Ball in Play Match Simulation Protocol for Specific Rugby Demands.

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BSc (Honours)

Submitted in fulfilment of the requirements of the degree of:

MSc (Research) Sports Science

School of Life Sciences

College of Medical, Veterinary and Life Sciences

University of Glasgow

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Submitted: 2021

Accepted:

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Abstract

The birth of professionalism in rugby union (1995) brought an increased level of interest in performance enhancement through research, which has grown steadily over time. This interest has warranted research into the demands of the modern game. This analysis can be done through the combination of advanced technology, Global Positioning System (GPS) and time motion analysis (TMA). The aims of the present study are therefore two-fold. Firstly, to establish position specific ball-in-play (BIP) match demands, elicited through a combination of GPS-Performance metrics to create the hardest rugby outcome in a set period of time. This methodology is commonly referred to as the application of the Worst-Case Scenario (WCS). Secondly, to create a BIP match protocol termed Glasgow Rugby Intermittent (GRIT) simulation. The levels of performance decrement after completion of the GRIT can be established through changes in fitness tests, specifically Power Profile scores from pre to post simulation.

Analysis on a full season of matches (n= 21) from a professional rugby union club in the Guinness Pro 14 and European competition from the 2017-18 season took place. BIP times were split into four categories of specific durations which were used to design the GRIT simulation. The same methodology occurred for ball-out-of-play (BOP) durations and categories. The subsequent BIP and BOP periods were combined in a stochastic nature to replicate specific match play demands.
Power profile scores took place both prior (baseline) and post players completing the GRIT simulation to establish the performance decrement in terms of Whole Squad and Positional analysis. The tests used in the Power Profile scores were Countermovement Jump (CMJ), Banded-Bench Press and Speed Tests with variables to measure aspects of physiological performance appropriate for rugby union.

Through Kruskal Wallis post-hoc analysis, each position (n= 8) was subject to their own demands as no positions could be grouped together. The BIP categories, Short (15s, n=17), Moderate (20s, n=12), Long (40s, n=7) and Very Long (90s, n=3) totalled 16 mins. The BOP categories, Short (15s, n= 17), Moderate (40s, n= 12), Long (54s, n=7) and Very Long (85s, n=3) totalled 22 mins 48s. The total duration of the GRIT simulation was 38mins 48s.

GRIT simulation: The position Back 3 covered the greatest Total Distance (4001m) and Sprint Distance (310m) for the whole simulation. The position Hooker had the greatest number of collisions (n= 25) and the greatest Moderate Acceleration metres of the forwards unit (188m). Centres had the largest distance covered for High Speed Running metres (880m) with Back 3 having the largest distance covered in Hard Acceleration metres (68m).
Power Profiling: Whole Squad analysis illustrated a small increase in Effect Sizes (ES) for the speed tests 0-10m, 0m-20m and 10m-20m ($d = 0.25$, $d = 0.34$ and $d = 0.40$, respectively). Trivial ES were seen for all variables of the CMJ ($d < 0.20$), and a mix of trivial and moderate ES were evident for Banded-Bench Press variables.
The Backs unit group illustrated the largest increase compared to forwards ($d = 1.08$) for the 10-20m speed test. Forwards unit group illustrated larger decrements in Banded-Bench Press variables (concentric mean power (W), $d = -1.02$) and CMJ variables (mean velocity (m/s), $d = -0.45$) from pre to post GRIT simulation.

The GRIT simulation is based on real professional data across the 2017-18 season and provides a promising, efficacious and feasible match simulation protocol to the WCS using BIP demands. Future work could address the refinement of specific variables such as Moderate and Hard Acceleration metres alongside limiting HSR and increasing Sprint Distance to meet the specific demands.

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List of Abbreviations

95% CIs – 95 Percent Confidence Intervals

BIP – Ball in play

BOP – Ball out of play

BT Murrayfield – British Telecom Murrayfield

BURST – Bath University Rugby Shuttle Test

CMJ – Countermovement Jump

GPS – Global Positioning System

GRIT- Glasgow Rugby Intermittent simulation

IRB – International Rugby Board (now World Rugby)

KPIs – Key Performance Indicators

M/min - metres per minute

MSFT – Multi-Stage Fitness Test

MVC – Maximum Voluntary Contraction

m/s - metres per second

M/s/s - metres per second per second

PIS – participant information sheet

RLMSP-i – Rugby League Movement Simulation Protocol

S&C – Strength & Conditioning

SSEP – Soccer specific exercise protocol

SWC – Smallest Worthwhile Change

TMA – Time Motion Analysis

WCS – Worst Case Scenario

Acknowledgement

I would like to thank my primary supervisor, Victoria Penpraze, for her non-stop help and commitment throughout the entire project. Her attention to detail and passion for research and sports is second to none. Special attention is made for the personal help and support throughout the latter stage of the project. I would also like to thank my secondary supervisor, Dr. Ole Kemi, for his expert assistance and guidance whenever called upon.

A massive recognition is given to the Scottish Rugby Union, in particular the Glasgow Warriors. Without their vision and ambitions to grow as an organisation, this project would not have been made possible. In particular George Petrakos, for being instrumental throughout each stage of research and testing. I am extremely grateful to all management, coaching staff and players at Glasgow Warriors, for the opportunity to be integrated within their team and made to feel part of the family throughout the entire internship.

To the players at the club, I am greatly appreciative of your willingness to contribute and take part in the research study.

To my family, without their love and unwavering support from start to finish. Not only for the research, but my whole academic career.

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: Matthew James Hamilton

1. Systematic Literature Review

From March 1871 to the present date, rugby union has evolved drastically. There is great attraction and promotion of athleticism within the sport, ever greater kudos and reward available to those who are successful in this sport. Such reward and need for success have led to the development of methods to improve performance. This includes the proliferation of the application of data analytics and sports science in rugby union.

From the birth of rugby union, Scotland has played a major role in the sport's timeline-dating as far back in the amateur era, when Scotland played host to England for the very first international test match in March 1871 at Raeburn Place, Edinburgh, to professionalism today. Fast forward fifteen years from Scotland's victory and the governing body of rugby union was founded, with Scotland being one of four countries that founded the organisation, International Rugby Football Board (IRB). This illustrates the integral part that Scottish Rugby has played in the development of this great sport. Currently, the Scottish Rugby Union hosts two professional rugby union teams, Edinburgh Rugby and the Glasgow Warriors who play in the United Rugby Championship and Heineken Champions Cup competitions. The national team has now expanded and moved away from Raeburn Place, from a capacity of 400 spectators, to a larger stadium at BT Murrayfield which hosts a capacity of 67,144: the seventh largest stadium in international test rugby. This illustrates the massive strides in progression by both the IRB and the Scottish Rugby Union as a whole.

These strides are gaining lengths to which the present study's research into the specific match demands from professional rugby union can contribute. Coaches and sport scientists are ever present in their practice methods and research to gain an advantage over the opposition. The assessment of in-game demands provides coaches with an insight into what locomotor and collision demands are expected of their players. Such assessments are often done by measuring and understanding the demands on players when the ball is in play (Ball-In-Play (BIP) demands) through rolling averages or set time periods (Pollard et al., 2018). The present study therefore investigates the use of BIP periods and the feasibility of this in-game assessment to incorporate the Worst-Case Scenario (WCS) demands into training, i.e. eliciting the highest achieved playing demands. The present study also aims to identify the specific BIP demands, per position, according to specific BIP durations and subsequently replicating these demands to create a match-simulation protocol, using the Worst-Case Scenario (WCS). Power profiles were also recorded pre and post this simulation to determine the level of performance decrement, per position as a result of this match-simulation protocol.

1.1 Rationale

Ball-in-Play (BIP) refers to the duration (s) from when the referee blows the whistle to start play, to the next time the whistle sounds, signifying the end of that period of play. The period in between the two whistles is the time in which the ball is in play.

The stochastic nature of BIP durations in rugby union gives rise to the question of how to design and plan appropriate Strength and Conditioning (S&C) training sessions to meet such demands of the BIP methodology. This, in turn, provides an insight into how to gain optimal performance within this high intensity intermittent sport. Each individual playing position has unique physical and playing characteristics with respect to, conditioning stimulus, tactical prowess and physical attributions and so it is beneficial to understand the position-specific demands. By reviewing the current literature, the author aims to highlight and establish how the BIP demands differ not only between different playing groups (i.e. forwards and backs; unit analysis), but also between specific positions. The following systematic literature review will assist in the completion of this thesis as, to date, there is limited research in BIP demands per position of rugby union to assess the WCS.

1.1.1 Worst Case Scenario (WCS) definition and an overview of its role in the study

The WCS can be defined, in the sporting context, by the author, as "*the greatest physical output recorded, which amalgamates both locomotor and collision-based metrics, over a specific duration.*" It can be statistically defined as the highest outcome value above the 95th Percentile, for a given metric. Novak and colleagues (2021) defined WCS slightly differently as "the maximal physical load in a given time-window". The WCS, as a whole, in this study is therefore the combination of the highest value, above the 95th Percentile, across the 6 relevant GPS-Performance metrics (Total Distance (m), Moderate Acceleration metres, Hard Acceleration metres, High Speed Running (m), Very High Speed Running (m) and number of Contacts). The specific duration was calculated using BIP periods durations (s) to create BIP categories (Short, Moderate, Long and Very Long durations) described in more detail in section 3.1.3(i).

Positions were filtered into 8 playing groups; Prop, Hooker, Second Row, Back Row, Scrum Half, Stand Off, Centre and Back 3, to allow specificity of each position to have their own individual WCS. The WCS was then determined across each of the BIP categories; Short, Moderate, Long and Very Long, for each of the 8 playing positions. This illustrates the holistic approach used to measure the WCS using 6 identified GPS-Performance metrics as opposed to a single metric or duration of play, previously presented by Reardon et al., (2017). With the author's definition of the WCS, the author attempts to create a match-like stimulus, encompassing rugby union specific elements, to replicate the BIP match demands. This simulation was created by the author and given the title "**Glasgow Rugby Intermittent Simulation**" (GRIT).

This Systematic Literature review attempts to acknowledge the main aims. The primary aim, to identify and determine the specific WCS match demands of varying lengths of BIP periods. The WCS demands to be determined for each of the 8 playing positions and therefore to bridge the gap in the sports science of rugby union with other such simulations shown in the literature. The secondary aim endeavours to assess the feasibility, creation and design of a match-based simulation (GRIT) in an easy and replicable fashion. This match-based simulation will be used to determine if there is any performance decay in a battery of power profiling tests after the GRIT simulation.

GRIT is the integration of all the BIP categories (Short, Moderate, Long and Very Long in duration) including each position's specific WCS, with the aim to replicate the greatest physical demand experienced in match play. By using the GRIT simulation, the author can analyse the level of performance decay when testing each performing athlete in a battery of tests both pre and post the GRIT simulation.

1.2 Systematic Literature Review Methods

The protocol for conducting this literature review followed the systematic nature of the published document suggested by Preferred Items for Systematic Reviews and Meta-Analyses. This is also known as The PRISMA statement (Moher et al., 2009).

An eligibility criterion for inclusion in the review was that the sport was field-based and of similar nature to rugby union (Australian Football League, soccer and other codes of rugby) in addition to sports for which simulations have been designed. This widens the field of research as simply including field-based sports similar to rugby union would narrow the available options. Differences between the playing levels, such as elite, sub-elite and recreational were also included in this study.

The systematic review of the current literature was completed between the 11th January to 16th February 2020 through electronic databases PubMed, Web of knowledge, MEDLINE (Ovid) and Google Scholar. The search strategy used for the Boolean used a combination of key words and phrases which were inputted into the database.

Examples of the key words or phrases which were chosen to achieve an appropriate systematic review were as follows:

1. S1 TI rugby OR TI “rugby union” OR TI “rugby league”
2. S2 football OR soccer
3. S3 “Australian football league” OR “aussie rules” or AFL
4. S4 S1 OR S2 OR S3
5. S5 TI “match activity” OR TI “match demands” OR AB “match activity” OR AB “match” OR AB “game” OR “match play” OR “play”
6. S6 AB simulat* OR AB protocol
7. S7 AB fatigue OR fatigue* OR AB neuromuscular OR AB recovery
8. S8 S4 AND S5 AND S7

Note: * indicates truncation allowing for a larger search. Quotation marks were used to indicate the exact word or phrase.

Appropriate studies were identified by title and abstract, with the primary criteria being that they specifically had, or the derivatives included the demands from match play. Once the identified chosen search criteria were completed, the chosen papers were read in full to confirm that they followed the set inclusion criteria. During the process of reading the selected studies duplicated were removed.

Data regarding participant characteristics (number and playing level) and simulation requirements (velocity bands and duration) were noted, extracted and included in this review.

1.3 Results

The systematic review search resulted in identifying a total of 292 studies. Following the PRISMA process, this was reduced to 33 after the removal of duplicates and the screening process identified those that were not thought to be relevant for the study. The search process of this systematic review can be examined in the following flow diagram, Figure 1.

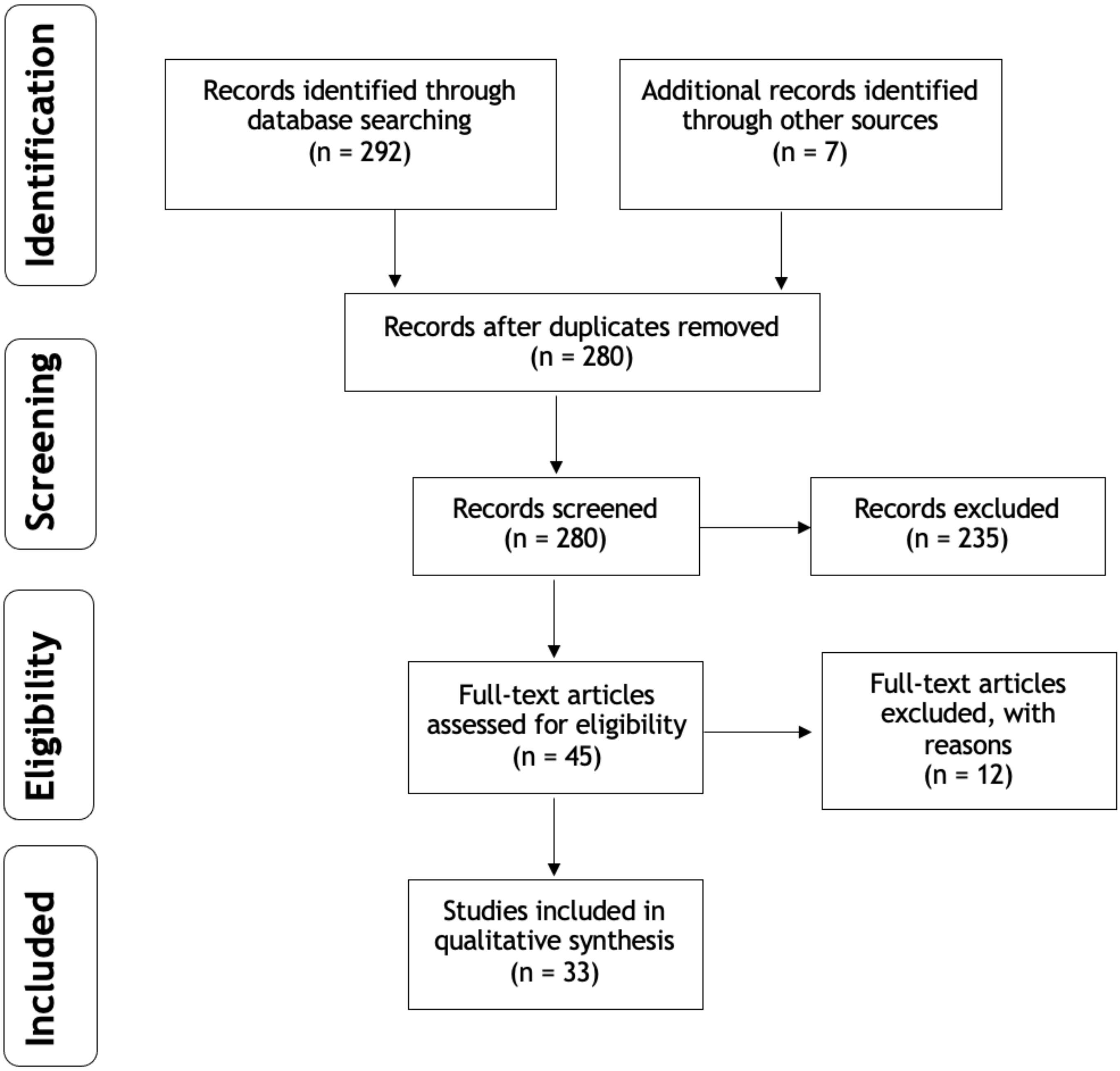

Figure 1. *Systematic Review identification Flow Chart*

1.4 Search Summary

A variety of sports were included in this search if they were classified as high intensity intermittent and field-based sports. This search string included the likes of Australian Football League, Hockey, Soccer and 3 codes of Rugby. After screening and completing the eligibility criteria, only 4 sports were chosen: rugby league, rugby sevens, rugby union and soccer.

There were 3 codes of Rugby included in the search and presented below in the systematic literature review, these were Rugby League, Rugby Sevens and Rugby Union. Papers after 1995 were included in this study that was the year rugby entered the professional era.

All papers discussed in this systematic literature review covered only/ derivatives of match data, simulation and protocol in accordance with the inclusion criterion. Training data were therefore excluded. A summary of the studies included in the systematic analysis can be found in Appendix 1.

1.5 Rugby Union Study Summary

A detailed summary of rugby union studies can be found in Appendix 1. The level of participation varied from recreational, university to elite and professional level. The studies of these groups of playing abilities were completed in different countries and provides a rounded representation of the standard of physical demands alongside tactical-technical ability. As far as the author is aware, there has been no study researching the WCS using BIP demands for each position in professional rugby union, and then develop this information to create a position specific match-like simulation.

Rugby union studies were carried out with participants playing in the Guinness Pro12 league, Super Rugby and International competitions (Schoeman and Schall, 2019). Positional groupings varied between studies, some using the generic unit analysis groups of Backs and Forwards, whilst others used more specific profiles for player groups. The more specific groups used between 4-5 positions to get a more refined analysis of the physical demands as opposed to a Backs and Forwards unit split. The Forwards unit was commonly broken down to i) Front Row, consisting of Props and Hooker, ii) Second Row comprising of two Locks, with the remaining category in the Forwards unit iii) Back Row, specifically two Flankers (Openside and Blindside) and the Number 8 position (Reardon et al., 2017). The Backs unit were generally split into Inside Backs, concerning Scrum Half, Stand Off and Centres. Outside backs were then made up of both wings and the full back.

Quarrie, Watkins, Anthony and Gill, (2013) grouped positions as units, simply as Backs and Forwards with little difference between the two. With these unit groups aggregated several positions into a further sub-group: front and loose forwards comprised of Prop, Hooker and Lock (numbered 1-5 on the playing shirts) with the loose forwards consisting of both flankers (open and blind side) and Number 8 position. Backs were subdivided into Inside Backs, Midfield and Outside Backs. These groups have the positions, Scrum half and Stand-off, Inside and Outside Centre and both Wings with the Fullback, respectively. The requirements for each of these positions differ, with respect to total distance covered and distance covered at varies speed zones, represented through absolute (Pollard et al., 2018) or relative terms (Reardon et al., 2017). Number 8 and Scrum Half positions covered most total distance during "active time in a game" for each unit, 3700m and 4500m respectively. Prop and hooker covered greatest distance at lower speeds of 2m/s and 4m/s when compared with flankers.

Active game time per match totalled 36 minutes and 21 seconds. Players were subsequentially stationary between 9% - 15% of active time. Forwards were stationary for approximately 5 minutes per match, which was between 90-120 seconds longer per match when compared with backs. Scrum Half spent 32% of active time at speeds >4m/s, more than any other positional group (Quarrie, Watkins, Anthony and Gill, 2013).

Differences between units and positions, in addition to playing ability, can be related to the constraints and laws of the game. This is where inside backs handle and pass the ball more frequently and the number of tackles/ collisions per game varies (Quarrie, Hopkins, Anthony and Gill, 2013).

As far as the researcher is concerned at the time of the review, there is a dearth of literature available and completed research for BIP demands, linking locomotor and collision analysis across every playing position to assess the WCS.

1.6 Ball-in-Play Match Demands Summary

A variety of different sports and codes were used to complete this search summary, through Boolean strings mentioned previously labelled points 1-8 in section 1.2 Systematic Literature Review Methods. This Boolean string uses key words and phrases to create the initial search, with subsequent Boolean's linking previous searches together, to create a refined search string analysis.

Specifically, rugby union analysis, not only included playing positions, but also referees when methodological analysis to research WCS when determining BIP demands. Key words and phrases were used to complete the systematic literature review, with a combination of field-based sports to meet the chosen inclusion criteria. These key words, phrases and search strings can be found in section 1.2 Systematic Literature Review Methods, listed from points 1-8.

A detailed summary of Ball-in-Play match demands can be found in Appendix 1. Brett et al., (2019) illustrated the maximum Ball-in-Play demands for sub-elite rugby union referees in domestic club rugby. With GPS metrics such as Total Distance and Distance per minute (m/min) used for the analysis, the WCS was defined as the single longest bout in each game. The longest BIP period was recorded using the criteria *"from the time the ball entered play until the ball went dead or until the play was stopped"*. Mean whole match durations were established as 86minutes 32seconds (1st half = 42minutes 57 seconds, 2nd half = 43minutes 34 seconds). Maximum BIP periods ranged from 91s – 313s with a mean of 172 ± 71s. This was detailed analysis for referees in a domestic league, but it did not consider the flow of the BIP periods throughout the 1st and 2nd half, to illustrate if there was a stochastic nature from match BIP periods. This would have been of great interest, especially with a lower standard of play in the domestic league, if there was a specific style and pattern of BIP periods throughout match play.

