University of Glasgow

Macleod, Amy Elizabeth (2016) *A comparison of the physiological demands of rugby union match-play when determined by absolute (ABS) or individual (IND) velocity bands in Global Positioning System (GPS) analysis.* MSc(R) thesis.

http://theses.gla.ac.uk/7571/

# A comparison of the physiological demands of rugby union match-play when determined by absolute (ABS) or individual (IND) velocity bands in Global Positioning System (GPS) analysis.

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BSc (Hons)

Submitted in fulfilment of the requirements of the degree of:

MSc (Research) Sports Science

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**Submitted March 2016**

**Accepted September 2016**

# Abstract

Since turning professional in 1995 there have been considerable advances in the research on the demands of rugby union, largely using Global Positioning System (GPS) analysis over the last 10 years.

A systematic review on the use of GPS, particularly the setting of absolute (ABS) and individual (IND) velocity bands in field based, intermittent, high-intensity (HI) team sports was undertaken. From 3669 records identified, 38 studies were included for qualitative analysis. Little agreement on the definition of movement intensities within team sports was found, only three papers, all on rugby union, had used IND bands, with only one comparing ABS and IND methods. Thus, the aim of this study was to determine if there is a difference in the demands within positions when comparing ABS and IND methods for GPS analysis and if these differences are significantly different between the forward and back positional groups.

A total of 214 data files were recorded from 26 players in 17 matches of the 2015/2016 Scottish BT Premiership. ABS velocity zones 1-7 were set at 1) 0-6, 2) 6.1-11, 3) 11.1-15, 4) 15.1-18, 5) 18.1-21, 6) 21.1-15 and 7) 25.1-40km.h$^{-1}$ while IND zones 1-7 were 1) <20, 2) 20-40, 3) 40-50, 4) 50-70, 5) 70-80, 6) 80-95 and 7) 95-100% of player's individually determined maximum velocity (Vmax). A 40m sprint test measured Vmax using OptaPro S4 10 Hz (catapult, Australia) GPS units to derive IND bands. The same GPS units were worn during matches. GPS outputs analysed were % distance, % time, high intensity efforts (HIEs) over 18.1 km.h$^{-1}$ / 70% max velocity and repeated high intensity efforts (RHIEs) which consists of three HIEs in 21secs.

General linear model (GLM) analysis identified a significant difference in the measurement of % total distance covered, between the ABS and IND methods in all zones for forwards ($p<0.05$) and backs ($p<0.05$). This difference was also significant between forwards and backs in zones 1, shown as mean difference ± standard deviation (3.7±0.7%), 6 (1.2±0.4%) and 7 (1.0±0.0%) respectively ($p<0.05$). Percentage time estimations were significantly different between ABS and IND analysis within forwards in zones 1 (1.7±1.7%), 2 (-2.9±1.3%), 3 (1.9±0.8%), 4 (-1.4±0.8%) and 5 (0.2±0.4%), and within backs in zones 1 (-10±1.5%), 2 (-1.2±1.1%), 3 (1.8±0.9%) and 5 (0.6±0.5%) ($p<0.05$). The difference between groups was significant in zones 1, 2, 4 and 5 ($p<0.05$). The number of HIEs was significantly different between forwards and backs in zones 6 (6±2)

and 7 (3±2). RHIEs were significantly different between ABS and IND for forwards (1±2, $p<0.05$) although not between groups.

Until more research on the differences in ABS and IND methods is carried out, then neither can be deemed a criterion method. In conclusion, there are significant differences between the ABS and IND methods of GPS analysis of the physical demands of rugby union, which must be considered when used to inform training load and recovery to improve performance and reduce injuries.

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## Acknowledgements

I would like to thank my principal advisor, Victoria Penpraze, for her enthusiasm and passion for the project. Without her time and dedication to the team, this project would not have been possible. I would also like to thank my secondary advisor, Niall MacFarlane, for lending his expertise in the area to the study and for our extensive use of the GPS equipment.

I am very grateful to all management, coaching staff and players at Glasgow Hawks RFC. Their support and welcoming attitude towards me has made this masters most enjoyable.

Lastly, I would like to thank my family and friends for their on-going support during my further education.

This thesis is dedicated to my Mum, without whom, this wouldn't have been possible.

## Author's Declaration

I declare, except where explicit reference is made to the contributions of others, that this thesis is the result of my own work and has not been submitted for any other degree here at the University of Glasgow or at any other institution.

Signature:

Printed name: Amy Elizabeth Macleod

## Definitions/Abbreviations

| | |
|---|---|
| ABS | Absolute velocity bands |
| AFL | Australian Football League – Aussie Rules |
| B5 | Back 5 positions (centres, wings & full back) |
| F5 | Front 5 positions (props, hooker and second rows) |
| GPS | Global Positioning System |
| HDOP | Horizontal Dilution of Precision |
| HIA | Head Injury Assessment |
| HI | High Intensity |
| HIE | High Intensity Effort |
| HIR | High Intensity Running |
| HSR | High Speed Running |
| IND | Individual velocity bands |
| M5 | Middle 5 positions (flankers, No.8, scrum half & fly half) |
| MIR | Moderate Intensity Running |
| PRISMA | Preferred Reporting Items for Systematic Reviews and Meta Analyses |
| RHIE | Repeated High Intensity Effort |
| SD | Standard Deviation |
| SRU | Scottish Rugby Union |
| VDOP | Vertical Dilution of Precision |
| Vmax | Maximum velocity |

# 1. Introduction

## 1.1. Overview of Rugby Union

Rugby union is a high intensity (HI), intermittent team sport consisting of repeated periods of high intensity running (HIR), sprinting and tackling interspersed with periods of walking/jogging (McLellan et al., 2013; Roberts et al., 2008). It is characterised by full contact tackling and set piece scrummaging and lineouts.

Scotland has a long rugby union tradition with the first international match played between Scotland and England in 1871. Despite a long history, with the first rugby rules dating back to 1845, rugby union only became professional in 1995. Since then the game has changed dramatically, in pace, playing strategy and the physicality of players.

The Scottish Rugby Union (SRU) now oversees Scotland's two professional clubs, Edinburgh Rugby and Glasgow Warriors, both of whom compete in the Guinness Pro 12 league. The SRU also oversees the national club game and the four regional academies that have been set up to develop and feed young talent into the professional clubs, largely through the top amateur/semi-pro league, the BT Premiership, in which the players in this study play (SRU Annual Report, 2014).

Rugby union is played over two, forty-minute periods with fifteen players from each team on the pitch at any time, with the exception of sin bin periods or a sending off. In international matches there can be eight replacements/substitutes on the bench. Temporary replacements can also be made for injuries requiring medical treatment, known as 'blood replacements', this is a prime example of the physical nature of the sport and the expectation that following physical injuries such as facial lacerations and Head Injury Assessment (HIA), players may return to the pitch. Points in rugby union can be scored by a try, conversion, penalty and drop goal. A try is scored when the ball is carried across the goal line and grounded, for five points. A conversion is then awarded after a try is scored and is kicked for two points. A drop goal is also worth two points but is scored in open play, with the ball touching the ground immediately before being kicked. A penalty kick is given to penalise foul play from the opposition, from which three points are awarded for a successful kick between the posts above the crossbar. Depending on pitch position and team tactics, penalties may also be taken quickly without attempting to kick a goal to restart play or kicked into touch for a line out.

The dimensions of a rugby pitch must be between 94m-100m in length and 68m-70m in width, the in goal area must be between 6m-22m in length. The dimension of the goal posts, situated centrally on the goal line are 5.6m between the posts, the top edge of the cross bar is at a height of 3m and the posts must have a minimum height of 3.4m above the cross bar (World Rugby).

## 1.2. Positional Characteristics

The playing positions in rugby union are separated in to 'forwards' and 'backs'. Forwards are numbered 1 to 8 while backs are numbers 9 to 15. Each playing position has a corresponding position number, these are as follows: 1 - loose head prop; 2 – hooker; 3 - tight head prop; 4 – lock; 5 – lock; 6 - blind side flanker; 7 - open side flanker; 8 – No.8; 9 - scrum half; 10 - fly half; 11 - left wing; 12 - inside centre; 13 - outside centre; 14 - right wing and 15 - full back.

Rugby union differs from other team sports in the fact that each of the aforementioned playing positions requires distinct physiological demands and discrete anthropometrical characteristics when compared to sports such as hockey or football where anthropometrics are largely homogenous across the team (Nichols, 2007). The specific roles of each position lend themselves to specific body types, with forwards being heavier than backs (McLellan et al., 2013), which is beneficial as they are involved in more impacts, contest set piece scrums and are the principal players in rucks and mauls (Nichols, 1997). An example of anthropomorphic characteristics playing their part in which position a player will play is the role of the second row in the lineout. Trends show that players in the second row are commonly the two tallest in the squad and it is generally these two that contest the lineouts in the air due to their greater absolute jump height (Duthie et al., 2003).

Current literature shows that there are in fact anthropometric differences between forwards and backs, as shown in Appendix 1. Forwards have been reported as being on average 22.3kg heavier and 6cm taller than backs (McLellan et al., 2013). Austin et al. (2011) highlighted that as well as differences in physical characteristics between forwards and backs, there are also differences within these broad groupings. For instance, it was shown that the front row is on average 21kg heavier than the back row despite their average height being the same. The inside backs are shown to be the lightest group, being 13kg lighter than the outside backs, although on average only 3cm shorter. It can also be seen that when players are not separated into positional groups, there is a greater standard deviation showing the large range in heights and weights across a squad.

As well as differences in height and weight characteristics between backs positions, there are also differences in aerobic fitness. While many of the high intensity efforts (HIEs) are fuelled by anaerobic pathways, a high aerobic capacity is still needed to recover from these efforts. Mean $\dot{V}O_2max$ ($mL.kg^{-1}.min^{-1}$) for an elite rugby union player ranges from 45 ml/kg/min – 55.5 $mL.kg^{-1}.min^{-1}$, as shown in Appendix 2. When comparing forwards and backs, it would appear, from looking at $\dot{V}O_2max$ ($L.min^{-1}$) that forwards have a higher aerobic capacity than backs. However, when corrected for body mass, the backs come out with higher values for maximum aerobic capacity. It has been shown that there is also a marked difference in $\dot{V}O_2max$ within the forwards, with the flankers and No. 8s showing values of 50.9$mL.kg^{-1}.min^{-1}$and 55.8$mL.kg^{-1}.min^{-1}$respectively (Bell et al., 1979 cited in Duthie et al., 2003). Similar $\dot{V}O_2max$ results were found in rugby sevens players, 54$mL.kg^{-1}.min^{-1}$, showing that aerobic demands are not only similar between union disciplines but have also not developed greatly despite the professionalism of the sport (Higham et al, 2012).

There are also differences within the broad groups of forwards and backs, with inside backs being lighter than outside backs and the back row having higher aerobic capacities than the front row. These anthropometric differences are indicators of the differences in positional demands in rugby union. However, these differences are not always taken in to account when analysing performance quantitatively using modern performance analysis methods, including Global Positioning Systems (GPS). By not doing so, team practitioners may not be getting a true depiction of the work done by individual players, which can have a knock on effect on aspects such as training load monitoring, injury management and perception of performance in a match situation.

## 1.3. The Role of Performance Analysis and GPS in Rugby Union

Performance analysis has the aim of improving our understanding of the game behaviour in order to improve future performances (McGarry, 2009). The English Institute of Sport describes the discipline of performance analysis as "the provision of objective feedback to performers trying to get a positive change in performance". To support this description they provide an unreferenced statistic, stating that athletes and coaches recall about 30% of a performance, performance analysis is there to recall the other 70%.

As well as coaching feedback on technical and physical performance, performance analysis methods can also play a role in team selection; hence they need to be accurate and well understood by those using them to inform decisions. This is demonstrated by the Oakland Athletics Major League Baseball team's construction of a winning team on a shoestring budget, which was later documented in the book "Moneyball" and adapted in to a feature film. Hakes and Sauer (2006) conducted an economic evaluation of the Moneyball hypothesis, which highlights that not all performance statistics are weighted evenly. A point also believed to be true by (McGarry, 2009). In baseball there are three key offensive statistics: batting average, slugging percentage and on-base percentage. Of the three stats, on-base percentage has the highest correlation with winning when using linear regression analysis, almost twice that of slugging percentage (Hakes and Sauer, 2006). This shows that when collecting a large amount of data on quantitative measures of performance, and making judgements and decisions based on these, not all measures have the same correlation with performance.

Current methods of performance analysis in rugby union use video coding technology to create statistical reports on team, opposition and individual performances. The aspects of performance recorded are completely individual to different teams and nations, and are largely a closely guarded secret. In the applied setting, video analysis methods are rarely combined or considered in context with GPS outputs and vice versa. It is common practice that GPS currently comes under the umbrella of strength and conditioning coaches while video analysis is the scope of the performance analysts. However, I would also consider GPS as a method of performance analysis, albeit a physical one rather than a tactical one. There are many aspects of analysis in which video analysis techniques are more advanced than GPS, particularly in the individualisation of match statistics. Reports are created on each individual player's performance, but in the case of GPS this individualisation is somewhat undermined by the blanket application of velocity bands and description of movement intensities across the whole squad.

As has been shown by the "Moneyball" example, there is clearly a different weighting in the correlation between specific statistics and match outcomes, which may also be the case in physical quantitative analysis methods, i.e. GPS. It may also be the case that quantitative measure outputs not only have a different correlation with performance, but there may also be a difference in this weighting between positions and even individuals when using GPS analysis.

It is important to have an understanding of other methods used to quantify rugby union performance as it provides a context in which the GPS measurements are being applied in a practical setting and to also take elements of best practice from other areas of analysis, in the case of performance analysis, that different outputs have a different correlation with performance and the potential importance of individualised analysis. Overall it highlights the need for more robust research in to different methods of GPS analysis as they may result in different output results and as a consequence potentially different correlations with match outcome.

## 1.4. GPS technology

In brief, GPS is able to calculate geographical position by computing the time of flight of the signal that is constantly sent from the orbiting satellites. GPS technology is now commonplace in everyday life, with smart phones now carrying the technology and modern cars having built-in navigation systems. The advancements of GPS technology, particularly the reduction in its size has made it possible for it to become portable and be applied to sport.

Portable micro-technology, wearable out-with the lab setting, was pioneered in Australia by an association between a Cooperative Research Centre and the Australian Institute of Sport. There is a long connection between rugby union and GPS, with one of the market leaders, Catapult Sports (Catapult Sports, Canberra, Australia) having been developed in southern hemisphere rugby teams, now over 10 years ago (Cunniffe et al, 2009) having been commercialised in 2006 when two of the researchers working on the original project launched Catapult Sports (Catapult Sports, Canberra, Australia).

GPS portable micro-technology comes in the form of small units, with the smallest on the market measuring 74mm x 42mm x 16mm and weighing 67g (GPSports, Sydney, Australia). The units contain accelerometers, which sample at a rate of 100Hz and can detect forces of up to 10G, although the latest advancements allow units to detect forces up to 16G (GPSports, Sydney, Australia). Advancements in GPS micro-technology include, a slimmer shape, better fitting vests to reduce movement of unit and improve comfort increasing of sampling frequency from 1Hz, to 5Hz and now 10Hz and 15Hz (SPI High Performance Unit, GPSports). Currently, top end units sample at rates of 10Hz and 15Hz, although 5Hz units are still commonplace.

Outputs of interest in rugby union include distance covered, player load, repeated high intensity efforts (RHIEs), accelerations, decelerations and time/distance spent in various speed zones. These outputs are used as markers of physical exertion by mainly strength and conditioning staff who feedback to coaches on elements such as training load, recovery strategies and physical exertion during matches as well as developing an understanding of the unique physical demands of the discrete positions. Thus it is vitally important that the GPS analysis method used is accurate to ensure that the information on workload is valid.

Often these outputs are also used, whether rightly or wrongly, as a measure of player effort. One of the pitfalls of GPS use is the lack of rationale behind the velocity zone settings which are largely derived from those initially recommended by those who transferred the technology to a sporting setting.

It is the manual setting of velocity bands in the GPS software (Catapult Sprint 5.1) that determines the velocities that players have to reach to register as being at different movement intensities, i.e. the velocity band that corresponds to walking (e.g. 0-6km.h$^{-1}$) or HIR (e.g. 18-21km.h$^{-1}$). This can be done using either absolute (ABS) values in km.h$^{-1}$ which are applied globally to the whole squad or a % of an individual's (IND) maximum velocity (Vmax) which will give each player their own set of velocity bands. In the Scottish Rugby Union, the national and professional sides define their velocity bands in absolute terms as 1) standing/walking 0-6km.h$^{-1}$, 2) jogging 6.1-11km.h$^{-1}$, 3) cruising 11.1-15km.h$^{-1}$, 4) moderate intensity running (MIR) 15.1-18 km.h$^{-1}$, 5) HIR 18.1-21km.h$^{-1}$, 6) sprinting 21.1-25km.h$^{-1}$ and 7) maximal sprint 25.1-40km.h$^{-1}$.

Velocity bands not only define movement intensity but also RHIE, which are user-defined, and to be concurrent with those used within the professional and national Scotland squads, were counted as any three of the following events occurring within 21 seconds;

- sprint >18km.h$^{-1}$
- acceleration >3m.s$^{-1}$
- deceleration <-3m.s$^{-1}$
- tackle load >3.

Velocity bands form the foundation of the GPS analysis of players' intensity and physical exertion during training and match-play. For this reason, it is crucial that this is understood as otherwise the conclusions drawn from the output will not be representative of the actual work done by players in specific positions.

## 1.5. Validity and Reliability of GPS

When using a quantitative method such as GPS for analysis of speed, distance and impact, it is important to understand its validity and reliability. Concurrent validity can be described as how accurately the result of this testing method correlates to criterion method results, for example how accurate GPS is at measuring a known distance. Reliability is the consistency of these values, so if the same distance was measured ten times, what would the range in values be given by GPS. However, it is difficult to make direct comparisons between validity and reliability studies due to the range of sporting simulations, criterion methods and sampling frequency of GPS units used.

To date, much of the data available on the accuracy and reliability of GPS units has been collected on 1Hz and 5Hz units; less is available on 10Hz and 15Hz units as they are newer to the market. Methods used to simulate and standardise sporting movement patterns include (i) linear courses completed at different movement intensities, (ii) non-linear courses (Gray et al., 2010) and (iii) sport specific circuits designed to replicate the movement demands of a specific sport (Vickery et al., 2014). Criterion methods range from 22 Camera VICON systems (Vickery et al., 2014), Radar (Rampini et al., 2014), laser (Akenhead et al., 2013; Varley et al., 2011) and photoelectric cells (Castellano et al., 2011). Radar can only measure linear movements so is not an applicable criterion method for a team sport simulation. Studies also include inter unit and inter manufacturer validation and reliability (Coutts & Duffield, 2010; Jenning et al., 2010).

While showing a good level of accuracy (within 5% of criterion method) GPS tends to under-report distance and speed, although not significantly (Vickery et al., 2014; Castellano et al., 2011; Gray et al., 2010). This underestimation is exaggerated at shorter distances, shown by improved accuracy over 30m compared to 15m (Castellano et al., 2011). Velocity also has an effect on validity as GPS is less accurate at measuring high speed running and sprinting (Rampini et al., 2014; Gray et al., 2010) and accelerations over $4m.s^{-1}$ (Akenhead, 2013). The movement demands of team sports (football), i.e. high speeds, non-linear movement patterns and continual change in direction lead to a lower validity and reliability than linear based sports (Gray et al., 2010; Vickery et al., 2014).

Circuits can be devised, like that by Coutts and Duffield (2009), to reflect the movement demands of team sports. As mentioned previously, team sport simulation drills and non-linear courses have a lower level of accuracy. It is likely that a portion of this error is due to the difference between actual course taken by participants and the measured course. Despite this, all units were reasonably accurate, all within 5% of lap distance.

However, higher sampling frequencies show improvements in limiting these issues as they have been found to have greater validity and reliability for recording both speed and distance (Varley et al., 2011; Jennings et al., 2010). Rampini et al., (2014) used radar with a sampling frequency of 32Hz as a criterion method to measure the accuracy of 5Hz and 10Hz SpiPro units (GPSports, Sydney, Australia). It was found that the 10Hz units had lower coefficient of variation and % bias than 5Hz so it can be concluded that a higher sampling frequency improves the accuracy of GPS data. While increased sampling frequencies improve reliability, GPS units can still be affected by unavoidable practical issues such as limited line of site due to stadia or weather phenomena e.g. sudden pressure changes or electrical storms.

Another factor out-with the control of practitioners is the Horizontal Dilution of Precision (HDOP) which affects the accuracy of identifying geometric position. Reporting the HDOP value allows for internal validation of the accuracy of that particular GPS recording. HDOP generally has a value of one or two. To put these values for the HDOP in to context, Vertical Dilution of Precision (VDOP) is usually above three and can be as high as seven (Langley, R.B., 1999), this is because satellites measuring vertical height can only be located directly above the location whereas HDOP is lower as satellites can measure location from all angles. HDOP will vary dependent on the number of satellites and their location in reference to the unit from which they are sending/receiving signals. For example, Langley, R.B. (1999) saw that when the number of satellites fell to five, there was an increase in HDOP, the position of the satellites was also suboptimal as they were arranged linearly rather than spread equally in each direction. Another factor which can affect the HDOP and therefore accuracy of outputs is the strength at which the device's receiver can pick up the satellite signal, for example cloud cover or blocked signal to the sky for partial roof coverage. In the context of rugby union match-play GPS analysis, the thick cloud cover is a high risk as it is a winter sport, therefore poor weather is common, particularly in Scotland where these matches were played. However, the researchers do not anticipate stadia to be of great effect as pitch coverage by stadium roofs is extremely minimal.

With improving sampling frequencies and a better understanding of its limitations, GPS is widely regarded as an appropriate method of measuring demands of team-sports and is now commonly used by sport science practitioners. A summary of the current literature on the validity and reliability of GPS units is presented in Appendixes 3 and 4 respectively

# 2. Systematic Literature Review

## 2.1. Rationale

As previously mentioned, GPS is widely used in team sports, particularly rugby union, but there is little clarification in the current published literature on the most appropriate application of this technology in terms of the velocity bands set for different movement intensities. By reviewing the current literature, the author aims to highlight the range of velocity bands and movement intensities used in team sport literature. Further to identifying the velocity bands used, the literature will also be reviewed for whether ABS or IND velocity bands were applied. These questions are most appropriate when comparing physical demands of positional groups.

A systematic review of the methods of GPS use in field based team sports, including all codes of rugby, the Australian Football League (AFL – Aussie rules), football (soccer) and field hockey was conducted with the aim of comparing reported velocity bands and application of these across squads.

## 2.2. Methods

The protocol followed for conducting the review was that suggested by Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement (Moher et al., 2009).

The eligibility criteria for inclusion in the review was that the sport was a field-based intermittent, HI team sport (AFL, soccer, field hockey and all codes of rugby), including both male and female teams and analysis was done using GPS during match-play. Youth teams were also included but not for any age-groups younger than 18 years.

The search was conducted between the 15th of April and 12th of May 2015 through the electronic databases PubMed, Web of Knowledge, MEDLINE and Google Scholar. The search strategy involved the same combination of key words being inputted to each database.

The key words and combination were as follows:

1. GPS AND Phys* AND (Team Sport) (Rugby) (AFL) (Field Hockey) (Soccer)

2. GPS AND movement demands

3. GPS Velocity Sport

4. GPS OR Accelerometery OR Time Motion Analysis AND Rugby

5. GPS AND (Rugby Union) (Field Hockey) (AFL) (Soccer)

Note: * indicates truncation and brackets indicate a repeated search alternating the words in brackets.

Appropriate studies were identified by title and abstract, with the primary criteria being that they included GPS, a team sport or physical demands from match play. Review studies were not included. Studies identified in the initial search were then read in full and inclusion in this review was based on whether they identified the velocity bands in which they defined intensities of motion, if they described the method in which they applied these velocity bands, i.e. ABS velocity bands applied to the whole squad or IND velocity bands presented as a % of maximum velocity, or if they described positional differences in physical demands within rugby union squads. Duplicates were noted as the search was carried out.

Data regarding participant characteristics (number, age, gender and athletic level), the velocity bands and whether they were set for individuals or the whole squad were extracted from all papers. In addition to this, HI running distance, Vmax, RHIE, % total distance at HI, number of HI impacts and total impacts was collected from papers on rugby union in order to gain an in depth view of the HI physical demands of the sport at a positional level. Further details were taken for rugby union studies to including number of matches that competition data was recorded in, the positions included in groups and whether velocity bands were ABS or IND.

## 2.3. Results

The search resulted in a total of 3668 studies; this was reduced to thirty-eight after the removal of duplicates and screening. The search and screening methods are depicted in the flow diagram in Figure 1.

