</td>
<td>0.069</td>
<td>1.01</td>
</tr>
<tr>
<td>Static (between device)</td>
<td>0.062</td>
<td>0.05</td>
<td>0.065</td>
<td>0.055</td>
<td>0.081</td>
<td>1.10</td>
</tr>
<tr>
<td>Dynamic 0.5 G (within device)</td>
<td>0.748</td>
<td>0.019</td>
<td>0.007</td>
<td>0.006</td>
<td>0.008</td>
<td>0.91</td>
</tr>
<tr>
<td>Dynamic 0.5 G (between device)</td>
<td>0.748</td>
<td>0.007</td>
<td>0.008</td>
<td>0.007</td>
<td>0.009</td>
<td>1.04</td>
</tr>
<tr>
<td>Dynamic 3.0 G (within device)</td>
<td>7.698</td>
<td>0.090</td>
<td>0.081</td>
<td>0.070</td>
<td>0.098</td>
<td>1.05</td>
</tr>
<tr>
<td>Dynamic 3.0 G (between device)</td>
<td>7.698</td>
<td>0.080</td>
<td>0.079</td>
<td>0.068</td>
<td>0.095</td>
<td>1.02</td>
</tr>
<tr>
<td>Sports Specific (between devices)</td>
<td>227.692</td>
<td>101.246</td>
<td>5.064</td>
<td>4.497</td>
<td>5.841</td>
<td>1.94</td>
</tr>
</tbody>
</table>

Table 1. Summary of reliability results expressed as the mean and SD of raw data from all trials; technical error (TE); Confidence interval (CI); and coefficient of variation (CV%).
Figure 1. Raw player load values (square root of the sum of the squared instantaneous rate of change in acceleration in each of the three vectors, divided by 100). A.) Between device –
shaken at 0.5 G for ten trials of 10-seconds; B) Between device – shaken at 3.0 G for ten trials of 10-seconds.

![Graph A](image1.png)

![Graph B](image2.png)
Figure 2. Raw player load values (square root of the sum of the squared instantaneous rate of change in acceleration in each of the three vectors, divided by 100). A.) Within device – shaken at 0.5 G for ten trials of 10-seconds; B.) Within device – shaken at 3.0 G for ten trials of 10-seconds.
Figure 3. The Relationship between two accelerometers placed on the same player during AF matches. The solid line is a line of best fit, hatched lines represent 95% confidence limits; the slope of the line is also given in text. n= 104