Mullen, Highton and Twist (2013) created their own simulation methodology, Rugby League Movement-Simulation Protocol of Interchanged Players (RLMSP-i). This was based on mean durations of play which they then repeated over 2x 23 minutes of play to simulate rugby league demands. This later got refined to include a stochastic nature of rugby events (Mullen, Twist and Highton, 2019). Players were also told to run alone to avoid competition bias and allow an audio stimulus to dictate movement patterns. However, a small cohort was used for the study with participants included only from the forwards unit group and not the whole team.

Pollard et al., (2018) established BIP demands of international male rugby union and noted that the ability to repeat high intensity efforts, such as with sprints and collisions, is linked to successful outcomes of international rugby. Pollard et al., (2018) stated that previous studies solely focused on whole match or per half demands. Using whole match averages may not give a true reflection of actual match play. Pollard's definition of WCS was established to be the highest recorded intensity within match play. This was recorded using the peak rolling average method, as confirmed by Cunningham et al., (2018). Pollard's study showed the longed BIP times to be on average between 152-161 seconds, with the mean BIP time between 50-55 seconds. The mean and max BIP times were analysed for three periods of 30-60 seconds, 61-90 seconds and 90 seconds and longer. The most frequent BIP time was recorded to be 30 seconds or longer (Pollard et al., 2018), that are pragmatic to technical, tactical and conditioning stimulus utilised in game training.

1.7 Simulation Studies Summary

A detailed summary of simulation studies can be found in Appendix 1. Several attempts have been made to investigate, and validate, a specific intermittent test for rugby union match play. Dobbin et al., (2018) used both the Prone YoYo-IR1 intermittent test and RLMSP-i, previously created by Highton et al (2013). Both being signalled by an audio stimulus; these tests evaluate the physical demands using speed zones established by GPS measurement. The YoYo-IR1 test uses a general demand comprising of a 40m shuttle run, with athletes tasked to complete as many shuttles as possible with 10s active recovery after each shuttle. Whereas the RLSMP-i is more refined to the BIP timing system. The RLMSP-i protocol was designed to replicate mean movement speeds, distances and playing times of interchanged players. The RLSMP-i outline consists of 2x 23 minutes bouts of activity with 20minutes passive recovery acting as half time. This methodology was used to re-create the mean duration and activity profile of elite rugby league players. The application of the YoYo-IR1 prior to the study allows the reader to infer if the two fitness modalities are comparable. It was concluded that theYoYo-IR1 performance was associated with aspects of the RLMSP-i performance, most notably, the maintenance of peak and repeated sprint speeds. This illustrates a decreased performance decrement in the RLMSP-i if participants achieved 'good' YoYo-IR1 performances. The RLMSP-i protocol was then further refined in 2019 in an attempt to mimic match play further, by randomising the sequence order of events, termed stochastic ordering, of rugby match demands. This evidence-based approach led to a more realistic pattern of events throughout the simulation when attempting to emulate the flow of match play.

Stone et al., (2014) used a simulation protocol to actively replicate soccer demands. A methodology consisting of 6 repetitions of 16minute sets active time with 3minute rest per set, was established with a 15minute half time rest to replicate half time. Sprint efforts were included in this methodology every 15 seconds of the penultimate and final set. Greig and Siegler (2009) used an intermittent treadmill protocol to replicate average activity profile of soccer match play, totalling to 90minutes with a passive 15-minute interval. Various barriers were evident due to the use of a treadmill which did not consider spontaneous and reactive movements in soccer, such as acceleration, deceleration and change of direction. Kunz et al., (2019) introduced both pre (baseline) and post-tests to intersect their 2x40 minute protocol. Preliminary tests involved athletic profiling measures such as Countermovement Jumps (CMJ), skipping, creatine kinase concentrations, Maximal voluntary contractions (MVC), and a variety of subjective questionnaires. U-shaped patterns were evident for pre- and post-athletic profiling tests (agility and 20m speed tests) which revealed pacing strategies were utilised by participants. This may be due to a learned effect from the familiarisation period, with the participants knowledge of what is required of them, in addition to knowing each stage throughout the test. Aldous et al., (2014) also noticed a learned effect after their x2 familiarisation period prior to the peak assessment period and x2 Intermittent Performance Test (iSPT). This had a negative effect as the participants could anticipate each stage of the test and therefore gauge the level of effort required to complete the Performance Test effectively. This takes away the match-play element of reactive ability to an unexpected stimuli and external behaviours. Other findings from this study were that the iSPT did not take into account multi-directional movements.

In comparison to actual match play, simulations may lead to different pacing strategies to maintain performance and prevent premature fatigue (Skorski and Abbiss, 2017). It was identified that although free running-soccer-specific exercise protocols (SSEP) may offer increased ecological validity when compared to treadmill-based protocols (Spencer et al., 2004), free-running SSEP's do not typically standardise the running speeds performed by the participants. This consequently makes it more difficult to mechanistically interpret the differences in the physical fatigue response.

1.8 Systematic Literature Review Findings

The inconsistency in methodological data collection for rugby demands, especially with the use of match play, averages or BIP, at a range of levels is evident in Appendix 1. The number of studies in rugby union which aim to gain an understanding for physical BIP demands and then use this to create a BIP specific ad-hoc simulation is lacking. Despite this, there has been extensive research in the creation of simulations in other sports but lacking in professional rugby union, especially whilst using the WCS as a template for the assessment of fatigability or fatigue-resilience of players.
When comparing to actual match play data, simulations lead to pacing strategies to i) enhance performance ii) prevent premature fatigue iii) in some, a lack of multidirectional movements. These tertiary outcomes are in fact limitations as this is not the natural motion of match play, or indeed sport. The answer to this could lie in the investigation using the WCS demands from BIP times to stress the athletes as an intervention and then complete pre- and post-power profiling tests to evaluate the degree of fatiguability or fatigue-resilience for each playing position. This will give a truer reflection of the physical demands of professional rugby union players.

The use and application of BIP shown by Reardon et al., (2017) and Pollard et al., (2018) displays an enhanced reflection of match demands. Therefore, this is a preferable method of determining match demands in rugby union compared to whole match play times. Reardon et al., (2017) accounted for the WCS at professional club level but the WCS was only assessed as "*the single longest period of ball-in-play*" between positional groups. The reader potentially could interpret this as, there is a positive linear correlation between BIP period length and WCS severity. Therefore, this needs clarification and further research is warranted. Other studies have reported on positional differences in physical game demands based on an average and singular bout basis. Here, the emphasis is based on locomotor and collision metrics such as Total Distance covered in addition to metres per minute and collisions per minute. This was validated through the use of video analysis and GPS micro-technology but the methodology and definition of WCS could be improved upon.

According to match data, simply stating that the WCS is solely reliant on the longest bout of BIP time does not take into account the stochastic nature of match play, which in turn limits other variables. Simply stating this, the reader infers that as BIP duration increases so does the intensity of match play, whereas this may not be the case. Metrics based on relative terms (accelerations per minute and metres per minute etc) may be affected by Reardon's definition of the WCS. This may not display an accurate picture of the true WCS of rugby union match play. In addition, this does not take into account the flow of BIP durations over the course of the game, is there a pattern of BIP durations over the course of a match? Highton, Mullen and Twist (2019) researched the stochastic pattern of BIP times as a result of this.

As well as discrepancies in the literature regarding data collection of match play vs BIP for game demands, there are also differences in the methodologies of simulations on which the game demands were based. It has now been made evident that the use and application of BIP times is better for accuracy of match-demand data to give a clearer understanding of the physical demands placed on professional rugby union players. As the WCS was applied to different standards of play (International and club level), with different definitions of the WCS, there are implications and a lack of transparency into what defines WCS. Can this be done to create a new definition, one that combines rugby related GPS-Performance (locomotor and collision based) into the single WCS definition? Is there only a single BIP period on which to assess the WCS as defined by Reardon et al., (2017)? Therefore, this highlights the need for this topic to be researched further.

The importance of establishing different BIP period categories (Short, Moderate, Long and Very Long) of different lengths (s), rather than a single duration, can further enhance the knowledge of match demands of each playing position being placed on professional rugby union players. This will refine what the WCS is for the different lengths of BIP periods across all playing positions. This will conclude if there are different lengths of BIP periods across match play and establish what the WCS is across each BIP category.

1.9 Aim

It is clear there is a lack of evidence in the literature i) to identify the WCS for each specific position ii) define the different BIP categories with respective durations and iii) using the stochastic method for the order of events in professional rugby union match play. Additionally, this knowledge can be used to assess the fatiguability of each playing position against the creation of the ad-hoc match-like simulation, GRIT. This creates an extensive-holistic approach of position specific analysis in professional rugby union. This review shows that further research is needed to specifically measure the WCS and then create a simulation to re-create these physical playing demands (incorporating locomotive and collision elements of rugby union).

It is hoped that the results of this study could shed a light onto the extensive depth of analysis needed to accurately measure the specific playing demands, of varying durations of BIP categories, of professional rugby union which can be used to create this simulation.

Therefore, the aims of this study were to:

i) Determine the specific worst-case scenario match demands for varying lengths of BIP periods in professional Scottish rugby union.

ii) Design and test a match-based simulation determined by aim (i) and to use this to assess the degree of fatiguability of the WCS for each position.

2. Introduction

The requirements of the modern game of rugby union comprises a vast range of fitness attributes. These include the ability to perform high volumes of aerobic work, with high number of accelerations, decelerations and quick changes of direction, for the intermittent style of gameplay, in this full contact sport. These demands require high levels of athleticism from players, illustrating the paramount importance for the multi-disciplinary aspects of athletic profiling linking to successful performance outcomes. This is exemplified by Smart et al., (2014) when correlations were shown between physical characteristics (Power Profiling) and game statistics (Key Performance Indicators). These athletic profiles included a variety of acceleration and speed tests (10m and 20m sprints), power derivatives of 1 RM's (Power Clean and Bench Press) and fatigue levels. These small correlations between speed variables and game behaviours verifies the importance of this attribute in which has been known by S&C/ Athletic Performance coaches. Other aspects of rugby performance include jumping and derivates of full contact collisions. These elements of athleticism bring an argument why rugby union is arguably one of the most exciting field sports in the world.

2.1 Evolution for the Role of Performance Analysis

Since becoming a professional sport in 1995, rugby union has evolved rapidly owing to intermittent law changes making it necessary to continuously re-evaluate game demands (McLellan, Lovell and Gass., 2011). The evolution of law changes coincides with the newly established role of Performance Analysis and use of microtechnology to understand and enhance performance. McGarry (2009) summarises the aim of Performance Analysis is to improve the understanding of behaviours to enhance future game performances. The evolution and use of technology to analyse rugby union performance has become the norm for the daily reporting of performance and workload from training sessions and games. As well as being used as a coaching tool for performance feedback, this technology has also illustrated secondary benefits for player selection, based on statistics/ metrics that are of most value to the team, known as Key Performance Indicators (KPI's). This has been previously used in baseball known as the “Moneyball” hypothesis, were three offensive KPI’s of batting average, slugging performance and on-base percentage are used to predict success based on correlations with winning when using linear regression analysis (Hakes and Sauer, 2006).

Developments in non-invasive forms of technology have been favourable when used to elicit specific KPI’s and to quantify performance. Time Motion Analysis (TMA) is one such technology that provides a general insight into the physiological demands through movement patterns of athletes. If the main objective of training is to improve on-field performance, the quantification of events occurring during the game for each team, position and player must be accounted. TMA typically consists of analysing game movements and time spent in each movement through the non-invasive methodology of video analysis systems. This procedure can be used as it is economical in terms of visual feedback and statistics, however, requires specialised equipment for maximal benefitted use, especially when teams are playing away from their home training and playing grounds. TMA can be beneficially used in rugby union to not only quantify the physiological outputs, but also to establish KPI’s by supporting the tactical and technical aspects of successful performance, utilised as a coaching tool (Hughes et al., 2012; Vaz, Hendricks and Kraak, 2019). While video TMA has provided a great deal of valuable information to research, its practical application can be compromised considering the time required for highly skilled coding of player movements and subjectivity in the categorisation of locomotive events (Coutts and Duffield., 2010).

Another form of non-invasive technology used for performance analysis are Global Positioning System (GPS) devices. GPS is a satellite-based navigational system which was first deployed by the military. This modality gained popularity as it utilises three-dimensional movement characteristics of individuals over time in air, aquatic, or land-based environments. There have been further developments from its first employment in the late 1990s (Schutz and Chambaz, 1997) which has made these GPS devices now accessible out with military work, portable and therefore wearable forms of technology. This is beneficial in a variety of settings, especially thriving in the sporting world for describing the spatial context of activity. It also benefits from its simplicity;

in that, it solely relies on the availability of satellites and can be used with ease in any open-air environments (when connection with satellites is available). In sport, this method is used to quantify performance by calculating the geographical placement, and therefore the measurement of player position, velocity and movement patterns of athletes. The development of GPS microtechnology that provides accurate, non-invasive movement analysis has significantly reduced the time to collect, analyse and report player movement data, compared to traditional methods such as time motion analysis (TMA). Roberts et al., (2006) explained the time-consuming nature of using traditional methods of video-based TMA, as it potentially takes up to 8 hours from trained analysts to analyse and report a single player's data from an eighty-minute game of rugby. The majority of time spent consumed for highly skilled coding. With this in mind, the length of time to analyse and provide feedback for fifteen players is inevitably costly on the timing of feedback to players and coaches. In conjunction, using GPS microtechnology has brought about greater understanding of performance by quantifying the specific locomotor demands.

GPS analysis can therefore quantify the performance demands as mentioned previously. One brand of GPS provider is by Catapult Sports (Catapult Sports, Canberra, Australia) which provides a vast number of performance metrics (200+) calculated within their S5 unit and can be exported from the unit into their software, "OpenField". From the software, these metrics can also be exported to Microsoft excel or other statistical packages for further analysis. Knowing which metrics to analyse from the available selection, provided by the GPS provider, can be a challenge for researchers and practitioners and needs to be taken into consideration alongside the KPI's.

The binary use of both forms of non-invasive technology, GPS and TMA, have been linked to the growth in professionalism within rugby union. GPS provides the data through spatial context; TMA through video, provides the data with visual context. The sport scientist role is therefore to provide the support, knowledge and understanding of both forms of non-invasive technology, illustrating the holistic approach to Performance Analysis.

2.2 Characteristics of Playing Positions

An abundance of research has gone into the sport of rugby union in recent times to characterise the physical demands being placed on these athletes. This work includes establishing *work: rest* ratios through BIP times, using GPS microtechnology to capture the locomotor demands and video analysis to illustrate tactical-technical aspects of performance, alongside collision aspects. Traditionally, these research studies have characterised the fitness attributes of the different positional units and laterally, characterised the actual performance demands of the different positions for this team sport.

Rugby union has been established as an intermittent sport which consists of repeated periods of repeated high intensity efforts, explosive and eccentric movements, such as accelerations and decelerations, alongside maximal sprint efforts and tackling. These high intensity actions are also interspersed with periods of repeated high intensity collisions, but also less extensive demands - walking and jogging (Darrall-Jones et al., 2016; McLellan et al., 2013; Roberts et al., 2008). Deutsch, Kearney and Rehrer ((2007) illustrated that forwards spent ~10mins/ match engaged in static, high-contact activities such as tackling, scrummaging, rucking and mauling. Physical contact has been shown to lead to reductions in total, low-intensity and high-intensity running vs non-contact games (Johnson and Gabbett., 2014).

Rugby union requires both teams to have a set of fifteen players to participate in a match, with the exception of sin bin periods and players being sent off (yellow and red cards respectively). The fifteen players can be broken down into units and specific positions based on their physical attributes and anthropometry. The units are divided into two groups, Forwards and Backs, with 8 and 7 players in these units respectively. The Forwards unit is comprised of Props, Hookers, Second Row, Flanker and Number 8, whereas the Backs unit is comprised of Scrum Half, Stand Off, Centre, Wing and Full Back. Each of the listed positions have specific requirements typically based around three elements i) speed, ii) size and iii) skill (Lindsay et al., 2015) with a priority of these three elements in accordance with each position. As a whole, speed variables are intrinsically important to rugby outcomes, as faster players will arrive at the defensive line quicker, potentially forcing the opposing player(s) into poor defensive decisions and positions. Sayers & Washington-King (2005) and Wheeler & Sayers (2009) identify this as an essential metric in dominating the contact and creating tackle-breaks.

Smart et al., 2014, illustrated that faster players are more likely to break the gain line, break tackles, evade opposing players and score tries more frequently. Typically, forwards are involved in more collision activity than backs (total impacts, tackles and rucks), while backs are involved in more ball carries and achieved higher numbers of total distance covered. There are marked differences between positional groups in the amount of distance covered at various acceleration and speed zones through match-play (Quarrie, Hopkins, Anthony and Gill et al., 2013).

One area of research that has received a large amount of attention is the profiling of the physical characteristics of players. The measurement of players' physical characteristics has therefore highlighted position specific attributes. This led to the discussion to research position specific physical and collision demands in professional rugby union in accordance with their BIP and *work: rest* ratio of match-play performance.

The old adage of positional units still stands tall with rugby union in that famous quote "*Forwards win matches and backs decide by how* much." The Forwards unit group are predominantly involved in set-piece plays such as scrums, lineouts and mauls. These key areas are mainly due to physical competition and contacts elements are made against the opposing team and more specifically position (i.e., front row of scrums). The Backs unit beating opposition in open play necessitates speed, acceleration and agility (Holway and Garavaglia, 2009). This is suited for a fast-flowing game where there are more opportunities for wider passes and longer sprints (Austin et al., 2011). Roberts et al., (2008) estimated that the typical total distance covered ranges from 5000m and 7000m per game. Research by Cunniffe et. Al., (2009) documented that the Backs unit; ran further than Forwards, completed high number of maximal sprints and spent more time standing and walking.

Each half of rugby lasts forty minutes in length (eighty minutes in total), with a half-time break of ten minutes, although the reported duration in which the ball is actually ‘in play’ has been recorded to be much shorter than this, specifically between 35 and 45 minutes in total (Lacome et al., 2014).

Points can be scored by a try, conversion, penalty and drop goal. A try is scored by placing the ball down across the try line, worthy of 5 points. A conversion takes place immediately after a try and 2 points are scored if the player successfully kicks the ball between the posts and over the crossbar. A penalty scores 3 points if the player successfully kicks the ball between the posts and over the crossbar after a penalty foul has been conceded. A drop goal rewards a team 3 points when a player kicks immediately after being dropped, which then travels between the posts and over the crossbar, in open gameplay.

2.3 Ball-in-Play Demands

A more refined specification of rugby union match play is to look at the demands for when the ball is in play instead of the demands across the eighty-minute duration, including when the ball is out of play (referee has stopped play and players may be stationary and not physically engaged in gameplay). The recognition of the specific ball-in-play time periods in a match can be illustrated across each half, into two sub-categories, traditionally known as *work: rest* ratio, but instead now termed Ball-in-Play (BIP) and Ball-out-of-Play (BOP) periods. The BIP and BOP times are calculated with the use of time-motion analysis (TMA) using specific video codes for the start and end times of the periods. Both codes for BIP and BOP can be used for further analysis and categorised into periods won and periods lost by the specified team alongside the duration of each period. One such research topic in rugby union is quantifying the physical demands being placed on the athletes in each BIP duration. This is of paramount importance to further our understanding the demands of professional rugby union match play and can be utilised with the use of GPS microtechnology and TMA.

Within the BIP periods, key facets of performance may be in the form of repeated bouts of high-intensity sprints and high frequency of contact collisions with players having to perform a high number of intensive efforts with varying work to rest ratios (Pollard et al., 2018). The discrete maximum BIP durations (Short= 10s, Moderate= 20s, Long= 40s and Very Long= 90s, analysed and recorded by the author in the current research study) offers a great insight into the specificity and development of match fitness. The ability to repeat these high intensity efforts, across the duration of the BIP periods could potentially be linked to success in rugby union and higher match running demands (Wass et al., 2019). The multi-directional nature of this high-intensity intermittent sport highlights the importance of using the GPS microtechnology to quantify such movement demands. Combining the use of both TMA and GPS units, the practitioner can document what the specific BIP times are and the associated GPS metrics within the BIP times. This form of performance analysis gives a holistic approach to sports science analysis and quantifies the match-play demands in professional rugby union.