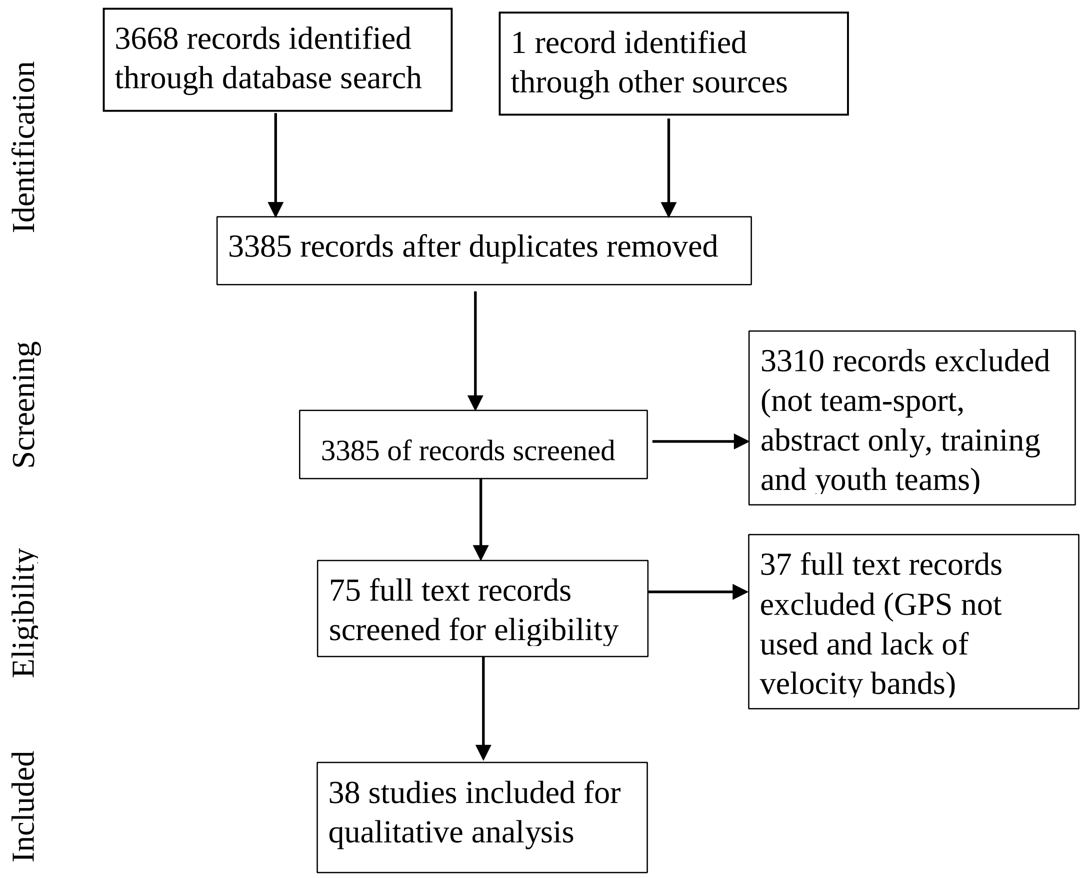


**Figure 1**. Systematic study selection flow chart.

## 2.4. Study summary

Six sports were included in the search, these were all intermittent HI, field-based team sports, AFL (n=7), hockey (n=6), soccer (n=3), and the three codes of rugby; union (n=12), sevens (n=5) and league (n=5). Across the 38 studies, a total of 1259 athletes were included, 95.5% of these being at the elite level. The mean age ranged from 18–30 years, showing prime athletic age in the elite group. All papers only covered match data as training data was a criterion for exclusion. A summary of the studies included for analysis is shown in Appendix 5.

## 2.5. Velocity Bands in Field-based Team Sports

The velocities extracted from the papers included in the systematic review that define a HI run, range from 14 -25km.h$^{-1}$ and are shown in Appendix 6. In rugby union, all the studies that use pre-set velocity bands for the whole squad are in agreement that 18km.h$^{-1}$ is a threshold for HI velocity. The highest cut-off point for HI was 25km.h$^{-1}$, found in a hockey match-play study (Gabbett, 2010). AFL studies differ from the other sports as they largely adopt a simple two intensity approach, in that an effort is either deemed to be low or high intensity depending on whether it is higher or lower than a given velocity, for the majority of AFL studies, this was 14km.h$^{-1}$.

Not all studies created a full complement of velocity bands ranging from standing/walking to maximal sprint. Some simply created bands within the HI bracket. To exclude these in data analysis excludes a large amount of information on the demands of field-sport match-play and the ratio between high intensity bouts and recovery.

Three of the thirty-five studies in which velocity band settings were quoted used IND bands (Reardon et al., 2015; Cahill et al., 2013; Venter et al., 2011). Cahill et al., (2013) and Venter et al., (2011) both used 81% as the cut off for HIR and 96% for maximal sprinting while Reardon et al., (2015) defined as all velocities over 60% of Vmax as high speed running (HSR) and didn't include maximal sprinting as a discrete movement intensity. Cahill et al., (2013) and Venter et al., (2011) were also both in agreement about the cut offs for low standing/walking, jogging, moderate intensity running (MIR) and sprinting.

## 2.6. Rugby Union Study Summary

A detailed summary of the rugby union studies can be found in Appendix 7. The level of competition at which the rugby union studies were carried out was very high, with participants playing in the Super Rugby league, the English Premiership and the Celtic/Magners/RaboDirect Pro12 League, currently known as the Guinness Pro12, in which teams from Scotland, Northern Ireland, Republic of Ireland, Wales and Italy play. Positional groupings varied between studies, some used the most generic groupings of backs and forwards while other studies use much more specific player groups. The more specific grouping strategies generally use five or six groups, with three for the forwards and two or three for the backs. The forwards are commonly broken down in to the front row (loose-head prop, hooker and tight-head prop), second row (the two locks) and the back row (blindside flanker, openside flanker and No.8). The backs are generally split in to inside backs (scrum half, fly half, inside centre and outside centre) and outside backs (right wing, left wing and full back). However, both Cahill et al., (2013) and Owen et al., (2015) have depicted the scrumhalf has a distinct position while Jones et al., (2015) has included it in the inside back group.

As the only semi-pro/under19 age category players were captured in the study by Venter et al., (2011) who applied IND bands to their subjects, a comparison between set band values at elite and semi-pro levels cannot be made to determine whether playing level is taken in to account when setting velocity bands. Three of the studies cover an entire season of matches for one team (Jones et al., 2015; Owen et al., 2015; McLellan et al., 2013). Cahill et al., (2013) conducted the most comprehensive study as their participants were from a number of teams across the English Premiership and therefore were able to collect data from forty-four matches. Not all studies included a full team of players, so not all positions were covered in each study. Although they were separated in to positional groups of forwards and backs, the specific position was not always cited so this data cannot be used in further analysis in the comparisons of physical demands between specific playing position (Suarez-Arrones et al., 2014; McLellan et al., 2013; Coughlan et al., 2011; Cunniffe et al., 2009).

## 2.7. High Intensity Running

The HIR demands of elite and semi-pro rugby union as published in the current literature are displayed in Appendix 8. Vmax ranges between 22-27.8km.h$^{-1}$ for forwards and 24.4-32km.h$^{-1}$ for backs. Within forwards, the distance run in HI and sprint speed zones is shown to increase from the front row forwards to the back row. The same trend is seen between the scrum halves, inside backs and outside backs (Jones et al., 2015; Cahill et al., 2013). When grouped as forwards and backs, it appears that backs cover far greater distances than forwards in HI zones. Reid et al., (2013) showed that forwards ran 330m at HI while the backs ran 539m, the backs also ran further at a sprint (68m) than the forwards (32m). McLellan et al., (2013) also found that forwards travel less distance than backs in

HI speed zones, with distances of 93±71m and 38±41m recorded by forwards for HIR and sprint zones respectively. The backs from the same study covered vastly higher distances at HI than forwards with values of 309±99m at HIR and 287±137m sprinting. This trend also applies for the number of HIEs and % total distance spent in HI speed zones by backs and forwards. The elite Spanish forwards that took part in the study conducted by Suarez-Aronnes et al., (2010) recorded 1.8±1.7 HIEs compared to 8.7±2.9 recorded by the backs. McLellan et al., (2013) also recorded forwards making less HIEs (2±3) than backs (13±6) as did Coughlan et al., (2011) (forwards: 59, backs: 100) and Cunniffe et al., (2011) (forwards: 67, backs: 77). However the converse is true for RHIEs, with both tight forwards (11±8) and loose forwards (13±7) recording more RHIEs than inside backs (7±7) and outside backs (6±6) (Jones et al., 2015).

## 2.8. Impacts

When positions are grouped simply as forwards and backs, forwards record more total impacts than backs do in all studies bar the one conducted by Suarez-Aronnes et al., (2014). Impacts are regarded as any deceleration with a force of over 5Gs on any of the three axes of the body (Owen et al., 2015), measured using the accelerometer within the GPS unit. HI impacts were deemed to be over 7Gs. When forwards are grouped further in to front row, second row and back row, the front row forwards record the highest total number of impacts with 499 and the second row recorded the least number of total impacts with 410. When grouped more distinctly than simply forward and backs, it can be seen that the backs group of scrum halves recoded more total impacts than the forward group of the second row (Owen et al., 2015), thus providing more evidence that sub-grouping forwards and backs provides a more distinct and accurate view of the demands of the positional groups. Total impacts per match range from 314 to 1274, the lowest being recorded by the inside back group, 314 (Owen et al., 2015) and the highest, 1274, by forwards (Cunniffe et al., 2009) as shown in Appendix 9.

## 2.9. Findings

The inconsistencies in the setting and application of velocity bands both within sports and between them are evident in Appendix 5. There is a lack of clarity as to which velocity corresponds to each of the movement intensities, which makes comparisons between studies difficult. The answer to this could be to investigate moving towards using sport specific thresholds, however in order to do this, substantial research is needed to clarify the best way in which to do this, as there is currently little literature on the differences between possible methods.

Reardon et al., (2015), Cahill et al., (2013) and Venter et al., (2011) are the only three of the thirty-eight studies included to have used IND velocity bands, so rather than absolute values in $km.h^{-1}$, the velocity bands are presented as % of player's Vmax. The distance spent in the IND sprinting velocity band, as set by Cahill et al., (2013), shows a very different image of the HI demands of each position when compared to the results shown in the study by Jones et al., (2015) who used similar positional groups but used ABS velocity bands. The distance covered in the sprinting velocity band is lower for all positions when IND velocity bands are used in the study conducted by Cahill et al., (2013). The mean values quoted by Jones et al., (2015) are 51m higher for the front/tight forwards, 130m higher for loose forwards/back row, 178m higher for the inside backs and a 312m higher for the outside backs. These differences could suggest two possible explanations: ABS velocity bands overestimate the distance covered at HI or IND velocity bands underestimate it.

In theory, by setting velocity bands using the IND method, resulting in each player having their own threshold for HIR and sprinting, we could deem IND results as a more truthful representation of work done by players. Should this be found to be the case then it would be the results for distance covered sprinting by Cahill et al., (2013) that would now be the basis for practitioners understanding of the physical requirements of rugby union, which are much lower than those recorded in other studies which use the traditional ABS method. The studies were only conducted two seasons apart so there would not have been a large shift in the playing style of the game to account for the far lower number of sprints recorded when applying velocity bands relative to maximum match velocity. Moving towards the use of IND bands could potentially prove to be a leveller between different stages of rugby union, i.e. between elite, amateur/semi-pro and age grade squads as currently the same bands are used for the senior national squad as the U20 squad. As the age grade players would largely be less developed as the senior squad, as only a couple of players would have senior contracts, it would appear from the results that they may sprint less than senior players, however they are in fact being judged against velocity bands that were set for use by senior players.

Reardon et al., (2015) is the only paper to have compared outputs between ABS and IND methods, and showed that the ABS method returned lower distances of HIR for both forwards and backs contradicting what is seen when comparing Cahill et al., (2013) and Jones et al., (2015). However the sole HSR velocity band set by Reardon et al., (2015) at >60% was lower, than the sprinting threshold of >80% set by Cahill et al (2013) which makes drawing direct comparisons difficult between the two results. While Cahill et al., (2013) and Jones et al., (2015) both included multiple velocity zones ranging from standing to HIR and sprinting, Reardon et al., (2015) only used one velocity zone, citing anything above 60% of Vmax or 18km.h$^{-1}$ as HI for ABS and IND methods respectively. This provides little scope to decipher the range of distances covered at the different intensities.

There is yet to be clarification in the literature in what is the best way to create IND velocity bands. Venter et al., (2011) and Cahill et al., (2013) used maximum match velocity to construct their IND zones, but Cahill et al., (2013) conceded that this may overestimate forward positions HIR as their match maximum velocity is unlikely to be their actual maximum, whereas back positions have more opportunity to cover the distance needed to reach actual maximum during a match. Reardon et al., (2015) used a Vmax recorded from match and training data. Cahill et al., (2013) and Venter et al., (2011) used the same %Vmax which provides an element of comparability between those two studies, but the Reardon et al., (2015) paper used a lower %max of 60% derived by dividing the arbitrary value which is used in the GPS software as the cutoff for HSR.

As well as discrepancies in the literature of set velocity bands, there are also differences in the methodologies used to report playing position in rugby union. When at least five positional groups were used rather than two, a far greater level of understanding on the demands of each position, and on each athlete in a match, can be gained. This has potential implications for tailoring training more accurately for the demands of a match and also in terms of preventing injury and aiding recovery if the positional demands are analysed more closely.

The importance of breaking the forwards and backs in to more specific positional groups is also illustrated by the number of impacts recorded. The back row recording the highest number of very heavy and severe impacts in of between 8-9Gs and over 9Gs may be due to the back row being able to run at higher velocities for more metres, creating more G forces in tackles, therefore recording higher force impacts.

### 2.9.1. Aim

In conclusion, current literature has shown that there is little consistency in the definition of movement intensities when using GPS. Rugby union was shown to have the most consistent velocity bands across the literature and it was the only sport to demonstrate that either ABS or IND velocity bands could be used. This review shows that further research is needed to clarify any potential difference in our assessment of the physical demands of rugby union, between positional groups, when using ABS or IND velocity bands.

It is hoped that the results of this study will shed more light on the differences between the two methods of GPS analysis, providing coaches and medical staff with a better understanding of the meaning behind GPS outputs. This will aid in their understanding of different positional workloads, match demands and training sessions and the subsequent recovery needs and also provide information surrounding impacts, HI work and overall physical demands, from which strength and conditioning coaches can prescribe the best possible physical training regimes.

Therefore the primary aim of this study was to determine if there is a difference in the estimation of the physical demands of rugby union positions when using IND velocity bands compared to the traditional ABS method for GPS analysis and secondly, if these differences are different between the positional groups of forwards and backs, allowing for better comparison across published data.

# 3. Methods

## 3.1. Participants

Twenty-six players, fifteen forwards (Height: 187.2±6.9cm, Weight: 101±9.4kg, %Body Fat: 15.0±3.6%) and eleven backs (Height: 183.5±6.4cm, Weight: 89.9±4.7kg, %Body Fat: 12.0±4.1%) (values are presented as mean ± SD) from one amateur/semi-professional club took part in the study during the entirety of 2015/2016 BT Premiership season in Scotland. SD Data files were collected from both home and away matches between August 2015 and January 2016 at the grounds of the ten participating BT Premiership teams, located in the central belt and borders regions of Scotland on a Saturday afternoon. In total, two hundred and fourteen GPS data files were collected from seventeen matches. The final match of the regular season was not included in the study as it was postponed due to adverse weather conditions and the rescheduled date was out with the time scale for data gathering and analysis.

Ethical approval was granted for this study by the College of Medical, Veterinary & Life Sciences Research Ethics Committee at the University of Glasgow. All participants were given a briefing by the researcher and an information sheet before providing written consent for their data to be included in the study.

## 3.2. Positional Groupings

Players were grouped at three positional levels; (i) Forwards n=15 and Backs n=11, (ii) Front 5 (F5) (props, hookers and second row, n=9), Middle 5 (M5) (flankers, No. 8, scrum half and fly half, n=9) Back 5 (B5) (centres, wings and full back, n=10) and (iii) their individual position: prop n=3, hooker n=2, second row n=4, flanker n=4, No. 8 n= 1, scrum half n=3, fly half n=1, centre n=4, wing n=5, full back n=5. Note that players often moved between the distinct positions, hence why individual position numbers exceed total for the study. The fly half position was omitted due to only one data file being collected from one player. This was a consequence of the drafting system where a professional player generally played that position, on other occasions it was filled by a player who did not take part in the study. Omitting a distinct playing position rather than merging with another position follows the precedent of Lacome et al., (2014). While only one player was also recorded playing at No. 8, this player provided thirteen data files.

## 3.3. GPS Units

OptimEye X4 10 Hz GPS units (Catapult Innovations, Canberra, Australia) were worn in anti-bacterial moisture management cropped vests with a padded pouch for the unit located in the back which were designed by the GPS manufacturers Catapult. When placed in the vest, the unit sits in the upper thoracic region of the spine between the scapulae. The GPS units (96mm x 52mm x 14mm, 67g) have 3-axes accelerometer, gyroscope and magnetometer sampling frequencies of 100Hz. Participants were all familiar with wearing GPS units as they had worn them in the previous season. Each unit was assigned to a particular positional number i.e. 1, 2, 3 so that as much as possible players wore the same unit.

## 3.4. Sprint Test Procedures

Sprint testing took place in late-July, during the pre-season training period. Vmax for each squad player was recorded by completing a 40m sprint on grass whilst wearing an OptimEye X4 GPS unit. The test was conducted on grass to replicate match-play surface. The distance was measured using a measuring tape. Speed gates were used as a secondary measure of the time taken to cover the 40m distance. The test was repeated three times, with appropriate rest period between tests, and to allow for any improvement through learning. The best (highest) Vmax reached in any of the three trials was taken as that player's Vmax on grass.

## 3.5. Velocity Bands

ABS velocity bands were set according to the bands currently being used by the SRU professional and national squads. The IND velocity bands were derived as a percentage of each player's Vmax. The IND bands were derived from Cahill et al., (2013) and Venter et al., (2011). However, each of those studies only used five bands (see Appendix 6) and the aim of this paper was to compare directly with the velocity bands already used by the

Scottish rugby teams, which is seven. It was also thought that a HIR speed also needed to be included and that 50-80% was too broad a band, considering that “High Intensity” is commonly thought of as over 70% of maximal work rate.

Table 1 below shows the movement intensity and both the absolute velocity and individual percentage of Vmax associated with it.

**Table 1.** ABS and IND velocity bands and corresponding movement intensity

| Velocity Zone | Movement Intensity | ABS Velocity ($km.h^{-1}$) | Percentage of IND Vmax (%) |
|---|---|---|---|
| 1 | Standing/Walking | 0 - 6 | <20 |
| 2 | Jogging | 6.1 - 11 | 20 – 40 |
| 3 | Cruising | 11.1 - 15 | 40 – 50 |
| 4 | MIR | 15.1 - 18 | 50 – 70 |
| 5 | HIR | 18.1 - 21 | 70 – 80 |
| 6 | Sprinting | 21.1 - 25 | 80 – 95 |
| 7 | Maximal Sprint | 25.1 - 40 | 95-100 |

## 3.6. GPS Output Variables

Four key GPS output variables were compared between ABS and IND methods:

- % distance covered in zones 1-7
- % time spent in zones 1-7
- the number of efforts in the three HI zone of 5, 6 & 7
- the number of RHIEs (3 of the following events occurring within 21 seconds)
    - sprint >18km.h-1
    - acceleration >3m.s-1
    - deceleration <-3m.s-1
    - tackle load >3.

Descriptive variables which were also recorded for an overview were: total distance (m), relative distance ($m.min^{-1}$), player load and match Vmax ($km.h^{-1}$).

## 3.7. Match Procedure

GPS units were switched on before the warm-up, allowing approximately 30mins for the GPS signal to be picked up before the start of play. The units were kept stationary during this time to reduce HDOP and pick up as many satellites as possible. Units were placed in the vests by the investigators either before or after the warm up depending on player's preference. The Greenwich Mean Time (GMT) for the start of match, half time, start of second half, full time, sin bins and substitutions were recorded.

Although HDOP was not noted for each match during the season, it would be justifiable to assume that the matches taking place in December/January, which had the most cloud coverage and heavy rain, could have potentially had a lower level of validity than those taking place in the Autumn, when conditions were mainly clear skies or light cloud coverage. It is the author's belief that the changing stadia would not have had an effect on the validity of the GPS due to their small size, all just being a stand on one side of the pitch, with no stadia roofs and also no tree coverage.

Post-match, the raw data were downloaded from the GPS units using a mass USB device in the charging box, to the proprietary software (Catapult Sprint 5.1) on a laptop (Toshiba). Field time was applied to each player's raw file by inserting $1^{st}$ half and $2^{nd}$ half periods and the benching times. Excel (Microsoft, California, USA) reports for each match were created using both the ABS and IND velocity bands.

## 3.8. Inclusion Criteria

Match data were only included for analysis if field time was equal to or greater than the average field time (minutes) for that position, which are as follows: forward - 65mins; back - 73mins; F5 - 62mins, M5 - 67mins; B5 - 77mins; prop - 51mins; hooker - 71mins; second row - 67mins; flanker - 62mins; No. 8 - 81mins, scrum half - 61mins; centre - 72mins; wing - 83mins and full back - 77mins.

## 3.9. Statistical Analysis

Once the data collection period was completed, the excel files were transferred to Minitab (version 17, Minitab Inc., State College, Pennsylvania, USA) for statistical analysis. The inclusion criteria for match data was that field time had to be equal or greater to the average field time for that position (see section 3.8.). Twelve data files were omitted from analysis due to GPS units not recording any distance. GPS metrics of interest; % of the total distance in zones 1-7, % time in zones 1-7, number of efforts in zones 5-7 and RHIEs were extracted.

For each of the four GPS outputs investigated, two box plots have been produced. One visualises the raw outputs from the ABS and IND methods for each of the seven velocity bands for forwards and backs while the second depicts the difference between the two methods for forwards and backs and also illustrates whether this difference was significant or not. Scatterplots were produced to provide a subjective impression of the effect of applying ABS and IND bands to the GPS metrics outlined previously as the focus for analysis at different levels of positional groupings as well as the match-to-match variance across the season for all outputs.

A general linear model (GLM) was constructed to determine if the differences between ABS and IND methods within the positions of forwards and backs were significant. The GLM was also used to determine whether the differences found within groups, were different between the forwards and backs. Formal analysis was only conducted on the forward/back groups as these were the only two with a sufficient number of observations to allow for thorough objective analysis. The factors included in the GLM were match number, individual player and the fixed player positions of forward and back. It was deemed that this level of positional analysis would be sufficient to derive a conclusion on whether the estimations of the physical demands of rugby union are different when using ABS or IND bands and whether the differences found within the rudimental positions of forwards and backs are different.

All data are presented as mean ± SD.

# 4. Results

The results of the season long motion-analysis study will be displayed in five sub-sections. Firstly, in terms of the pre-season sprint testing used to determine Vmax, from which IND bands were derived. Secondly the season averages of the locomotive variables recorded for the three levels of positional groups: forwards/backs, F5, M5, B5 and the nine individual positions will be displayed. The locomotive variable section will also focus on the statistical difference between the outputs recorded for forwards and backs. And finally the third, fourth and fifth sub-sections will provide the main focus of the results section, displaying the results recorded for the outputs of % total distance covered in zones 1-7, % time spent in zones 1-7 and the number of HIEs and RHIEs recorded (the HIEs and RHIEs results are grouped in the same section).

Sub-sections three, four and five aim to develop an understanding of the differences between ABS and IND methods for each of the three levels of positional groups, how physical demands differ between positions and also across the season. Each section culminates in formal analysis of the difference between ABS and IND methods within the forward and back positions and then with whether these differences are then different between the forwards and backs.

## 4.1. Sprint test results

The Vmax achieved by players during pre-season sprint testing is detailed in Table 2. A Two Sample T-Test showed that backs were significantly faster than forwards (30.1±1.3km.h$^{-1}$ vs. 28.9±1.3km.h$^{-1}$, P<0.05, 95% CI -2.8, -0.7). The 95% CI shows that the forwards Vmax is between 0.7km.h$^{-1}$ and 2.8km.h$^{-1}$ slower than backs.

**Table 2.** Mean, Maximum and Minimum Vmax for each positional group.

| **Position** | **Mean Vmax (km.h$^{1-}$) ± SD** | **Range (km.h$^{-1}$)** |
|---|---|---|
| Forward | 28.9 ± 1.3 | 27.5 - 31.3 |
| Back | 30.1 ± 1.3 | 28.7 - 32.3 |
| F5 | 28.5 ± 1.1 | 27.5 - 30.5 |
| M5 | 29.6 ± 1.3 | 27.9 - 31.3 |
| B5 | 30.8 ± 1.3 | 28.7 - 32.3 |
| Prop | 28.2 ± 0.6 | 27.7 - 28.9 |
| Hooker | 29.4 ± 1.6 | 27.5 - 30.5 |
| Second Row | 28.0 ± 0.5 | 27.5 - 28.5 |
| Flanker | 29.9 ± 1.4 | 28.6 - 31.3 |
| No. 8 | 29.7 - | - |
| Scrum Half | 29.8 ± 0.7 | 29.3 - 30.3 |
| Centre | 31.1 ± 1.1 | 30.0 - 32.2 |
| Wing | 32.0 - | - |
| Full Back | 31.0 ± 1.6 | 28.7 - 32.3 |

## 4.2. Locomotive Variables

The locomotive variables of total distance covered, work rate (displayed as m.min$^{-1}$), player load and match Vmax were recorded to provide context for the formal investigation. Details of locomotive variables are displayed in the subsections below.

***Distance***

As shown below in Table 3, the forward and back groups cover similar distances during match play of 5867±953m and 5772±886m respectively. A Two-sample T-Test showed no significant difference between the distance run between the forwards and backs with a 95% CI of -219, 409 and a P>0.05. The gap widens between the F5 (5917±1063m), M5 (5648±991m) and B5 (5756±846m). The F5's high mean total distance can be attributed to the mean distance covered by the second row (6365±868m) which is 812m further than the hooker covered and 1328m further than the prop covered. The back positions all cover similar distances, ranging between 5638m and 5840m.

**Table 3.** Distance covered during match play by all positional groups.

| Position | Distance (m) (mean ± SD) | Distance range (m) |
|---|---|---|
| Forward | 5867 ± 953 | 2324 - 7538 |
| Back | 5772 ± 886 | 2323 - 7128 |
| F5 | 5917 ± 1063 | 2324 - 7538 |
| M5 | 5648 ± 991 | 2363 - 7128 |
| B5 | 5756 ± 846 | 2323 - 7100 |
| Prop | 5037 ± 1305 | 2324 - 6484 |
| Hooker | 5553 ± 1060 | 2922 - 6622 |
| 2nd Row | 6365 ± 868 | 3201 - 7358 |
| Flanker | 5431 ± 758 | 4460 - 6815 |
| No. 8 | 6060 ± 465 | 5480 - 6737 |
| Scrum Half | 5730 ± 1090 | 3472 - 7128 |
| Centre | 5638 ± 761 | 3766 - 7100 |
| Wing | 5840 ± 610 | 4397 - 6700 |
| Full Back | 5735 ± 1420 | 2323 - 6633 |

***Work rate***

Work rate is very similar between forwards (69.3±10.1m.min$^{-1}$) and backs (69.3±0.6m.min$^{-1}$) with no significant difference found from a Two-sample T-Test (95% CI: -1.34, 5.71 and P>0.05). Work rate across all positions is very similar with the exception of the second row, which with a work rate of 74.2±8.6m.min$^{-1}$, is higher than all others.

**Table 4.** Work rate during match play for all positions as measured by m.min$^{-1}$.

| Position | m.min$^{-1}$ (mean ± SD) | m.min$^{-1}$ range |
|---|---|---|
| Forward | 69.3 ± 10.1 | 26.1 - 75.9 |
| Back | 69.3 ± 10.6 | 25.8 - 85.8 |
| F5 | 69.9 ± 11.6 | 26.1 - 86.6 |
| M5 | 68.8 ± 9.2 | 40.7 - 85.8 |
| B5 | 66.0 ± 9.8 | 25.8 - 81.6 |
| Prop | 66.6 ± 12.4 | 26.1 - 80.1 |
| Hooker | 65.2 ± 12.0 | 33.2 - 77.9 |
| 2nd Row | 74.2 ± 8.6 | 47.1 - 86.6 |
| Flanker | 67.5 ± 5.9 | 59.9 -78.3 |
| No. 8 | 69.1 ± 5.7 | 61.6 - 77.4 |
| Scrum Half | 68.0 ± 13.0 | 40.3 - 85.8 |
| Centre | 66.5 ± 8.9 | 44.8 - 81.6 |
| Wing | 66.8 ± 6.9 | 51.7 - 76.8 |
| Full Back | 65.7 ± 16.8 | 25.8 - 79.0 |

### *Player Load*

Player load was devised originally by Catapult Sports and the Australian Institute of Sport as a way to measure effort in rugby union by investigating the external stress exerted on the muscular-skeletal system. Player load is an important metric in rugby union as it gives an alternative measure of effort that isn't reliant on distance, which is key as rugby union player's workload is largely related to actions that aren't distance dependant. The inertial accelerometer in the GPS unit measures forward, sideways and vertical accelerations which are used in catapult's algorithm for calculating player load, which is measured in arbitrary units, hence why no units will be used in Table 5 below.

Player load is significantly higher for forwards (595±107) than backs (492±11) according to a two-sample T-Test (95% CI: 69.3, 136.3; $P<0.05$). Within the forwards, the F5 position of second row has the highest player load of 638±103. The other F5 positions of prop (502±126) and hooker (552±116) have lower player loads than the M5 positions of flanker (616±115) and No.8 (583±41). The scrum half position has the highest mean player load (549± 103) within the backs, with the B5 position of centre having the lowest player load (444±77), closely followed by the wing (485±60).

**Table 5.** Player load during match play for all positions.

| Position | Player load (mean ± SD) | Player Load range |
|---|---|---|
| Forward | 595 ± 107 | 226 - 664 |
| Back | 492 ± 11 | 251 - 685 |
| F5 | 590 ± 116 | 226 - 787 |
| M5 | 576 ± 113 | 203 - 884 |
| B5 | 472 ± 79 | 251 - 644 |
| Prop | 502 ± 126 | 226 - 671 |
| Hooker | 552 ± 116 | 244 - 665 |
| 2nd Row | 638 ± 103 | 339 - 787 |
| Flanker | 616 ± 115 | 429 - 884 |
| No. 8 | 583 ± 41 | 527 - 649 |
| Scrum Half | 549 ± 103 | 346 - 685 |
| Centre | 444 ± 77 | 303 - 611 |
| Wing | 485 ± 60 | 371 - 605 |
| Full Back | 514 ± 118 | 251 - 644 |

### *Maximum Match Velocity*

According to a two-sample T-Test the backs recorded significantly higher match Vmax (28.47±2.1km.$h^{-1}$) than forwards (24.7±2.6km.$h^{-1}$) with a 95% CI of -4.59 and -0.30 and $P<0.05$. The highest match Vmax was recorded on the wing (33.1km.$h^{-1}$).

**Table 6.** Maximum velocity during match play for all positions.

| Position | Match Vmax (km.$h^{-1}$) mean ± SD | Match Vmax range (km.$h^{-1}$) |
|---|---|---|
| Forward | 24.7 ± 2.6 | 18.9 - 29.0 |
| Back | 28.5 ± 2.1 | 23.2 - 33.1 |
| F5 | 24.5 ± 2.7 | 18.9 - 29.0 |
| M5 | 25.5 ± 2.4 | 21.5 - 30.8 |
| B5 | 29.1 ± 1.7 | 25.5 - 33.1 |
| Prop | 21.8 ± 2.2 | 18.9 - 26.8 |
| Hooker | 26.6 ± 1.3 | 24.6 - 29.0 |
| 2$^{nd}$ Row | 24.4 ± 2.4 | 20.5 - 28.3 |
| Flanker | 25.9 ± 1.8 | 23.1 - 28.8 |
| No. 8 | 24.5 ± 2.5 | 21.6 - 28.9 |
| Scrum Half | 26.4 ± 2.1 | 23.2 - 30.8 |
| Centre | 28.7 ± 1.6 | 26.3 - 31.5 |
| Wing | 29.8 ± 1.7 | 26.0 - 33.1 |
| Full Back | 28.0 ± 1.5 | 25.5 - 30.7 |

In terms of maximal sprinting requirement of positions, the props show the greatest difference in range from the sprint test (27.7-28.9km.$h^{-1}$) to match Vmax (18.9-26.8km.$h^{1}$). This shows that rather than props not being capable of high maximal sprint times, there may not be the requirement for it in their specific position. The other forward positions had match Vmax closer to their sprint.

## 4.3. Percentage of distance covered at each movement intensity

***ABS method***

Table 7 shows that in ABS terms, backs covered 42.6±5.0% of their total distance in zone 1 compared to forwards who covered 37.7±4.5% of their total distance in zone 1. The backs also cover more % distance at HI in zones 5, 6 and 7 than forwards. Forwards covered 3.6±1.7%, 1.7±1.3% and 0.3±0.5% in zones 5, 6 and 7 which is lower than the backs who covered 5.2±1.4%, 3.8±1.6% and 1.5±1.1% in zones 5, 6 and 7 respectively. Props cover the lowest distance of all positions in the HI zones of 5, 6, & 7 while the other forward positions cover similar % distances in the HI zones.

**Table 7.** Percentage of total distance covered in zones 1-7 using the ABS method.

| **Position** | **Zone 1 (mean ± SD)** | **Zone 2 (mean ± SD)** | **Zone 3 (mean ± SD)** | **Zone 4 (mean ± SD)** | **Zone 5 (mean ± SD)** | **Zone 6 (mean ± SD)** | **Zone 7 (mean ± SD)** |
|---|---|---|---|---|---|---|---|
| Forward | 37.7±4.5 | 26.3±3.8 | 22.0±4.2 | 8.4±2.3 | 3.6±1.7 | 1.7±1.3 | 0.3±0.5 |
| Back | 42.6±5.0 | 21.6±3.0 | 16.9±3.4 | 8.3±1.8 | 5.2±1.4 | 3.8±1.6 | 1.5±1.1 |
| F5 | 36.3±4.3 | 26.7±4.2 | 23.7±3.8 | 8.1±2.5 | 3.2±1.7 | 1.7±1.4 | 0.3±0.4 |
| M5 | 40.6±4.0 | 24.7±3.1 | 19.7±2.8 | 8.9±1.7 | 4.1±1.3 | 1.6±0.8 | 0.3±0.4 |
| B5 | 43.4±4.9 | 21.3±3.1 | 15.5±2.3 | 8.1±1.7 | 5.5±1.2 | 4.3±1.1 | 1.8±1.0 |
| Prop | 39.2±3.3 | 32.0±3.1 | 22.2±3.8 | 4.3±1.8 | 1.6±1.8 | 0.4±0.9 | 0.0±0.1 |
| Hooker | 37.8±4.4 | 23.3±1.8 | 23.4±4.5 | 8.5±1.4 | 3.7±1.1 | 2.7±0.9 | 0.5±0.4 |
| 2nd Row | 34.2±3.9 | 26.5±3.1 | 24.4±3.2 | 9.3±1.9 | 3.5±1.3 | 1.5±1.3 | 0.3±0.5 |
| Flanker | 39.5±4.1 | 26.3±2.5 | 19.5±3.6 | 8.4±1.7 | 4.1±1.5 | 1.9±1.0 | 0.3±0.4 |
| No.8 | 41.4±3.1 | 25.1±3.2 | 17.8±1.2 | 8.9±2.1 | 4.5±1.9 | 1.7±1.4 | 0.3±0.7 |
| Scrum Half | 41.4±4.3 | 22.3±2.4 | 21.0±2.4 | 9.2±1.6 | 3.9±1.0 | 1.7±0.7 | 0.4±0.3 |
| Centre | 43.4±4.7 | 20.9±2.4 | 16.3±3.3 | 8.5±1.9 | 5.5±1.5 | 3.9±1.6 | 1.3±0.6 |
| Wing | 44.2±4.9 | 20.7±3.2 | 14.7±2.1 | 7.9±1.9 | 5.5±1.3 | 4.6±1.0 | 2.1±0.5 |
| Full Back | 39.9±4.7 | 24.8±2.8 | 17.1±2.1 | 7.6±0.8 | 5.1±1.1 | 3.7±0.8 | 1.7±1.1 |

*IND method*

The IND method of analysis recorded the backs covering 44.0±5.7% of total distance in zone 1 while it showed forwards covering 35.4±5.0% of their total distance in zone 1. Again, the backs cover a higher % distance at HI than forwards, with backs covering 2.8±1.2%, 1.5±1.1% and 0.1±0.2% in zones 5, 6 and 7 respectively while the forwards covered 1.9±1.2%, 0.7±0.7% and 0.0±0.1% in the HI zones.

**Table 8.** Percentage of total distance covered in zones 1-7 using the IND method.

| Position | Zone 1 (mean ± SD) | Zone 2 (mean ± SD) | Zone 3 (mean ± SD) | Zone 4 (mean ± SD) | Zone 5 (mean ± SD) | Zone 6 (mean ± SD) | Zone 7 (mean ± SD) |
|---|---|---|---|---|---|---|---|
| Forward | 35.4±5.0 | 32.0±4.1 | 16.4±3.5 | 13.7±3.6 | 1.9±1.2 | 0.7±0.7 | 0.0±0.1 |
| Back | 44.0±5.7 | 26.7±0.5 | 11.8±2.9 | 13.0±2.8 | 2.8±1.2 | 1.5±1.1 | 0.1±0.2 |
| F5 | 34.0±4.8 | 32.5±4.3 | 17.9±2.9 | 13.2±3.6 | 1.7±1.1 | 0.6±0.7 | 0.0±0.1 |
| M5 | 39.5±4.6 | 30.2±4.2 | 14.0±2.7 | 13.8±3.6 | 1.9±1.2 | 0.7±0.7 | 0.0±0.1 |
| B5 | 45.1±5.6 | 26.1±3.9 | 10.9±2.2 | 12.8±2.5 | 3.1±1.0 | 1.7±0.9 | 0.1±0.2 |
| Prop | 34.7±3.7 | 38.1±2.3 | 18.1±3.1 | 8.2±2.2 | 0.5±0.4 | 0.0±0.0 | 0.0±0.0 |
| Hooker | 38.0±4.5 | 29.6±2.2 | 17.2±3.5 | 12.1± 2.0 | 2.2±0.7 | 0.0±0.0 | 0.0±0.0 |
| 2nd Row | 31.4±3.8 | 31.6±3.3 | 18.1±2.5 | 16.0±2.6 | 1.8±1.1 | 0.1±0.2 | 0.1±0.2 |
| Flanker | 39.6±4.6 | 31.4±4.3 | 13.8±3.2 | 15.7±2.9 | 1.9±1.4 | 0.0±0.0 | 0.0±0.0 |
| No.8 | 37.1±3.4 | 30.9±3.2 | 12.9±1.3 | 12.5±3.4 | 2.6±1.5 | 0.0±0.1 | 0.0±0.1 |
| Scrum Half | 42.1±3.4 | 28.8±4.9 | 14.7±3.1 | 12.5±3.4 | 1.4±0.7 | 0.0±0.1 | 0.0±0.1 |
| Centre | 44.3±4.7 | 25.7±1.5 | 11.3±2.1 | 14.1±2.8 | 3.1±1.1 | 0.1±0.1 | 0.1±0.1 |
| Wing | 46.8±5.5 | 25.1±4.4 | 10.5±2.3 | 12.5±2.6 | 3.2±0.7 | 0.2±0.3 | 0.2±0.3 |
| Full Back | 40.4±5.8 | 30.1±3.2 | 11.7±2.4 | 12.6±1.8 | 3.0±0.8 | 0.1±0.1 | 0.1±0.1 |

***Visualisation of % distance in each zone by the three levels of positional groups***

The numerical values shown above in Table 7 are illustrated overleaf in Figure 2. The difference in % distance covered, between ABS and IND for forwards and back groups in each velocity zone can be seen in Figure 2.

The boxplots in Figure 2 show the decreasing % distance covered in each zone by both forwards and backs. It also shows backs covering more % distance than forwards in zones 1, 5, 6 & 7. The median lines of each boxplot can be used to help understand if there is any difference between the % distances covered when ABS or IND bands for each zone. In zone 1 median lines are similar with the plots largely overlapping. However the direction of the difference is not the same for both positions, when the IND method is used the forwards record a lower % distance in zone 1 while the backs record a higher % distance in zone 1. This is the only zone in which this occurs. In zones 2 and 4 the boxplots indicate that the IND method gives higher values for %distance covered than the ABS method. The converse is true in zones 2, 5, 6 and 7, which show that the ABS method has given higher values than IND for the same metric.

The use of a scatterplot allows for the visualisation of the relationship between the ABS and IND method, aided by the line of equality, and if this difference is systematic across the whole axes range.

The F5, M5 and B5 groupings give a more position sensitive representation of positional demands and differences in these demands using ABS and IND methods of GPS analysis. The plots in Figure 3 show that the three positional groups do not follow the same spacing pattern along the line of equality in each zone or share the same difference between ABS and IND. The F5 cover the lowest % of total distance in zone 1 but cover the highest % distance in zones 2 and 3. The B5 are the only group to lie below the line of equality in zone 1, while all groups fall below the line of equality in zones 2 and 4. All groups become less tightly grouped in zone 4 onwards and move further from the line of equality, which is also the case in the HI zones, especially in zone 7, which is predominantly the B5.

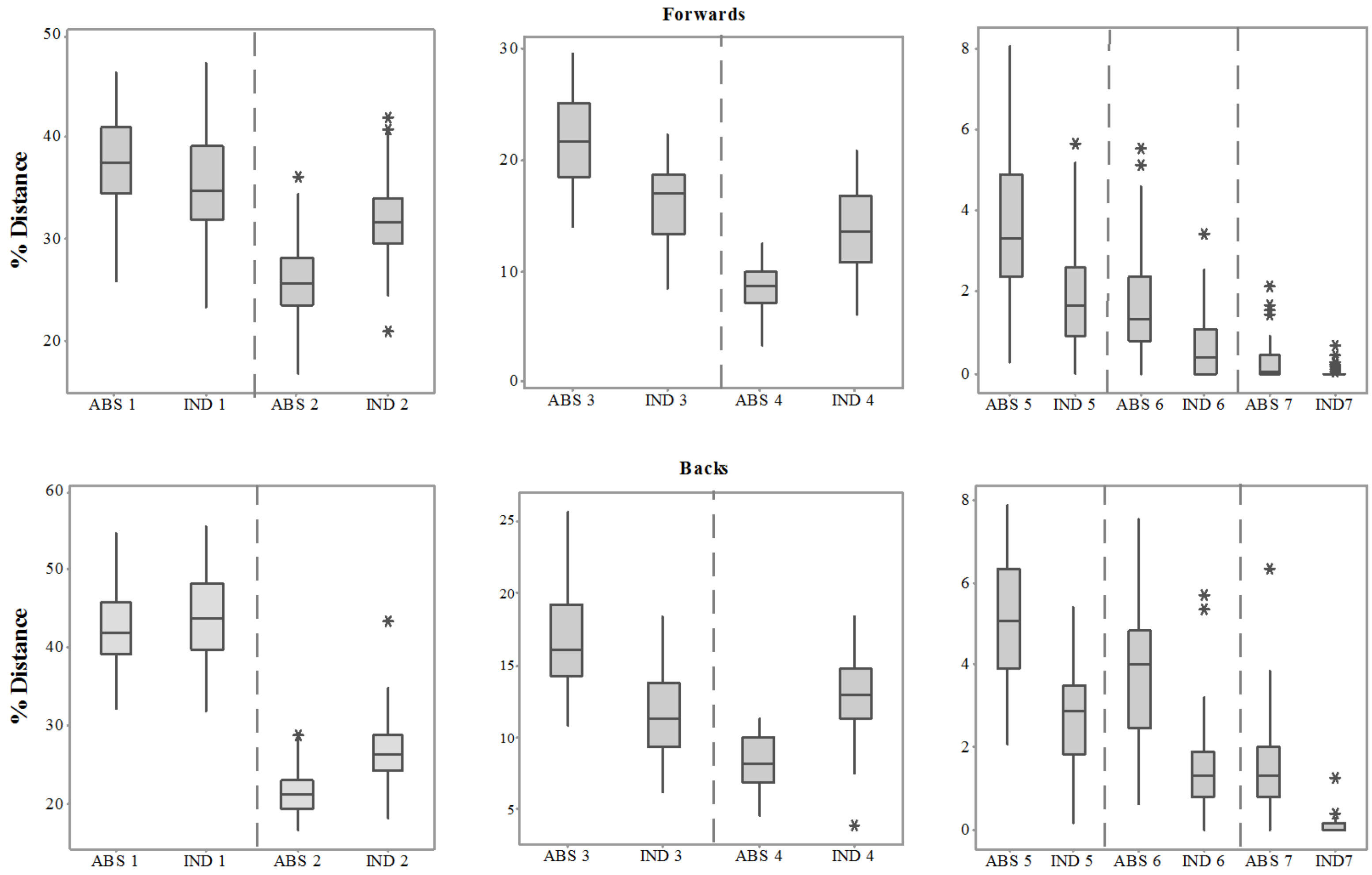


**Figure 2.** Comparison of % distance covered by forwards and backs in each velocity zone for ABS and IND methods.

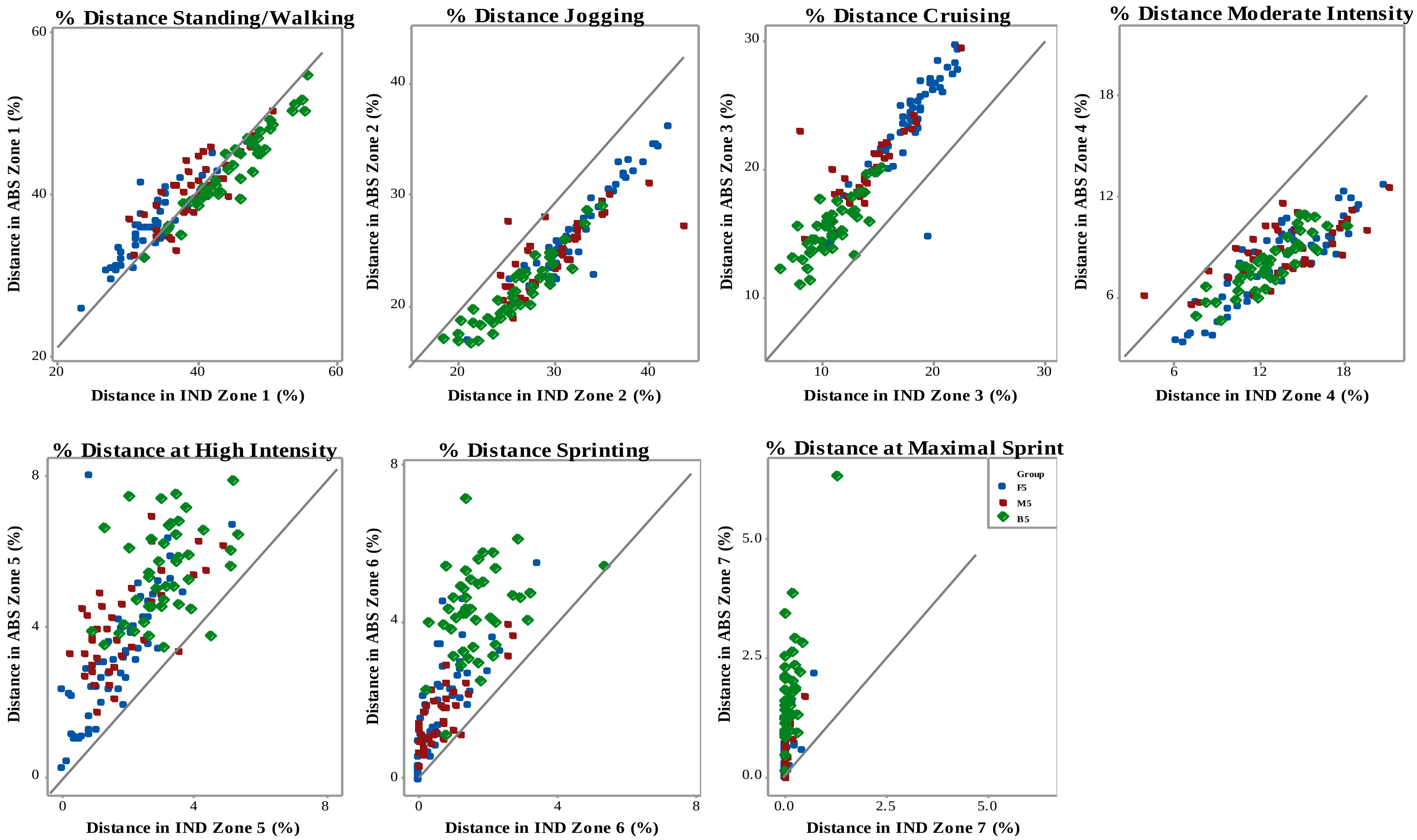


**Figure 3.** Comparison of % distance covered by F5 (blue), M5 (red) and B5 (green) positional groups in each movement intensity zone as measured by the ABS method (y-axis) and IND method (x-axis). The solid diagonal line indicates the line of equality between ABS and IND measurements, points lying above the line signify the ABS method recording a higher value than the IND, with points below the line signifying

In Figure 4 overleaf, the individual positional groups are plotted in zones 1, 3 and 5 for each of the 17 matches in the season to illustrate that the variations in the output of % distance between matches. Only these three zones were analysed due to the high level of similarity between zones 1 & 2, 3 & 4 and then the low meterages recorded in zones 6 & 7. The emphasis of this section is aimed as a snapshot of the change in metric outputs across the season, hence limiting the zones used was intended to make the comparison between matches clearer.

Teams move as a group along the line of equality illustrating the overall tempo of each match, the differences in which between matches can be seen using the dashed reference line as basis for comparison. For example, matches 14 and 15 could be classed as low tempo as many positions lie above the reference line in zone 1 and below the reference line in zone 5. Consistencies within positions can be seen throughout the season such as the centre (blue triangle) being consistently high in terms of % distance covered at HI. It can also be seen that the second row is perhaps higher in % distance covered at HI than may be predicted for a forward. The opposite is true for the props which are consistently the lowest in terms of % distance covered at HI in zones 5, 6 and 7.