Now that there has been established periods within a rugby union game, research studies could therefore investigate either whole match analysis or per-half demands of rugby matches. However, whole match averages may not reflect a true representation of the demands and match analysis is required to elicit these positional demands in rugby union match-play (Pollard et al., 2018). There has been some research previously into what constitutes the highest intensity of work performed by athletes in match play, i.e., the Worst-case scenario (WCS) that athletes have experienced (Reardon et al., 2017; Cunningham et al., 2018). Reardon et al., (2017) described the WCS to incorporate "*the single longest period of continuous ball-in-play time from a game*". Primarily, the fundamentals of this thinking seem to be the most logical, however, it may be that the most intense period of play may not necessarily occur in the longest duration BIP or fall into set categories (small set time periods can fluctuate in intensity due to external factors such as the opposition, competition and score in the game), but instead at non-specific periods of match play (10minutes pre- and post-half time and/ or the last 10-20minutes of a game) (Bishop and Barnes, 2013). This brings to light the effectiveness of using BIP time periods, instead of whole match durations, as using BIP time periods is the most consistent and accurate methodology to analysis and report the specific requirements in elite professional rugby union. Whole match durations underestimate the requirements (shown by m/min values) and is therefore less reliable. Therefore, using the BIP methodology enhances the specificity of physical metric parameters when calculating the WCS. Calculations from work done by professional rugby matches illustrate the longest BIP period (average duration 152-161s) (Reardon et al., 2017) and attacking plays in the opposition half (Cunniffe et al., 2009) (Cunningham et al., 2018). These previous studies illustrated higher running metres per minute (117m/min and 98.8 - 115.6m/min) through the BIP methodology than average whole match metres per minute. This analysis was the average of the longest play from each game, or specific action by a team, therefore neither reports typical demands within a match nor maximum physical demands on movements and collision activities (Pollard et al., 2018).

2.4 Rationale

The aims of the current study are to i) determine the specific worst-case scenario match demands for varying lengths of BIP periods in professional Scottish rugby union. ii) Design and test a match-based simulation determined by aim (i) and use this to assess the degree of fatiguability of the WCS for each position.

This was used by the research team and S&C performance staff at the professional rugby union team at the time the research was conducted. After the completion of the GRIT simulation (created by the researcher) and the determination of the tests for the Power Profiling, analysis of the measurement on performance decay can occur, using the pre scores as a baseline to determine each player's level of fatigue-resilience to the power tests as a result from the GRIT simulation. This analysis can be in the form of i) Whole Squad analysis and ii) Position/ Unit specific in the power profiling test to allow a comparison and measurement of performance decay to the physiological demands.

2.5 Study Aim

Therefore, the aim of this study is two-fold:

I) Determine the specific worst-case scenario match demands for varying lengths of BIP periods in professional Scottish rugby union.
II) Design and test a match-based simulation determined by aim (i) and to use this to assess the degree of fatiguability of the WCS for each position.

The aims of the current study are to collaborate all the locomotor and collision-based metrics and create a BIP rugby simulation using the WCS to illustrate performance decrement. This will be used by the S&C performance staff at the professional rugby club during the time of testing.

The data collected and analysed for study aim (i) will document the WCS of BIP demands from match play, using both locomotor and collision based metrics. This gives a great insight into position specific characteristics of demands placed in elite rugby union players, and used by the S&C performance staff at the professional rugby club at the time of testing. Once this has been achieved, using this information, a BIP match simulation can be created, study aim (ii). By analysing the pre and post results from the Power Profiling, with the created simulation sandwiched in between, illustrates the level of performance decay from match play. The larger the performance decrement in the battery of Power Profiling, from the first and second tests, illustrates a low fatigue resilience and therefore a high-performance decay. This research has not previously been investigated and therefore warranted.

3. Methodology

3.1 Creation of the Ball-in-Play simulation using 2017-18 season performance analysis Data (GPS & TMA video coding).

3.1.1 Experimental Procedure

This was completed as secondary analysis of previously collected match data from the 2017-2018 Pro14 and European Rugby Champions Cup season from a professional rugby union squad. These data included GPS and video analysis information for each match throughout that season. The dataset provided GPS output and video-coded events for each player, for every BIP period, for every match. This compromised 15790 rows of data in a customised excel format (.xlsx) of all the GPS and video analysis coded information. Additional descriptive information for each player and match included:
Date, Opposition, Home/ Away, Game Number, Competition, Player Name, Unit, Position, BIP Number, Attack/ Defence and *BIP* and *BOP duration*.

3.1.2 GPS and Video Analysis Variables

After the collation of the customised .xlsx export, the researcher was then able to establish the important relevant metrics. The chosen metrics were based on a triad of factors, (i) discussion with the coaching staff to establish their style of play, (ii) discussion with the S&C performance staff and research team to deem which metrics are considered high-performance and (iii) consideration of previous literature to allow the chosen metrics, and subsequent analysis to be comparable against other studies. The identified and extracted metrics of interest, illustrated in Table 1, were then used from each data file to be reflected in the GRIT simulation by the researchers and S&C performance staff. After the collation of data across the season 2017-18, statistical analysis was performed to illustrate the playing demands and therefore identify the WCS from a selection of BIP categories, from the 2017-18 season. Preliminary analyses were conducted to check for normality using the Anderson-Darling method. This was used to check the data distribution with the $P < 0.05$ indicative for normality.

Work by Reardon et al., (2017), illustrated the WCS to be "*the single longest period of continuous ball-in-play time from a game*". This definition of the WCS provided an insight into the activity profile for "*positional running and collision demands*" of prolonged periods of match play. The current research's definition of WCS differs, as it was calculated based on the WCS of *each of the BIP categories* as opposed to the single longest bout of a combined activity. WCS is defined in this research as "*the highest summed combination of the 6-performance metrics, above the 95th Percentile, across each BIP category*". This definition was established and utilised by the professional club prior to and for the entire duration of this research project. This definition of WCS is well established throughout the performance department (S&C) and the analysis department (video analysts). This definition and method of analysis was fed back to the coaching staff and players. These 6-performance metrics are defined in Table 1. To collect the WCS of match play demands, a filtering process was completed for each position and each respective BIP category. Within specific BIP categories, subsequent analysis determined the highest bout of combined previously determined GPS and Video Coded metrics. This will be described in more detail in section '3.1.5 Creating the Worst-Case Scenario.' This gives light to the systematic and evidence-based approach to identify the WCS through match BIP demands. It is well established that rugby union is characterised by repeated high-intensity collisions and running efforts interspersed with sporadic lengths of rest (Austin, Gabbett and Jenkins, 2011). This level of knowledge from game demands, therefore, needs to be replicated for training threshold demands. By researching the WCS demands of match play, taken from a combination of GPS-Performance metrics, this can help the reader create a WCS situation in which training demands can be replicated. However, no two BIP periods are of the same duration, which makes it difficult to determine the set threshold durations. Therefore, the researchers determined which metrics to analyse within the WCS; specific BIP and BOP time durations, for each period. Profiling these specific demands for each position allows a systematic and methodological way of screening match-play demands which can be used to quantify match-like training. Previous research used to replicate match-play match demands have documented their specific GPS and performance metrics. Both soccer and rugby league (Rampini et al., 2007b and Sykes et al., 2013 respectively) differentiated locomotor demands as broadly as low intensity (< 4.0m/s), high (4.0-5.4m/s) and very high intensity running (≥5.5m/s). Work done by Harper et al., (2019) illustrated the importance of accelerations in competitive match play, which also warrants including acceleration metres and intensity into the simulation protocol. Contact elements were also included in the rugby league simulation (Sykes et al., 2013), where a contact was defined as "the point of initial contact to the point at which the defender ceased contact with the attacker for defenders". However, this simulation was replicated for the code of rugby league, therefore the contact definition needed to be adjusted to match the contact element of this study's code of interest, rugby union. The metrics that were previously used in the literature were deemed appropriate from the vast variety of metrics available from their respective GPS tracking provider. In addition to these GPS-derived metrics, a video-coding determined metric, *total contacts*, was also included for the simulation. This is the summation of the number of all occurrences of contacts coded by the performance analysis team at the professional rugby club. These extracted codes were exported to Excel for subsequent analysis. Contacts codes included 'hit ruck', 'hit scrum', 'hit maul', 'hit defensive contact' and 'completed tackles'. Each of these codes was defined as contacts by the defence coach at the club at the time of research.

The performance metrics deemed viable for this research was established in collaboration between all the researchers, S&C coaches and performance analysis team at the professional rugby club. The metrics used for this study were collated from evidence-based research within the literature alongside discussions with all the named researchers for this study. These specific metrics were extracted from the GPS units (Catapult, OptimEye S5, Melbourne, Australia), using retrospective GPS software (Catapult, OpenField) and video analysis software (SportsCode) and used to determine this specific BIP simulation protocol. The finalised chosen metrics identified were *Total Distance*, *Moderate Acceleration metres (m > 2m/s/s)*, *Hard Acceleration metres (m > 3m/s/s)*, *High Speed Running (m > 18km/h)* and *Very High Speed Running (m > 28km/h)*. The locomotor metrics were all established in absolute velocity bands and left as the default settings from Catapult's OpenField software. These GPS derived metrics were reported daily by the S&C coaches to the players and coaching staff, for performance outcomes during training sessions and games. All performance metrics used for the study can be found in Table 1.

Table 1. *A collaboration of both GPS and Video coded derived metrics used for the BIP simulation.*

Metric	Technology Used	Definition	Unit
Total Distance	GPS	Total distance covered in distance band 1 – 8.	Metres (m)
Total Contact	Video	Total number of all occurrences of contacts.	Count (n)
Moderate Acceleration	GPS	Total distance covered in acceleration band 6 – 8.	Metres (m > 2 m/s/s)
Hard Acceleration	GPS	Total distance covered in acceleration band 7 – 8.	Metres (m > 3 m/s/s)
High Speed Running	GPS	Total distance covered in velocity band 4 – 8.	Metres (m > 18km/ h)
Sprint Distance	GPS	Total distance covered in velocity band 5-8.	Metres (m > 28km/ h)

Global Positioning Systems (GPS), Ball-in-Play (BIP)

3.1.3 Identifying Ball-in-Play and Ball-out-Play periods

3.1.3(i) Establishing Ball-in-Play duration

With the use of a customised '.xlsx' file export for all the GPS-Performance metrics, both BIP and BOP period durations could therefore be established. This was performed using the statistical software in Excel (Microsoft Office 365), specifically using a Histogram (Appendix 2), from the 15790 rows of raw data. To replicate the match play nature for this BIP simulation, stochastic ordering of BIP periods was used. This included the random ordering of the BIP periods to simulate the style of play of professional rugby match-play, first derived by Mullen et al., (2019). Each BIP period has its own respective duration and level of intensity, shown by the number of contacts and specific distance covered of High Speed Running, Sprint Distance and acceleration metres. Each of the specific speed/ acceleration-based metrics must be achieved within the specific BIP category duration.

With this knowledge, statistical analysis was performed to determine different BIP periods, now termed BIP categories. Appendix 2 illustrates a histogram of all BIP period length (s) against the frequency of occurrence. Using this data, the BIP categories were identified using specific quartiles on the histogram, with each quartile equating to a specific category and respective duration. These were translated as Short, Moderate, Long and Very Long BIP categories, respectively. The BIP categories can be identified below, in Table 2.

Table 2. *The categorisation of BIP durations and their associated duration (s).*

BIP Category	Duration (s)
Short	≤10
Moderate	>10 ≤20
Long	>20 ≤40
Very Long	>40 ≤90

Ball-in-Play (BIP)

3.1.3(ii) Establishing Ball-out-of-Play duration

The same protocol used to identify and categorise the BIP periods was also used for the categorisation of the BOP periods. This kept in line with the systematic approach for analysis. With the use of Excel (Microsoft Office 365) and Minitab (version 18), specifically using a Histogram (Appendix 2) of the entire 15790 rows of BOP times were used for statistical analysis to identify the 4 quartiles for BOP categories. These points were then translated into the BOP categories; Short, Moderate, Long and Very Long. These category names were kept consistent with the BIP categories name throughout the study for ease of translation when creating the BIP simulation template. Determining the BOP categories allowed the researcher to establish the rest times for the simulation. Each BOP period would follow a BIP period in the simulation thus creating a *work: rest* pattern as would be experienced in a match (I.e., some recovery time after the referee blows the whistle to stop play. The BOP categories were also given the structure of stochastic ordering for throughout the simulation thus leading to randomised ordering of BIP and BOP periods throughout the entirety of the simulation. This was similar to the intermittent style of rugby union match-play.

3.1.4 Positional Grouping

The researcher wanted to identify and establish positional groupings for this simulation from the raw '.xlsx' file. Traditional groupings have previously been documented to illustrate the playing demands of rugby union. These were grouped simply into Forwards and Backs with further varying subset groups. Work by McQuarrie et al., (2013) documented the set of positions into two groups, Forwards and Backs with five forwards subgroups (*Props*, *Hookers*, *Second Row*, *Flankers* and *Number 8)* and 5 backs subgroups (*Scrum-Half*, *Fly-half*, *Mid-field backs*, *Wings* and *Fullbacks*). Reardon et al., (2017) organised positional groups into *Tight 5* and *Back Row* (Forwards) along with *Inside backs* and *Outside backs* (Backs). The positional subgroups for this study were identified to reflect those already established and those groups already used in the literature. These groups were categorised into Forwards and Backs, in line with traditional research, however with *Props*, *Hookers*, *Second Row* and *Back Row* being sub-grouped as Forwards. *Scrum-Half, Stand Off, Centre* and *Back 3* were further sub-grouped as Backs.

3.1.5 Creating the Worst-Case Scenario

Creating these positional groupings provided the researcher with the opportunity to analyse and identify the WCS for every playing position across the 4 BIP categories, constructed off evidence-based match-play demands. The WCS for each BIP category was then identified for the 6 GPS-Performance derived metrics, per position.

After the creation of both BIP and BOP categories and their respective match play demands from the 6 determined GPS-Performance metrics, the creation of the WCS for each BIP category was completed for every playing position.

Using Excel, (Microsoft Office, 365) each playing position had its own worksheet analysis tab in which 4 statistical measures were performed for each GPS-Performance metric for the 4 BIP categories.

The following stages of analysis occurred to calculate the WCS:

- Each position had its own individual analysis tab which contained the 6 metrics, for the 4 BIP categories, i.e., every position had 4 pivot tables (Short, Moderate, Long or Very Long BIP category) each containing 6 columns of the GPS-Performance metrics. This totalled 24 pivot tables, across the 8 playing positions, which equated to a total of 192 pivot tables.
- Within each pivot table, 4 variables were calculated; the Maximum value, 95th, 90th and 80th percentiles based on every BIP period were calculated, this was performed within Excel (Microsoft Office, 365).
- Creating a 'master' table allowed representation of each of the 4 variables, for every position, across the 4 BIP categories. These 4 variables were then categorised into being termed "Low", "Moderate", "High" and "Very High" illustrated in Table 3.

Table 3. *The categorisation of the GPS-Performance Derived Variables against the raw data.*

	GPS-Performance Derived Variable			
Raw Data	Low	Moderate	High	Very High
X	X < 80th PC	80th PC ≤ X < 90th PC	90th PC ≤ X < 95th PC	X ≥ 95th PC

Global Positioning Systems (GPS), Percentile (PC)

The collation of the player's match play demands into their respective positions using the combined GPS-Performance metrics allowed the researcher to filter and identify the WCS for each position across the four BIP categories, Table 3. This created an evidence-based template of game-specific demands, for every position, to be categorised against the 4 BIP categories.

With Table 3 acting as the reference for the now created 'master' table of Maximum values, 95th, 90th and 80th Percentile, this was used to cross-reference every raw data entry for the BIP periods against the now categorised "Low – Very High" spectrum, in which the WCS was based off. A ranked system was utilised to score each of the 4 levels shown in Table 3. This would illustrate the level of severity, based on the "Low – Very High" spectrum, of each BIP period. A final column was added to the 'master' table, which illustrated a total count of categories termed “Very High.” The BIP period which had the highest count of “Very High” across the 6 GPS-Performance metrics, was deemed to be the WCS. i.e., If a BIP period scored every metric as “Very High” that BIP period would have a total of 6 “Very High” categories, which was deemed the WCS. This method of analysis was performed for every position, across the 4 BIP categories. An example is shown in Table 4.

Table 4. *Example calculation of the WCS based on the accumulated number of the "Very High" category.*

BIP Period Number	Contact	Total Distance	Moderate Acceleration	Hard Acceleration	High Speed Running	Sprint Distance	Count of "Very High"
1	Very High	Very High	Very High	Very High	Very High	Very High	**6**

Worst Case Scenario (WCS), Ball-in-Play (BIP)

The methodology used in Table 4 was used for every positional group, across the 4 BIP categories using the 6 GPS-Performance derived metrics.

3.1.6 Stochastic ordering

Once the WCS of each BIP category was completed, the BIP and BOP periods were ordered. Using the combination of both the raw dataset and the statistical analysis methods previously used in the section 3.1.3, the BIP and BOP periods were summed to illustrate the total duration of the simulation. A total time of 16 minutes 0 seconds, and 22 minutes 48 seconds, was calculated for both the BIP and BOP times respectively, for the whole simulation. With this knowledge, the structure and order of the simulation was identified.

3.1.6(i) Ball-in-Play and Ball-out-of-Play ordering for the simulation

With the use of Excel (Microsoft Office, 365) Pearson's correlation coefficient was used to illustrate and identify a potential the relationship between the BIP categories with the duration of match play i.e., as the match time progresses, was there an identifiable relationship with BIP categories? This was used to determine if the BIP duration increased as time-in-match increased or if there was a pivotal time in matches in which BIP time decreased? This allowed the researcher to identify if there was a sequential order of BIP categories (Short, Moderate, Long or Very Long) as the match minutes increase, i.e., is it more likely to have shorter BIP periods at end of a match when players are fatigued? This allowed the order of the BIP categories throughout the simulation to be determined. This brings to light the systematic evidence-based protocol for BIP ordering for this simulation. As there was a null correlation co-efficient (Appendix 3), it was determined random ordering of the BIP categories would be most appropriate for the simulation, specifically stochastic in nature. To create this stochastic order, a random order generator was used within Excel (Microsoft Office, 365). The same protocol was also carried out for the BOP categories. The same correlational analysis was completed for BOP and game time to illustrate if there was a sequential order of BOP categories i.e., is it more likely to have an increased BOP period at the end of the game as the match progresses? Again, with the use of Pearson's correlation, a null correlation coefficient was evident (Appendix 3). It was concluded that a random stochastic order for the BOP periods throughout the simulation would be most appropriate. To create this stochastic order of the BOP periods, a random order generator was used with formulas performed in Excel (Microsoft Office, 365). This systematic evidence-based protocol allowed for a stochastic nature of both BIP and BOP categories throughout the simulation to accurately reflect the gameplay demands from the 2017-18 Pro14 professional rugby union season. After the completion of the analysis for BIP and BOP periods in conjunction with the WCS and the stochastic ordering, this gave rise to the creation of the Glasgow Rugby Intermittent (GRIT) simulation.

3.2 The Glasgow Rugby Intermittent (GRIT) Simulation

3.2.1 Recruitment to GRIT simulation

Ethical approval was obtained from the College of Medical, Veterinary and Life Sciences (MVLS) Research Ethics Committee at the University of Glasgow. Potential participants from a professional rugby union club were invited to take part and received information about the study verbally and from a Participant Information Sheet (PIS). A verbal presentation and PIS outlined the background information regarding the study, the action and involvement of the athletes and the use of their data throughout the study. There were opportunities for potential participants to ask questions throughout the entire study period and those who wished to take part in the research gave written informed consent. The whole squad for the professional rugby club were invited to take part in the Glasgow Rugby Intermittent (GRIT) simulation.

3.2.1(i) Participants

Sixteen players agreed to participate in the study during the 2018-19 season and met the inclusion criteria. Their mean ± SD age (22 years ± 3), Body Mass (102.56kg ± 10.70) and Height (185cm ± 5.90) were recorded. Every player who willingly gave consent to participate in this study had to go through a screening protocol. This screening protocol had the following inclusion and exclusion criteria;

Inclusion Criteria

- Classed as fit to train and play by the Medical and Performance staff of professional rugby club.
- Currently available to play.

Exclusion Criteria

- Classed as unfit to train and play by the Medical and Performance staff.
- Players unavailable due to international duty leading up to 2019 Rugby World Cup.

The willing participants that completed the whole study participated in the following battery of tests, shown in Table 5.

3.2.2 Experimental Procedure

3.2.2(i) Measurements

Body mass (kg) was measured to the nearest 0.1kg, for each player using SECA scales prior to the start of testing. After these measurements were taken and recorded, the researcher provided a verbal and visual presentation of both the power profiling and GRIT simulation protocols. This presentation included how each test was performed. The players were also given key instructions on the protocols at each stage of the power profiling and the structure of the GRIT simulation. Each participating player had a familiarisation period of 2 weeks prior to the testing day.

The participants were required to complete their standardised full body warm-up prior to the GRIT Simulation, comprising of warm-up activities, similar to that of match day. Such activities included accelerations, high speed running, sprints, contacts and banded activation exercises for strength and power. The participants were accustomed to this specific warm-up activity as it was the same protocol performed for daily training sessions and weekly games. The warm-up protocol was also led by the researcher and S&C coach to ensure adequate activity for injury prevention. Once completed, the testing began.

3.2.2(ii) Power Profiling

Power profiles were measured prior to, and after, completion of the GRIT simulation. Power profile measures included lower body power and upper body power followed by speed testing. Each exercise performed in the power profiling has been previously carried out by all players on their traditional testing days and therefore the athletes were accustomed to each exercise and respective protocol(s). Athletes were asked to group into their respective positional unit (Backs or Forwards) and playing position when available. Maximum verbal encouragement and motivation were given to the athletes throughout each protocol. The power profile measures, and the performance outcomes of interest, are listed in Table 5 below. All equipment used was provided by the professional rugby union team for the duration of the study.