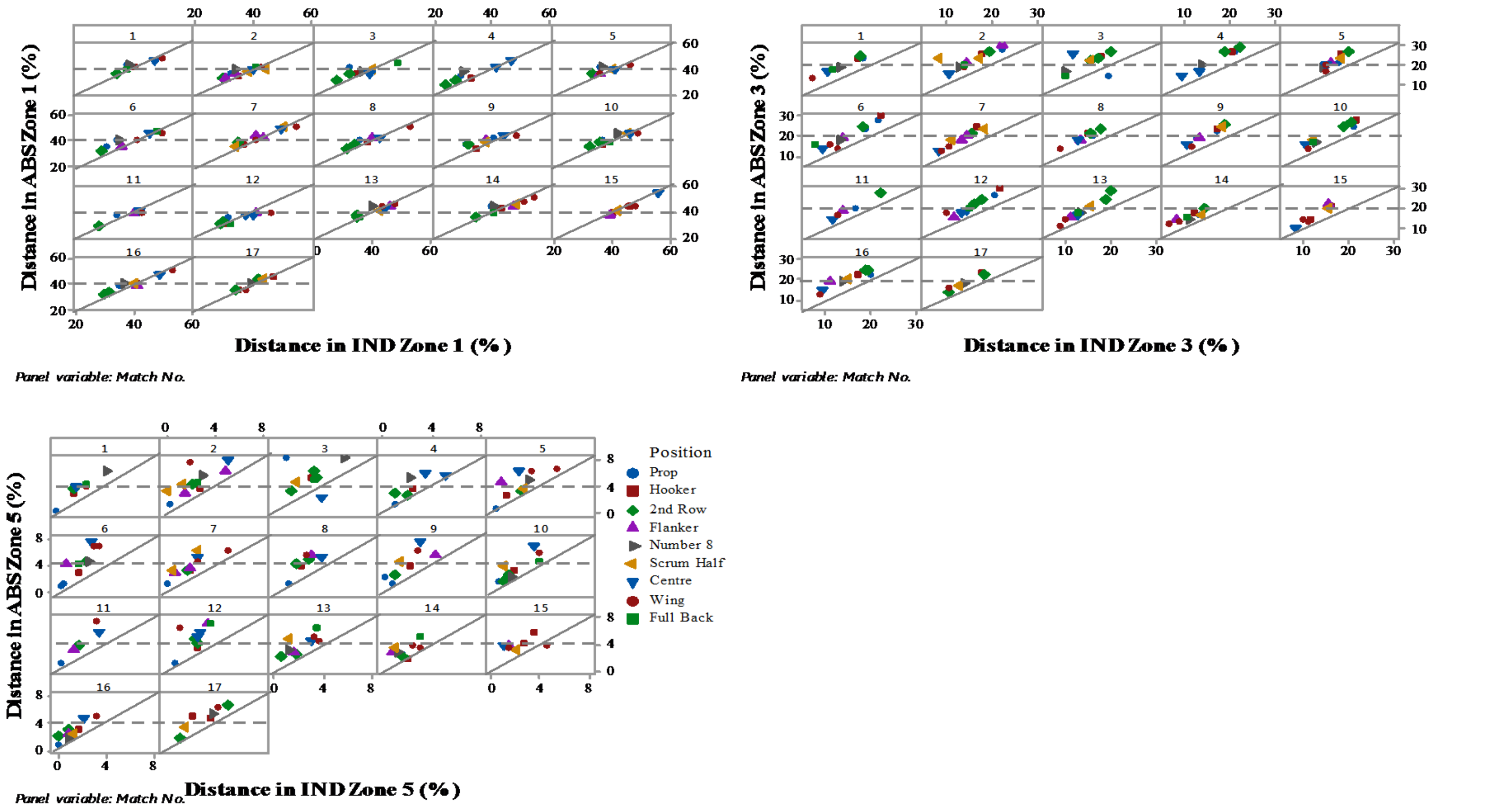


**Figure 4.** Comparison of the % distance covered in zones 1, 3 & 5 by all positions between all 17 matches in the BT Premiership season, illustrating match-to-match variation in physical demands. Solid diagonal lines signify the line of equality between the ABS method (y-axis) and the IND method (x-axis). The dashed horizontal line is a reference point to aid comparison between matches

***Comparison between ABS and IND methods***

**Table 9.** Difference between the ABS and IND methods of analysis for % distance covered in zones 1-7 (ABS – IND). Statistical significance between ABS and IND methods within positional group is indicated by *.

| Position | Zone 1 | Zone 2 | Zone 3 | Zone 4 | Zone 5 | Zone 6 | Zone 7 |
|---|---|---|---|---|---|---|---|
| Forward | 2.3±2.4* | -5.7±1.5* | 5.6±1.7* | -5.3±2.1* | 1.7±1.1* | 1.0±0.9* | 0.3±0.4* |
| Back | -1.4±1.7* | -5.1±2.3* | 5.0±2.1* | -4.7±1.9* | 2.4±1.3* | 2.2±1.3* | 0.3±0.4* |
| F5 | 2.3±2.1 | -5.8±1.3 | 5.7±1.9 | -5.1±1.8 | 1.5±1.1 | 1.0±0.9 | 0.2±0.4 |
| M5 | 1.1±2.8 | -5.8±2.7 | 5.7±1.8 | -4.9±2.7 | 2.2±1.0 | 1.0±0.5 | 0.3±0.4 |
| B5 | -1.7±1.7 | -5.6±1.6 | 4.5±1.4 | -4.8±1.3 | 2.4±1.3 | 2.6±1.2 | 1.7±0.9 |
| Prop | 4.5 ±1.7 | -6.1±1.5 | 4.1±2.6 | -3.9±1.0 | 1.1±1.7 | 0.3±0.7 | 0.0±0.0 |
| Hooker | -0.2±0.2 | -6.2±1.3 | 6.2±1.3 | -3.6±1.1 | 1.5±0.7 | 1.8±0.8 | 0.5±0.4 |
| 2nd Row | 2.9±0.9 | -5.2±0.7 | 6.2±0.9 | -6.7±1.3 | 1.7±0.6 | 0.8±0.6 | 0.2±0.3 |
| Flanker | -0.1±1.6 | -5.1±2.3 | 5.7±1.3 | -4.2±3.0 | 2.2±1.0 | 1.2±0.8 | 0.3±0.4 |
| No.8 | 4.3±1.5 | -5.8±1.4 | 5.0±0.7 | -6.7±1.0 | 1.9±0.7 | 1.0±0.9 | 0.3±0.6 |
| Scrum Half | -0.6±1.2 | -6.6±3.1 | 6.3±2.7 | -3.3±2.1 | 2.6±0.9 | 1.2±0.5 | 0.4±0.3 |
| Centre | -0.9±1.9 | -4.7±2.2 | 4.1±1.6 | -5.6±2.2 | 2.4±1.5 | 2.4±1.6 | 1.3±0.5 |
| Wing | -2.6±1.9 | -4.4±1.9 | 4.2±1.6 | -4.5±1.2 | 2.4±1.6 | 3.0±1.1 | 1.9±1.0 |
| Full Back | -0.5±1.5 | -5.3±1.2 | 5.5±1.2 | -5.1±1.3 | 2.1±0.9 | 1.6±0.3 | 1.6±1.1 |

In zone 1, the direction of difference between ABS and IND is positive for forwards (2.3±2.4%) and negative for backs (-1.4±1.7%). Zone 1 is the only zone in which there is a difference in the direction of difference between ABS and IND for forwards and backs. Zones 2 & 4 both have a negative difference between ABS and IND for forwards and backs. In zone 2 forwards have a difference of -5.7±1.5% while the backs have a difference of -5.1±2.3%. In zone 4, forwards show a difference of -5.3±2.1% while backs have a difference of -4.7±1.9%. In the three HI zones, the % distance covered when ABS was used was higher than when IND bands were used. Backs had a larger difference between methods than forwards for zones 5, 6 & 7, with differences of 2.4±1.3%, 2.2±1.3% and 0.3±0.4% for each zone respectively compared to the difference for forwards of 1.7±1.1%, 1.0±0.9% and 0.3±0.4% in zones 5, 6 & 7 respectively. The difference between the differences in % total distance covered determined by ABS or IND methods for forwards and backs is statistically significant in zones 1, 6 & 7 ($P<0.05$) as indicated by ** in Figure 5 overleaf.

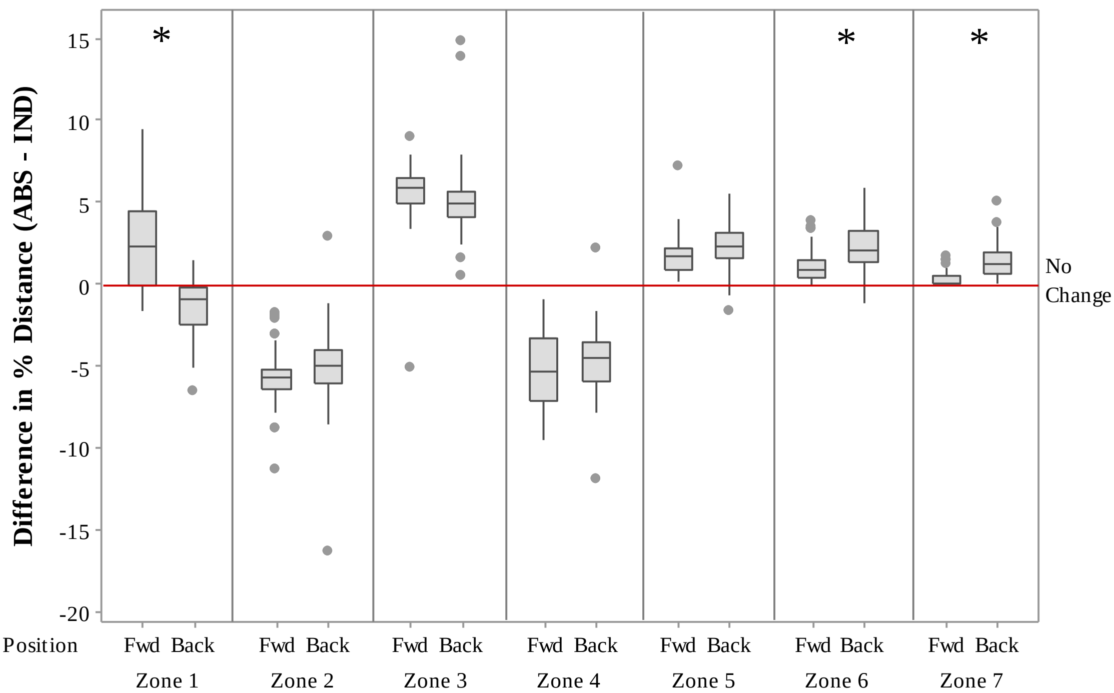


**Figure 5.** Difference in % total distance covered in each zone by forwards (Fwd) and backs (Back). Statistical significance between positions is indicated by *.

According to the GLM constructed, the difference within forwards and backs is significantly different from 0 for all zones as the 95% CIs do not cross 0. The lower 95% CI, mean difference and upper 95% CI are shown below in Figure 6, with the lower depicted in blue, the mean in red and the upper in green. Figure 6 depicts not only the direction of the difference, but the magnitude and also gives a visualisation of how close the mean difference and CIs are to zero.

The lower 95% CI, mean difference and upper 95% CI are displayed in text as (lower 95% CI, mean difference, upper 95% CI). The lower 95% CI, mean difference and upper 95%CI for forwards in zones 1 - 7 are as follows: zone 1 (1.6, 1.8, 1.9), zone 2 (-5.5, -5.3, -5.1), zone 3 (5.1, 5.4, 5.6), zone 4 (-5.4, -5.2, -5.0), zone 5 (1.8, 1.9, 2.1), zone 6 (1.1, 1.2, 1.3) and zone 7 (0.2, 0.3, 0.3). The lower 95% CI, mean difference and upper 95% CI for backs in zones 1 -7 are (-1.8, -1.6, -1.4), (-6.3, -5.7, -5.2), (5.4, 5.9, 6.4), (-5.2, -4.7, -3.7), (2.0, 2.3, 2.6), (1.9, 2.1, 2.4) and (1.4, 1.6, 1.8) respectively.

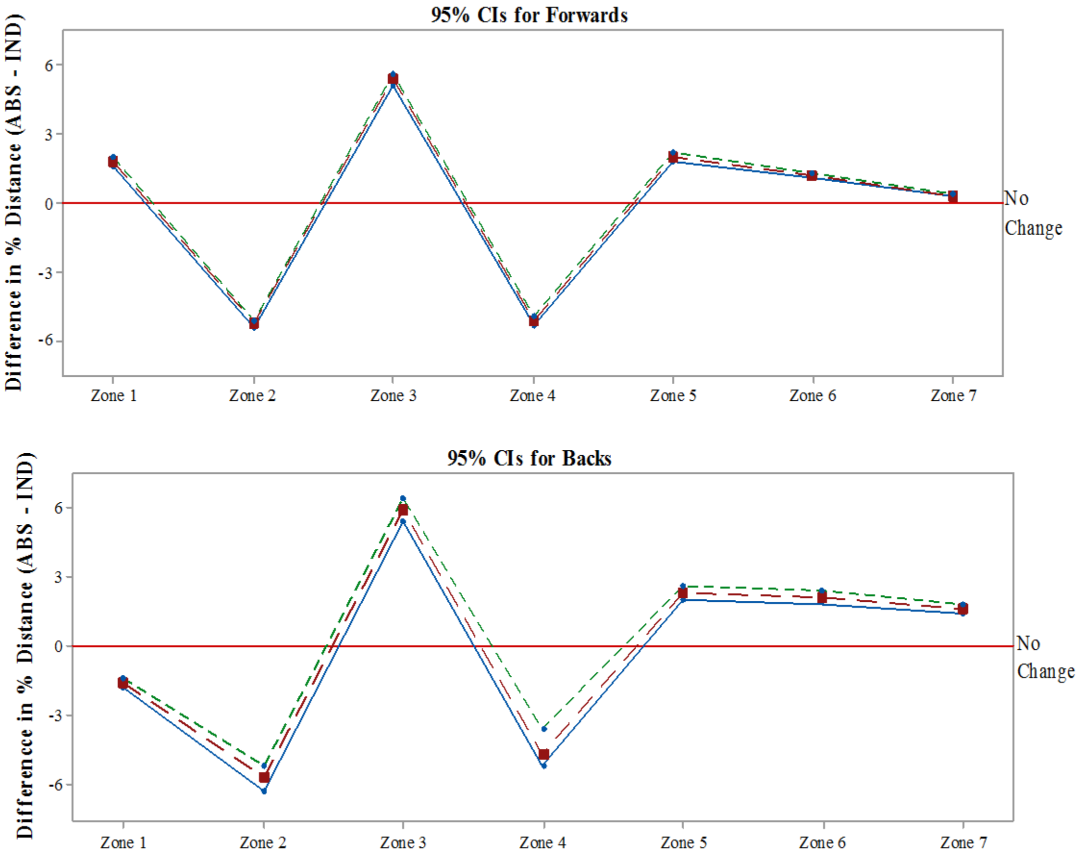


**Figure 6.** Mean difference, lower and upper 95% CIs of the difference, in estimated % total distance, between ABS and IND bands within forwards and backs in zones 1-7. Mean difference: red line. Lower 95% CI: blue line. Upper 95% CI: green line.

***Summary of data***

It is seen from this study that whether ABS or IND methods are used, backs cover more % in zone 1, but also more % distance in the three HI zones of 5, 6 and 7, whereas forwards cover more % distance in zones 3 and 4 than backs do. What this can tell us about the physical demands of rugby union is that backs have a more intermittent game, with a higher % distance sprinting, but this is then compensated with a higher % distance covered walking. The match demands of forwards appear to be more continuous at a jogging and cruising pace. This would fit the traditional view of forwards and backs and is in agreement with previous literature (Cahill et al., 2013).

When using the broadest possible positional groups of forwards and backs, the method of analysis doesn't change the general view of which group covered the highest percentage in each zone, it also doesn't have an impact at the F5, M5 and B5 grouping level, however, it does have an impact when looking at positions at an individual level. Using zone 1 as an example, when using the ABS method, props cover a higher % of total distance (39.2±3.3) than hookers (37.8±4.4), while the No.8 (41.4±3.1) covers a higher % distance walking than flankers (39.5±4.1) but the same as scrum halves (41.4±4.3). However, when using IND bands hookers cover a higher % total distance (38.0±4.5) walking than props (34.7±3.7) and flankers now cover a greater % distance walking (39.6±4.6) than No.8s (37.1±3.4) as do the scrum halves (42.1±3.4). This is not the case for all zones, but the size of difference between positions is also altered in other zones. Taking zone 5 as an example, the difference between HIR distance between the No.8 and scrum half doubles, with the No.8 covering 0.6% more distance at HIR than the scrum half when the ABS bands are used but 1.2% more distance when the IND band is used. So while these differences don't occur to the same extent for all positions there is potential for the different methods of analysis to give us different impressions of the difference in physical demands between distinct positions.

## 4.4. Percentage of time spent at each movement intensity

***ABS method***

The most notable result is that over 70% of field time in matches for all positions is spent standing/walking in zone 1 for both ABS and IND methods.

According to the ABS method the forwards spent 73.5±6.2% of total field time in zone 1 while the backs spent 77.1±8.5% of total field time in zone 1. The mean % time spent in zone 1 ranged from 71.1±6.4% for the second row up to 78.9±6.0% for the full back. Percentage time spent in each zone drops off dramatically from zone 2 onwards, with forwards spending 12.2±19% in zone 2, 6.7±1.9% in zone 3 and 1.6±0.8% in zone 4. Backs spent 9.5±2.3% in zone 2, 4.7±1.6% in zone 3 and 1.5±0.7% in zone 4. At HI forwards spent 0.3±0.5%, 0.0±0.2% and 0.0±0.0% in zones 5, 6 and 7, while backs spent 0.6±0.5%, 0.1±0.3% and 0.0±0.0% in zones 5, 6 and 7 respectively.

**Table 10.** Percentage of total time spent in zones 1-7 using the ABS method of analysis.

| Position | Zone 1 (mean ± SD) | Zone 2 (mean ± SD) | Zone 3 (mean ± SD) | Zone 4 (mean ± SD) | Zone 5 (mean ± SD) | Zone 6 (mean ± SD) | Zone 7 (mean ± SD) |
|---|---|---|---|---|---|---|---|
| Forward | 73.5±6.2 | 12.2±1.9 | 6.7±1.9 | 1.6±0.8 | 0.3±0.5 | 0.0±0.2 | 0.0±0.0 |
| Back | 77.1±8.5 | 9.5±2.3 | 4.7±1.6 | 1.5±0.7 | 0.6±0.5 | 0.1±0.3 | 0.0±0.0 |
| F5 | 72.2±6.2 | 12.5±2.8 | 7.3±1.9 | 1.5±0.9 | 0.2±0.1 | 0.0±0.1 | 0.0±0.0 |
| M5 | 77.4±5.6 | 11.4±1.9 | 5.8±1.4 | 1.7±0.7 | 0.4±0.5 | 0.0±0.0 | 0.0±0.0 |
| B5 | 77.4±9.2 | 9.1±2.1 | 4.1±1.2 | 1.3±0.6 | 0.6±0.5 | 0.1±0.3 | 0.0±0.0 |
| Prop | 75.0±1.3 | 14.1±2.8 | 6.6±2.0 | 0.5±0.6 | 0.1±0.3 | 0.0±0.0 | 0.0±0.0 |
| Hooker | 72.6±5.9 | 10.3±2.2 | 6.8±2.3 | 1.4±0.6 | 0.1±0.2 | 0.0±0.0 | 0.0±0.0 |
| 2nd Row | 71.1±6.4 | 13.1±2.1 | 7.9±1.5 | 2.0±0.8 | 0.3±0.5 | 0.0±0.2 | 0.0±0.0 |
| Flanker | 76.1±6.0 | 11.7±1.1 | 5.6±1.5 | 1.5±0.7 | 0.3±0.5 | 0.0±0.0 | 0.0±0.0 |
| No.8 | 75.8±5.0 | 11.7±1.4 | 5.2±0.6 | 1.6±0.8 | 0.6±0.5 | 0.1±0.3 | 0.0±0.0 |
| Scrum Half | 76.5±6.2 | 10.1±2.3 | 6.1±1.6 | 1.8±0.7 | 0.4±0.5 | 0.0±0.0 | 0.0±0.0 |
| Centre | 75.7±12. | 8.5±2.3 | 4.3±1.5 | 1.5±0.6 | 0.6±0.5 | 0.1±0.2 | 0.0±0.0 |
| Wing | 78.1±6.3 | 9.3±1.3 | 4.1±1.1 | 1.3±0.6 | 0.6±0.5 | 0.2±0.4 | 0.0±0.0 |
| Full Back | 78.9±6.0 | 11.0±3.3 | 4.8±1.8 | 1.3±0.7 | 0.8±0.5 | 0.0±0.0 | 0.0±0.0 |

*IND method*

The IND method recorded the forwards spending 71.9±6.3% and backs spending 78.1±8.6% of total field time in zone 1. Forwards spent 15.1±3.3% in zone 2, 4.5±1.6% in zone 3 and 3.0±1.3% in zone 4, while backs spent 10.7±2.6% in zone 2, 2.9±1.3% in zone 3 and 2.4±1.0% in zone 4. At HI, a mean time above 0.0% was not recorded for either the forward or back groups. Within the forward group the flanker and No.8 both recorded mean % total times in zone 5 of 0.1±0.3%. The wing was the only back position to record a mean time above 0.0% at HI (0.1±0.2% in zone 5).

**Table 11.** Percentage of total time spent in zones 1-7 using the IND method of analysis.

| **Position** | **Zone 1 (mean ± SD)** | **Zone 2 (mean ± SD)** | **Zone 3 (mean ± SD)** | **Zone 4 (mean ± SD)** | **Zone 5 (mean ± SD)** | **Zone 6 (mean ± SD)** | **Zone 7 (mean ± SD)** |
|---|---|---|---|---|---|---|---|
| Forward | 71.9 ±6.3 | 15.1±3.3 | 4.5±1.6 | 3.0±1.3 | 0.0±0.2 | 0.0±0.0 | 0.0±0.0 |
| Back | 78.1±8.6 | 10.7±2.6 | 2.9±1.3 | 2.4±1.0 | 0.0±0.2 | 0.0±0.1 | 0.0±0.0 |
| F5 | 70.7±6.3 | 15.4±3.7 | 5.3±1.5 | 2.9±1.3 | 0.0±0.1 | 0.0±0.0 | 0.0±0.0 |
| M5 | 75.1±5.8 | 13.6±2.6 | 3.8±1.2 | 2.8±1.2 | 0.0±0.2 | 0.0±0.0 | 0.0±0.0 |
| B5 | 78.5±9.5 | 10.3±2.5 | 2.5±1.0 | 2.3±0.8 | 0.0±0.2 | 0.0±0.0 | 0.0±0.0 |
| Prop | 72.1±5.9 | 17.6±3.6 | 5.4±1.7 | 1.6±0.9 | 0.0±0.0 | 0.0±0.0 | 0.0±0.0 |
| Hooker | 72.7±5.9 | 12.4±3.0 | 4.5±1.7 | 2.2±0.7 | 0.0±0.0 | 0.0±0.0 | 0.0±0.0 |
| 2nd Row | 69.0±6.3 | 16.3±2.5 | 5.8±1.1 | 3.9±1.1 | 0.0±0.2 | 0.0±0.0 | 0.0±0.0 |
| Flanker | 76.1±6.1 | 15.4±1.5 | 3.6±1.3 | 2.6±1.2 | 0.1±0.3 | 0.0±0.0 | 0.0±0.0 |
| No.8 | 72.4±4.9 | 15.6±1.9 | 3.9±1.5 | 3.5±1.0 | 0.1±0.3 | 0.0±0.0 | 0.0±0.0 |
| Scrum Half | 76.9±6.1 | 11.9±2.9 | 2.6±0.9 | 2.3±1.2 | 0.0±0.0 | 0.0±0.0 | 0.0±0.0 |
| Centre | 76.7±12.6 | 9.8±1.9 | 2.6±0.9 | 2.5±0.8 | 0.0±0.0 | 0.0±0.0 | 0.0±0.0 |
| Wing | 79.8±6.6 | 10.0±1.8 | 2.5±1.0 | 2.2±0.8 | 0.1±0.2 | 0.0±0.0 | 0.0±0.0 |
| Full Back | 79.1±6.1 | 12.6±3.7 | 2.9±1.5 | 2.4±1.2 | 0.0±0.0 | 0.0±0.0 | 0.0±0.0 |

***Visualisation of % time spent in each zone by the three levels of positional groups***

Figure 7 overleaf shows that the % time spent in each zone are very similar for both forwards and backs, with just a couple of percent separating them. It can be seen that the difference between ABS and IND becomes larger for both forwards and backs in zones 3 and 4. The boxplots of the HI bands show that while backs do record more % time in zone 6, the difference is negligible.

Figure 8 splits the positional groups up further in to the F5, M5 and B5 showing explicitly how the time spent in each zone differs between the three groups as well as the relationship between ABS and IND for each group. In Figure 8, the majority of points on the plot of zone 1 lie along the line of equality, with only the points representing the B5 slightly below, as shown numerically in Table 5. The plot of zone 1 also illustrated the wide range of % standing/walking time from ~45% - ~90%. The points lie below the line of equality for zones 2 and 4 indicating that IND values were higher for all three groups than ABS values for these two zones alone. Points also lie above the line of equality at the HI zones 5 and 6. No line of equality was drawn for zone 7 as no % time was recorded by the F5, M5 or B5.