Table 5. *List of the Power Profile tests, and the measurement outcome associated with each measurement.*

Power Profile	Outcome Measurement
Lower Body Power	Countermovement Jump (GymAware)
Upper Body	Banded-Bench Press (GymAware)
Full Body - Speed	0m-10m, 0m-20m, 10m-20m (Witty Speed Gates)

3.2.2(iii) Lower Body Power

The first stage of power profiling was the lower body power test. This was conducted using a wooden dowel and GymAware PowerTool (Kinetic Performance Technology, Canberra, Australia) equipment for the performance outcome. No additional weight was attached to the wooden dowel as the researcher wanted to elicit maximum voluntary contraction speed. As described by GymAware, the apparatus was attached magnetically to the floor, with the tether attached perpendicularly beneath the wooden dowel. The starting position for this exercise would be the traditional testing protocol of a CMJ, however with the hands holding onto the dowel as opposed to being placed on the hips. This allowed for maximal accuracy of data collection from the starting position, as this position takes into account the dip time and jump height for each repetition. The athlete was given clear instructions for each jump on how to complete the protocol repetition and subsequently returning to the starting position. The next repetition could only commence when instructed so by the researcher and/or S&C coach. The CMJ exercise was completed for 1 set of 3 repetitions. The performance outcome was measured to record the maximum jump height (cm), mean and peak velocity (m/s), concentric mean and peak power (W).

3.2.2(iv) Upper Body Power

The second stage of power profiling was the upper body power test, which was conducted using Eleiko Strength equipment (Chicago, USA), resistance bands (medium resistance) and the GymAware PowerTool. The forwards and backs positional units were instructed to perform the bench press exercise with weights attached, 70kg and 60kg respectively, with the *medium strength* band attached around the barbell and the bench to provide resistance. The athletes were given clear verbal and visual instructions on how to complete this exercise. The athletes were instructed to perform the bench press exercise for a total of 3 repetitions, for a total of 3 sets. This exercise was performed in a rolling sequence after each completed set per athlete, to allow for adequate recovery between each set. The performance outcome was measured to record the mean and peak velocity (m/s) in addition to concentric mean and peak power (W).

3.2.2(v) Speed

The last stage of the power profiling was speed tests, deemed a whole-body movement. Speed was tested by the completion of a 20m sprint, where time to complete 0-10m,10m-20m and 0m-20m was recorded (seconds). This was carried out on indoor athletics track with the use of speed gates (Witty Timing System, Perform Better, UK). Speed gates were set at 0m, 10m and 20m. Participants were instructed to start 0.5m behind the 0m speed gate. Each participant completed three 20m sprints, in rotational order to ensure 2mins recovery between each sprint. This would give an adequate duration between each sprint so the athlete could perform this test with maximum effort. The performance outcomes were measured to record time taken to complete the 20m sprint (s).

3.2.3 Glasgow Rugby Intermittent (GRIT) Simulation Protocol

Upon completion of the power profile testing, players were instructed to attend the outdoor grass pitch area to participate in the simulation. Players were asked to bring all the required kit as if this was game day, e.g., a Pro14 league or European Cup game. Each athlete who took part in the simulation was assigned a specific GPS device (Catapult, OptimEye System, S5, Australia) which they had been assigned for the season, to negate any inter-unit variability. The GPS devices were turned on outside, for at least 10mins, before the simulation to allow for connection to the maximal number of satellites available, in addition to, high accuracy of the satellite signal i.e., low Horizontal Dilution of Precision. The GPS devices were then placed in a bespoke harnessed GPS vest, with the device being fitted in the vest so sitting in the region of the upper back in between shoulder blades. After placement of the GPS devices in the vests and the players' arrival at the grass pitch, the verbal instructions were repeated whilst the athletes were getting ready with their final preparations for the GRIT simulation. This allowed any player(s) to ask final questions regarding the protocol and the task ahead. A schematic diagram for the order of play and GRIT simulation are displayed in the Figure 2.

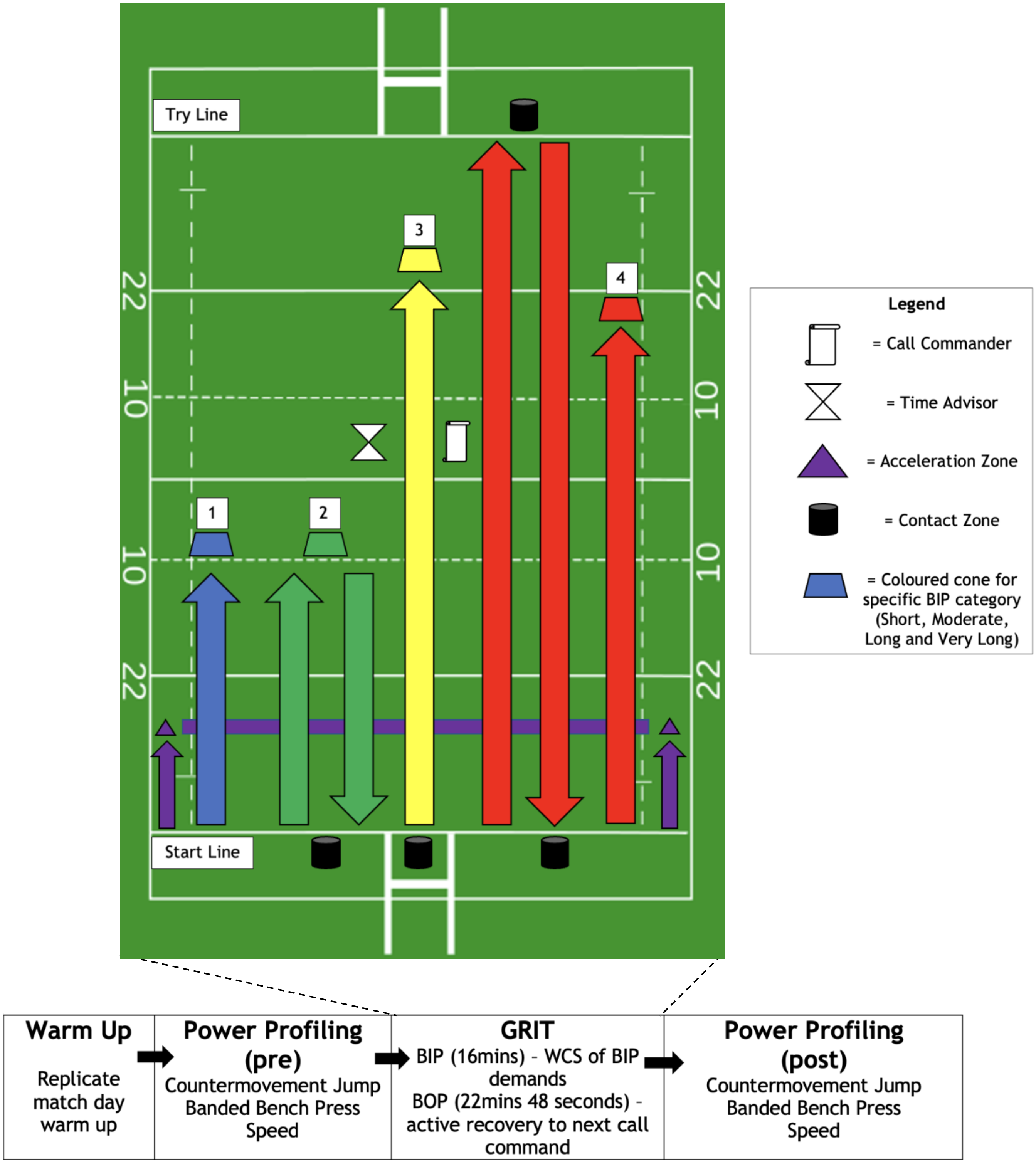

Figure 2. *Schematic diagram illustrating the order of play for the GRIT simulation. 1 = Short (Blue), 2 = Moderate (Green), 3 = Long (Yellow), 4 = Very Long (Red) durations. Acceleration zone = start line to purple line.*

Participants completed the simulation protocol, GRIT, which was designed to replicate the WCS of BIP match play demands experienced, within their specific position in rugby union. The simulation aims participants to perform the WCS for distance, speed and contact collisions completed, elicited from the 6 GPS-Performance metrics. These WCS demands for each position can be found in Table 13. These demands are aimed to be completed within the calculated BIP time of 16 minutes. The 22 minutes and 38 seconds of BOP time is allocated for active recovery and time to move to the next stage of the simulation. Specific ordering of the GRIT simulation can be found in Appendix 12.

The participants were required to complete a standardised full body warm-up prior to the GRIT Simulation, comprising of warm-up activities, similar to that of match day. The participants were accustomed to this specific warm-up activity as it was the same protocol performed for daily training sessions and weekly games. Participants then performed the GRIT simulation on a grass pitch at the training ground of this professional rugby team. The participants ran alongside each other and in a 'shuttle run' fashion, commencing the simulation at designated start line. Coloured cones were used in conjunction with the start line and try line to act as points of reference for the subsequent start and end destinations. The coloured cones reflects the BIP category to be performed (Short = Blue, Moderate = Green, Long = Yellow and Very Long = Red) illustrated in Figure 2. These movement and collision characteristics, colour coded by the cones, were matched with the randomised ordering, meaning that there was limited repeated events of BIP categories. This methodology was agreed by all members of the research team as it is the most feasible to complete with many participants completing this at any one time. The shuttle run fashion means that every participant has an allocated start and end destination, and the activity to be completed within the required time frame for the BIP category. This can be found in more detail in Appendix 12. The 2 researchers performed a very important role to dictate the movement and collision demands for each BIP category throughout the simulation. To ensure the simulation was performed well and efficiently, the 2 researchers aligned the BIP categories with rugby union specific terms. This allowed for greater understanding and compliance between the participants and what was expected of them for each BIP category. This was detailed to the participants prior to and during the GRIT simulation.

The researchers carried a script which detailed each stage of the simulation to give specific orders to the participants (Appendix 12). Throughout the simulation, the 2 researchers had different roles and responsibilities to allow for a smooth flowing protocol. The first researcher's role was the *'call commander.'* This role was to instruct all participants of the expected game demands for each BIP category. This included the number of contacts, specific locomotor demands for each category, alongside the subsequent time duration of each BIP and BOP category, illustrated in Table 6. The second researcher was the '*time advisor*'. This role was in command of the timings for both BIP and BOP durations, where they would call when participants should start the next BIP or BOP period, how many seconds they have left to complete that BIP or BOP period.

Table 6. *An example of the audio call commands and instructions announced by the researchers to the participants for a given BIP and BOP category.*

BIP/ BOP	**Category**	**Description**	**Researcher's Role**		**Next activity**	**Duration (s)**
			Call Commander	Time Advisor		
BIP	Short	Game demands within that BIP period	Concise instructions for BIP period	Time duration until the end of the BIP period.	Rest for the duration of the BOP period	10
BOP	Short	Active Recovery	Prepare for the next BIP, if needed to, walk to the next colored cone.		Prepare for the next BIP period	15

Ball-in-Play (BIP), Ball-out-of-Play (BOP)

After completion of the GRIT simulation, participants were instructed to return to the gym and indoor track area to complete the post-simulation power profile testing. The same protocols were used in accordance with sections 3.2.2(iii), 3.2.2(iv) and 3.2.2(v).

3.2.4 Statistical Analysis

The analysis was performed in Microsoft Office 365, Excel (Effect Sizes and 95% Confidence Intervals) and Minitab (version 18), including Descriptive Statistics, boxplots, one and two-sample t-tests. Data were described as means ±Standard Deviation (SD). Preliminary analyses were conducted to check for normality using the Anderson-Darling method. This was used to check the data distribution with the P<0.05 indicative for normality.

Power profile outcomes were compared between pre- and post-simulation by a one-sample t-test on the difference in pre-post values, resulting 95% Confidence Intervals (95% CI) indicating statistical significance (p<0.05). This process was completed for the absolute difference from pre-to-post measures and for the relative difference (%) in pre to post power measures. The Effect Sizes and corresponding 95% CI for each Power Profile test are displayed through Forest plots (Figure 4). Effect Sizes were calculated through Cohen's method (d) with the descriptors illustrating magnitude of change, trivial (d = 0.0 - 0.19), small (d = 0.20 – 0.49), moderate (d = 0.5 – 0.79), large (d > 0.8). Where d = Effect Size, M = mean and SD = Standard Deviation.

$$\textbf{\textit{Effect Size (d)}} = M_{group1} - M_{group2} / SD_{pooled}$$

Smallest Worthwhile Change (SWC) is a statistical method which acts as a reference to determine if a change in true score is likely to be meaningful in an applied setting, where cohort sizes are often small and difficult to identify change deemed statistically significant. The reference value of 0.2 is taken from Hopkins (2004). The formula for SWC is as follows:

Smallest Worthwhile Change (SWC) = Standard Deviation (SD) * 0.2

When assessing the effectiveness of the study, the practitioner evaluated if the result illustrated a true positive or negative value score change (post-pre) through both Effect Sizes and SWC. CI were included where deemed appropriate.

An examination of GPS metrics collected from completion of the GRIT simulation was compared with the desired metrics expected in the GRIT simulation i.e., actual vs expected was carried out by using a one-sample t-test on the difference between actual and expected GPS values. The resulting 95% CIs were used to indicate statistical significance. The Pearson Correlation statistic was used to illustrate if a proposed relationship can be made between the two variables, the actual and expected values, from the participants completing the GRIT simulation.
Comparison of the change in power profiles between forwards and backs was done by way of two-sample t-test by comparing the positional units. This illustrated which positional unit had the biggest change from pre to post power profile measures.
Respective ad-hoc statistical analysis occurred according to the result of the normality test for parametric or non-parametric data.

4. Results

4.1 Analysis Informed Simulation Design

4.1.1 Ball-in-Play and Ball-out-of-Play Duration

Each section of the results from the current study will focus on answering the research aims outlined in section 2.5.

As previously stated, the first study aim was to (i) identify the WCS demands for the different duration BIP periods, across every playing position of elite professional rugby union, using the holistic approach by combining GPS and TMA performance derivatives.

The following results section details (i) the determined duration of each BIP category and (ii) the respective number of events that will occur throughout the GRIT simulation. Finally, to and (iii) Identified the WCS of the 6 GPS-Performance derived metrics against the respective BIP periods.

The BIP categories were split up into 4 sections as displayed below in Table 7. This provided the researcher with the BIP categories, and respective durations, to create this GRIT simulation. The stochastic ordering method specifically replicated the game demands placed on this professional rugby union team from the 2017-18 season. The categorisation of BIP periods and their respective durations are displayed in Table 7. This illustrates descriptive information regarding the BIP category and respective duration, alongside the count of each BIP category throughout the GRIT simulation. This gave the researcher the template of the simulation, which in turn, gave way for random stochastic order of these BIP periods. From the previously described methodology, any BIP time duration that was greater than 90 seconds was extracted from the study as it did not meet the prerequisite demands for the simulation.
The BIP categorisation makeup for the whole simulation, is categorised in Table 7.

Table 7. *The* **c***ategorisation of each BIP period with their respective duration (s) and count for the GRIT Simulation.*

BIP Category	Time (s)	Count
Short	10	17
Moderate	20	12
Long	40	7
Very Long	90	3
Total	960	39

Ball-in-Play (BIP), Glasgow Rugby Intermittent (GRIT) Simulation

The total BIP time was calculated to be 960 seconds (16 minutes 0 seconds). Thus, the active part of the simulation was determined as 960 seconds, made up of different BIP periods as described in Table 7, from which the stochastic ordering of BIP categories would be based. This was performed by evenly splitting up the 4 BIP duration categories. To create an even spread of the 4 BIP categories, each of the category durations were divided against the total time duration. This equated to creation of the count of each BIP category (Table 7), with a total count of 39 BIP periods throughout the GRIT simulation.

The BIP categories and their respective total duration for the entire simulation were as follows:

- Short – 170 seconds
- Moderate – 240 seconds
- Long – 280 seconds
- Very Long – 270 seconds

To calculate the BOP time, the same analysis occurred as performed for the BIP time described in section 3.1.3.1. A histogram of every BOP time duration was used to calculate and categorise the BOP time frames. The recorded histogram and boxplot were then further analysed to display the mean, Interquartile Range (IQR) and extremities of the data. The researchers used this method to calculate and therefore categorise each of the BOP time frames, shown in Table 8.

Table 8. *The categorisation of each BOP period with their respective duration (s) and count for the GRIT Simulation.*

BOP Category	Time (s)	Count
Short	15	17
Moderate	40	12
Long	54	7
Very Long	85	3
BOP	1368	39

Ball-out-of-Play (BOP), Glasgow Rugby Intermittent (GRIT) Simulation

The total BOP time was calculated to be 1368 seconds (22 minutes and 48 seconds), i.e. the BOP total time for the simulation. Using the duration and count of periods for each BOP category, to total the 22 minutes and 48 seconds, allowed the researcher to structure the BOP periods alongside the BIP periods, to complete the overall structure of this simulation. For BOP, to calculate the period count, analysis was performed by evenly splitting up the BOP durations against the total BOP duration.

This equated to the counts of the of each BOP category, Table 8, with a total of 39 counts for the overall BOP duration. The BOP categories and their respective total duration for the entire simulation were as follows:

- Short – 255 seconds
- Moderate – 480 seconds
- Long – 378 seconds
- Very Long – 255 seconds

4.1.2 Positional Analysis for the Worst-Case Scenario Demands

The data in this research study was already collected from a previous study. Therefore, for the current study, this was completed through secondary analysis of the already collected data. Analysis was carried out to see if positions could be grouped together or kept individual. The outcome of this analysis, alongside the view to increase the specificity for the GRIT simulation, positions were kept individual rather than grouped. For example, "Tight 5," "Middle 5" and "Back 5". To optimise specificity for the GRIT simulation, positions were kept as individuals rather than grouped.

Each table shows a summary of the single WCS for each position, which was recorded by a single player from each of the 8 playing positions. Although this professional rugby team, at the time of the study, has a squad of players, with multiple players per position, the WCS was completed by a single player, in a single game. If a position has more than one player involved (Prop, Second Row, Back Row, Centre and Back 3) then the maximum value for the position is recorded as the WCS. This has come from a single player with all the position options available. The values shown, are the single greatest physical output determined from both locomotor and collision-based metrics. The specific duration refers to the table number. Therefore, the value shown in the tables describe the calculated WCS output that the position will experience for the selected BIP category. These are the expected values for each position to carry out in the GRIT simulation.

Tables 9-12 describe the position-specific game-demands (i.e., based on 6 GPS-Performance metrics) for each of the specific BIP categories (Short, Moderate, Long and Very Long durations) respectively.

Table 13 illustrates the total physical playing demands for each position across the whole GRIT simulation.

These data are displayed as absolute values based on each BIP category, for the cohort of 8 positional groups. For the 4 BIP categories, these are illustrated in Tables 9-12, for Short, Moderate, Long and Very Long respectively. A detailed description of the GRIT simulation is documented in Appendix 12, which illustrates the order 46of events of the GRIT Simulation from start to finish. Appendix 12 details each BIP category, the respective duration and detail used by the call commander, the total number of contacts to be completed, by position, with the start and end time for the timekeeper. The stochastic ordering of events for the flow of BIP categories is also presented in Appendix 12.

Table 9. *A summary of the combined GPS and performance analysis derived metrics for the short BIP duration category.*

Position	Contact (n)	Total Distance (m)	Moderate Acceleration Distance (m)	Hard Acceleration Distance (m)	High Speed Running Distance (m)	Sprint Distance (m)
Forwards						
Prop	0	53	2	1	6	0
Hooker	0	56	2	1	6	2
Second Row	0	60	2	0	5	0
Back Row	0	53	1	0	5	0
Backs						
Scrum Half	0	38	1	0	0	0
Stand Off	0	41	1	0	4	0
Centre	0	41	2	1	3	0
Back 3	0	54	2	0	6	3

Global Positioning Systems (GPS), Ball-in-Play (BIP)

Numerical values are illustrated for the Short BIP duration above in Table 9. This displays each position in rugby union, the GPS-Performance analysis derived metrics to be completed within the Short BIP category, of 10 seconds in duration. Throughout every position, there were no contacts to be completed in this BIP category. The lowest distance to be covered by any of the positions was the Scrum Half, who had to cover 38 metres, whereas the group with the highest total distance to cover was the Second Row, with a total distance of 60 metres. The positions Prop, Hooker, Second Row, Centre and Back 3 were required to complete the highest moderate acceleration metres, at 2 metres (Table 9). The positions Back Row, Scrum Half and Stand Off were required to complete a total of 1 metre under moderate acceleration (Table 9).

Every position, excluding the Scrum Half, was expected to cover metres of High Speed Running but only the positions Hooker and Back 3 positions were expected to cover Sprint Distance metres.

Table 10. *A summary of the combined GPS and performance analysis derived metrics for the moderate BIP duration category.*

Position	Contact (n)	Total Distance (m)	Moderate Acceleration Distance (m)	Hard Acceleration Distance (m)	High Speed Running Distance (m)	Sprint Distance (m)
Forwards						
Prop	0	76	2	0	7	0
Hooker	1	63	3	0	6	0
Second Row	0	68	3	1	10	0
Back Row	0	71	2	0	10	0
Backs						
Scrum Half	0	86	3	1	23	9
Stand Off	0	72	4	1	15	4
Centre	0	108	3	1	21	2
Back 3	0	101	4	1	21	12

Global Positioning Systems (GPS), Ball-in-Play (BIP)

The Moderate BIP category brings an introduction of 1 contact in the positional groups, illustrated by the Hooker position (Table 10). All remaining positions stay the same with 0 contacts in this category. The highest Total Distance covered in this BIP category was performed by the Centre position, with a total of 108 metres covered in 20 seconds, with the lowest Total Distance covered by the Hooker position with a total of 63 metres. There is a maximum difference of 2 metres for the Moderate Acceleration metric and a difference of 1m in the Hard Acceleration metric. This BIP category elicits an increase in High Speed Running in all positions but only for Scrum Half, Stand Off, Centre and Back 3 for the Sprint Distance metric. The lowest distance covered for High Speed Running and Sprint Distance metric was 6 metres (performed by the Hooker position) and 0 metres (all the forwards) respectively. All the backs were expected to perform Sprint Distance metres, the most distance covered being the Back 3 position group with 12m.