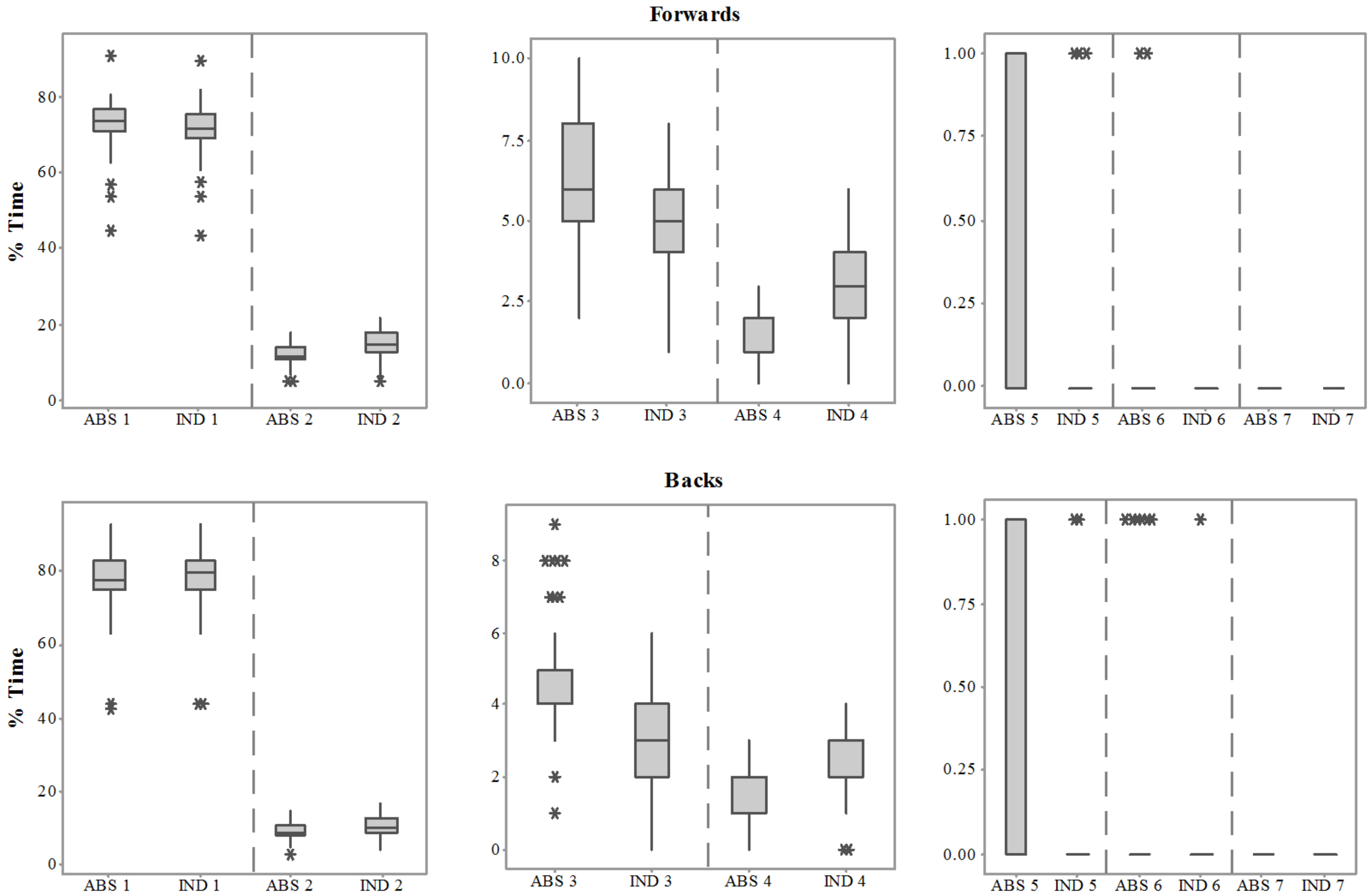


**Figure 7.** Comparison of % total time spent by forwards and backs in each velocity zone for ABS and IND methods.

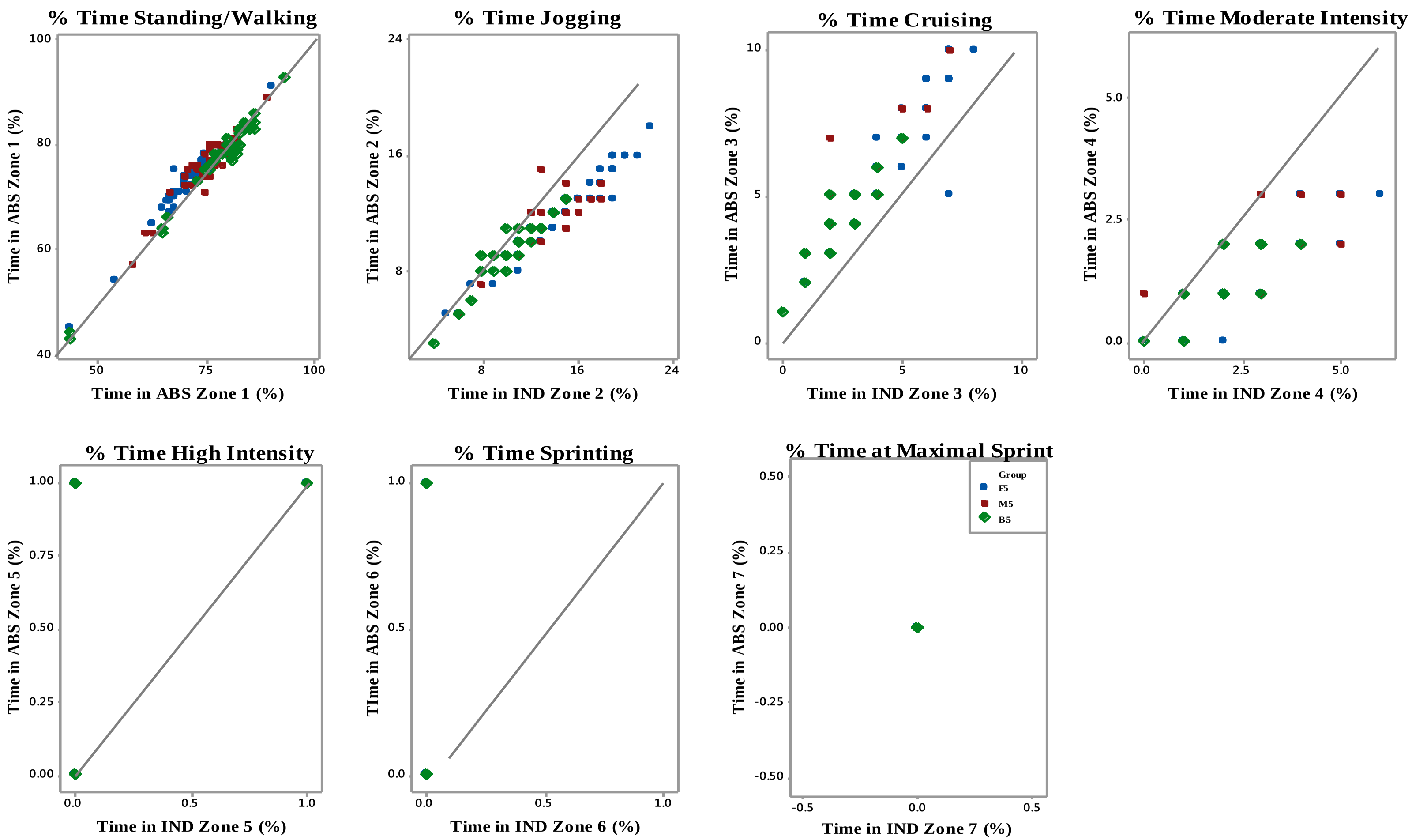


**Figure 8.** Comparison of % time spent by F5 (blue), M5 (red) and B5 (green) in each movement intensity zone as measured by the ABS method (y-axis) and IND method (x-axis). The solid diagonal line indicates the line of equality between ABS and IND measurements, points lying above the line signify the ABS method recording a higher value than the IND while points below the line signify the opposite.

From figure 9 we can see that the % time spent in zone 1 across the matches of the season highlights variation in demands match to match. In matches 4, 15 and 17, % time for all positions ranges from below 50% to 75% while in other matches they are consistently grouped around 75% and above, indicating that this match is played at a higher intensity than the majority of the season. Match 17 also shows lower % time in zone 3 and the only record from Zone 5 shows the centre, wing and full back all record 1% of time spent at HI.

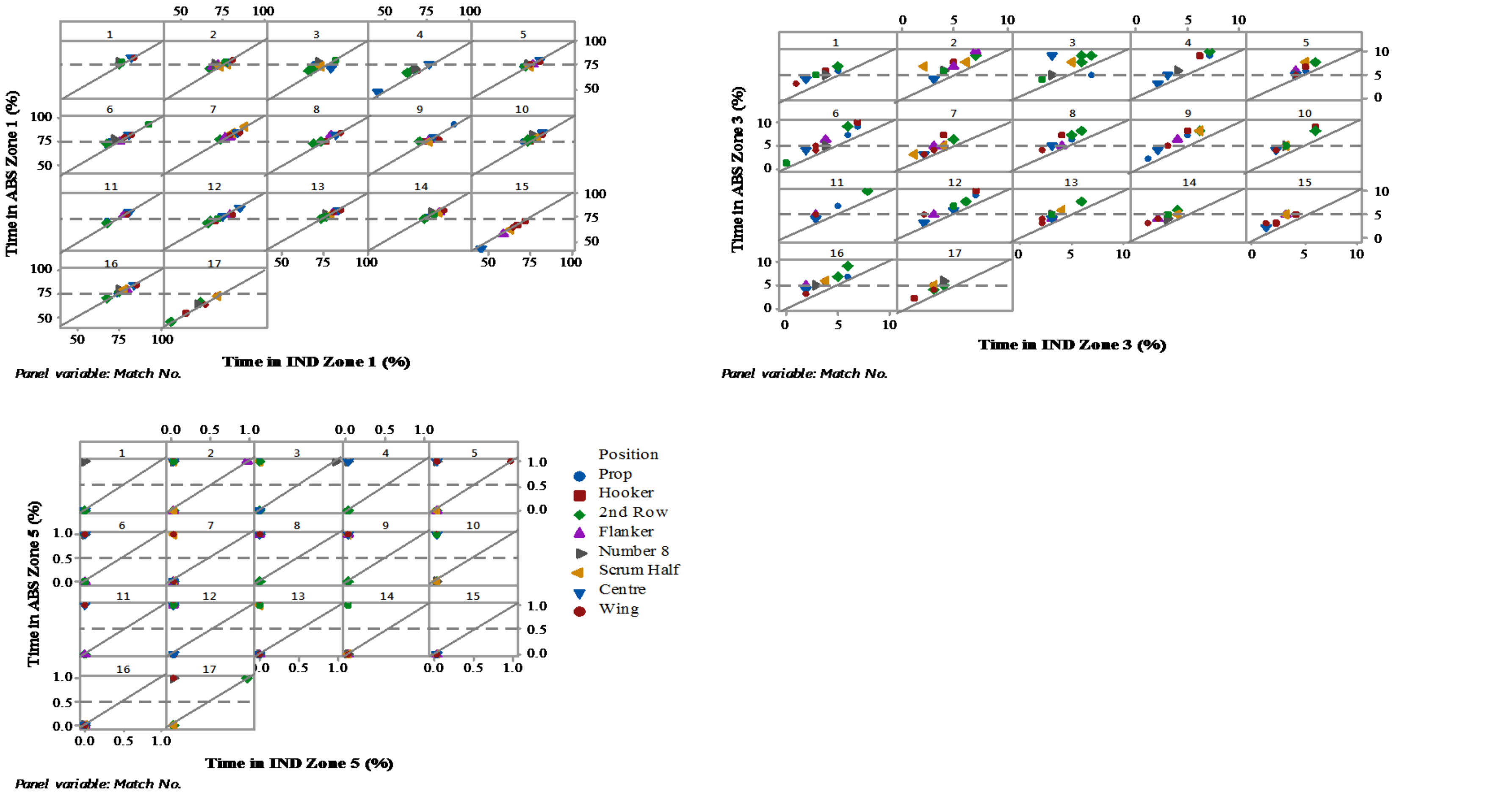


**Figure 9.** Comparison of the % total time spent in zones 1, 3 & 5 by each position between all 17 matches in the BT Premiership season, illustrating match-match variation in physical demands. The solid diagonal lines signify the line of equality between the ABS method (y-axis) and the IND method (x-axis). The dashed horizontal line is a reference point to aid comparison between matches.

***Comparison of ABS and IND methods***

**Table 12.** Difference between the ABS method and IND method of analysis for % time spent in zones 1-7 (ABS-IND). Statistical significance between ABS and IND method within positional group is indicated by *.

| Position | Zone 1 | Zone 2 | Zone 3 | Zone 4 | Zone 5 | Zone 6 | Zone 7 |
|---|---|---|---|---|---|---|---|
| Forward | 1.7±1.7* | -2.9±1.3* | 1.9±0.8* | -1.4±0.8* | 0.2±0.4* | 0.0±0.2* | 0.0±0.0 |
| Back | -1.0 ±1.5* | -1.2±1.1* | 1.8±0.9* | -0.9±0.6 | 0.6±0.5* | 0.1±0.3 | 0.0±0.0 |
| F5 | 1.7±1.5 | -3.0±1.2 | 2.0±0.9 | -1.4±0.7 | 0.2±0.4 | 0.0±0.1 | 0.0±0.0 |
| M5 | 0.8±2.1 | -2.2±1.4 | 2.0±0.8 | -1.1±0.9 | 0.4±0.5 | 0.0±0.0 | 0.0±0.0 |
| B5 | -1.1±1.3 | -1.1±0.9 | 1.6±0.5 | -0.9±0.5 | 0.6±0.5 | 0.1±0.3 | 0.0±0.0 |
| Prop | 2.9±1.3 | -3.5±1.2 | 1.3±1.0 | -1.1±0.7 | 0.1±0.3 | 0.0±0.0 | 0.0±0.0 |
| Hooker | -0.1±0.2 | -2.1±1.0 | 2.3±0.8 | -0.8±0.4 | 0.1±0.2 | 0.0±0.0 | 0.0±0.0 |
| $2^{nd}$ Row | 2.1±0.7 | -3.2±0.8 | 2.1±0.6 | -1.8±0.6 | 0.2±0.4 | 0.0±0.2 | 0.0±0.0 |
| Flanker | 0.0±1.4 | -1.6±0.7 | 1.9±0.6 | -1.1±1.1 | 0.2±0.4 | 0.0±0.0 | 0.0±0.0 |
| No.8 | 3.5±1.0 | -3.9±1.3 | 1.6±0.5 | -1.8±0.4 | 0.6±0.5 | 0.1±0.3 | 0.0±0.0 |
| Scrum Half | -0.4±1.0 | -1.9±0.8 | 2.2±1.0 | -0.5±0.7 | 0.4±0.5 | 0.0±0.0 | 0.0±0.0 |
| Centre | -0.9±1.7 | -1.4±1.2 | 1.7±1.2 | -1.0±0.7 | 0.6±0.5 | 0.1±0.2 | 0.0±0.0 |
| Wing | -1.8±1.3 | -0.6±0.9 | 1.7±0.6 | -1.0±0.4 | 0.6±0.5 | 0.2±0.4 | 0.0±0.0 |
| Full Back | -0.3±1.2 | -1.6±0.7 | 1.9±0.4 | -1.1±0.6 | 0.8±0.5 | 0.0±0.0 | 0.0±0.0 |

The difference between ABS and IND for % time in each zone follows the same pattern as % distance. The difference within forwards in zone 1 is positive (1.7±1.7%) while the backs difference is negative (-1.0 ±1.5%). The difference in % time between ABS and IND is negative for zone 2 (-2.9±1.3) (-1.2±1.1) and zone 4 (-1.4±0.8) (-0.9±0.6) for both forwards and backs respectively. Zones 3, 5 and 6 all had positive differences, although many of the zone 6 differences were 0.0% as only the second row, number 8, centre and wing recorded a % time above 0.0%. All zone 7 differences were 0.0% as 0.0% time was recorded for all positions using both methods.

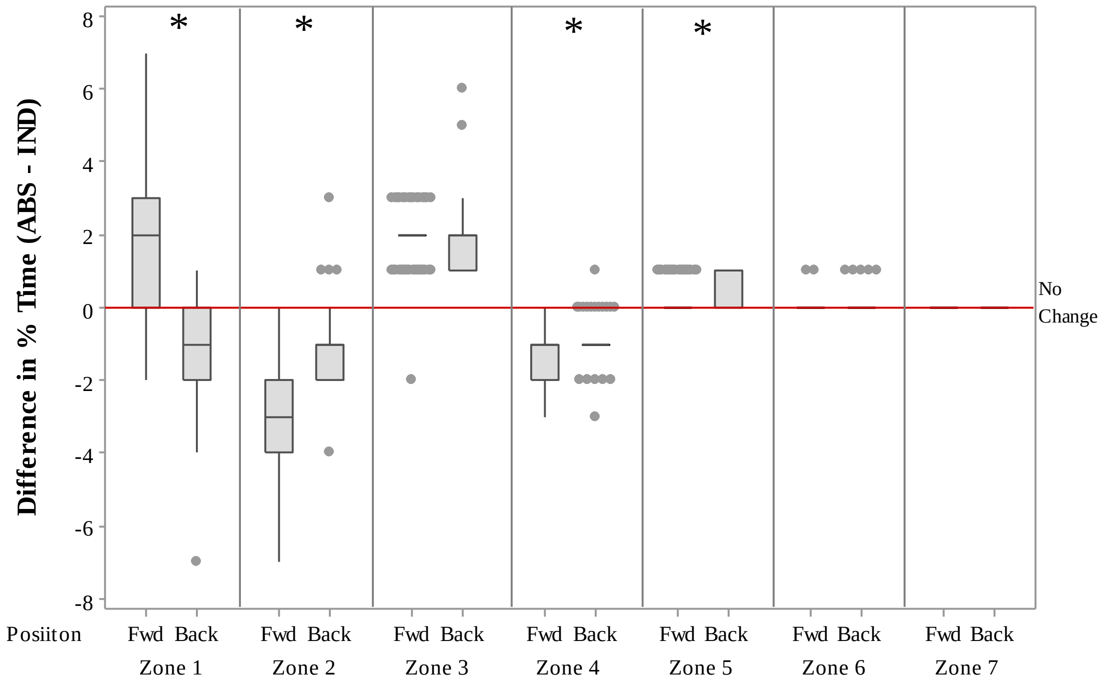


**Figure 10.** Difference in % total time spent in each zone between ABS and IND methods for forwards (Fwd) and backs (Back). Statistical significance between positions is indicated by *.

According to the GLM, the difference within forwards between the ABS and IND methods of GPS analysis is significantly different from 0 for all zones 1 to 6 as the 95% CI doesn't cross zero. Zone 7 was not included in the analysis as no % time was recorded in this zone.

The difference within backs is also significantly different from 0 in zones 1, 2, 3, 4 and 5 as the 95% CI do not cross 0. The lower 95% CI mean difference and upper 95% CI for forwards and backs in each of the seven zones are illustrated overleaf in Figure 11 with colour key included in figure legend. The lower 95% CI, mean difference and upper 95% CI are displayed in text as (lower 95% CI, mean difference, upper 95% CI).

The lower 95% CI, mean difference and upper 95% CI for forwards in zones 1 - 7 are as follows: zone 1 (1.2, 1.4, 1.5), zone 2 (-2.6, -2.5, -2.3), zone 3 (1.6, 1.7, 1.8), zone 4 (-1.4, -1.3, -1.2), zone 5 (0.1, 0.2, 0.1), zone 6 (0.1 0.1, 0.1) and zone 7 (0.0, 0.0, 0.0). The lower 95% CI, mean difference and upper 95% CI for backs in zones 1 -7 are (-1.4, -1.1, -0.8), (-1.5, -1.2, -1.0), (1.7, 2.0, 2.7), (-0.8, -0.7, -0.5), (0.5, 0.6, 0.7), (-0.1, 0.0, 0.1) and (0.0, 0.0, 0.0) respectively.

As with % distance, the only zone in which the direction of difference between ABS and IND for % time is different for forwards and backs is zone 1, with a P value of <0.05 showing that the difference is significant. The difference between the ABS-IND for forwards and backs is also significant for zones 2, 4 and 5. The differences between ABS and IND for % time are smaller than % distance although the same trends appear.

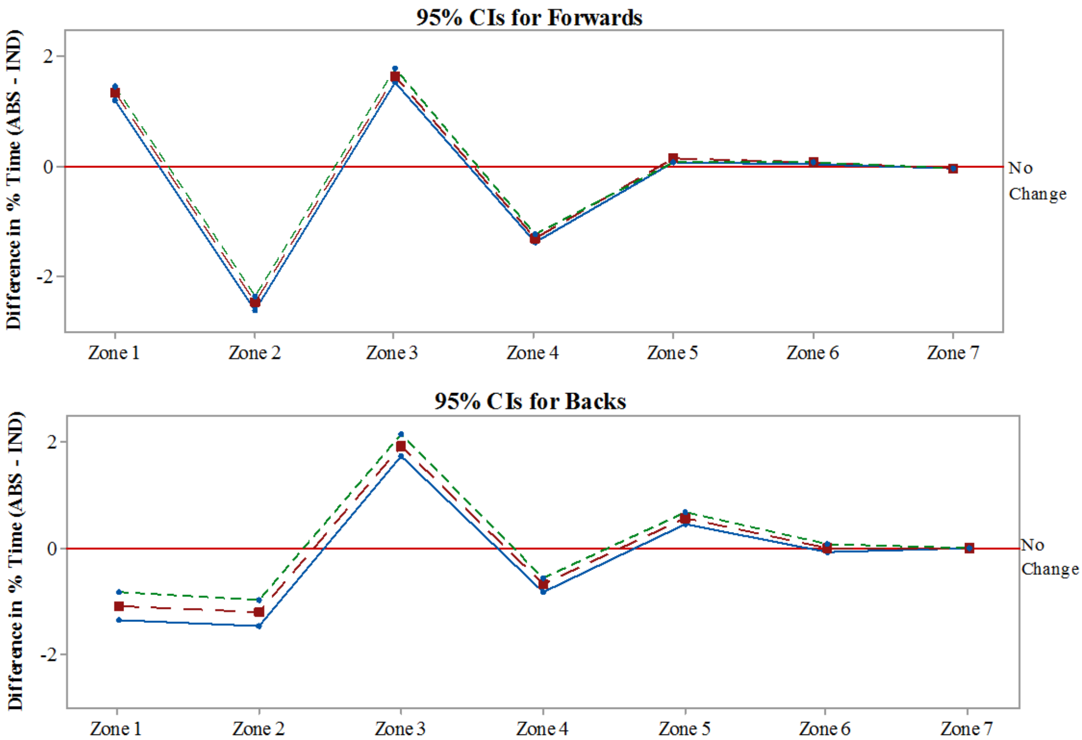


**Figure 11.** Mean difference, lower and upper 95% CIs of the difference in, estimated % total time, between ABS and IND bands within forwards and backs in zones 1-7. Mean difference: red line. Lower 95% CI: blue line. Upper 95% CI: green line.

***Summary of data***

As displayed throughout this section, the vast majority of field time is spent in zone 1 by all positions. As with % distance, when looking simply at forwards and backs in zone 1 backs spend a higher % of total field time in zone 1 than forwards. However unlike % distance, where the M5 acted as a bridge between the F5 and B5 in terms of % distance in zone 1 for with % time the M5 and B5 spent the same % time in zone 1 (77.4%). However this value is for the ABS bands, and again we can see that the IND band gives us a different impression, with the B5 again spending a higher % time in zone 1 (78.5±9.5) than the M5 (75.1±5.8).

An attributing factor to the high % of time spent in zone 1 by all positions is that this study didn't exclude periods of the match when the time was off, so rather than the

80mins of game time played, this study includes full field time, which was regularly approximately 90mins. This will have shifted the % time in each zone down, having a larger effect at HI, where % time is low to begin with. Full field time was included as it gives the full impression of how much recovery time players are getting throughout the duration of the match. The inclusion of full field time shouldn't impact on the validity comparisons between positions as the time that the clock is stopped will be uniform across the team.

Due to the small percentages recorded at HI it isn't possible to draw positional comparisons about HI from this output. This will be done using the number of HIE, a more sensitive measure of the HI demands of rugby union.

## 4.5. Number of HIEs and RHIEs

***ABS method***

When the ABS method of analysis was employed, forwards recorded 16±8, 6±5 and 1±2 efforts in zones 5, 6 and 7 and 2±2 RHIEs while backs recorded 24±8 efforts in zone 5, 14±7 in zone 6, 4±3 efforts in zone 7 and 4±1 RHIEs. The three B5 positions recorded the most HIEs and RHIEs within the squad, with 26±8 in zone 5, 17±5 in zone 6 and 5±2 in zone 7. On average it was the wing position that recorded the most HIEs.

**Table 13.** No. of HIEs (zones 5, 6 & 7) and RHIEs when using the ABS method.

| | | **Efforts** | | **RHIEs** |
|---|---|---|---|---|
| **Position** | **Zone 5** | **Zone 6** | **Zone 7** | |
| | **(mean ± SD)** | **(mean ± SD)** | **(mean ± SD)** | **(mean ± SD)** |
| Forward | 16 ± 8 | 6 ± 5 | 1 ± 2 | 2 ± 2 |
| Back | 24 ± 8 | 14 ± 7 | 4 ± 3 | 4 ± 1 |
| F5 | 14 ± 8 | 6 ± 5 | 1 ± 1 | 2 ± 2 |
| M5 | 17 ± 6 | 6 ± 3 | 1 ± 1 | 3 ± 1 |
| B5 | 26 ± 8 | 17 ± 5 | 5 ± 2 | 4 ± 1 |
| Prop | 6 ± 7 | 2 ± 3 | 1 ± 0 | 0 ± 1 |
| Hooker | 16 ± 5 | 9 ± 3 | 2 ± 1 | 3 ± 1 |
| 2nd Row | 17 ± 8 | 6 ± 5 | 1 ± 2 | 2 ± 2 |
| Flanker | 17 ± 8 | 6 ± 3 | 1 ± 1 | 2 ± 2 |
| No.8 | 21 ± 9 | 7 ± 6 | 1 ± 2 | 3 ± 2 |
| Scrum Half | 17 ± 5 | 6 ± 3 | 1 ± 1 | 3 ± 1 |
| Centre | 25 ± 8 | 15 ± 6 | 4 ± 2 | 4 ± 0 |
| Wing | 26 ± 8 | 18 ± 5 | 6 ± 2 | 3 ± 1 |
| Full Back | 25 ± 9 | 15 ± 5 | 5 ± 2 | 4 ± 0 |

*IND Method*

When applying the IND method, forwards recorded 8±6, 2±3 and 0±1 efforts in zones 5, 6 and 7 respectively. The backs recorded 11±6, 5±3 and 0±1 efforts in zones 5, 6 and 7. The forwards recorded 1±2 RHIEs with the backs recording 3±1. The position which recorded the lowest number of HIEs using the IND method was the prop, recording 2±1 in zone 5, 0±1 in zone 6 and 0±0 in zone 7.

The range of efforts made by forwards and backs in each zone can be seen below in Figure 12, illustrating the fewer number if efforts made by forwards than backs at HIE as well as difference in ABS and IND.

**Table 14**. No. of HIEs (zones 5, 6 & 7) and RHIEs when using the IND method.

| | | **Efforts** | | **RHIEs** |
|---|---|---|---|---|
| **Position** | **Zone 5** | **Zone 6** | **Zone 7** | |
| | **(mean ± SD)** | **(mean ± SD)** | **(mean ± SD)** | **(mean ± SD)** |
| Forward | 8 ± 6 | 2 ± 3 | 0 ± 1 | 1 ± 2 |
| Back | 11 ± 6 | 5 ± 3 | 0 ± 1 | 3 ± 1 |
| F5 | 7 ± 5 | 2 ± 3 | 0 ± 1 | 1 ± 2 |
| M5 | 8 ± 6 | 2 ± 2 | 0 ± 0 | 2 ± 2 |
| B5 | 13 ± 5 | 5 ± 2 | 1 ± 1 | 3 ± 1 |
| Prop | 2 ±1 | 0 ± 1 | 0 ± 0 | 0 ± 0 |
| Hooker | 9 ± 3 | 3 ± 2 | 0 ± 0 | 3 ± 2 |
| 2nd Row | 9 ± 6 | 3 ± 3 | 0 ± 1 | 1 ± 2 |
| Flanker | 8 ± 7 | 2 ± 3 | 0 ± 0 | 1 ± 2 |
| No.8 | 12 ± 6 | 3 ± 3 | 0 ± 1 | 2 ± 2 |
| Scrum Half | 6 ± 3 | 2 ± 1 | 0 ± 1 | 2 ± 2 |
| Centre | 12 ± 4 | 5 ± 3 | 0 ± 0 | 3 ± 0 |
| Wing | 13 ± 5 | 5 ± 2 | 1 ± 1 | 3 ± 1 |
| Full Back | 13 ± 5 | 6.± 2 | 0 ± 0 | 3 ± 0 |

### *Visualisation of HIEs and RHIEs recorded by all three positional groups*

The difference between the number of HIEs recorded between forwards and backs in each zone is visualised in Figure 12. As displayed numerically in Tables 13 and 14, the backs record a higher number of HIEs than forwards in all zones, independent of which method of analysis was used.

The series of boxplots in Figure 12 illustrate that there is a marked difference in the number of HIEs recorded by both the forwards and backs with more being recorded in when the ABS method is used compared to when the IND method is used. The difference is not as great between the number of RHIEs recorded when using ABS or IND methods, although the ABS method does give a higher value for both forwards and backs. While it is clear that the medians for the ABS and IND methods in the three HI zones in the boxplots are different for both forwards and backs, the use of the lines of equality on the scatterplots in Figure 13 can illustrate whether these differences are likely to be systematic across the axes range and significant once formal analysis is conducted.

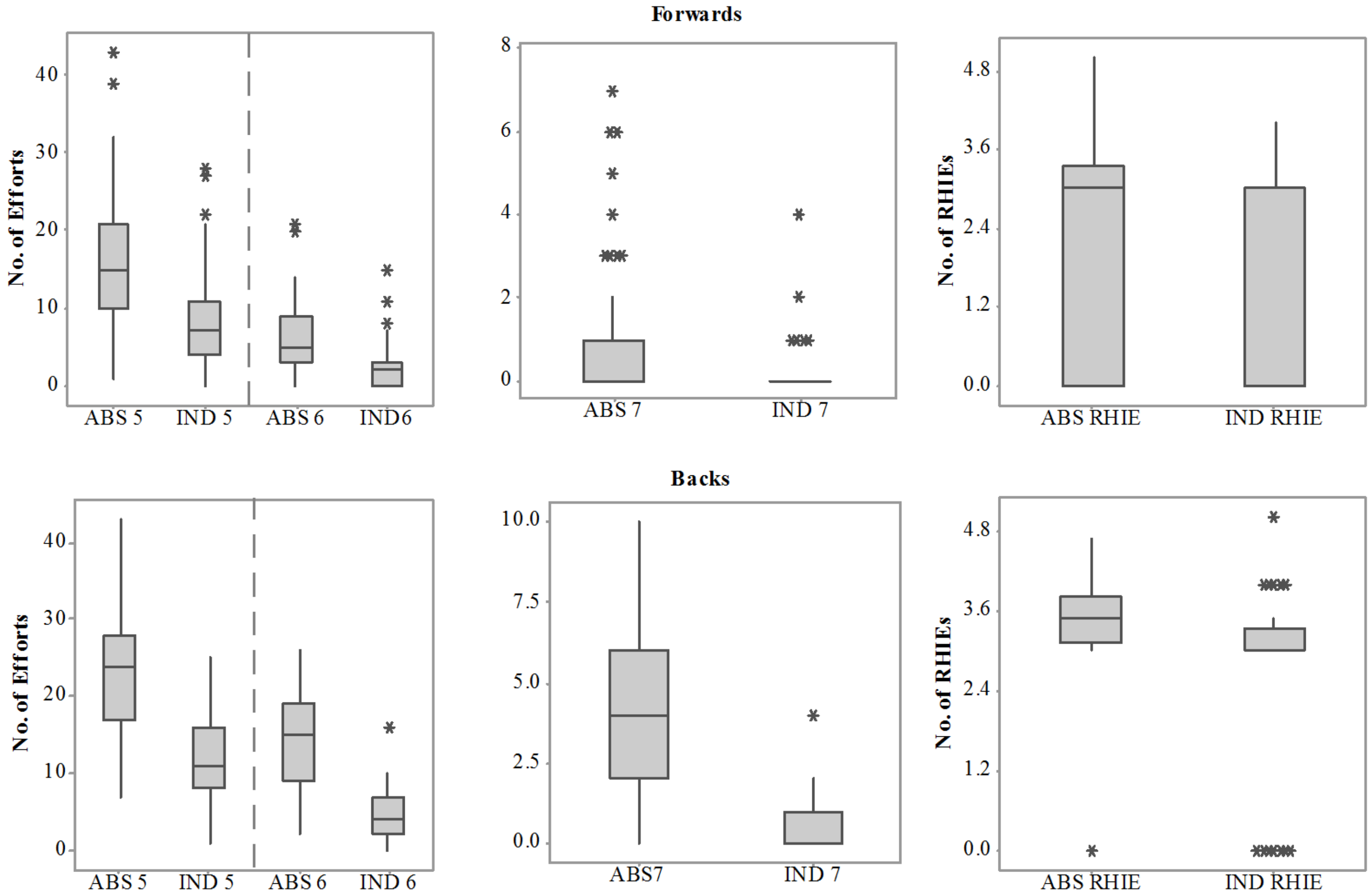


**Figure 12.** A comparison of the No. of HIEs and the No. of RHIEs by forwards and backs for both ABS and IND methods.

This series of four scatterplots below shows that as would traditionally be expected, it is the B5 who record the most maximal sprint efforts in zone 7. In all three HI zones (5, 6 & 7) the number of efforts lies above the line of equality for the F5, M5 and B5, illustrating how few HIEs are recorded when using the IND method. For the number of RHIEs, predominantly more of the points lie above the line of equality. The plots aid in illustrating the trend in number of HIE made by each group, with the F5 and M5 grouped lower down the line of equality than the B5 in zones 5 & 6. The B5 have a greater difference between ABS and IND for No. of HIEs than both F5 & M5, shown by the green points lying the furthest above the line of equality.

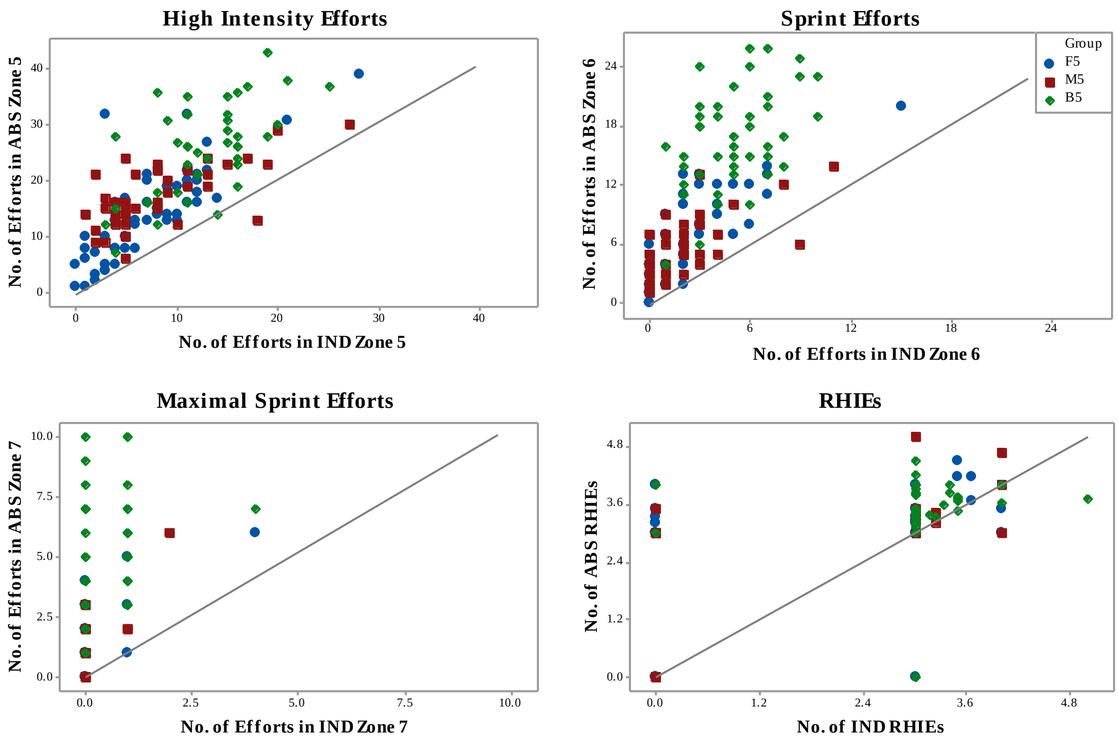


**Figure 13.** Comparison of No. of HIEs (zones 5, 6 & 7) and RHIEs by F5 (blue), M5 (red) and B5 (green) as measured by the ABS method (y-axis) and IND method (x-axis). The solid diagonal line indicates the line of equality between ABS and IND measurements. Points lying above the line signify the ABS method recording a higher value than the IND, with points below the line signifying the opposite.

By comparing the number of HIEs in each match of the season (see Figure 14) we can see that there are match-to-match differences in the number of HIEs made in zones 5, 6 and 7 by each position.

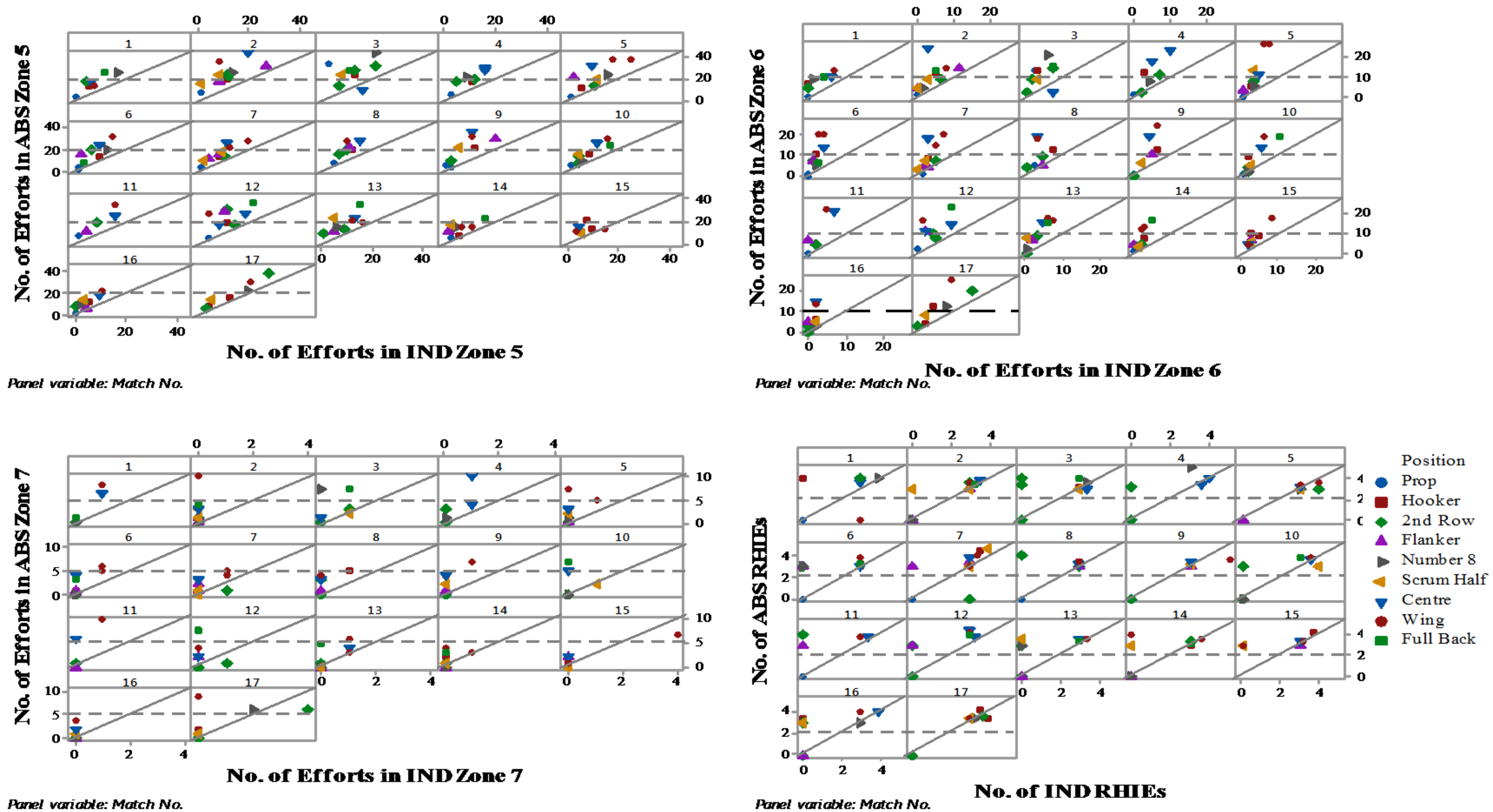


**Figure 14.** Comparison of the No. of HIEs (zones 5, 6 & 7) and RHIEs by each position between all 17 matches in the BT Premiership season illustrating match-match variation physical demands. The solid diagonal lines signify the line of equality between the ABS method (y-axis) and the IND method (x-axis). The dashed horizontal line is a reference point to aid comparison between matches.

A position of note is the wing position, which regularly records the highest number of sprint and maximal sprints efforts in zones 6 and 7. While the tempo of matches may change, it is still the same positions recording the highest and lowest number of HIEs. It can be seen from Figure 14 that the B5 positions of centre, wing and full back lie furthest from the line of equality for No. of HIEs.

***Comparison of ABS and IND method***

The difference between ABS and IND efforts is positive for all positional groups across all three HI zones, showing that the ABS method recorded more HIEs than IND. The same relationship is seen for RHIEs, with the difference between ABS and IND again being positive for all positional groups.

**Table 15.** Difference between the ABS and IND methods of analysis for number of HIEs and RHIEs (ABS-IND). Statistical significance between ABS and IND method within positional group is indicated by *.

| **Position** | **Efforts** Zone 5 (mean ± SD) | **Efforts** Zone 6 (mean ± SD) | **Efforts** Zone 7 (mean ± SD) | **RHIEs** (mean ± SD) |
|---|---|---|---|---|
| Forward | 8 ± 5* | 4 ± 3* | 1 ± 1* | 1 ± 2* |
| Back | 13 ± 7* | 10 ± 5* | 4 ± 3* | 1 ± 1 |
| F5 | 7 ± 5 | 4 ± 3 | 1 ± 1 | 1 ± 2 |
| M5 | 9 ± 5 | 4 ± 2 | 1 ± 1 | 1 ± 1 |
| B5 | 13 ± 6 | 12 ± 5 | 5 ± 2 | 1 ± 1 |
| Prop | 4 ± 7 | 1 ± 3 | 0 ± 0 | 0 ± 1 |
| Hooker | 7 ± 3 | 6 ± 2 | 2 ± 1 | 1 ± 2 |
| 2nd Row | 8 ± 4 | 3 ± 2 | 1 ± 1 | 1 ± 2 |
| Flanker | 9 ± 5 | 4 ± 2 | 1 ± 1 | 1 ± 1 |
| No.8 | 9 ± 5 | 4 ± 4 | 1 ± 2 | 1 ± 1 |
| Scrum Half | 12 ± 4 | 5 ± 2 | 1 ± 1 | 1 ± 2 |
| Centre | 12 ± 8 | 10 ± 6 | 4 ± 2 | 0 ± 0 |
| Wing | 13 ± 7 | 13 ± 5 | 5 ± 2 | 1 ± 1 |
| Full Back | 12 ± 6 | 9 ± 3 | 5 ± 2 | 1 ± 0 |

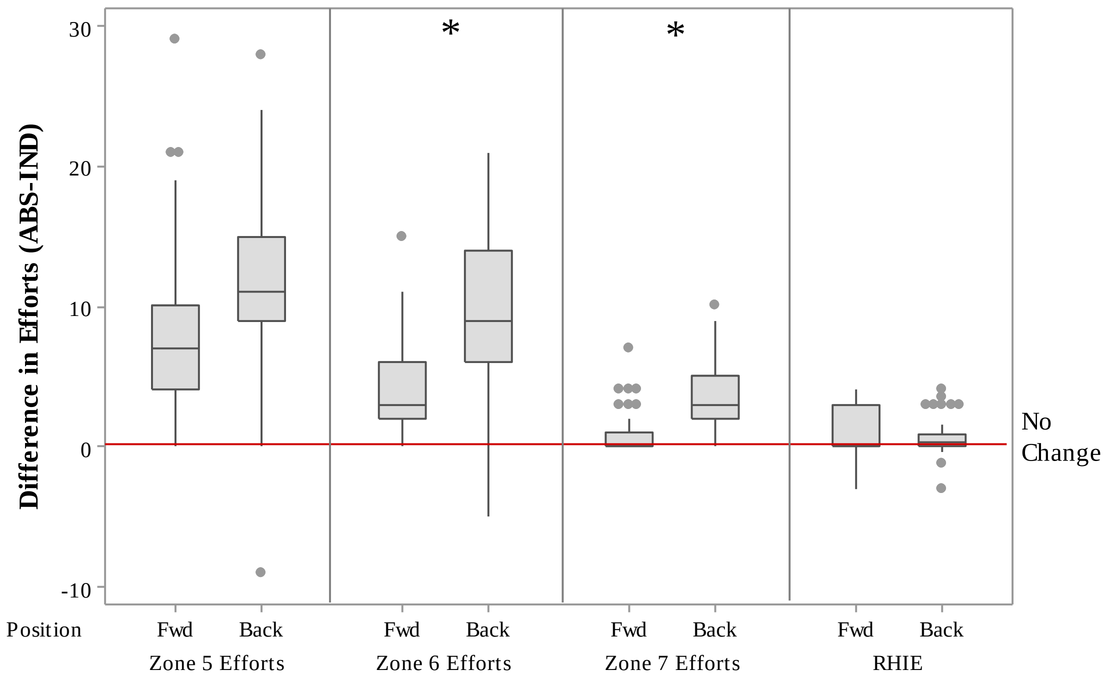


**Figure 15.** Difference in the No. of HIEs and RHIEs by forwards (Fwd) and backs (Back). Statistical significance between groups is indicated by *.

Formal statistical analysis in the form of a GLM showed that the difference between number of HIEs as measured by ABS and IND methods is significantly different from 0 within forwards. The values for lower 95% CI, mean difference and upper 95% CI are (7.9, 8.7, 9.6), (3.3, 3.7, 4.0) and (0.4, 0.6, 0.9) for zones 5, 6 and 7 respectively. The GLM also showed that the number of RHIEs recorded by forwards is significantly higher when there is a significant difference between the number of RHIEs recorded by forwards when the ABS bands are used rather than the IND bands, as indicated by the lower 95% CI, mean difference and upper 95% CI not crossing zero (0.6, 0.8, 1.1). These values are illustrated above in Figure 15 and overleaf in Figure 16.

Backs have a positive difference, indicating that the ABS method gave higher numbers of HIEs in zones 5, 6 & 7 as well as for RHIEs. The mean differences were significantly different from zero, with neither the lower or upper 95% CIs crossing zero. The backs have a lower 95% CI, mean difference and upper 95% CI of (9.4, 10.8, 12.3), (7.7, 8.6, 12.3) and (3.6, 3.9, 4.2) for zones 5, 6 and 7. According to the GLM, the difference between ABS and IND for RHIE for backs is not significantly different to 0 as the 95 % CI crosses cross 0 (-0.1, 0.4).

Figures 15 and 16 show that there is a larger difference between ABS and IND for backs than forwards in all HI zones, with differences for forwards and backs being significantly different in zones 6 & 7 (P<0.05).

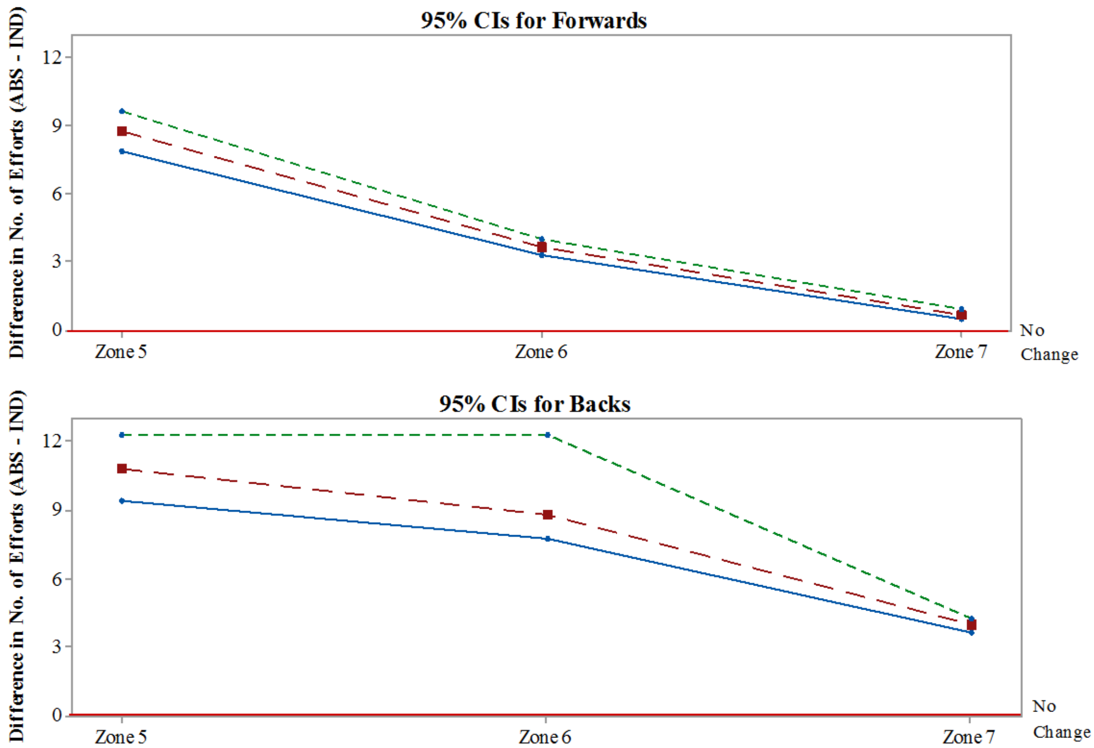


**Figure 16.** Mean difference, lower and upper 95% CIs of the difference in No. of HIEs between ABS and IND bands within forwards and backs in zones 5-7.
Mean difference: red line. Lower 95% CI: blue line. Upper 95% CI: green line.

### *Summary of data*

The results for the number of HIEs and RHIEs using the ABS method are as would be expected when only comparing forwards and backs, given current perceptions of the demands of these broad positional groupings, with backs recording more HIEs in all three zones (refer to Table 13). This is also the case with the F5, M5 and B5 groupings; in zone 5, the B5 record more HIEs (26±8) than the M5 (17±6) who in turn record more than the F5 (14±8). In zones 6 and 7 the B5 record far more HIEs (17±5 and 5±2 respectively) than the M5 who recorded 6±3 and 1±1 and F5 who record and 6±5 and 1±1. However, when looking at the positions individually a different picture appears as there is a large divide in the number of HIEs made by the positions in the front row. The props have considerably lower numbers of HIEs than the hooker and 2nd row, whose number of HIEs are in line with the M5. Possible reasons for this could be: the positional demands of the prop not requiring as many HIEs as their F5 counterparts; the individuals who played at hooker and second row choosing a game style of fast paced ball carrying and line-breaks; or a methodological issue regarding the number of matches recorded by each position and the conditions in which these were played.

The IND method gives much lower numbers of HIEs for all positions, while trends in differences remain the same between the two methods. A conservative statement would be that the number of HIEs recorded using the IND method is half of that when using the ABS method, although in reality the difference is greater for some positions. For example, the wing which recorded 26±8, 18±5 and 6±2 efforts in zones 5, 6 and 7 respectively when the ABS method of analysis was used compared to 13±5, 5±2 and 1±1 when the IND method was used.

There is a noticeable difference in the number of RHIEs recorded when the ABS method of analysis is used if only looking at forwards (2±2) and backs (4±1). While the number of RHIEs is, lower for IND in both forwards (1±2) and backs (3±1), unlike the HIEs output, it is not to the same extent, which could be due to the smaller numbers recorded initially. As with % distance covered at HI and number of HIEs, the props have the lowest number of RHIEs according to both ABS (0±1) and IND (0±0) methods when compared to the other distinct positions. There is little difference between the other positions with them recording between 2-4 RHIEs in the according to the ABS method and 1-3 when the IND method was used.

# 5. Discussion

This season-long study of time-motion analysis measured by GPS during amateur/semi-professional rugby union match-play, found that there are significant differences between the ABS and IND methods of measuring the distance covered, time spent, number of HIEs and RHIEs within groups of forwards and backs. The study also found that the magnitude of difference between the analysis methods was different between the forwards and backs.

## 5.1. Comparison of ABS and IND methods

Although there is not a clear trend in the difference between ABS or IND methods, it can be said that overall, there is a significant difference in analysis outcomes between the ABS and IND methods of GPS analysis. Not only is there a difference in direction between zones, with zones 2 and 4 having a negative difference between ABS and IND while all other zones had a positive difference but there is also a difference in direction of difference within zones, because within zone 1, the forwards have a positive difference and the backs have a negative difference for both % distance and % time. As the IND bands results were subtracted from the ABS bands, a negative difference means that the results for ABS method was lower than those for the IND method. In the HI zones of 5, 6 and 7 the traditional ABS method gives a higher % distance, % time and number of HIEs and RHIEs for all positions when compared with the IND method.

***Percentage of total distance***

The difference in % distance covered in zone 1, in which the direction of difference between ABS and IND within groups is different between the forwards and backs, with the difference within the forwards being 2.3±2.4% and the difference between the backs being -1.4±1.7%. This difference was shown to be statistically significant by the GLM constructed. The difference indicates that should the new IND method be applied rather than the traditional ABS method we wouldn’t always see the same effect on our perception of the work done by forwards and backs, in the case of zone 1 we would see a lower value of % total distance covered in zone 1 by forwards and a higher value for % total distance covered in zone 1 by backs than we currently see.

Forwards and backs both displayed negative differences between the ABS and IND methods in both Zones 2 and 4, which means that should IND bands be introduced, we would see higher values of % total distance covered by both positions in zones 2 and 4. There difference is ~-5% in both zones and 4 between the ABS and IND methods for both forwards and backs.

In practical terms this means that all players will be perceived to have run 5% further at a jogging and cruising pace than when the ABS method is used. A similar magnitude of difference is also seen in zone 3, where there is a 5.6±1.7% difference for forwards and a 5.0±2.1% difference for backs between the methods.