Table 11. *A summary of the combined GPS and performance analysis derived metrics for the long BIP duration category.*

Position	Contact (n)	Total Distance (m)	Moderate Acceleration Distance (m)	Hard Acceleration Distance (m)	High Speed Running Distance (m)	Sprint Distance (m)
Forwards						
Prop	1	129	6	1	15	0
Hooker	1	114	7	2	6	0
Second Row	1	124	6	1	25	0
Back Row	1	133	5	1	32	0
Backs						
Scrum Half	1	122	7	2	28	0
Stand Off	1	154	7	0	15	0
Centre	1	145	7	2	28	3
Back 3	1	170	14	5	25	1

Global Positioning Systems (GPS), Ball-in-Play (BIP)

The Long BIP category introduces 1 contact element for all positional groups (see Table 11). All positions are expected to cover over 100m of total distance, with the largest distance covered by the Back 3 position at 170m and lowest covered by the Hooker position at 114m. Moderate and Hard Acceleration metres are also increased to a high of 14m and 5m respectively for the Back 3. The forwards have a maximum difference of 2m for Moderate Acceleration and 1m for Hard Acceleration. The difference between positions in the Backs group is larger than the Forwards group, larger, with a maximal difference of 5m between the Back 3 and Stand Off. The Backs group covers the most distance of High Speed Running and Sprint Distance, however, the Back Row position covers the most distance at High Speed Running of 32m. The Centre and Back 3 positions are the only positions expected to cover any metres of Sprint Distance.

Table 12. *A summary of the combined GPS and performance analysis derived metrics for the very long BIP duration category.*

Position	Contact (n)	Total Distance (m)	Moderate Acceleration Distance (m)	Hard Acceleration Distance (m)	High Speed Running Distance (m)	Sprint Distance (m)
Forwards						
Prop	3	249	20	6	40	0
Hooker	2	258	23	0	108	0
Second Row	5	279	19	4	116	0
Back Row	2	281	22	11	88	0
Backs						
Scrum Half	2	260	27	6	112	24
Stand Off	3	261	17	4	125	2
Centre	3	266	30	0	127	0
Back 3	3	227	26	7	84	36

Global Positioning Systems (GPS), Ball-in-Play (BIP)

The Very Long BIP category has the highest locomotor and collision demands across all positions, as described in Table 12. The Backs are expected to complete more collisions and produce more metres of both High Speed Running and Sprint Distance. The Second Row position has the highest number of collisions to complete at 5 in this category and Scrum Half complete the least number of collisions at 2. The Back Row position covers the most distance for this BIP category at a total of 281m with the highest amount of Hard Acceleration metres at 11m. The Second Row is due to cover the most High Speed Running distance at 116m, with the Centre covering the most High Speed Running distance of 127 for the Backs and the entire squad. Only three positions are due to cover Sprint Distance metres, the Scrum Half at 24m, Stand Off at 2m and the Back 3 at 36m.

Table 13. *Total BIP physical playing demands for each position across the whole GRIT simulation.*

Position	Contact (n)	Total Distance (m)	Moderate Acceleration Distance (m)	Hard Acceleration Distance (m)	High Speed Running Distance (m)	Sprint Distance (m)
Forwards						
Prop	16	3463	160	42	411	0
Hooker	25	3280	188	31	540	34
Second Row	22	3541	169	31	728	0
Back Row	13	3527	142	40	693	0
Backs						
Scrum Half	13	3312	183	44	808	180
Stand Off	16	3422	165	24	728	54
Centre	16	3806	209	43	880	45
Back 3	16	4001	258	68	781	310

Ball-in-Play (BIP), Glasgow Rugby Intermittent (GRIT) Simulation

Table 13 illustrates the entire collision and locomotor demands from the 6 GPS-Performance metrics for the GRIT simulation, on which the statistical analysis was based. The Second Row position has the highest value of collisions with 22 and the lowest value of collisions is shared by the Scrum Half and Back Row position. The Back 3 position covers the most Total Distance across the whole simulation at 4001m with the most Total Distance covered by any Forward being 3541m for the Second Row. The Back 3 position also covers the highest amount of Moderate and Hard Acceleration metres across the entire cohort with 258m and 68m respectively and with a highest total of Sprint Distance metres at 310m. Centre covers the highest amount of High Speed Running distance across the entire cohort at 880m, however covers the lowest Sprint Distance at 45m for the Backs group. The lowest amount of High Speed Running distance covered is Prop at 411m and shares the lowest value of Sprint Distance with Second Row and Back Row positions.

Summary of Results for aim (i)

- BIP and BOP periods were classified into 4 categories – Short, Moderate, Long and Very Long durations.
- WCS demands for each BIP category determined, for each playing position. Positions could not be grouped together.
- Both collision and locomotor metrics required to create the WCS.

4.2 Results for Glasgow Rugby Intermittent (GRIT) Simulation (sections 4.2.1- 4.2.4) and Power Profiling (section 4.2.5)

The second aim of this study was to:
(ii) design a simulation to reflect aim 1 and determine any potential performance decrement in power profiling scores (post-GRIT power profiling) after having completed the GRIT simulation, using the pre-simulation scores as a baseline.

The results from the second phase of the study, (feasibility of the GRIT simulation and pre and post simulation power profiling), are displayed in sub-sections 4.2.1 and 4.2.5 respectively. The GRIT Simulation includes (4.2.1) *Whole Squad analysis* and (4.2.2) *Position Specific analysis*. This illustrates any differences that were recorded from the testing days against what was required by the GIT simulation (seen in Tables 9-13). The Power Profiling includes (4.2.5 (i)) Whole Squad analysis (4.2.5 (ii)) Unit analysis (Backs vs Forwards).

4.2.1 Ball-in-Play Simulation - Whole Squad Analysis

Whole squad analysis was performed using boxplots and the one sample t-tests for ad hoc statistical analysis, to identify if there were any significant differences between the expected value and the actual value of each GPS metric according to the GRIT simulation. Ninety-five percent confidence intervals (95% CIs) illustrate whether the difference is significant and by how much.
The aim was to ensure that the GRIT simulation can replicate the expected demands for each position, of the four BIP categories, according to the GRIT design, i.e., participants are able to complete no more or less than what was determined appropriate in the simulation design.

A line of no change was added to the boxplots, (Figure 3A-D) which intersects the chart at the point “0”. This was calculated as ‘expected value minus actual value’ for each locomotor derived metric. The line of no change acted as a reference point to show if the differences were either positive (above the line) or negative (below the line). If positive, the value recorded when the player completed the simulation (actual) was less than what was expected (required by the simulation, stated in Tables 9-13). If the difference was negative, the value recorded when the player completed the simulation (actual) was higher than that required by the simulation, i.e., the player did too much of that metric in the simulation.

These data are displayed in Figure 3A-D (letters labelled according to the respective BIP category), with written formal analysis provided underneath in Table 14. The boxplot in Figure 3 demonstrates the differences from the overall GRIT simulation, according to each respective BIP category demand. Statistically significant differences are highlighted using 95% CI. Correlation co-efficient (r^2) is displayed to illustrate the strength of relationship between the expected and actual values.

4.2.1(i) Total Distance

Appendix 4 displays the difference between the expected vs the actual value recorded from the simulation, using the whole squad for analysis. This is displayed across all 4 BIP categories (A-D) with the categories explained above in section 4.2.

The Short BIP category illustrated a difference of -4m, meaning that the whole squad completed, on average, -4m less than what was the expected in the simulation. This difference was significant (Table 14), although there was a strong positive relationship (r^2 0.8) between what distance was *actually* covered when running the simulation and what was required in the simulation.

There was no statistical difference for the Moderate BIP category, explained by the 95% CI in Table 14. All other remaining BIP categories displayed statistical differences. The largest difference between the means was displayed in the Very Long BIP category, with a mean difference of 23.0m. Across the whole squad, in the Very Long BIP category, there was a mean difference of 23.0m. This translates that the participants, on average, ran 23.0m in excess of what was expected.

Again, the Moderate BIP category displayed the smallest mean difference, with a value of -0.6m, across the whole squad for analysis, meaning the average was 0.6m less than what was expected. Each BIP category had a strong positive correlation, r^2 ranging from 0.8 to 1.0, with the Long BIP category's actual distance showing the closest relationship to the expected distance.

4.2.1(ii) Moderate Acceleration

There were statistically significant differences between expected and actual moderate acceleration for all the BIP categories, displayed in Table 14. The shortest 2 BIP categories (Short & Moderate) with the highest count of total periods across the simulation, had the greatest mean differences, i.e., expected value higher than expected value. Whereas the longest 2 BIP categories (Long & Very Long) with the fewest counts of moderate acceleration metres, showed fewer of these metres in the actual simulation compared to the expected values for moderate acceleration, with differences as large as -19.5m. The 95% CI indicates that the BIP categories were significantly different and that the moderate acceleration metres metric was deemed to be statistically significantly different from the expected values of the GRIT simulation. The Short and Moderate BIP categories shared a correlation co-efficient value of 0.4, whereas the Long BIP category displayed a weak relationship, specifically a negative correlation of -0.0 (r^2) and Very Long of 0.1 (r^2), respectively.

4.2.1(iii) Hard Acceleration

The mean differences for hard acceleration metres were closer to the expected value of the GRIT simulation, Table 14, with differences as little as 0.5m and 0.3m for Short and Moderate BIP categories respectively. There was no significant difference between the expected vs actual value for the Long BIP category, Table 14, with the use of the 95% CI, were the difference lies between -2.0m and -0.3m. The remaining 3 BIP categories (Short, Moderate and Very Long) are all statistically different in accordance with the 95% CI in Table 14, as the values do not cross the value "0". However, the mean difference is stated to be low across all BIP categories, with the greatest difference being -6.9m for the whole squad, in the Very Long BIP category.

This metric displayed a moderate strength of correlation between the expected and actual values, with the Short and Moderate BIP categories sharing a positive correlation of 0.4. The Long and Very Long BIP categories also shared a negative correlation value of -0.2. A negative value for correlation co-efficient demonstrates that as the expected value increases, the actual value decreases.

4.2.1(iv) High Speed Running

This GPS-Performance metric displayed the greatest difference in means when comparing the expected and actual values, with all the BIP categories were deemed to be statistically different as the 95% CI did not cross "0". The mean differences, alongside their respective SD/ IQR and lower and upper 95% CIs, are illustrated in Table 14. Although the largest mean difference was displayed in the Short BIP category, with a value of 31.5m, this category shares the strongest relationship with Moderate BIP, when comparing the expected vs actual values, with a positive correlation of 0.7. The Long and Very Long BIP categories have less strength in their correlation relationship, with values displayed as 0.5 and 0.3 respectively.

4.2.1(v) Sprint Distance

Although the Sprint Distance GPS-Performance metric displayed a mean difference of 0m, this metric displayed high values in the IQR with the highest displayed in the Very Long BIP category of 27.6m. With the use of 95% CI, only the Short BIP category was deemed to be statistically different as the values did not cross "0", with the remaining categories unable to produce 95% CI values. Correlation co-efficient values could not be calculated due to the mean difference being 0m across all BIP categories.

Table 14. *Output measures across the 5 GPS derived metrics analysed by the 4 BIP categories, illustrating the absolute difference, via Normal/ Non-Parametric tests, with 95% CI to signify statistical differences. Correlation values illustrate the strength of the relationship between expected and actual values. *Denotes significant difference (p<0.05)*

Variable				
Total Distance	N	Mean (±SD)/ Median (IQR)	95% CI	Correlation (r^2)
Short	272	-4.0 (±3.2)*	-4.4, -3.6	0.8
Moderate	192	-0.6 (5.8)	-2.1, 1.6	0.9
Long	112	7.4 (±3.2)*	6.8, 8.0	1.0
Very Long	48	23.0 (±11.6)*	19.6, 26.4	0.8
Moderate Acceleration				
Short	272	3.4 (±1.5)*	3.1, 3.6	0.4
Moderate	192	2.3 (5.8)*	2.0, 2.6	0.4
Long	112	-2.7 (5.6)*	-3.3, -2.1	-0.0
Very Long	48	-19.5 (±4.0)*	-20.6, -18.3	0.1
Hard Acceleration				
Short	272	-0.2 (1.8)	-0.2, 0.1	0.4
Moderate	192	-0.0 (1.3)*	-0.3, -0.0	0.4
Long	112	-1.4 (2.8)*	-2.0. -1.3	-0.2
Very Long	48	-6.9 (10.2)*	-6.9, -6.2	-0.2
High Speed Running				
Short	272	31.5 (14.7)*	30.9 32.7	0.7
Moderate	192	15.5 (43.0)*	10.2, 17.6	0.7
Long	112	28.5 (50.5)*	25.1, 38.0	0.5
Very Long	48	-19.2 (±46.3)*	-32.6, -5.7	0.3
Sprint Distance				
Short	272	0.0 (2.7)*	0.0, 0.0	-
Moderate	192	0.0 (12.2)	-	-
Long	112	0.0 (1.1)	-	-
Very Long	48	0.0 (27.6)	-	-

Ball-in-Play (BIP), Global Positioning Systems (GPS), 95% Confidence Intervals (CI), Standard Deviation (SD), Interquartile Range (IQR).

4.2.1(vi) Session Analysis - Whole Squad

Session analysis describes the overall difference in each GPS metric, for the whole squad, after the completion of the GRIT simulation.

Session analysis of each positional group allowed the researcher to see the differences between the actual versus expected outcomes of the entire GRIT simulation

Table 13 refers to the whole session demands for the GRIT simulation. This analysis is displayed in Table 15, illustrating the difference (m) across the 5 GPS-Performance metrics between what was expected from the athletes and what was actually recorded (i.e., carried out) by the athlete during the simulation. Appendix 4 illustrates a line of no change (line observed) manifests a reference if there is no difference between the *actual* and *expected* GPS-outputs. Descriptive statistics are illustrated to see if these changes are statistically significant, through 95% CI, and how strong the relationship is between the expected and actual value, correlation co-efficient (r^2).

Session analysis of the whole squad allowed the reader to examine the differences between the expected and actual values, for the GRIT simulation as a whole (Table 15). High Speed Running metric displayed the largest mean difference of 948.0m with the Moderate Acceleration metric displaying the smallest mean difference of 5.2m (Table 15). The metrics of Hard Acceleration, High Speed Running and Sprint Distance were deemed to be significantly different between the expected outcome and the actual outcome, as the 95% CIs values do not cross the “0” value. The participants completed more High Speed Running metres and less Sprint Distance than what was required for the GRIT Simulation, specifically 661.4m, 1234.6m and -54.0, -0.0m, respectively with the use of the 95% CI. The metrics Total Distance and Moderate Acceleration were deemed not significantly different to what as expected of the players, as the 95% CIs crossed the value “0”. Specifically, the differences were seen to be at -130.0m and 229.9m for Total Distance and -17.4m and 27.8m for Moderate Acceleration.

Table 15 also shows that Total Distance has the strongest relationship between the expected and actual values, with a correlation co-efficient value of 0.9. Hard acceleration and High Speed Running share a strong correlation of 0.7 and Moderate acceleration has a moderate strength relationship of 0.5. Sprint Distance is the only metric to have a negative correlation, value of -0.3, illustrating that the participants did not achieve any Sprint Distance.

Table 15. *Descriptive Statistics showing significant differences between expected vs actual values, alongside the strength of relationship through correlation analysis. *Denotes significant difference (p<0.05).*

Variable	N	Mean (±SD)/ Median (IQR)	95% CI	Correlation (r^2)
Total Distance	16	51.9 (68.8)	-130.0, 229.9	0.9
Moderate Acceleration	16	5.2 (±42.4)	-17.4, 27.8	0.5
Hard Acceleration	16	-17.3 (±21.0)*	-28.5, -6.0	0.7
High Speed Running	16	948.0 (±538.0)*	661.4, 1234.6	0.7
Sprint Distance	16	-34.0 (246.0)*	-54.0, -0.0	-0.3

Standard Deviation (SD), Interquartile Range (IQR), 95% Confidence Interval (CI)

4.2.2 Ball-in-Play Simulation – Positional Analysis

Positional specific analysis was carried out with the use boxplots (Appendix 6-10) for the expected vs actual values across the GRIT simulation, including descriptive statistics to illustrate the mean and 95% CI. Boxplots are evident across the GPS-Performance derived metrics, these display the differences between the expected value vs the actual value, with a line of no change (red dashed line) intersecting the boxplot at the value "0". These data are displayed in Figures 5-9, with formal written analysis in Table 16 and 17.
BIP categories are illustrated by letters showing each category.

Preliminary analysis was conducted to check for normality using the Anderson-Darling method. This was used to check the data distribution with the *p<0.05* indicative for normality. Respective ad hoc statistical analysis occurred according to the result of the normality test for parametric or non-parametric data.

4.2.2(i) Total Distance

Short BIP category (A, Appendix 6) illustrated that the Stand Off position had the smallest difference from expected vs actual values with the mean difference of -0.1m and the largest median difference was the Prop position with -7.3m. Overall, every position had less Total Distance metres than expected with only the Stand Off position showing no significant differences with 95% CI intervals of -2.0m, 0.9m. The Moderate BIP category (B, Appendix 6) illustrated a mix of results with the positions; Back Row, Hooker and Second Row presenting a positive median value of the differences of 2.4m, 5.0m, 0.5m for the positions respectively and the remaining positions showing a negative median value of the differences. The remaining two BIP categories Long and Very Long (C and D, Appendix 6), all positions demonstrated a positive median difference. This illustrates that each position completed more Total Distance than what was required during the GRIT simulation.

4.2.2(ii) Moderate Acceleration

The Short and Moderate BIP category (A and B, Appendix 7), all positions demonstrate a positive median difference, meaning all positions covered more moderate acceleration metres than they were expected to. Short category, the Back 3 displayed the largest difference of 4.5m whilst the Centre displayed the smallest difference with 1.7m. The Centres elicited the largest difference for the Moderate category 2.7m and Hookers the smallest with 0.9m Using both of the BIP categories, there were positive significant differences for all positions using the 95% CI. The Long and Very Long category (C and D, Appendix 7) all positions demonstrated a negative median difference, meaning all positions covered fewer moderate acceleration metres than expected. Long category, the Back 3 had the largest negative difference of -8.8m with Back Row the smallest at -0.4m. The Very Long category showed that Centres had the largest difference with Stand Off the smallest difference, eliciting -24.5m and -2.9m respectively.

4.2.2(iii) Hard Acceleration

The Short and Moderate BIP categories (letters A and B in Appendix 8) illustrate the greatest median difference, whereas the differences in the Long and Very Long BIP categories (C and D, Appendix 8) are less evident. The Back 3 position displays the largest median difference with values of 1.9m and 1.3m for Short and Moderate categories respectively. Back Row was the only position deemed to have no significant differences using the 95% median CI, for the Short category. For the Moderate category, there was no significant differences for the positions; Back 3, Back Row, Centre and

Stand Off. Every position was deemed to be significantly different for the Long and Very Long categories. Back 3 had the largest median difference in the Long category with -4.8m and Second Row position had the largest difference of -14.0m.

4.2.2(iv) High Speed Running

High Speed Running illustrated the largest median differences across all 5 metrics (Table 15 and 16). The Short category illustrated all the positions of a positive difference, with the largest difference of 39.5m by the Second Row position. With the exception for the Centre, this position elicited a negative difference of -3.1m. Every position illustrated significant differences with the exception of Stand Off, with the 95% Median CI of -3.6m and 17.6m. Centre had the largest median difference of 59.5m for the Moderate category, with Prop and Stand Off being the only positions not to display significant differences. Prop was the only position to display a negative difference in the Long category, whereas every position with the exception of Back 3 documented a negative difference in the Very Long category. Significant differences were shown for Prop and Second Row in the Long category and Back 3 and Back Row for the Very Long category.

4.2.2(v) Sprint Distance

Sprint Distance documented the smallest median difference from all 5 GPS metrics as not all positions were expected metres of Sprint Distance. Back 3 and Hooker illustrated a negative median difference of -2.9m and -1.8m for the Short category. The Second Row position had an outlier occurring in a single BIP period, however not affecting the median difference. Outliers were also seen for the Second Row position in the Moderate category. Back 3, Centre and Stand Off had negative median differences of -12.2m, -2.2m and -3.7m respectively. Back 3 had a negative median difference for both Long and Very Long categories, Centre and Stand Off displayed negative median differences for Long and Very categories respectively.

Table 16. *Descriptive Statistics displaying the difference between the expected vs actual value for all 5 performance metrics in Short and Moderate Ball-in-Play (BIP) categories. The Mood's Median Test was used to illustrate the significant difference using the 95% Confidence Intervals (CI). * Denotes significant difference (p<0.05)*

BIP Category	**Short**					**Moderate**			
Variable	**Position**	**N**	**Median**	**IQR**	**95% Median CI**	**N**	**Median**	**IQR**	**95% Median CI**
Total Distance	Back 3	68	-2.7*	2.2	-3.0, -2.2	48	-3.2*	3.6	-4.3, -2.4
	Back Row	51	-4.2*	3.3	-4.6, -3.1	36	2.4*	1.9	1.6, 2.7
	Centre	34	-2.5*	3.9	-3.4, -1.5	24	-5.4*	6.1	-8.1, -2.9
	Hooker	34	-5.6*	4.6	-7.0, -4.7	24	5.0*	3.9	3.9, 6.5
	Prop	34	-7.3*	3.2	-8.3, -5.7	24	-0.2	4.0	-2.0, 1.4
	Second Row	34	-5.8*	2.3	-6.2, -5.4	24	0.5	3.2	-0.6, 1.5
	Stand Off	17	-0.1	3.2	-2.0, 0.9	12	-2.5	1.9	-3.5, -1.6
Moderate Acceleration	Back 3	68	4.5*	1.5	4.2, 4.7	48	2.6*	2.0	2.2, 3.1
	Back Row	51	3.8*	1.8	3.4, 4.3	36	2.7*	1.9	2.1, 3.6
	Centre	34	1.7*	1.3	1.3, 2.1	24	3.7*	2.7	2.8, 4.7
	Hooker	34	2.5*	1.5	2.1, 3.2	24	0.9*	1.9	0.0, 1.8
	Prop	34	2.2*	0.6	2.1, 2.5	24	1.8*	0.8	1.4, 1.9
	Second Row	34	3.9*	1.3	3.7, 4.5	24	2.4*	1.4	1.4, 2.7
	Stand Off	17	2.8*	2.2	1.8, 3.5	12	1.0*	1.9	0.5, 2.4
Hard Acceleration	Back 3	68	1.9*	2.3	1.4, 2.4	48	1.3	2.9	-0.1, 1.9
	Back Row	51	0.1	1.2	-0.3, 0.4	36	-0.0	1.2	-0.4, 0.3
	Centre	34	-0.6*	0.0	-0.6, -0.6	24	0.2	1.5	-0.4, 0.8
	Hooker	34	-0.8*	0.3	-0.8, -0.5	24	-0.3*	0.0	-0.3, -0.3
	Prop	34	-0.6*	0.3	-0.6, -0.3	24	0.0*	0.6	0.0, 0.3
	Second Row	34	0.8*	0.9	0.4, 0.9	24	-0.5*	1.1	-0.8, -0.1
	Stand Off	17	-0.4*	0.0	-0.4, -0.4	12	-1.2	1.3	-1.2, 0.1
High Speed Running	Back 3	68	33.7*	4.8	32.4, 34.5	48	48.1*	11.7	46.1, 52.6
	Back Row	51	32.0*	6.5	29.7, 33.7	36	10.1*	12.5	5.9, 12.6
	Centre	34	-3.1*	0.0	-3.1, -3.1	24	59.5*	14.1	56.1, 65.4
	Hooker	34	32.5*	6.1	31.2, 34.8	24	11.4*	19.6	6.9, 20.7
	Prop	34	19.9*	18.3	14.0, 22.4	24	-1.8	19.2	-5.9, 10.9
	Second Row	34	39.5*	3.0	38.6, 40.4	24	8.9*	9.7	3.6, 11.4
	Stand Off	17	6.0	22.0	-3.6, 17.6	12	-2.3	11.8	-4.3, 7.4
Sprint Distance	Back 3	68	-2.9	0.0	-2.9, -2.9	48	-12.2*	0.0	-12.2 -12.2
	Back Row	51	0.0*	0.0	0.0, 0.0	36	0.0	0.0	0.0, 0.0
	Centre	34	0.0	0.0	0.0, 0.0	24	-2.2*	0.0	-2.2, -2.2
	Hooker	34	-1.8*	0.0	-1.8, -1.8	24	0.0	0.0	0.0, 0.0
	Prop	34	0.0	0.0	0.0, 0.0	24	0.0	0.0	0.0, 0.0
	Second Row	34	0.0	0.0	0.0, 0.0	24	0.0	0.0	0.0, 0.0
	Stand Off	17	0.0	0.0	0.0, 0.0	12	-3.7*	0.0	-3.7, -3.7

Table 17. *Descriptive Statistics displaying the difference between the expected vs actual value for all 5 performance metrics in Long and Very-Long Ball-in-Play (BIP) categories. The Mood's Median Test was used to illustrate the significant difference using the 95% Confidence Intervals (CI). * Denotes significant difference (p<0.05).*

BIP Category	**Long**					**Very Long**			
Variable	**Position**	**N**	**Median**	**IQR**	**95% CI**	**N**	**Median**	**IQR**	**95% CI**
Total Distance	Back 3	28	6.4*	5.8	4.6, 8.0	12	31.7*	23.3	18.1, 41.2
	Back Row	21	10.0*	5.5	6.5, 11.4	9	17.7*	26.0	9.3, 37.8
	Centre	14	9.7*	1.6	8.8, 10.4	6	28.6*	5.4	22.3, 32.3
	Hooker	14	7.0*	4.2	5.6, 9.3	6	18.1*	24.4	5.8, 33.3
	Prop	14	6.5*	8.9	1.7, 10.5	6	22.2*	21.2	12.7, 34.7
	Second Row	14	6.3*	2.0	5.8, 7.8	6	15.6*	12.9	11.5, 27.9
	Stand Off	7	6.8*	1.5	5.9, 7.7	3	10.6*	9.3	4.2, 13.5
Moderate Acceleration	Back 3	28	-8.8*	2.4	-10.0, -8.3	12	-23.1*	3.6	-25.0, -21.4
	Back Row	21	-0.4*	1.3	-1.1, -0.2	9	-17.7*	1.6	-18.6, -16.6
	Centre	14	-2.6*	2.2	-4.0, -2.0	6	-24.5*	2.0	-25.1, -22.1
	Hooker	14	-3.2*	1.3	-3.6, -2.4	6	-20.3	2.9	-21.7, 18.7
	Prop	14	-4.4*	2.3	-5.0, -2.7	6	-16.6*	4.2	-19.4, -14.8
	Second Row	14	-1.1*	1.0	-1.5, -0.6	6	-15.7*	2.2	-17.1, -13.7
	Stand Off	7	-0.5*	1.1	-1.1, 1.8	3	-12.9*	3.4	-13.8, -10.4
Hard Acceleration	Back 3	28	-4.8*	0.0	-4.8, -4.8	12	-6.9*	0.0	-6.9, -6.9
	Back Row	21	-0.9*	0.2	-0.9, -0.9	9	-11.2*	0.0	-11.2, -11.2
	Centre	14	-2.0*	0.0	-2.0, -2.0	6	0.0*	0.3	0.0, 0.3
	Hooker	14	-2.0*	0.0	-2.0, -2.0	6	-0.4*	0.0	-0.4, -0.4
	Prop	14	-0.6*	0.0	-0.6. -0.6	6	-6.2*	0.2	-6.2, -5.8
	Second Row	14	-1.3*	0.0	-1.3, -1.3	6	-14.0*	0.0	-14.0, -14.0
	Stand Off	7	0.4*	2.0	0.0, 2.3	3	-3.8*	0.9	-3.8, -3.0
High Speed Running	Back 3	28	89.2*	43.9	77.8, 100.5	12	-2.9	76.9	-27.3, 49.2
	Back Row	21	24.9*	30.0	16.4, 36.8	9	12.1	40.6	-8.6, 41.3
	Centre	14	33.5*	40.9	24.3, 64.8	6	-15.9	73.2	-66.7, 24.8
	Hooker	14	30.9*	20.7	22.4, 40.4	6	-63.7*	28.2	-81.3, -40.2
	Prop	14	-2.2	31.5	-15.2, 15.7	6	-25.5*	35.7	-39.4, -3.7
	Second Row	14	13.2	27.0	-7.6, 18.6	6	-51.4*	50.5	-103.1, -38.3
	Stand Off	7	61.4*	57.6	27.7, 89.9	3	-78.9*	105.8	-108.8, -2.9
Sprint Distance	Back 3	28	-1.1*	0.0	-1.1, -1.1	12	-36.1*	0.0	-36.1, -36.1
	Back Row	21	0.0*	0.0	0.0, 0.0	9	0.0	0.0	0.0, 0.0
	Centre	14	-3.2*	0.0	-3.2, -3.2	6	0.0	0.0	0.0, 0.0
	Hooker	14	0.0	0.0	0.0, 0.0	6	0.0	0.0	0.0, 0.0
	Prop	14	0.0	0.0	0.0, 0.0	6	0.0	0.0	0.0, 0.0
	Second Row	14	0.0	0.0	0.0, 0.0	6	0.0	0.0	0.0, 0.0
	Stand Off	7	0.0	0.0	0.0, 0.0	3	-2.2*	0.0	-2.2, -2.2

4.2.3 Session Analysis

Session analysis of each positional group allowed the researcher to see the differences between the actual versus expected outcomes of the entire GRIT simulation. For each playing position, this is described by the overall difference between the actual versus observed output for each metric after the completion of the GRIT simulation. This analysis was displayed via the scatterplot below (Figure 3) with correlation analysis between the Expected vs Actual values of the 5 GPS-Performance metrics. A line of equality (identity line) illustrates a reference of no difference between actual and observed output.

The line of equality in Figure 3 can help the reader identify the degree of difference from the expected and actual values from the GRIT simulation. Data presented to the left of this line identifies an actual recorded value higher than what was expected. Data points presented to the right of this line, illustrate an actual value lower than expected. How can the reader determine if any potential differences would be statistically different and by what degree are these significant? These differences can be determined significant through the use of 95% CIs. The descriptive statistics illustrated to see if these differences were statistically significant, through 95% CI are shown in Table 18. Percentage difference (%) considers the relative difference giving enhanced accuracy for differences as the sample sizes are mean values are different. By using the percentage value allowed a method for the researcher to readily compare all the metrics with the positional groups based categorically.

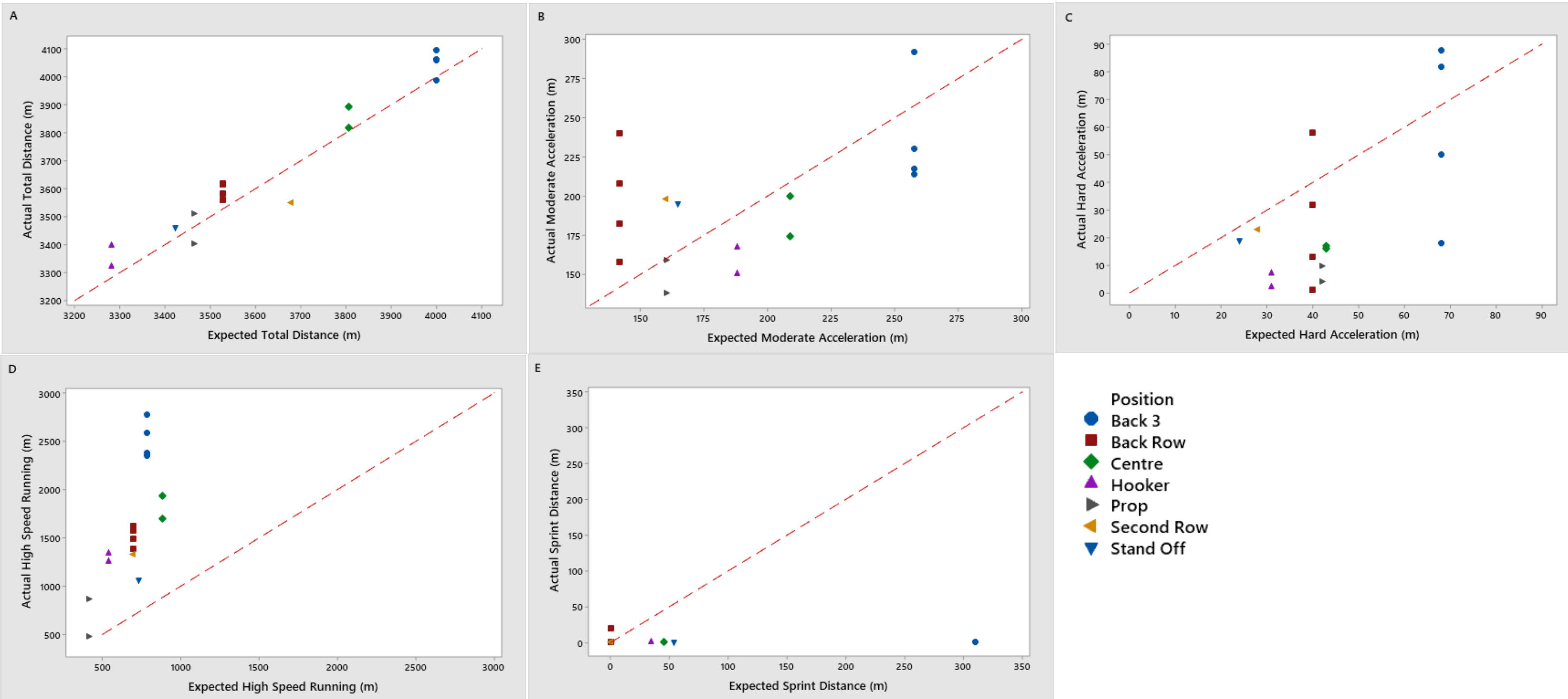

Figure 3. *Scatterplot illustrating the session analysis across the 5 GPS-Performance metrics, Total Distance (A), Moderate Acceleration metres (B), Hard Acceleration metres (C), High Speed Running metres (D) and Sprint Distance (E), categorically for each playing position.*

4.2.3(i) Total Distance

The Total Distance metric elicited the smallest mean and percentage difference (%) of all the GPS-Performance metrics. Every position, with the exception of Prop and Second Row, elicited a positive mean and percentage difference (%) illustrating that these positions covered more Total Distance than what was expected. Prop illustrated the smallest difference with -7.3m and 0.2% and Second Row with -130.0m and -3.5%. There was no significant difference, when referring to the 95% CIs, for Back 3, Centre and Prop. Although 95% CI could not be calculated for Second Row and Stand Off, due to the limited number of participants in these groups, using the percentage difference gave an indication of magnitude of difference. With Second Row already been reported, Stand Off elicited the second smallest difference, with a value of 39.0m and 1.1%. Figure 3 illustrated that for every subject, there were only three instances to the right of the line of equality, specifically at positions Prop, Second Row and Back 3. The remaining subjects results lie to the left of the line of equality, indicating that more Total Distance was covered in the GRIT simulation than was expected.

4.2.3(ii) Moderate Acceleration

The line of equality in Figure 3 shows the degree of difference from the expected and actual values from the GRIT simulation. For each position, with the exception of Back Row, each position follows the pattern as the line of equality, but by what degree and are there any significant differences? These differences can be determined significant through the use of 95% CIs.

The Back Row illustrated the largest difference of 55.0m and 38.7%, however this mean difference was not significant through the 95% CI. This shows that the Back Row completed 55m additional moderate acceleration metres that what was expected for the GRIT simulation, displayed with the Back Row positions lying to the left of the line of equality, Figure 3. In addition, the Centre and Prop positions were also deemed not to be significant through the 95% CI (-187.2m 143.2m and -145.3m, 121.9m respectively). The positions Back 3, Centre, Hooker and Prop all completed less

Moderate acceleration metres than what was expected for the GRIT simulation. The Hooker position was the only position to be deemed significantly different, with a difference lying between 37.5m and 78.5m. Of these positions, the Hooker had the largest percentage difference from the expected and actual value at -15.7%. The Prop position had the smallest percentage difference at -7.3%, with differences lying between -145.3m and 121.9m.

The positions Back Row, Second Row and Stand Off completed more moderate acceleration metres that what was expected during the GRIT simulation. The difference of 55.0m for the Back 3 position was not deemed to be significant, with the differences lying between -1.0m and 111.0m. Statistical analysis could not be completed for the Second Row and Stand Off positions due to the lack of participants (n=1), therefore percentage difference was calculated. Second Row position had the largest percentage difference with 23.8% with the Stand Off position displaying a percentage difference of 18.2%.

4.2.3(iii) Hard Acceleration

All positions had a negative mean difference between the expected vs actual values, meaning they completed less Hard Acceleration metres than they were expected to. There were only three instances of data to the left of the line of equality, signifying a positive difference, when the actual value was greater than the expected value, Figure 3. The positions Second Row and Stand Off share the smallest mean difference, -5.0m, however illustrated different percentage difference, -17.9% and -20.8% respectively. Statistical analysis for determining significant differences could not be determined for the Second Row and Stand Off positions due to the lack of participants available (n=1), therefore giving statistical power for the percentage difference calculation. The position with the largest mean difference was Prop with -35.1m, however the Hooker position had the largest percentage difference at -85.5%.

Back 3 had a small mean difference of -8.5m but acquired the smallest percentage difference of -12.5%, giving statistical power for this approach. Significant differences, shown in Table 18, were evident for only the Centre position -32.9m and -20.1m, whilst the remaining differences for positions were deemed not to be significant, through the 95% CI.

4.2.3(iv) High Speed Running

This metric elicited the largest mean and percentage difference across all 5 GPS-Performance metrics. Using the line of equality in Figure 3, all positions are positioned above the line and shifted to the left, illustrating that all positions completed more High Speed Running metres than what was required for the GRIT simulation. Such differences were as large as 1744.5m and 202%, more than expected, seen in the Back 3 position. The smallest difference of 339.0m and 46.6% was evident for the Stand Off position. Although these values are large, the mean differences for Centre and Prop positions were deemed not to be significant, -568.2m, 2443.2m and -2189.0, 2716.0m respectively, detailed in Table 18. There were large significant differences for the Back 3 (1442.8m, 2066.2m), Back Row (658.1m, 992.4m) and Hooker (235.0m, 2443.2m) positions. Statistical analysis could not be calculated for the Second Row and Stand Off positions due to the small sample size (n=1). These two positions saw large differences of 636.0m, 91.9% and 339.0m, 46.6%, giving statistical power for this approach.

4.2.3(v) Sprint Distance

Not all positions were required to sprint in the simulation. The sprint distance metric exemplified this, as percentage differences between the expected and actual values were seen of either -100.0% or 0.0%. This illustrates the positions who were required to sprint, did not achieve any sprint distance in the GRIT simulation. The Back 3, Centre, Hooker and Stand Off positions were required to cover Sprint Distance for the GRIT simulation, whereas the Back Row, Prop and Second Row were not required to complete any Sprint Distance for the GRIT simulation. Table 18 illustrates a range of differences in the 95% CI statistic. Table 18 shows this difference was therefore not significant as the mean difference ranged between -10.9m and 20.9m for the Back Row position.

Significant differences were evident for the remaining positions, Back 3 (-310.0m, -310.0m), Centre (-45.0m, -45.0m) and Hooker (-34.0m, -34.0m). The Stand Off position completed 54.0m less Sprint Distance metres than what was required for the GRIT simulation (-54.0m) and -100% percentage difference. This could therefore be interpretated as significant, also seen in Table 18.

Table 18. *Descriptive Statistics illustrating the mean and percentage difference (%) for each playing position across the 5 GPS-Performance metrics, with level of statistical significance through 95% CI. *Denotes significant difference (p<0.05).*

Variable	Position	N	Mean (±SD)	Difference (%)	95% CI
Total Distance	Back 3	4	52.0 (±45.6)	1.3	-20.6, 124.6
	Back Row	4	68.0 (±27.7) *	1.9	23.9, 112.1
	Centre	2	50.5 (±51.6)	1.3	-413.3, 514.3
	Hooker	2	79.0 (±55.2) *	2.4	416.5, 574.5
	Prop	2	-7.3 (±76.6)	-0.2	-695.8, 681.2
	Second Row	1	-130.0 (-)	-3.5	-
	Stand Off	1	39.0 (-)	1.1	-
Moderate Acceleration	Back 3	4	-19.8 (±36.5)	-7.7	-77.8, 38.3
	Back Row	4	55.0 (±35.2)	38.7	-1.0, 111.0
	Centre	2	-22.0 (±18.4)	-10.5	-187.2, 143.2
	Hooker	2	-29.5 (±12.0) *	-15.7	37.5, 78.5
	Prop	2	-11.7 (±14.9) *	-7.3	-145.3, 121.9
	Second Row	1	38.0 (-)	23.8	-
	Stand Off	1	30.0 (-)	18.2	-
Hard Acceleration	Back 3	4	-8.5 (±32.3)	-12.5	-59.9, 42.9
	Back Row	4	-14.0 (±24.9)	-35.0	-53.6, 25.6
	Centre	2	-26.5 (±0.7) *	-61.6	-32.9, -20.1
	Hooker	2	-26.5 (±3.5)	-85.5	-58.3, 5.3
	Prop	2	-35.1 (±4.0)	-83.6	-70.8, 0.6
	Second Row	1	-5.0 (-)	-17.9	-
	Stand Off	1	-5.0 (-)	-20.8	-
High Speed Running	Back 3	4	1744.5 (±202.2) *	223.4	1422.8, 2066.2
	Back Row	4	825.3 (±105.1) *	119.1	658.1, 992.4
	Centre	2	937.5 (±167.6)	106.5	-568.2, 2443.2
	Hooker	2	756.0 (±58.0) *	140.0	235.0, 1277.0
	Prop	2	263.5 (±273.0)	64.1	-2189.0, 2716.0
	Second Row	1	636.0 (-)	91.9	-
	Stand Off	1	339.0 (-)	46.6	-
Sprint Distance	Back 3	4	-310.0 (±0.0) *	-100.0	-310.0, -310.0
	Back Row	4	5.0 (±10.0)	0.0	-10.9, 20.9
	Centre	2	-45.0 (±0.0) *	-100.0	-45.0, -45.0
	Hooker	2	-34.0 (±0.0) *	-100.0	-34.0, -34.0
	Prop	2	0.0 (±0.0)	0.0	0.0, 0.0
	Second Row	1	0.0 (-)	0.0	-
	Stand Off	1	-54.0 (-)	-100.0	-

Global Positioning Systems (GPS), 95% Confidence Intervals (CI), Standard Deviation (SD)

Summary of results for aim (ii);

- Stochastic ordering of BIP periods was required to replicate the demands of match play.
- Total Distance elicited the smallest mean and percentage difference (%), in the Prop position (-7.3m, -0.2%), of all the GPS-Performance metrics.
- High Speed Running elicited the largest mean and percentage difference (%), in the Back 3 position (1744.5m, 223.4%), across all 5 GPS-Performance metrics. Figure 3 illustrates a shift above and to the left of the line of equality meaning all positions completed more High Speed Running than what was expected.
- The Back Row (38.7%), Second Row (23.8%) and Staff Off (18.2%) positions achieved more moderate acceleration metres than what was required.