In the HI zones the differences between % total distance covered when using ABS and IND methods is greater for backs than forward in zones 5, 6 and 7, with this difference shown to be significant in zones 6 and 7. The forwards have a 1.7±1.1% higher % total distance in zone5, a 1.0±0.9% higher % total distance sprinting in zone 6 and 0.3±0.4% for max sprints in zone 7. Whereas for backs the difference between ABS and IND are 2.4±1.3% in zone 5, 2.2±1.3% for sprinting in zone 6 and 0.3±0.4 % for max sprints in zone 7. The practical implications of these findings are that changing the method of analysis to IND bands will have a greater effect on the outputs recorded for backs at HI than forwards. Coaches, strength and conditioning coaches and analysts would see approximately a 2% reduction of the % distance covered by the backs in zones 5 and 6. At this stage it isn't possible to determine if this finding would have a practical impact on the training content and recovery times engineered into training programmes by support staff.

***Percentage total time***

The mean differences for % total time spent in each zone (see Table 12) are much smaller than those seen for the output of % total distance. The largest % difference seen for the forward/back groupings, on which the formal statistics were carried out, is -2.9±1.3% less time spent by forwards in zone 2, whereas the largest difference seen for the metric of % total distance was -5.7±1.5%, which was also recorded by forwards in zone 2.

Although the differences between ABS and IND method have a smaller magnitude for the metric of % total time than for % total distance, the trend in the direction of these differences is the same across the seven zones for the two metrics. In the case of the forwards, should the IND bands be introduced, their % total time in zones 1, 3, 5 and 6 would decrease, while their % total time spent in zones 2 and 4 would increase. If the IND bands were used the backs would see higher % total time values in zones 1, 2 and 4, and lower values in zones 3, 5 and 6. No % total time above 0.0 recorded by either forwards in backs for zone 7, therefore method of analysis used is currently elementary.

In regards to the extent of the difference between ABS and IND methods at HI, the same effect as % total distance is seen for % total time, with the backs having a larger mean differences in zones 5 (0.2±0.4%) and 6 (0.6±0.5%) than forwards did in the zones 5 (0.0±0.2%) and 6 (0.1±0.3%). However, the greater magnitude of difference for backs could be due to the positional group having spent more % time at HI.

***Number of HIEs and RHIEs***

With the results from the GLM confirming the difference between the numbers of HIEs recorded between forwards and backs as statistically significant, this verifies the trend seen by the previously discussed GPS metrics of % total distance and % total time that the ABS method gives higher values than the IND method in zones 5, 6 and 7. Should practitioners use the IND data, they would see a reduced number of HIEs recorded by both forwards than backs. This could lead to a reassessment of the HI physical demands of rugby union in terms of recorded HI runs, sprints and maximal sprints, therefore giving a lower overall impression of the HI demands of rugby union.

There is also a larger difference between the ABS and IND methods for the backs than forwards which is also seen for both % distance and % time spent in HI zones, with this being significant for % distance covered in zones 6 and 7. A 10.8% difference is seen between ABS and IND methods for the number of HIEs in zone 5 made by backs, whereas the corresponding difference for forwards is 8.7%. The same can be said for the number of HIEs made in zones 6 and 7, with the difference for backs being 8.6% and 3.9% compared to 3.7% and 0.6% for forwards. The difference between the differences in methods across the two groups was deemed statistically significant in zones 6 and 7, but not zone 5.

With the mean number of differences in number of RHIEs recorded being only 1±2 for forwards and 1±1 for backs, no significant difference was found.

Overall, the different methods of GPS analysis can give a very different understanding of the physical demands of rugby union, with many of these differences being shown to be statistically significant. In research terms this could affect the overall impression that the current literature has. Should the IND bands become the new gold standard method, the data previously presented would become out-dated as it is largely based on ABS methods as covered in the literature review. In an applied sense, the differences could be more acute, affecting individual players and management’s perception of their effort/intensity, as demonstrated with the differences between individual positions changing depending on the method used. In a very broad sense it appears that IND bands give an overall lower output for HI work. This finding could have an effect on day to day practices in professional sport, such as impacting training regimes, because our understanding of the physical demands of rugby union may be altered to such a degree that the emphasis of training may change, perhaps to increase the amount of HI work being done, especially if the practitioners working with teams are of the opinion that IND bands give the more truthful picture of physical demands of rugby union as measured by GPS. Conversely if the game has less demand for HI work by certain specific positions, then less HI work may be included in their regime, resulting in a more tailored training regime, rather than the traditional forward/back split, this will be discussed further later in this section.

## 5.2. Methodological comparisons with Current Literature

With portable GPS technology advancing, e.g. GNSS system where newer models of the units used in this study are able to access Russian satellites as well as the satellites available in this study there are also now more options on how to analyse the outputs. It is also becoming more affordable, meaning that it is being used more widely by professional teams and institutions. One of the areas that these teams and institutions are becoming interested in the possible use of IND bands rather than ABS. This is due to the growing belief that the IND velocity band method could be more sensitive in terms of measuring physical demands of individual players than the ABS velocity band method. With this growing interest comes the question of how best to devise IND bands. As is shown in Appendix 5 there are already great differences in the ABS bands used within HI intermittent field based team sports, and the IND method appears to be heading in the same direction.

As previously mentioned in the introduction, Reardon et al., (2015) only created one velocity band for HI, dividing the arbitrary value for HSR supplied by the GPS manufacturer of 0.5 $m.s^{-1}$ by the mean Vmax of the participants (8.3$m.s^{-1}$) to give a value of 0.6$m.s^{-1}$, thus the HSR threshold was thus set at 60% Vmax. The results showed that HIEs (>60% Vmax) are underestimated by ABS for forwards (ABS: 18.81±12.25 and IND: 24.78±8.30) but not backs (ABS: 41.55±11.25 and IND: 34.54±9.2) (Reardon et al., 2015). Whereas in this study, ABS gives a higher number of efforts for both forwards and backs than IND bands. This difference could be attributed to their HSR threshold of 60% being lower than that set in this paper of 70% and this study dividing HI in to three zones, while Reardon et al., (2015) only had one HI zone. In this study, zone 4 ranges from 50 – 70%, meaning that it includes a proportion of Reardon's HI zone which was determined as >60%. Rudimental calculations conducted by the author suggest that if this study's HI cut off was also set at one band >60% then the difference between ABS and IND would be ~-0.2% for % distance and ~-0.4% for % time. The difference between these results from simply changing the HI threshold and number of HI zones demonstrates the impact that methodology has on our understanding of the workload differences between the ABS and IND methods of GPS analysis.

Cahill et al., (2013) based their methodology on that of Venter et al., (2011). They created five movement intensities based on the match Vmax from any time throughout the season: <20% Vmax (standing & walking), 20-50% Vmax (jogging), 51-80% Vmax (striding), 81-95% Vmax (sprinting) and 96-100% Vmax (maximum sprint). Average Vmax for the forwards group in the study by Cahill et al., (2013) was 26.3$km.h^{-1}$ which is lower than the sprint testing results from this study, providing evidence that sprint testing is a more appropriate method to gauge absolute maximums for use in the construction of IND bands as it would be justifiable to expect that the elite English premiership players participating in that study would have a higher average Vmax than the amateur/semi-pro players in this study. The authors commented that the use of match Vmax as a measure from which to create IND bands has the effect of overestimating the amount of HI work by forwards. This is supported by the evidence in this study in that the props have the largest difference between Vmax from sprint testing and match Vmax.

For studies comparing velocity band methodologies it is important to consider matching the range of velocities in each zone, whether they be ABS or IND. Only zones 2 & 4 have a negative difference between ABS and IND for both % distance and % time. A possible reason could have been a mismatch in the range of velocities covered by each method for the equivalent zone. The ABS bands were 6.1-11km.h$^{-1}$ and 15.1-18km.h$^{-1}$ for zones 2 and 4 respectively, while the IND bands were 20-40% and 50-70%. When investigated using an example Vmax of 30km.h$^{-1}$ the ranges in velocity bands for zone 2 matched up very well, with 20% equating to 6.2km.h$^{-1}$ and 40% equating to 12km.h$^{-1}$ meaning the range was 6km.h$^{-1}$. Using the same example Vmax for zone 4, 50% equates to 15km.h$^{-1}$ but 70% equates to 21km.h$^{-1}$, making the IND range 6km.h$^{-1}$ compared to the 3km.h$^{-1}$ range for the ABS band. This could be used to explain the larger % time spent in zone 4 for IND rather than ABS as the range is wider. Future studies may benefit from matching the ranges of velocities in each method more closely in order to rule this out as a source of difference between methods.

Percentage of field time is not a commonly used output in GPS analysis of rugby union, with Venter et al., (2011) being the only other paper to have used it. With their IND sprinting bands set at the same bands as this study's (80-95% Vmax), there is opportunity for direct comparison, although their groups were organised slightly different. They found values for % distance covered sprinting of 0.42% for both front and back row forwards, 0.66% for inside backs and 1.05% for outside backs. These values are higher than those found in this study. As was shown in section 4.4 all positions recorded 0.0% for sprinting when using IND bands. Their subjects also spent less time in the standing/walking zones, alluding to a conclusion that RSA under-19 level rugby is perhaps played at a higher tempo than Scottish semi-pro/amateur rugby.

As has previously been covered, due to a lack of consistency throughout the published literature as to what threshold constitutes HI and the positional groups used, it is difficult to draw comparisons between results from other papers who have used HIEs as an output (Reardon et al., 2015; Suarez-Aronnes et al., 2014; McLellan et al., 2013; Coughlan et al., 2011; Cunniffe et al., 2009). McLellan et al., 2013 used the basic positional groups of forwards and backs and set the HI threshold at 18km.h$^{-1}$ as is the same with the ABS method for this study and the recorded 2±3 HIEs for forwards and 13±6 for backs. While lower than was recorded in this study, the relationship between the groups remains the same. The likely reason for their results being lower than this study's, despite being carried out over eleven matches in the super rugby league, is that they only had five subjects rather than the twenty-six in this study, one of which being a prop which as this study has already shown, record considerably less HIEs than any other position.

An important consideration for the IND method is the possibility that Vmax, on which the velocity bands are based, could change during the season. To overcome this, previous studies have used retrospective Vmax from data gathered over the course of the season (Venter et al., 2011; Cahill et al., 2013; Reardon et al., 2015). However, if these methods may only be appropriate should the analysis be retrospective too, if analysis is on-going throughout a season, then the Vmax needs to be current. The IND bands should also be representative of a player's Vmax at the time.

The present study's method of conducting sprint testing over a distance of 40m has had effective results as in only one incidence did an individual match Vmax ($33.1 km.h^{-1}$) exceed that of the Vmax from the sprint test during pre-season that the IND band was derived from ($32.0 km.h^{-1}$). To be fully confident that a Vmax has been recorded, it could be beneficial for practitioners to stage a mini trial of different sprint distances, e.g. 40m, 70m and 100m to ensure that a Vmax can be captured from the shorter distance. In this trial 40m was used as an emulation of common distances that would be run on field and to reduce injury risk as the session was the start of pre-season.

In an elite environment where GPS units are commonly worn during training each day it would be easy to monitor Vmax throughout the season for any velocity that exceeded the Vmax used for the IND band so it could be easily adjusted allowing for maximum accuracy in the GPS analysis. Hence the method in which this study employed can be deemed a strength as it overcomes problems encountered by previous studies regarding devising Vmax. Bar one match, Vmax exceeding the sprint test Vmax, sprint testing values were higher than match values throughout the season.

## 5.3. Locomotive Variable comparisons with Current Literature

To put the motion analysis of this study in to context with the current literature and to better understand the level at which the amateur/semi-pro players in this study are playing, locomotive variables described in section 4.1 need to be compared with the published research, which is largely carried out at the elite level. While it is important to understand the physicality at the elite level of rugby union, a lot can also be gained from carrying out studies on players in the league below to understand the vertical integration between sub-elite and professional teams, particularly in terms of young players in elite development or training programmes with professional squads, as was the case for four of the players who consented to be part of this study.

The distance covered by professional forwards from the English premiership (5850m) (Cahill et al., 2013) is similar to that covered by amateur/semi-pro forwards in the present study (5875m). The professional forwards from the Guinness Pro 12 (Reardon et al., 2015) covered 5638m, again very close, and in fact lower than the values for the amateur/semi-pro forwards from this study. The backs from this study covered less distance (5761m) than those in the English Premiership (6454m) and those playing in the Guinness Pro 12 (6171m). The relative distance is also close for the amateur/semi-pro and professional players, with the forwards and backs from this study both having a mean work rate of 69.3m.min$^{-1}$ while the English premiership and Guinness Pro 12 players recorded m/min values of 64.4m.min$^{-1}$ and 71.1m.min$^{-1}$ respectively. This shows that the results are comparable as the intensity of the matches played for of a similar level, with the BT Premiership players having a higher work-rate than the English professional players.

Therefore it can be deemed that the motion analysis carried out in this study is coherent with that of studies also conducted over the entirety of a season and using either just the IND method of analysis or comparing both.

## 5.4. Output Methodology

Composite GPS outputs of % distance and % time were used in order to make the outputs more comparable between different positions. Composite data also accounts for the difference in time spent on the pitch for different individuals and also the difference between average field times for positions, a point raised by Cahill et al., (2013). However, using composite data affected the results for % time spent in each zone, particularly the three HI zones of 5, 6 & 7. This was due to such a high % of total time being spent in zone 1, 73.5±6.2% using ABS and 71.9±6.3% when using IND for forwards and 77.1±8.5% using ABS and 78.1±8.6% when using IND for backs. Therefore there was very little that could be garnered from the % time at HI as these values were all <1% using both ABS and IND methods in zones 5 and 6 and 0.0% for zone 7. This was overcome by also including the number of efforts in HI zones, which gives a very clear indication of the HI work done by all positions. Future studies on this topic should take in to account the vast difference in work done, whether it is distance or time, between zones 1 and 5, 6 & 7 when solely using compositional data as it's harder to garner HI demands from such small percentages.

## 5.5. Positional Groupings

As well as moving towards the use of IND bands, there is evidence from this study to support the use of three basic positional groups (F5, M5 and B5) rather than using the main two positional groups of backs and forwards. The Vmax from the pre-season sprint tests provides evidence for the groupings of F5, M5 and B5 opposed to just forwards and backs as the positions within these groups have very similar max values. The F5 (prop, hooker & second row) recorded mean max velocities of 28.2±0.6, 29.4±1.6 and 28.0±0.5 $km.h^{-1}$ respectively; the M5 (flanker, No 8 and scrum half) recorded mean max velocities of 29.9±1.4, 29.7 & 29.8±0.7 $km.h^{-1}$ respectively while the B5 (centre, wing & full back) recorded mean Vmax of 31.1±1.1, 32.0 & 31.0±1.6 $km.h^{-1}$.

The player load of the scrum half (548.7±102.9) is closer to that of the No.8 (583±41) and flanker (616±115) than that of the centre (443.6±77.1), showing that the physical demands of scrum halves is more similar to that of the back row forwards than the other backs. The % distance covered at HI by the scrum half, although lower than both the back row and centres and wings, is also closer to the back row forwards than the other backs. Reardon et al., (2015) also showed that the % distance covered at HI by scrum halves is closer to that of the back row than the centres, wings and full backs.

However, in that study the scrum half covered a higher % distance at HI than the back row and less than the other backs. Conversely, Cahill et al., (2013) saw that the % distance covered at HI was closer to that of the fellow backs than the forwards. But this could be attributed to the previous point made about the Cahill et al., (2013) method of using match Vmax to derive IND bands overestimating HI work done by forwards, making this comparison less robust.

In terms of HIEs, the scrum half proves an anomaly for the back group, having the same number of efforts as the flanker in zone 5 (ABS: 17±5 IND: 6±3 /ABS: 17±8 IND: 8±7), zone 6 (ABS: 6±3 IND: 2±1 /ABS 6±3 IND 2±3) and zone 7 (ABS: 1±1 IND: 0±1 / ABS: 1±1 IND: 0±0) rather than the other back positions of centre, wing and full back, who themselves have similar values for zone 5 (ABS: 25±8 IND: 12±4 / ABS: 26±8 IND: 13±5 / ABS: 25±9 IND: 13±5), zone 6 (ABS: 15±6 IND: 5±3 / ABS: 18±5 IND 5±2 / ABS: 15±5 IND: 6±2) and zone 7 (ABS: 4±2 IND:0±0 / ABS: 6±2 IND: 1±1 / ABS: 5±2 IND: 0±0) respectively. Again Reardon et al., (2015) saw the same trend, that the difference between the number of HIEs made by the scrum halves is closer to the back row than the back three positions.

The use of these three positional groups would greatly add to the level of detail that can be gained from any motion analysis, without the much greater level of data analysis needed to look at each position individually.

## 5.6. Strengths and Weaknesses

It is the author’s thought that to garner the most representative data for the distinct positions, that ideally studies of this type should include more than one squad of players. It is not uncommon for studies to use players from different teams within the same league (Cahill et al., 2013; Quarrie et al., 2013) which not only provides the opportunity for more data files in total, but also for each distinct position, providing a more robust view of the demands of the position. This thinking is due to issues arising during the season which reduced the number of data files that were recorded by certain positions. This is illustrated by the highest number of files recorded for any position being seventeen and the lowest being one. This was exacerbated by the drafting system of professional players from the two full time teams in Scotland to the BT Premiership sides, who were provided with GPS units by their professional side and had not been sprint tested in pre-season or consented to be part of the study. In the case of this study, the fly half position was regularly drafted which resulted in this position being omitted from the study. The drafting system had more of an effect in the latter part of the season as more professional players were available due to the 2015 Rugby World Cup ending and the national players being available for their clubs again, more injuries occurring in professional squads, and players recovering from these injuries being drafted to BT Premiership sides as part of their match preparation. This system would be taken in to consideration for future studies in this rugby league, with the possible solution of identifying the potential draft players at the start of the season, as the notice during each week of the season as to who is being drafted each week is too short to organise inclusion on an on-going basis.

Studies using players from within an entire league rather than a single team will also be less susceptible to results being skewed by individual strengths and weaknesses within the team. For instance, in this study the second row and hookers are particularly strong positions, with consistently good performances from the same individuals playing in these positions throughout the season.

Figures 4, 9 and 14 show how physical match demands can vary match-to-match, as do the ranges of locomotive values shown in section 4.1. These match-to-match variances can be attributed to a number of things including: conditions (rain can result in muddy pitches slowing down running pace and result in a kicking game with handling errors slowing down match play), match tactics (playing the ball wide with quick line speed or playing a slower, pick and go, game will change total distance run) and number of set pieces, which will contribute to a change in the match demands. Hence researchers should be cautious when summarising match demands from data which has been collected from an entire season. Match-to-match variation was taken in to account in this study when constructing the GLM for formal analysis of the data.

Faults with the units themselves sometimes resulted in them not recording any distance, an issue most common for the F5 positions. It was sometimes the case that the unit turned off during the match, and in some cases turned back on, creating two files. The reason for this is thought to be them being switched off accidently during binding in the scrum. Due to data loss misrepresenting the amount of work done, these files could not be used in the study.

Cahill et al., (2013) have published the most comprehensive paper on positional demands of rugby union using GPS as they used players from more than one club in the English Premiership throughout the entirety of the season collecting two hundred and seventy-six data files from ninety-eight players. This highlights how far this area of research has moved on when this is compared to the study by Cunniffe et al., (2009) which only compared one forward and one back form one preseason friendly match. McLellan et al., (2013) had a smaller subject pool than that of Cahill et al., (2103) of five players, but unlike Cunniffe, they monitored eleven matches of the season rather than just one. Quarrie et al., (2013) also acknowledged the need for larger sample sizes in their analysis of the New Zealand international rugby team, however their method of analysis employed time motion analysis. This shows that this study's use of data from an entire season, and the aim of monitoring the whole squad, is in line with current practices in the literature.

## 5.7. Practical Implications & Future Research

Rather than purely being a research tool, GPS is used on a daily basis by professional and national teams; this means that a study such as this, which compares methods in which this daily data is analysed, has potentially impactful practical implications. By comparing arbitrary ABS values with those derived from an individual Vmax we can garner an understanding of potential misrepresentations in the outputs. If the ABS method is found to continuously give statistically significant higher values for GPS metrics which represent the physical demands of rugby union compared with those from the IND method of analysis, then the IND method should be considered for use by those responsible for monitoring of athletes in terms of injury monitoring and rest-recovery periods. It is of paramount importance that sport science practitioners, that are implementing this technology for athlete monitoring on a day-to-day basis, understand what the velocity band settings are and what they imply for different positions.

From the limited number of studies comparing the two methods, and the different methodologies employed, it is hard to determine either as a clear criterion method. In theory, the IND band method would appear the way forward, but there are still issues to rectify before it can be recommended that IND bands are used for GPS analysis. Ways to confirm the direction of difference between ABS and IND in future research would be to use absolute data rather than composite data in order to confirm degree of statistical significance. Ensuring that zones have equal ranges of velocity for both the ABS and IND methods would reduce efforts being attributed to different zones depending on the method being used. Larger cohorts, i.e. studying players within an entire league rather than one team enable future research to determine the effect the bands have on the distinct positions rather than broad groups of forwards and backs.

## 5.8. Conclusion

In conclusion, there are significant differences between the ABS and IND methods of GPS analysis of the physical demands of rugby union, both within the forward and back positions and between the differences in these groups. However there are still too many methodological issues to be able to categorically state that either method should be used over the other.

It is the author's belief that this study can add to the knowledge of the two methods of analysis and give future research the direction to make the differences clearer, and practitioners the ability to make an informed choice on the method of GPS analysis to use.

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**Appendix 1:** Anthropometry of rugby union players.

| Reference | Level | n | Position | Height (cm) | Weight (kg) |
|---|---|---|---|---|---|
| James *et al* 2015 | Elite (Wales) | 33 | - | - | 104 (10.6) |
| Cahill *et al* 2013 | Elite (England) | 120 | - | 187 (7) | 103.8 (12.6) |
| McLellan *et al* 2013 | Elite (Super 15) | 5(total) | Forwards | 193 (6.1) | 116 (1.4) |
| | | | Backs | 187 (1.2) | 93.7 (1.5) |
| Argus *et al* 2012 | Elite (Australia) | 43 | - | 184.7 (6.2) | 103.4 (11.2) |
| | Semi-Pro | 19 | - | 187.2 (7.6) | 100.7 (11.5) |
| | Academy | 32 | - | 186.9± 6.5 | 95.6± 11.0 |
| | High School | 19 | - | 180.9 (8.4) | 86.5 (13.7) |
| Austin *et al* 2011 | Elite (Australia) | 20(total) | Front Row | 183 (2) | 114 (4) |
| | | | Back Row | 183 (4) | 93 (9) |
| | | | Inside Backs | 179 (6) | 87 (3) |
| | | | Outside Backs | 182 (4) | 100 (12) |
| Venter *et al* 2011 | U19 (RSA) | 17 | - | 183 (6) | 89.8 (10.8) |
| Argus *et al* 2010 | Elite (NZL) | 33 | - | 186 (6) | 102.3 (10.3) |
| Cunniffe *et al* 2009 | Elite (Wales) | 3 | - | 193 (9.7) | 104.6 (10.4) |

*Values presented are means with standard deviations given in brackets. – denotes that information was not provided.*
*(total) indicates that the number of players in each position was not provided.*

**Appendix 2:** Overview of reported aerobic capacities of rugby union players.

| Reference | Level | n | Position | $\dot{V}O_2max$ (L/min) | $\dot{V}O_2max$ (ml/kg/min) | Method |
|---|---|---|---|---|---|---|
| Cunniffe *et al* 2009 | Elite (Wales) | 3 | - | - | 53.3 | - |
| *Bell | Semi Pro | - | Prop | 4.06 | 44.0 | CE |
| | | - | Hooker | 3.38 | 43.2 | |
| | | - | Lock | 4.51 | 44.9 | |
| | | - | Flanker | 4.49 | 50.9 | |
| | | - | no.8 | 4.07 | 55.8 | |
| *Maud & Shultz | Elite | - | Forward | 4.26 | 45.1 | CE |
| | | - | Back | 3.67 | 48.7 | |
| *Williams *et al* | University | - | - | 3.87 | 50.3 | CE |
| *Jardine *et al* | Semi Pro | - | Forward | 5.14 | 52.0 | T |
| | | - | Back | 4.1 | 55.8 | |
| *Maud | Semi Pro | - | Forward | 4.73 | 54.1 | T |
| | | - | Back | 4.77 | 59.5 | |
| *O'Gorman *et al* | International | - | - | - | 54.1 | T |
| *Warrington *et al* | International | - | Forward | 5.3 | 51.1 | T |
| *Holymard *et al* | - | - | Forward | 5.82 | 58.0 | MST |
| *Nichols & Baker | Elite | - | Forward | 5.04 | 51.8 | MST |
| | | - | Back | 4.46 | 56.3 | |
| *Tong & Mayes | Elite | - | Forward | 5.65 | 53.8 | MST |
| | | - | Back | 4.75 | 57.5 | |

*CE = cycle Ergometer T = Treadmill MST = Multi-stage Shuttle Test. *Data taken form Duthie et al 2003 review paper.*