4.2.4 Power Profiling

This section presents the results of the pre and post-simulation power profiling results. The order of events for the Power Profiling tests took place in a carousel rotational fashion as shown below, with at least 2 minutes of recovery between each of repetitions (Speed tests), sets and between each test performed for adequate restoration of the appropriate energy stores. The exercise selection, and carousel rotation order, are displayed below.

Countermovement Jump → Banded Bench Press → Speed

Power profiling results for each of the above tests, are presented for the Whole Squad and then for Positional Units.

4.2.4(i) Whole Squad

Whole squad results (Effect Sizes and 95% CI) for the change in power profiling test scores are shown in Figure 4 This Forest plot shows the Effect Size (ES) Cohen's d from the difference between the pre- and post-simulation power profiling tests (Countermovement Jump (CMJ), Banded Bench Press and Speed tests). Effect Sizes were calculated through Cohen's method (d) with the descriptors illustrating magnitude of change, trivial (d = 0.0 - 0.19), small (d = 0.20 – 0.49), moderate (d = 0.5 – 0.79), large (d > 0.8).

These data are displayed in Figure 4, with written formal analysis provided underneath in Table 19. Statistical significance differences were highlighted through 95% CI alongside the Smallest Worthwhile Change (SWC).

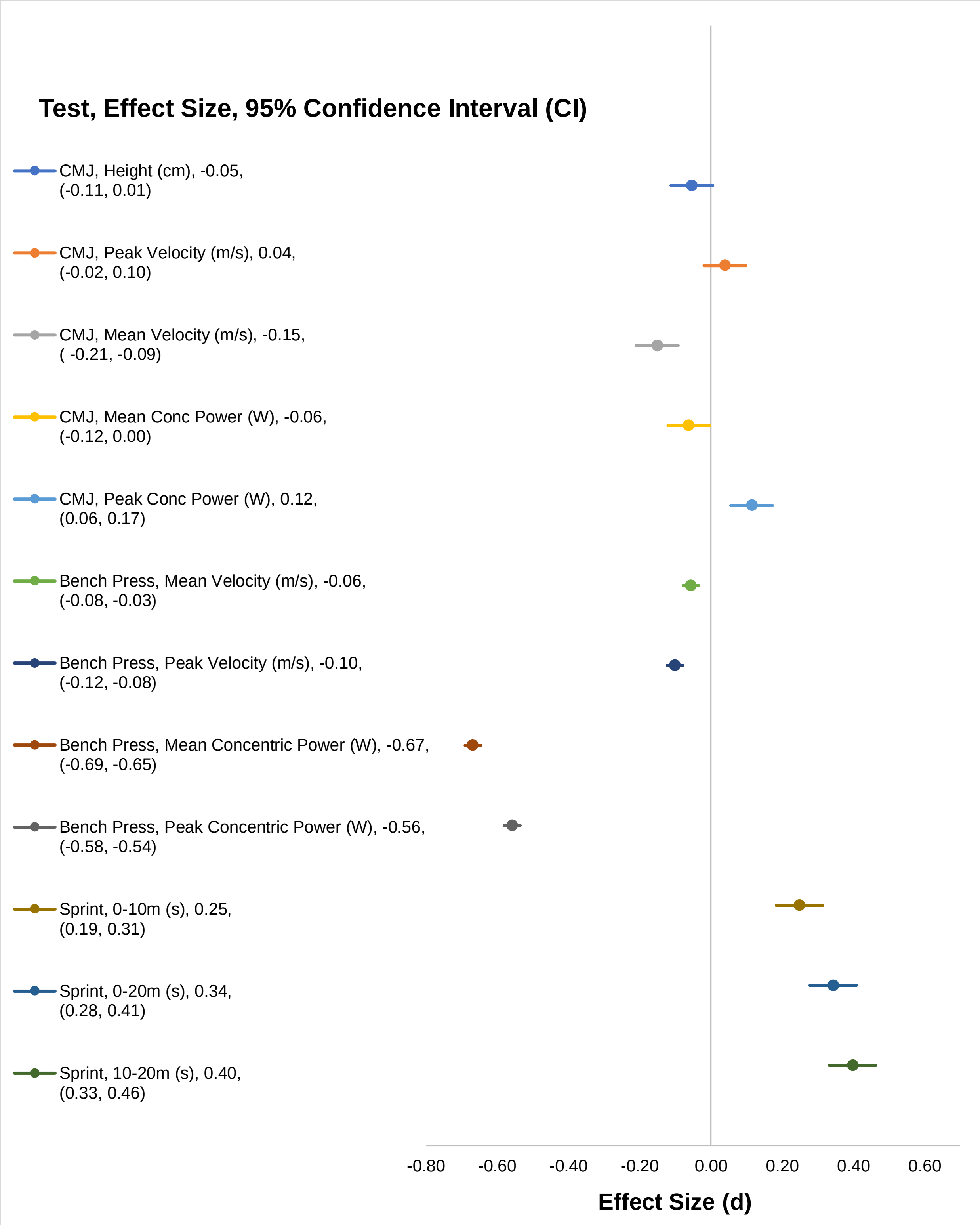

Figure 4. *Forest Plot illustrating the Effect Size (ES) and respective 95% Confidence Intervals (CI) for the difference between pre and post Power Profiling Test.*

Countermovement Jump

Trivial effect sizes were seen for all outputs of the CMJ test; Jump Height, Mean Velocity, Peak Velocity, Mean Concentric Power and Peak Concentric Power ($d < \pm 0.20$). All mean differences from these 5 outputs were also lower than the SWC statistic. This resulted in trivial differences between the pre- and post-test, also supported by the 95% CI in Table 19. Peak Velocity saw the smallest mean difference between pre and post-simulation, at 0.02m/s, with the true difference for the population (95% CI) lying between -0.09m/s and 0,13m/s. The change in peak velocity from pre to post-simulation was deemed not significant ($d = 0.04$). The largest mean difference, from pre to post-simulation was seen in Concentric Peak Power, with a difference of -351.09 (W). This difference was determined not significant ($d = 012$), with the difference lying between -1073.19 (W) and 371.01(W). Overall, CMJ, did not experience a significant performance decrement after completion of the GRIT simulation.

Banded Bench Press

Trivial effect sizes were seen for the velocity outputs (mean and peak velocity) from the Banded Bench Press test, ($d = -0.06$ and $d = -0.10$ respectively). The mean differences were also smaller than the SWC statistic. This resulted in trivial differences between the pre- and post-simulation tests. Significant differences were illustrated for Peak Velocity (95% CI (-0.04m/s, -0.00m/s)) and no significant difference was evident for Mean Velocity (95% CI (-0.03m/s, 0.00m/s)).

Moderate ES were evident for both power outputs (mean and peak power), $d = -0.67$ and $d = -0.56$ respectively. This is supported by the larger mean differences than the SWC statistic, meaning there was a magnitude of change from pre to post. These differences were significant in accordance with the 95% CI (-122.69W, -65.80W) and (-227.99W, -102.99W) respectively for Concentric mean and peak power outputs. A detrimental decrease in performance is seen for the Banded Bench Press exercise for both power variables (mean and peak), although only a trivial decrement in performance was noted for velocity variables, after the completion of the GRIT simulation.

Speed

For all outputs of speed performance, a small ES was evident, resulting in reduced speed performance (slowed) post the GRIT simulation, this is enhanced by the positive mean differences being larger than the SWC statistic. A range of ES were noted for the speed tests, specifically at 0-10m (d = 0.25), 10-20m (d = 0.34) and 0-20m (d = 0.40). Performance in the speed test, for all3 speed test outputs was deemed to be significantly impacted (see 95% CI in Table 19). The speed at 0-10m and 10-20m showed an increased mean difference of 0.03s, meaning that the whole squad were slower in the tests post-GRIT simulation compared to pre-GRIT simulation tests. The differences for each test lie between 0.01s and 0.04s for the 0-10m speed test and 0.02s and 0.05s respectively. The largest mean decrement in performance was noted for the speed test 0-20m, with a difference of 0.06s. This test also had the largest ES value (d = 0.40), with the difference being significant and lying between 0.04s and 0.08s.

The Cohen's d descriptor, small increase, is evident for all three speed tests, illustrating that sprint speed performance significantly slowed after performing the simulation.

Table 19. *Whole Squad analysis illustrating the differences between the Pre and Post Power Profiling scores with the statistical method of a one-sample t-test displaying 95% Confidence Interval (CI), Effect Size and Smallest Worthwhile Change (SWC). *Denotes significant difference (p<0.05).*

Power Profile	Whole Squad Analysis					
	N	Mean (±SD)	95% CI	Effect Size	Descriptor	SWC
Countermovement Jump						
Height (cm)	48	-0.31 (±3.35)	-1.29, 0.66	-0.05	Trivial	1.19
Mean Velocity (m/s)	48	-0.03 (±0.19)	-0.09, 0.03	-0.15	Trivial	0.04
Peak Velocity (m/s)	48	0.02 (±0.38)	-0.09, 0.13	0.04	Trivial	0.10
Concentric Mean Power (W)	48	59.98 (±683.19)	-138.40, 258.36	-0.06	Trivial	206.67
Concentric Peak Power (W)	48	-351.09 (±2486.83)	-1073.19, 371.01	0.12	Trivial	605.97
Banded Bench Press						
Mean Velocity (m/s)	131	-0.02 (±0.09)	-0.03, 0.00	-0.06	Trivial	0.04
Peak Velocity (m/s)	131	-0.02 (±0.11) *	-0.04, -0.00	-0.10	Trivial	0.04
Concentric Mean Power (W)	131	-94.24 (±164.54) *	-122.69, -65.80	-0.67	Moderate Decrease	35.99
Concentric Peak Power(W)	131	-165.49 (±361.59) *	-227.99, -102.99	-0.56	Moderate Decrease	73.89
Speed						
0-10m (s)	43	0.03 (±0.05) *	0.01, 0.04	0.25	Small Increase	0.02
10-20m (s)	43	0.03 (±0.05) *	0.02, 0.05	0.34	Small Increase	0.03
0-20m (s)	43	0.06 (±0.7) *	0.04, 0.08	0.40	Small Increase	0.02

4.2.4(ii) Unit Analysis

Unit analysis (Backs vs Forwards) was carried out with the use of 2-sample t-tests for the *pre- and post-values* across the power profiling test, including descriptive statistics to illustrate the mean values (±SD), 95% CI and the SWC value. These data are displayed in Table 20. A paired t-test illustrated the *pre vs post* differences for each unit, whilst a two-sample was utilised to determine if the change in power profiling scores from pre to post-simulation for the Backs was different to the change in power profiling scores for Forwards.

Unit analysis took place instead of position specific due to the low numbers of participants in some of the positions, thus preventing too small a sample size (n) available to complete statistical analysis.

Countermovement Jump

The ES demonstrates a moderate increase, for both mean and peak velocity (d = 0.20 and d = 0.21) for Backs, whilst mean velocity and mean power for the Forwards (d = -0.45 and d = -0.22) showed a moderate decrease from pre to post-simulation. The most noticeable ES for Backs was peak velocity, whilst for Forwards it was the mean velocity. Trivial ES were evident for all remaining outputs of the CMJ for both Backs and Forwards (d < 0.20). When comparing the difference in change from pre-to-post simulation between Forwards and Backs, a significant difference was evident for only the mean velocity (0.01m/s, 0.24m/s). Backs had increased their mean velocity and Forwards had decreased their mean velocity from pre- to post-simulation. The degree of change in the remaining outputs for CMJ were deemed not to be significantly different between Backs vs Forwards, using the 95% CI from Table 20. The most notable ES was illustrated in the Forwards unit, specifically for mean velocity (d = -0.45), a small decrease. When comparing Backs vs Forwards, there was a significant difference in the degree of change seen in the forwards and backs from pre to post-simulation for mean velocity (0.13m/s), with the difference lying between 0.01m/s and 0.24m/s. The remaining variables were deemed not to be significantly different from pre to post-simulation.

Banded Bench Press

All the outputs from the Banded Bench Press test showed trivial difference in post-simulation scores compared to pre for the forwards. Whereas the Forwards had either trivial (mean and peak velocity) or large (mean and peak power) ES for their change from pre to post GRIT simulation. Both values for the mean differences between Backs vs Forwards were larger than the SWC statistic for Mean and Peak Power, which supports the 95% CI in that these differences (98.69W, 197.99W and 167.70W, 393.55W respectively) were significant. The Forwards had a decrement effect from the Banded Bench Press test from pre- and post-values. The most notable ES of pre vs post values was illustrated in the Forwards, specifically for Mean Power (d = -1.02), with the descriptor large decrease. When comparing Backs vs Forwards, there were significant differences in both concentric and mean peak power (148.34W and 280.63W, with differences lying between 98.69m/s, 197.99 and 167.70, 393.55 respectively. The two variables of velocity, mean and peak, were deemed not to be significant (148.34m/s and 280.63m/s, respectively).

Speed

The 3 outputs of speed performance (0-10m, d = 0.07, trivial), (10-20m, d = 1.08, large) (0-20m, d = 0.51, moderate), for the Backs, showed a range whereas the Forwards consistently had a moderate descriptor for ES (0-10m, d = 0.45) (10-20m, d = 0.33) (0-20m, d = 0.42). For both Backs and Forwards, all three mean differences of speed performance were larger than the SWC statistic, illustrating that post the GRIT simulation all three speed tests experienced a performance decrement. When comparing Backs vs Forwards, the differences between the units were not deemed significant in accordance with the 95% CI for 0-10m (-0.04s, 0.01s), 10-20m (-0.01s, 0.05s) and 0-20m (-0.03s, 0.04s). The most notable ES of pre vs post values was illustrated in the Backs unit for 10-20m (d = 1.08), with the descriptor large increase.

Table 20. *Unit analysis and comparing Backs vs Forwards for the differences between pre- and post-values for the Power Profile, with two-sample t-test and descriptive statistics. Smallest Worthwhile Change (SWC) and Effect Size give statistical power for magnitude of change respectively. *Denotes significant differences (p<0.05).*

Power Profiling	Unit Analysis									
	Backs				Forwards				Backs vs Forwards	
	N	Mean ±SD	Effect Size	SWC	N	Mean ±SD	Effect Size	SWC	Difference	95% CI
Countermovement Jump										
Height (cm)	21	-0.19 ±3.44	-0.03	1.25	27	-0.41 ±3.34	-0.07	1.12	0.22	-1.78, 2.21
Mean Velocity (m/s)	21	0.04 ±0.22	0.20	0.05	27	-0.08 ±0.16	-0.45	0.04	0.13	0.01, 0.24
Peak Velocity (m/s)	21	0.12 ±0.48	0.21	0.12	27	-0.06 ±0.27	-0.15	0.09	0.18	-0.06, 0.42
Concentric Mean Power (W)	21	-143.96 ±740.02	0.16	180.60	27	218.60 ±602.31	-0.22	207.60	-362.55	-764.96, 39.86
Concentric Peak Power (W)	21	-459.70 ±270.28	0.15	548.80	27	-266.61 ±2682.85	0.09	632.80	-193.09	-1634.29, 1248.11
Banded Bench Press										
Mean Velocity (m/s)	63	-0.01 ±0.09	-0.10	0.03	68	-0.02 ±0.10	-0.15	0.03	0.00	-0.03, 0.03
Peak Velocity (m/s)	63	-0.02 ±0.10	-0.14	0.04	68	-0.02 ±0.12	-0.17	0.03	-0.01	-0.04, 0.03
Concentric Mean Power (W)	63	-17.24 ±58.41	-0.17	22.88	68	-165.58 ±196.56	-1.02	43.06	148.34 *	98.69, 197.99
Concentric Peak Power(W)	63	-19.82 ±164.31	-0.08	51.58	68	-300.45 ±436.20	-0.90	87.56	280.63 *	167.70, 393.55
Speed										
0-10m (s)	16	0.02 ±0.03	0.07	0.01	27	0.03 ±0.06	0.45	0.01	-0.01	-0.04, 0.01
10-20m (s)	16	0.04 ±0.04	1.08	0.01	27	0.02 ±0.05	0.33	0.01	0.02	-0.01, 0.05
0-20m (s)	16	0.06 ±0.04	0.51	0.02	27	0.06 ±0.08	0.42	0.03	0.01	-0.03, 0.04

5. Discussion

This study of collating a season's worth of GPS-Performance metrics and utilising them to identify the worst-case scenario for the physical demands of work required in professional rugby and then create a BIP-match simulation (GRIT), is a novel piece of research. The results of this study allowed; i) WCS of BIP game demands to be established for each playing position, ii) a WCS match simulation to be created using BIP and BOP durations and iii) power profile testing pre and post-simulation to determine any power performance decrement as a result of the simulation.

With the establishment of the WCS match demands using the GPS-Performance metrics, in accordance with the BIP categories (Short, Moderate, Long and Very Long) and the respective playing positions (Prop, Hooker, Second Row, Back Row, Scrum Half, Stand Off, Centre and Back 3), this study gives insight into the highest demands of match play at professional level of rugby union.

These data were then further used to create a BIP simulation to replicate such demands, with power profile scores collected pre- and post the GRIT simulation to determine the potential impact of the simulation on rugby-related power performance. The power profiling was used to illustrate the level of performance decrement, illustrated by the analysis in section 4.2.5 either by each unit (Forwards and Backs) or by position. This study illustrates that each position requires their own respective WCS demands and that no two positions elicited similar outputs, i.e., WCS match demands are highly position-specific and thus so should the training demands.

The findings from the current research illustrates the specificity required for each playing position when analysing training and game performance and the importance to treat each playing group individually. The GRIT simulation requires each playing position to replicate the demands of the WCS for the BIP duration of a single half of professional rugby union. To create this simulation, the methodology of stochastic ordering was used for each BIP category (followed by a BOP category) to total the duration of the simulation. If the GRIT simulation was completed successfully, then each position would have undergone the WCS for a single half of professional rugby union. This would mean that for every recorded metric, there would be no difference between the expected and actual values, however, differences were noted. These differences were dependant on the GPS metric *and* BIP category, therefore the simulation needs to be further considered in future research, to minimise these differences.

Rugby union is a well-established professional sport and widely researched in the literature, since the turn of its professionalism in 1995. Professionalism brought a blanket change in this sport for strength and conditioning and training modalities. Teams have strived to gain a physical advantage, in many facets, over the opposition. In particular, the methodology and approach for the physical preparation for match day. The element of conditioning appropriately to ensure players can reproduce their peak performance for games and minimise the risk of injury is of great importance and warrants such research. Therefore, having the knowledge of peak performance of games is a necessity for designing appropriately intense training. With such importance of this knowledge, there is a surprising lack of research in simulation protocols to replicate match demands, more precisely, the WCS match demands. With the previous body of research, the current study hopes to add value to this area of training and match demands, to ensure the high quality of practice is met in training, in accordance with the WCS of game demands. This study will hope to strengthen the connecting bridge between the differences shown in training vs games.

5.1 Ball-in-Play vs Whole Game Demands

To the author's knowledge, the current research is the first of its kind to establish professional club level BIP-demands, based on the WCS from matches. Moreover, the first of its kind to establish varying BIP and BOP durations, rather than a single average duration. This was then utilised to elicit the WCS for each playing position across varying BIP times. The assessment of in-game demands which only include periods when the ball is active (termed BIP) provides coaches with a greater understanding of the external demands being placed upon athletes during match play. This allows S&C

coaches to have a greater understanding of the standards set in match play, to then work towards those (or greater) when in training (Roberts et al., 2008), as the ability to replicate and repeat high intensity efforts over differing rest to work ratios has been linked to success in rugby union (Austin, Gabbett and Jenkins, 2011; Roberts et al., 2008).

BIP/ BOP times and demands have therefore been warranted as a necessity as it is during the BOP periods when players typically reset for the next phase, which inevitably decreases the demand in that specific time frame (Wass et al., 2019). When data is trimmed into BIP this excludes any period of stoppages, which can potentially create a more insightful approach of match demands being placed on the players. This in turn, allows practitioners and S&C coaches to impose more stringent targets and thresholds for training plans to better replicate the intensity evident in match play. Only a limited number of metrics, such as Total Distance and Low Intensity running, provides useful feedback in relation to the volume of activity covered regardless using BIP or Whole game durations. However, this does not truly reflect the real intensity of match-play, as certain "in-game" instances may account for fluctuations in the physical, technical or tactical intensities (Lacome et al., 2016). This will inevitably go on to depreciate the most intense periods (WCS) of match-play (Delaney et al., 2015). This may have a detrimental knock-on effect meaning the players are underprepared for when it matters most, including their physical activity profile in accordance with the requirements of the playing position. If the physical capacity of a player is not of sufficient standard to cope with the WCS of playing demands for the respective position, then the performance is likely to suffer. This information can be used for the planning and implementation for future sessions accordingly to certify the specific exposure requirements needed to play at the WCS standard. This aligns with Wass et al., (2019) who stated to produce and replicate such a conditioning stimulus then the GPS outputs for the required metrics should be dependent on the duration for the drill of choice i.e., drills lasting 40 seconds should elicit different absolute outputs than drills of 10 and 90 seconds.