## **Appendix 3:** Validity of GPS units for speed and distance.

| Reference | GPS unit | Methods | Criterion | Result Summary | Conclusion |
|---|---|---|---|---|---|
| Vickery *et al* 2014 | 5Hz 10Hz MinimaxX S4<br>15Hz GPS Sports | Sport specific (Tennis, cricket & soccer) 100Hz<br>2 moderately trained males (25.5±0.7yrs) | 22 Camera VICON system | All GPS: VICON<br>Distance $P<0.05$ Speed $P<0.05$ | No significant difference between any frequency of GPS unit and the criterion method when measuring both distance and speed. Both were generally under reported. |
| Rampini *et al* 2014 | 5Hz 10Hz MinimaxX S4 | Shuttle runs (soccer)<br>8 sub-elite footballers (15±1yrs) | Radar | *5Hz CV*<br>TD 2.8, HSR 7.5, VHSR 23.2<br>*10 Hz CV*<br>TD 1.9, HSR 4.7, VHSR 10.5<br>*5Hz %Bias*<br>TD 1.8, HSR -0.4, VHSR -17.8<br>*10Hz %Bias*<br>TD 0.6, HSR -1.1, VHSR -7.3 | GPS accuracy increased with sampling frequency but decreased with speed. |
| Akenhead *et al* 2013 | 10Hz MinimaxX S4 | Maximal 10m Acceleration<br>Unit attached to sled & towed by pro footballer (21yrs) | Laser | *SEE ± 95%CI*<br>0-1 m $s^{-1}$ 0.12 ± 0.02<br>1-2m $s^{-1}$ 0.16 ± 0.02<br>2-3m $s^{-1}$ 0.18 ± 0.03<br>3-4m $s^{-1}$ 0.19 ± 0.02<br>>4m $s^{-1}$ 0.32 ± 0.06 | Validity is inversely associated with acceleration speed. Accuracy is reduced at accelerations >4 m $s^{-1}$ |
| Castellano *et al* 2011 | 10Hz MinimaxX S4 | 15m & 30m Linear runs | Photoelectric cells | 15m Mean distance: 13.2m<br>15m Mean SEM (%): 10.9<br>30m Mean Distance: 28.1m<br>30m Mean SEM (%): 5.1 | Accuracy is improved over the longer distance of 30m. This is shown by the higher SEM over the 15m distance |
| Varley *et al* 2011 | 5Hz MinimaxX v2<br>10 Hz MinimaxX v4 | Linear drills<br>Starting Velocities (m $s^{-1}$)<br>1-3/3-5/5-8<br>3 sub-elite team sport athletes (27±3yrs) | Laser | *5Hz CV as %*<br>Constant Velocity 11.1/10.6/3.6<br>Acceleration 14.9/9.5/7.1<br>Deceleration (5-8m $s^{-1}$ starting vel.) 33.2<br>*10Hz CV as %*<br>Constant Velocity 8.3/4.3/3.1<br>Acceleration 5.9/4.9/3.6<br>Deceleration (5-8m $s^{-1}$ starting vel.) 11.3 | Higher sampling frequency improves validity at constant velocity.<br>The same is true for acceleration and deceleration<br>Both units underestimate velocity |

*Appendix 3 Continued*

| Reference | GPS unit | Methods | Criterion | Result Summary | Conclusion |
|---|---|---|---|---|---|
| Gray *et al* 2010 | 1Hz WiSPI Elite | Linear & 8 units<br>non-linear<br>200m course<br><br>Walk, jog, Run & sprint<br><br><br>1 Triathlete (25yrs) | | *Mean Linear GPS distance (range)*<br>Walk 205.8 ± 2.4 (202.2-213.8)<br>Jog 201.8 ± 2.8 (193.9-206.8)<br><br>Run 203.1 ± 2.2 (198.4-210.1)<br>Sprint 205.2 ± 4.0 (199.9-222.0)<br>*Mean Non-Linear GPS distance (range)*<br>Walk 198.9 ± 3.5 (191.4-207.0)<br>Jog 188.3 ± 2.0 (184.9-191.8)<br>Run 184.6 ± 2.9 (175.1-191.2)<br>Sprint 180.4 ± 5.7 (161.0-194.7) | Linear walk and sprint distances significantly greater than jog and run<br><br>The non-linear course shows a marked underestimation of distance for all movement intensities. This overall trend increases with increasing speed |
| Coutts & Duffield 2010 | 1Hz SPI - 10<br>1 Hz SPI Elite<br>1 Hz WiSPI | Intermittent intensity<br>128.5m<br>Team sport course<br><br>2 moderately trained males | Measuring tape | *Mean Lap distance ± SD (m) / bout (m)*<br>SPI-10 123.2±8.3 / 739±35<br>SPI Elite 126.1±5.6 / 756±29<br>WiSPI 129.1±8.2 / 776±64<br>*Zone distance (m) /peak (km.h⁻¹)*<br>LIA / HIR / VHIR<br>SPI-10 565±37 / 175±51 / 60±18 / 21.3±2.0<br>SPI Elite 524±32 / 147±47 / 83±18 / 21.9±1.7<br>WiSPI 553±61 / 145±45 / 82±19 / 21.7±1.8 | All devices were within 5% of actual distance which shows a good level of accuracy although there was a significant difference between unit recordings. |
| Jennings *et al* 2010 1Hz 5Hz | MinimaxX | Linear shuttle (10m, 20m, & 40m) (20) at different speeds, changes of direction & team movements Circuit.<br><br>20 Elite AFL Players 24±4yrs | 2 units/ subject | 1Hz Straight line SD of %diff GPS-Actual<br>Walk 23.8±5.9 / 17.4±3.7 / 9.6±2.0<br>Jog 25.7±5.5 / 18.3±3.9 / 11.5±2.4<br>Stride 31.1±6.6 / 20.9±4.4 / 11.3±2.4<br>Sprint 32.4±6.9 / 22.3±4.7 / 12.2±2.4<br>5Hz Straight line SD of %diff GPS-Actual<br>Walk 21.3±5.8 / 16.6±3.5 / 9.8±2.0<br>Jog 23.2±4.9 / 15.3±3.2 / 10.7±2.3<br>Stride 27.4±6.6 / 16.8±3.4 / 11.5±2.4<br>Sprint 30.9±5.8 / 17.0±3.6 / 11.9±2.5 | As movement intensity increased over all the given distances, accuracy of GPS measurement decreased.<br>At any given intensity the validity of GPS, both 1Hz & 5Hz, increased with increasing distance.<br>A higher sampling rate decreased error. |

*CV – coefficient of variation. TD – Total Distance, HSR – High Speed Running, VHSR – Very High Speed Running, LIA – Low Intensity Activity, HIR – High Intensity Running, VHIR – Very High Intensity Running*

**Appendix 4:** Reliability of GPS units for speed and distance

| Reference | GPS Unit | Method | Criterion | Result Summary | Conclusion |
| --- | --- | --- | --- | --- | --- |
| Vickery *et al* 2014 | 5Hz 10Hz minimaxX 15Hz GPS Sports | Sport specific *(tennis)* | 22 Camera VICON system | *5 Hz Distance* CV (9.1 - 29.0)<br>*15Hz Distance* CV (5.4-12.1)<br>*5Hz Speed (mean/peak)* CV (14.9/20.0 – 26.2/32.9) be<br>*15Hz Speed (mean/peak* CV (3.5/5.4 – 22.8/20.6) | Field based team sports drills have a lower reliability than that of court based sports. 5Hz units have a higher CV than 15Hz units, however, inter-unit reliability was found to better in the 5Hz units. GPS has a low-moderate level of reliability regardless of sampling frequency or movement pattern |
| | | (cricket & soccer) | | *5 Hz Distance* CV (17.7 – 22.8)<br>*15Hz Distance* CV (5.5 – 17.9)<br>*5Hz Speed (mean/peak)* CV (19.8/14.2 – 33.4/31.5)<br>*15Hz Speed (mean/peak)* CV (7.5/5.4 – 16.3/20.0) | |
| Akenhead *et al* 2013 | 10Hz MinimaxX S4 | 10m maximal acceleration Unit attached to Sled and pulled On monorail by Pro footballer (21yrs) | Laser | TE ($m\ s^{-1}$) / CV (%)<br>0-1m $s^{-1}$ 0.05 ± 0.01 /0.7 ± 0.1<br>1-2 m $s^{-1}$ 0.06 ± 0.01/ 1.1 ± 0.1<br>2-3 m $s^{-1}$ 0.09 ± 0.01/ 2.2 ± 0.2<br>3-4 m $s^{-1}$0.1± 0.01 / 3.9 ± 0.4<br>>4m $s^{-1}$ 0.12 ± 0.01 / 9.1 ± 1.0 | Inter-unit reliability decreases with increasing speed of acceleration |
| Castellano *et al* 2011 | 10Hz MinimaxX v4 | 15m & 30m sprints | Video & photoelectric cells | 15m Mean CV: 1.3%<br>30m Mean CV: 0.7% | Unit reliability is greater over a distance of 30m than 15m. It can be concluded that 10Hz GPS |
| reliability | | 9 trained males | | | reduced over short distances |
| Varley *et al* 2011 starting | 5Hz MinimaxX v2 | Linear drills | Laser | 5Hz inter unit reliability (TE as m $s^{-1}$) | Reliability improves at higher |
| | 10Hz MinimaxX v4 | Starting Velocities (m $s^{-1}$) 1-3/3-5/5-8 | | Constant Velocity 0.21/0.27/0.35<br>Acceleration 0.50/0.43/0.60<br>Deceleration (5-8m $s^{-1}$ starting vel.) 0.83<br>10Hz Inter unit reliability (TE as m $s^{-1}$)<br>Constant Velocity 0.12/0.13/0.11 | velocities. Reliability was also improved by a higher sampling frequency |

*Appendix 4 Continued*

| Reference | GPS Unit | Method | Criterion | Result Summary | Conclusion |
|---|---|---|---|---|---|
| Varley *et al* 2011 cont. | | | | Acceleration 0.18/0.20/0.13<br>Deceleration (5-8m $s^{-1}$ starting vel.) 0.16 | |
| Gray *et al* 2010 | 1Hz WiSPI Elite | Linear & non-linear 200m course (Walk/jog/ Run/sprint) | 8 units<br>1 subject | Intra-receiver 95% CV<br>Linear: 1.85/2.54/2.02/2.71<br>Non Linear: 2.79/1.98/2.60/4.80<br>Inter-receiver 95% CV<br>Linear: 2.02/2.33/1.46/3.38<br>Non Linear: 3.43/1.63/2.75/6/04 | All intra and inter unit CVs are similar, with the exception of non-linear sprinting which is the only one above 5% at 6.04 |
| Coutts & Duffield 2010 | 1Hz SPI - 10<br>1Hz SPI Elite<br>1Hz WiSPI | Intermittent intensity 128.5m<br>Team sport course<br><br>2 moderately Trained males | Measuring tape<br><br>3 brands | Intra model CV lap/bout<br>SPI-10 6.4 (5.7–7.4) / 4.5(3.5–6.6)<br>SPI Elite 4.0 (3.6–4.5) / 3.6 (2.8–5.2)<br>WiSPI 7.2 (6.4–8.4) / 7.1 (5.3–10.9)<br>Intra model CV Zone distance (m) /peak (km.$h^{-1}$)<br>LIA / HIR / VHIR / Peak<br>SPI-10 5.3 (4.1–7.7) / 32.4 (24.3–49.7) / 30.4 (22.8–46.4) / 5.8 (5.2–6.6)<br>SPI Elite 4.3 (3.3–6.2) / 11.2 (8.6–6.5) / 15.4 (11.7–22.9) / 2.3 (2.1–6.6)<br>WiSPI 12.5 (9.3–16.6) / 20.4 (15.1–32.5) / 11.5 (11.5–25.4) / 4.9 (4.3–5.7) | Inter unit reliability was deemed to be low for all units. Reliability was lowest at VHIR |
| Jennings *et al* 2010 | 1Hz 5Hz MinimaxX | Linear shuttle (10m, 20m, 40m) at different speeds, changes of direction & team movements Circuit.<br><br>20 Elite AFL players 24±4yrs | 2 units/subject | 1Hz Linear Inter unit reliability (CV%)<br>Walk 30.8 / 20.4 / 7.0<br>Jog 34.7 / 20.9 / 9.4<br>Stride 58.8 / 33.3 / 10.5<br>Sprint 77.2 / 44.9 / 11.5<br>5Hz Linear Inter unit reliability (CV%)<br>Walk 23.3 / 21.2 / 6.6<br>Jog 22.8 / 15.6 / 9.1<br>Stride 33.4 / 17.5 / 9.1<br>Sprint 39.5 / 23.0 / 9.2 | Reliability increased for all movement intensities when distance increased and sampling frequency was increased from 1Hz to 5Hz |

*CV – coefficient of variation. TD – Total Distance, HSR – High Speed Running, VHSR – Very High Speed Running, LIA – Low Intensity Activity, HIR – High Intensity Running, VHIR – Very High Intensity Running*

**Appendix 5:** Systematic review study characteristics

| Sport | Articles | Participants | %Male | Age range (years) | Athletic Level |
|---|---|---|---|---|---|
| Rugby Union | 12 | 265 | 97 | 18 – 30 | Elite (212) Semi-Pro (17) |
| Rugby Sevens | 5 | 222 | 95 | 21 – 27 | Elite (222) |
| Rugby League | 5 | 99 | 100 | 22 – 26 | Elite (99) |
| Soccer | 3 | 58 | 100 | 21 – 26 | Elite (38) Semi-pro (20) |
| Hockey | 6 | 110 | 65 | 19 – 30 | Elite (100) Semi-pro (12) |
| AFL | 7 | 505 | 100 | 22 – 25 | Elite (497) Semi-Pro (8) |

**Appendix 6:** Team sport velocity bands with corresponding movement intensity.

| Reference | Low Intensity Running ($km.h^{-1}$) | | | | | High Intensity Running ($km.h^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|
| | Stand/Walk | Jogging | Cruising | Striding | MIR | HIR | Sprint | Max Sprint |
| Rugby Union | | | | | | | | |
| Jones *et al* 2015* | 0-5.8 | 5.8-9.7 | 9.7-13.7 | 13.7-18 | | 18-19.8 | >20 | |
| Reardon *et al 2015*** | | | | | | 60% / 18 | | |
| Suarez-Arrones *et al* 2014 | 0-6 | 6.1-12 | 12.1-14 | | 14.1-18 | 18.1-20 | >20.1 | |
| Cahill *et al* 2013** | <20% | 20-50% | | 51-80% | | | 81-95% | 96-100% |
| McLellan *et al* 2011 | 0-6 | 6.1-12 | 12.1-14 | 14.1-18 | | 18.1-22 | >22.1 | |
| Reid *et al* 2013* | 0-1.8, 2.2-6.1 | 6.5-13 | 13.3-18 | | | 18.4-24.1 | >24.48 | |
| Coughlan *et al* 2011 | 0-1.8, 1.8-6.1 | 6.12-13 | | | 13-18 | 18-24.1 | | |
| Venter *et al* 2011** | <20% | 20-50% | | 51-80% | | | 81-95% | 96-100% |
| Cunniffe *et al* 2009 | 0-6 | 6-12 | 12-14 | 14-18 | | 18-20 | >20 | |
| | | | | | | | | |
| Rugby Sevens | | | | | | | | |
| Ross *et al* 2015* | | | | | <18 | >18 | | |
| Grantanelli *et al* 2014 | | | | | <14 | >14 | | |
| Murray *et al* 2014* | | | | | | 15 – 36 | | |
| Higham *et al* 2012* | 0–7.2 | 7.2–12.6 | 12.6-18 | | | 18-21.6 | | >21.6 |
| Suarez-Arrones *et al* 2012 | 0-6 | 6.1-12 | 12.1-14 | | 14.1-18 | 18.1-20 | | >20.1 |
| | | | | | | | | |
| Rugby League | | | | | | | | |
| Kempton *et al* 2014 (a) | | | | | | >14.4 | | |
| Gabbett *et al* 2013* | | | | | <18 | >18 | | |
| Gabbett *et al* 2011* | | | | | <18 | >18 | | |
| Waldron *et al* 2011 | 0.1-6 | | | | 7-13.9 | 14.0-21 | | >21 |
| Sirotic *et al* 2009 | 0-1, 1.1-7 | 7.1-13 | | | 13.1–18.5 | 18.6-24 | | >24 |

*Appendix 6 continued*

| Reference | | Low Intensity Running ($km.h^{-1}$) | | | | High Intensity Running ($km.h^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|
| | Stand/Walk | Jogging | Cruising | Striding | MIR | HIR | Sprint | Max Sprint |
| Soccer | | | | | | | | |
| Folgado *et al* 2015 | 0-3.5 | | | 3.6-14.3 | 14.4-19.7 | >19.8 | | |
| Hewitt *et al* 2014 | 0–0.4, 0.5-6 | 6-12 | | 12-19 | | >19 | | |
| Mugglestone *et al* 2013 | | | | | | >15 | >21 | |
| | | | | | | | | |
| Hockey | | | | | | | | |
| Buglione *et al* 2013 | 0.1-6 | 6.1-11 | | 11.1-14 | 14.1-19 | 19.1-23 | >23 | |
| White *et al* 2013 | 0-6 | 6-11 | 11-15 | | 15-19 | 19-23 | >23 | |
| Jennings *et al* 2012* | 0.36-15 | | | | >15 | | | |
| Lythe *et al* 2011 | 0-6 | 6.1-11 | 11.1-14 | 14.1-19 | | 19.1 – 23 | >23 | |
| Macutkiewicz *et al* 2011 | 0-0.6 / 0.7-6 | 6.1-11 | 11.1-15 | | 15-19 | >19 | | |
| Gabbett 2010* | 0-3.6 | 3.6-10.8 | | 10.8-18 | 18-25.2 | >25 | | |
| | | | | | | | | |
| Australian Football | | | | | | | | |
| Coutts *et al* 2014 | | | | | | >14.4 | >19.8 | >24 |
| Kempton *et al* 2014 (b) | | | | | | >14.4 | >19.9 | >23 |
| Sullivan *et al* 2013 | | | | | | >14.4 | | |
| Aughey 2011 | | | | | | 16.92-36 | | |
| Aughey 2010* | 0.36-15 | | | | | 15-36 | | |
| Brewer et al 2010 | | | | | | >15 | >20 | |
| Wisbey et al 2009 | | | | | | >18 | | |

**Converted from m/s to km.h*$^{-1}$*. ** Relative bands set from maximum match velocity. HIR – High Intensity Running. MIR – Moderate Intensity Running.*

**Appendix 7:** Rugby union studies: a summary of study design and GPS analysis method.

| Reference | #Subjects (M/F) | Level (Age) | #Matches | Competition | Groups | Positions | ABS method/ IND method |
|---|---|---|---|---|---|---|---|
| Jones *et al* 2015 | 33 (M) | Elite (25±4) | 13 | European & Celtic League | Tight forwards | 1 – 5 | ABS |
| | | | | | Loose forwards | 6 - 8 | |
| | | | | | Half backs | 9 & 10 | |
| | | | | | Inside backs | 12 & 13 | |
| | | | | | Outside backs | 11, 14 &15 | |
| Reardon *et al* 2015 | 36 (M) | Elite (27.2±3.9) | 20 | RaboDirect Pro 12 | Prop | 1 & 3 | ABS vs. IND |
| | | | | | Hooker | 2 | |
| | | | | | 2nd Row | 4 & 5 | |
| | | | | | Flanker | 6 & 7 | |
| | | | | | Number 8 | 8 | |
| | | | | | Scrum-half | 9 | |
| | | | | | Out-half | 10 | |
| | | | | | Centre | 12 & 13 | |
| | | | | | Wing | 11 & 14 | |
| | | | | | Full-back | 15 | |
| Owen *et al* 2015 | 33 (M) | Elite (25.2±3.5) | 14 | Super Rugby (first half only) | Front row | 1 - 3 | ABS |
| | | | | | Second row | 4 & 5 | |
| | | | | | Back row | 6 – 8 | |
| | | | | | Scrumhalf | 9 | |
| | | | | | Inside backs | 10, 12 & 13 | |
| | | | | | Outside backs | 11, 14 & 15 | |
| Suarez-Aronnes *et al* 2014 | 8 (F) | Elite (26.8) | 1 | International (ESP) | Forwards | - | ABS |
| | | | | | Backs | - | |

*Appendix 7 continued*

| Reference | #Subjects (M/F) | Level (Age) | #Matches | Competition | Groups | Positions | ABS method/ IND method |
|---|---|---|---|---|---|---|---|
| Cahill *et al* 2013 | 120 (M) | Elite (27.5±4.2) | 44 | English Premiership | Front row<br>Second Row<br>Back Row<br>Scrum half<br>Inside backs<br>Outside backs | 1 - 3<br>4 & 5<br>6 - 8<br>9<br>10, 12 & 13<br>11, 14 & 15 | IND |
| McLellan *et al* 2013 | 5 (M) | Elite (22.7) | 11 | Super Rugby | Forwards<br>Backs | -<br>- | ABS |
| Reid *et al* 2013 | 8 (M) | Elite (27.9±4.8) | 1 | Magners League | Forwards<br>Backs | 1, 4 & 6<br>9, 10, 12, 14 & 15 | ABS |
| Coughlan *et al* 2011 | 2 (M) | Elite (30) | 1 | International | Forward<br>Back | -<br>- | ABS |
| Venter *et al* 2011 | 17 (M) | Semi Pro (18.5±0.5) | 5 | Super League A (RSA) | Front row<br>Back Row<br>Inside backs<br>Outside backs | 1, 3 4 &5<br>2, 6-8<br>9, 10, 12 & 13<br>11, 14 & 15 | IND |
| Cunniffe *et al* 2009 | 3 (M) | Elite (25±3.6) | 1 | Magners League (friendly) | Forwards<br>Backs | -<br>- | ABS |

**Appendix 8:** HIR demands for different positional groups in rugby union.

| Reference | Positional Group | | HI Distance (m) HIR | Sprint | Max Sprint | HI Efforts | HI %Total distance | Vmax (km.h$^{-1}$) | RHIE |
|---|---|---|---|---|---|---|---|---|---|
| Jones *et al* 2015 | Tight forwards | | 81 ±43 | 65 ± 46 | | | 3 | | 11 ± 8 |
| | Loose forwards | | 140 ± 63 | 166 ± 116 | | | 5.8 | | 13 ± 7 |
| | Half backs | | 381 ± 172 | 155 ± 71 | | | 6.3 | | 5 ± 4 |
| | Inside backs | | 586 ± 182 | 209 ± 56 | | | 9.9 | | 7 ± 7 |
| | Outside backs | | 566 ± 171 | 378 ±149 | | | 9 | | 6 ± 6 |
| Reardon *et al* 2015* | Forwards | ABS | 296 ± 172.02 | | | 18.81 ± 12.25 | 5.15 ± 3.18 | | |
| | | IND | 354 ± 99.22 | | | 24.74 ± 8.30 | 7.06 ± 2.48 | | |
| | Backs | ABS | 697 ± 196.11 | | | 41.55 ± 11.25 | 10.85 ± 2.82 | | |
| | | IND | 570.02 ± 171.14 | | | 35.54 ± 9.24 | 8.95 ± 2.76 | | |
| Suarez-Aronnes *et al* 2014 | Forwards | | | | | 1.8 ±1.7 | 1.4 | 22.0 ± 3.5 | |
| | Backs | | | | | 8.7 ± 2.9 | 5.4 | 24.4 ±0.8 | |
| Cahill *et al* 2013* | Front Row | | | 14 | 0 | | 0.3 | 24.5 | |
| | Second Row | | | 36 | 0 | | 0.6 | 25.0 | |
| | Back Row | | | 69 | 0 | | 1.2 | 27.8 | |
| | Scrum half | | | 24 | 0 | | 0.4 | 29.0 | |
| | Inside backs | | | 31 | 0 | | 0.5 | 29.9 | |
| | Outside backs | | | 66 | 0 | | 1 | 31.7 | |
| McLellan *et al* 2013 | Forwards | | 93 ± 71 | 38 ± 41 | | 2 ± 3 | 2.7 | 26.3 | |
| | Backs | | 309 ± 99 | 287 ±137 | | 13 ± 6 | 9.9 | 32 | |
| Reid *et al* 2013 | Forwards | | 330 | 32 | | | | 28.4 | |
| | Backs | | 539 | 68 | | | | 31.1 | |

*Appendix 8 continued*

| Reference | Positional Group | HI Distance (m) | | | HI Efforts | HI %Total distance | Vmax | RHIE |
|---|---|---|---|---|---|---|---|---|
| | | HIR | Sprint | Max Sprint | | | ($km.h^{-1}$) | |
| Coughlan *et al* 2011 | Forward | | | | 59 | 5.9 | 26.1 | |
| | Back | | | | 100 | 9.1 | 30.8 | |
| Cunniffe *et al* 2009 | Forwards | 342 | 313 | | 65 | | 26.3 | |
| | Backs | 292 | 524 | | 77 | | 28.7 | |
| | | *% Time in speed Zones (mins)* | | | | | | |
| Venter *et al* 2011 | Front Row | | 0.42 | 0.06 | | | | |
| | Back Row | | 0.42 | 0.05 | | | | |
| | Inside backs | | 0.66 | 0.06 | | | | |
| | Outside backs | | 1.05 | 0.06 | | | | |

*All values are expressed as means apart from Cahill et al where median values were given*

**Appendix 9:** High impact and total impacts per positional group in rugby union

| Reference | Positional Group | No. of High Intensity Impacts | | | Total Impacts |
|---|---|---|---|---|---|
| | | Zone 4 | Zone 5 | Zone 6 | |
| Owen *et al* 2015 | Front Row | 59 ± 43 | 44 ± 29 | 23 ± 10 | 499 |
| | Second row | 44 ±16 | 31 ±11 | 18 ±15 | 410 |
| | Back row | 54 ± 14 | 50 ± 13 | 34 ±11 | 432 |
| | Scrumhalf | 45 ± 10 | 32 ± 9 | 19 ± 5 | 426 |
| | Inside backs | 38 ± 20 | 32 ± 22 | 23 ±13 | 314 |
| | Outside backs | 48 ± 14 | 36 ± 15 | 23 ± 13 | 386 |
| Suarez-Aronnes | Forwards | 39.2 ± 31 | 39 ± 7.6 | 5.2 ± 3.5 | 628 |
| *et al* 2014 | Backs | 104 ± 91.3 | 51.6 ± 35.3 | 6.3 ± 0.6 | 828 |
| McLellan *et al* 2013 | Forwards | 127 ± 123 | 70 ± 43 | 18 ± 7 | 849 |
| | Backs | 91 ± 32 | 54 ± 42 | 11 ± 6 | 582 |
| Coughlan *et al* 2011 | Forward | 66 | 105 | 53 | 838 |
| | Back | 54 | 40 | 13 | 573 |
| Venter *et al* 2011 | Back Row | | | | 683.4 ± 295 |
| | Outside backs | | | | 474.33 ± 81.92 |
| Cunniffe *et al* 2009 | Forwards | 101 | 56 | 13 | 1274 |
| | Backs | 38 | 24 | 4 | 798 |

*Six zones are used to categorise rugby impacts measured by GPS in rugby union in G-forces (G). Zones 4, 5 & 6 are classifies as high intensity. Zone 4: 7-8 G. Zone 5: 8-9 G. Zone 6: >9 G.*