Pollard et al., (2018) published innovative work with international rugby union to compare the mean and maximum BIP demands against whole game. As hypothesised, the mean and maximum BIP demands were significantly higher than the whole game averages. Mean BIP metrics significantly differed between backs and forwards, primarily with High Metabolic Load Distance (HMLD), HSR and Collisions. These metrics are shown to be high-intensity work as HMLD is the distance covered above the metabolic power value 25.5W/kg. This metric is derived from Osgnach et al., (2010) as the distance covered while accelerating above $2m/s^2$ and sprinting over 5.5m/s (19.8km/h), along the metabolic power curve of 25.5W/kg. With regards to Maximum BIP metrics, this followed suit but also included additional metrics termed m/min. Pollard et al., (2018) categorised BIP durations and variables in the following format: Mean Whole Match, Mean/ Max BIP, Mean/ Max for plays 30-60s, Mean/ Max for plays lasting 61-90s and Mean/Max for plays >90s. This makes it comparable for the present study as the researchers illustrated BIP times too (Table 2). For this reason, it is possible to only compare the BIP demands using the category Max for plays 61-90s as it is the only category which shares the end point maximum duration.

The current study utilises a refined approach, with the total distance covered in a period of 90s, with each position entitled to their own specific distance to meet for the WCS, whereas Pollard et al., (2018) separates this into Forwards and Backs. The maximum distance covered for periods of play lasting 61-90s was 143.3m/min (Forwards) and 164.8m/min (Backs), with the average of 153.0m/min. The current study established a range of total distances from 249m – 281m for a period of 90s, depending on the playing position. The lowest total distance of 249m (covered by the Prop position) in 90s equates to an intensity calculation of 166m/min. The highest total distance of 281m in 90s of GRIT (covered by the Back Row position) equates to an intensity value of 187.3m/min. This illustrates that the current study presents a higher playing demand when using m/min than that identified by Pollard and colleagues (2018). Mean values are evidently presented lower than the outputs for both BIP (106.0m/min and 111.4m/min, Forwards and Backs respectively) and Whole match values (65.7m/min and 69.7m/min for Forwards and Backs respectively).

According to Pollard et al., (2018) the intensity metric 'm/min' for the Forwards and Backs significantly differed across all BIP periods. However, their work differs to work done by Reardon et al., (2017), when they researched the WCS in locomotor and collision demands. The values with Reardon's study and the present study should link up more closely as they represent the same standard of playing ability, elite professional club level rugby union. Reardon investigated the WCS using the longest bout of play, with an average duration of 152s-161s. Again, similar to the present study, there were significant differences between sub-groups and positions. With the longer reported BIP time in Reardon et al., (2017) study, this illustrated a substantially lower m/min value. They expressed Tight five (combination of playing positions Prop, Hooker and Second Row) 109m/min with Back Row at 111m/min. This may be due to the fact that Reardon et al., (2017) had a different definition of WCS, as they analysed the average of the longest plays. In fact, all three studies have a different definition of WCS. Pollard et al (2018) define WCS as plays that involves the highest running demands. Work by Delaney et al (2015) reported different WCS demands with 154-184m/min and 122-147m/min. Again, this can be accounted for by their method of data collection and analyse, utilising the 1- and 2-min peak rolling averages respectively. It was also reported that Backs ran significantly further than other playing groups (Tight 5).

The differentiation of values from BIP and whole match values is further emphasised by Wass et al., (2019). They identified significant differences in the assessment of demands between all methods of duration analysis, including Whole Match, Mean/ Max BIP and Mean/Max BOP, for their selected metrics (m/min, HSR/min, Accelerations/ min, Decelerations/ min and HML/min).

Wass et al., (2019) noted the metrics with the largest differences between whole match averages and using the BIP method were HSR, accelerations and decelerations. Interestingly, the metrics High Speed Running and Acceleration metres (Moderate and Hard) displayed the largest discrepancy values from expected vs actual values from the GRIT simulation. Illustrating both the difficulty and importance of the selected metrics.

To counteract the large discrepancies and adjust the GRIT simulation to allow adequate exposure of the expected results, GRIT needs to be refined through future research.

In summary, WCS BIP demands offer a microscopic view of the conditioning requirements to reach, and sometimes supersede, match demands as opposed to whole match outputs. To elicit such higher demands, practitioners may wish to delve deeper into other aspects not covered in the current literature or this study, e.g., in the form of inter/ intra position competition (effect of social facilitation), pitch and simulation dimensions and more refined acceleration zone marking. The current research attempts to replicate the metric demands for acceleration metres (Moderate and Hard) through zonal marking of coloured cones (purple, Figure 2), however, the results suggest this needs to be re-examined to design a simulation where it is more feasible to achieve the WCS values.

5.2 Specific GPS metrics & Thresholds

5.2.1 Rationale of Metrics & Thresholds

The identification and application of the appropriate GPS-performance metrics is of highest value for S&C coaches/ practitioners. This not only determines the conditioning stimulus that is researched but can be used as a comparison against other studies whole completed in simulations. By monitoring the traditional GPS performance metrics for load markers, such as Total Distance, High Speed Running and Sprint Distance, in isolation, has been recognised with its limitations and how it hinders the aspiration to instil a holistic approach. West et al., (2019) explains how heterogeneity in data collection can hold research back. The advancement of technology in sport has allowed for a myriad of application and the potential integration of all avenues, however, to be become truly aligned there needs to be a global classification for thresholds and bands. With the addition of tri-axial accelerometers in GPS devices, this enhances their profile not only for applicability but also feasibility and efficiency. West et al., (2019) promoted that practitioners should go towards the "time-consuming video analysis" to get accurate and reliable outputs. Therefore, the development and enhancement of collision detection in rugby union is of invaluable importance. With such devices now providing reliable and sensitive collision data (MacLeod et al., 2018) illustrates disparity within the market for which devices are of best value. Nevertheless, GPS technology allows practitioners to use any number of metrics that is deemed most useful and relevant to their practice. Of the extensive metrics available, speed zones were determined to be of great importance in rugby union, with the most commonly used metric being High Speed Running. This metric, alongside sprint distance, can be recorded in either absolute or relative terms, with 58% of practitioners favouring absolute, 25% utilising relative and the remaining 16% implementing both (West et al., 2019). The application of relative terms helps to balance the equilibrium of distance covered at high speeds, and in turn potentially the "effort exerted", for each position. This balances the distance in terms of distance covered for each relative term speed zone, as absolute terms favours positions who can elicit faster speeds with greater ease (Back 3) compared to other positions (Props). The use of relative terms illustrates the distance covered in a comparable manner i.e., against the relative percentage of the player's recorded maximum speed. The contrast in application of relative and absolute terms illustrates the disparity across which technique to use. Moreover, High Speed Running zones have been differentiated into six categories of relative zones (40-70%, >49%, >50%, >60%, >70% and >80% of a player's maximum speed) (Wass et al., 2019; Reardon et al., 2017), absolute zones have two categories (5m/s and 5.5m/s) (Pollard et al., 2018). There has been a shift in tendencies away from relative zones towards absolute zones, with Wass et al., (2019) employing absolute zones, backing up West et al., (2019) statement of 58% practitioners using absolute terms. However, Reardon et al., (2017) study for WCS employing relative zones. The current study shares the same absolute speed zones of 5m/s (18km/h). The imbalance is also seen with the metric Sprint Distance as Reardon et al., (2017) documents this as >90% of a player's maximum speed. This illustrates the huge disparity in variation when considering these metrics. For the purpose of the present study, the researcher's implemented absolute speed zones. The benefits of this are amplified with the success of the GRIT simulation in its feasibility in use of all playing levels and comparable against other research and simulations. Using absolute speed zones (5m/s or 18km/h) allows the reader to easily compare against other studies utilising absolute speed zones of the same threshold. The drawbacks of using relative speed zones are evident in its definition, the thresholds are set at the player's speed capability. Hence, if the player's maximum speed capability improves or is negatively impacted, then both the High Speed Running and Sprint Distance outputs are not consistent due to the adjusted calculation from which they are based. This continues the debate between the use of best practice, to utilise absolute terms, relative terms or both.

5.2.2 High Speed Running

As the study by Pollard et al., (2018) utilised the same threshold for High Speed Running (HSR) (18km/h), for this reason the outputs are comparable. They stated that High Metabolic Load (HML) and HSR were significantly higher for Backs vs Forwards across the mean whole match, like Cunningham et al., (2016) and mean and max BIP periods. Although there were no significant differences between mean BIP m/min, the positional differences for both HML and HSR/min suggests that Backs cover these similar distances at higher speeds than Forwards.

The present study findings for the metric HSR follows in a similar fashion to Pollard et al., (2018) with the higher rate of HSR from BIP demands when compared to Whole Match values. The maximum output for plays lasting 61-90s is defined at 35.0m and 62.8m HSR per position for Forwards and Backs respectively. The present study's findings have greater outputs when using the same BIP category (Very Long – 90s). The Forwards max output for HSR was 116m, covered by the Second Row and 127m covered by the Centre. The Backs cover greater distances at higher speeds (74.7m HSR/min) compared to forwards (58.7m HSR/min) for the Very Long BIP category. For the Backs, the highest HSR/min output was 127m in a period of 90s (84.7m HSR/min) completed by the Centre position, whilst the highest HSR/min output was 112m in the same BIP category (77.3m HSR/min), completed by the Second Row position. Reardon et al., (2017) presented lower outputs for HSR/min with values ranging from 4.9m - 14.1m HSR/min. These differences from Reardon et al., (2017) may be attributed to the use of individualised relative speed zones at 60% max speed. Waldron, Highton and Twist et al., (2013) documented further differences in zone definition with high intensity running to be >14km/h. This may explain their outputs of high intensity running to be 17.2m/min and 14.9m/min (bout 1 and 2 respectively).

5.2.3 Acceleration

Previous research illustrates the importance of the acceleratory metrics regarding roles characterised per position, which are fundamentally related to success in rugby union (Austin, Gabbett and Jenkins, 2011; Roberts et al., 2008). The role of the Backs unit group is to utilise space, whereas Forwards contest for the ball in more contact facets of the game (Quarrie et al., 2016). This explains, simply by the positional roles, that the average distance for High intensity running in the Forwards is 6-14m (Eaton and George, 2006; Austin, Gabbett and Jenkins, 2011), therefore the Forwards acceleration capability and capacity is more important than High Speed running in respect to their playing roles (Delaney, Thornton and Pryor (2016). Pollard et al., (2018) found that there were no differences when comparing Forwards and Backs when analysing mean and max BIP accelerations ($3m/s^{-3}$ /min) and for the max BIP periods of 30-60s, 61-90s and >90s. For 61-90s plays, Forwards showed outputs of 3.2m/s/s for Forwards and 2.9m/s/s for Backs or this acceleration category. The Pollard et al., (2018) study presented this metric based as a frequency count (n) whereas the present study utilised acceleration a distance covered (m).

During elite competitive team sport match play requires substantial physiological and mechanical efforts to perform successfully. At the highest standard of match play there has been an evident proliferation in high intensity actions in team sports (Aughey., 2013) (Reardon et al., 2017). The frequency of very high intensity accelerations and decelerations are highly accountable for the overall workload however impose distinct differences for physiological and mechanical demands. Very high intensity accelerations have been proven to have a higher metabolic cost with decelerations imposing a higher mechanical load through the high-force impacts. This brings to light the question of density vs intensity, frequency or distance? Pollard et al., (2018) presented acceleration metrics through frequency, whereas the current study presented density of different magnitude accelerations, Moderate (2m/s^2) and Hard (3m/s^3). Reardon et al., (2017) presents an argument for including Repeated High Intensity Efforts (RHIE). This is defined as "*three or more sprint or collision exertions during the same passage of gameplay with less than 21 seconds between each exertion*". Front Row and Back Row forwards were reported to have higher RHIE when compared with inside and outside backs. This was due to the playing profile of these positions, in that forwards engage in an increased duration of high intensity activities and collisions such as rucks, mauls and scrummaging. The current study illustrates that the positions Back 3 and Centres covered more distance in Moderate (26m and 30m) and Hard (7m and 0m) accelerations, Sprint Distance (36m and 0m) and frequency of collisions (3 and 3) than Back Row, Props and Hooker. The position Back Row covered the highest distance of Hard Acceleration (11m) with the Back 3 taking second place (7m).

5.2.4 Sprint Distance

This study reports Sprint Distance as the total distance (m) covered above 28km/h. This definition differs from previous studies. This may be attributed to the discrepancy of methodologies and thresholds between studies. Reardon et al., (2017) utilised the individualised approach with the use of relative speed zones >90% max speed, Cunniffe et al., (2009) defined the sprint threshold to be 5.6m/s (20.16km/h), much lower than the current researcher's definition. Reardon et al., (2017) validate this by stating the Backs unit are capable of producing sprint efforts above 90% of their individualised max speed and in excess of 40m. This again differs from the current research in that the WCS for any Backs position totals to 36m sprinting. In fact, only 5 positions were required to achieve any Sprint metres (Back 3, Centre, Stand Off, Scrum Half and Hooker). Back 3 is the only position required to achieve Sprint metres in all BIP categories. The total distance covered whilst sprinting varies for all 5 of these positions. With respect to the Backs unit position, the Back 3 covering the greatest distance at 310m and Centre covering the least with 45m. The Hooker was the only position in the Forwards unit to cover any Sprint metres, with a total value of 34m. All remaining

Forward positions were not required to cover Sprint Distance for the entire duration of the GRIT simulation. This differs to Waldron, Highton and Twist., (2013) stating that the peak speed achieved for Forwards in Super League matches to be 26.9km/h and 26.0km/h (achieved in bout 1 and 2 respectively). This value is inferred to be lower than the current research as the Sprint Distance threshold in set at 28km/h, with multiple positions achieving distances whilst sprinting.

The positions that did not require to achieve Sprint metres were required to achieve high metres of both acceleration magnitudes, illustrating the upmost importance of including acceleration-based metrics for WCS match play. This is echoed by Reardon et al., (2017) by the lack of Sprint Efforts in their WCS demands, averaging at 0.03 efforts across all playing positions (Tight Five Forwards, Back Row Forwards, Inside Backs, Outside Backs).

5.2.5 Collisions

The metric for collision load and collision count is also important, with respect to the capability and capacity with the relevance to position specific tasks and success in rugby union (Jones et al., 2015) (Reardon et al., 2017). Therefore, it is intrinsically important to utilise a holistic approach when analysing the level of fatigue, rate of perceived exertion and decrement in performance for running based metrics and collision analysis. The influence of collisions for rugby performance tasks and pacing strategies have been previously researched (Morel et al., 2015) (Johnston et al., 2014) (Mullen, Highton and Twist, 2015) which demonstrates significant changes to movement patterns and style of play. This is especially true in the Forwards unit group as they are involved in ~89 static or collision actions throughout a game (Roberts et al., 2008) which equates to approximately 30% of all activity. Pollard et al., (2018) illustrate a significant difference between Forwards vs Backs over whole match analysis alongside mean and max BIP periods. Pollard et al., (2018) used GPS technology which detected collisions over a whole match to be 0.51 and 0.27 collisions/min for forwards and backs respectively. Like the current study, Lindsey et al., (2015) utilised the TMA method to detect collisions who illustrated 0.56 and 0.36 collisions/ min for Forwards and Backs respectively. The methodology of utilising TMA for collision detection is shared with the current researcher methodology alongside other studies (Roberts et al., 2008) (Austin, Gabbett and Jenkins, 2011) (Reardon et al., 2017). Although collision-based analysis has been detected and validated by GPS devices (MacLeod et al., 2018).

The technology used at the time of testing was not capable of detecting accurate collision counts, as stated by Reardon et al., (2017). However, further growth and requirement for collision-based metrics has brought to light the need for reliable and accurate data in the detection of collisions (count) and alongside the collision load (AU). This advancement and implementation of GPS technology can potentially close the gap for collision-based analysis and replace the traditional method of TMA with confidence. Positive strides have been taken to achieve this in rugby union in measuring different types of collision (MacLeod et al., 2018) and collision load (Tierney, Blake and Delahunt, 2020). MacLeod et al., (2018) illustrates the technology devices today can accurately, sensitively and specifically identify collision events with a high degree of confidence (93.3%, 93.8% and 92.8% respectively). The technology applied is a valid tracking device which can differentiate between varying styles of collisions alongside the respective load to be utilised collision events in training and matches. This bridges the gap in data reliability of collisions from GPS devices, in which TMA might cause disparity when utilising in conjunction with GPS devices. For TMA analysis to be used effectively and made comparable against other research, the inclusion definition of a collision/ contact must be shared.

The knowledge and perception of performance decrement, levels of fatigue and increased rate of perceived exertion when considering collision-based metrics alongside locomotor metrics aligns with the rationale of the current researcher's definition of WCS. A holistic approach must be considered with all performance metrics, as opposed to locomotor metrics only, to determine the definition and subsequent analysis for the WCS.

5.3 Feasibility of Glasgow Rugby Intermittent (GRIT) Simulation

The GRIT simulation was aimed for each rugby union playing position to complete the WCS of the BIP demands, through stochastic ordering of varying BIP categories of different durations. This was extended from the thoughts from an earlier study BURST (Roberts, Stokes, Trewartha, 2010) in that participants completed this in the style of shuttle runs, with varying acceleration and sprint zones, to make up the demands of GRIT. The flow of BIP categories were in the form of stochastic ordering, adopted from RLMSP-i (Mullen, Highton and Twist, 2019), although this was designed to replicate the mean movement speeds, distances and durations as opposed to the WCS chosen by GRIT. The participants were instructed to run alone for the duration of the simulation, to defect any pacing strategies, and followed and audio cue which dictated the specific movement instructions which matched up with specific-coloured cones. The duration of the RLMSP-i lasted 46mins. This corresponded to two bouts of 23mins activity with 20mins of passive recovery to emulate half time. This methodology may simply not be feasible and easily replicated in a professional rugby union environment, where the squad size commonly consists of 40+ players and to accurately test each one of them requires extensive kit, equipment needed and staff power per test. In addition, the specificity and accuracy for timing of the audio cues is difficult and may lead to overlap, causing confusion for the logistics of the simulation. This leads to players being in the wrong stage of the simulation. High specificity for all of the stages noted is required, to ensure all stages of the simulation are met accordingly.

The RLMSP-i simulation was designed to re-create mean movement demands of interchanged players, which produces a total of 100m/min, 1 contact/min and mean HR response of 85-90% HR_{max}. Specific metrics of interest were Total Distance, Low Intensity Running distance, High Intensity Running distance, Peak Speed, sprint to contact speed and time spent (s) at high metabolic power (>20w/kg). GRIT analysis included the Total Distance covered in addition to different magnitudes of acceleration distances (Moderate and Hard), with HSR and Sprint Distance. No measure of metabolic power was recorded, although previous studies have utilised this metric (Waldron, Highton and Twist, 2013) (Pollard et al., 2018) or metrics using a combination of sprint and collision (RHIE) by Reardon et al., (2017). The inclusion of sprint speed into contact reflects i) the level of intent into contact and ii) the rugby specific element where sprints occur in a match. As this simulation was aimed at the unit group Forwards, this is more likely the element of rugby performance where high speeds are gained, as opposed to backs who achieve high running speeds when utilising the space in attack/ defensive plays.

The current research is therefore not a study to determine to reliability, validity, and replicability of GRIT. The current study attempted to identify the WCS demands using BIP analysis and to produce a match-play simulation and test its feasibility in rugby training environment. Further research is needed on the GRIT simulation to address some of the practical challenges of implementing the simulation and to test the validity and reliability of the simulation through more testing opportunities.

5.3.1 Stochastic or Fixed Movement Patterns

With any training simulation, aiming to replicate and control the environment is imperative for reproducibility of the simulation stimulus. This has warranted such research into simulations that are laboratory treadmill based (Drust, Reilly and Cable, 2000) (Abt, Raeburn, Holmes and Gear, 2003). With this rationale the iSPT was created to replicate the playing demands of football (Aldous et al., 2014) on a non-motorised treadmill (NMT), this differs to motorised treadmills in that the latter is limited by ecological validity by the inability to express maximal running speed (Williams, Abt and Andrews, 2010). Utilising the NMT for simulation protocols allows for performance decrements and therefore performance quality to be analysed.

The iSPT is comprised of two 45 minute halves separated by a 15-minute interval, using the whole match methodology rather than BIP. Each half consisted of three identical cyclical blocks with 5 movement categories of varying movement speeds (stand, walk, jog, run, fast run, variable run and sprint). To keep on track with the expected running demand, there was a computerised red line within visual sight to help aid the participant through the simulation protocol, displaying the target speed and current speed, with the aim to match the red line. Audio cues were also presented to help with the 7 varying movement categories. Prior to a change in movement speed category, an audio cue was given in the form of a 3-beep notification before announcing the movement category.

The GRIT protocol differs from this. Firstly, the venue of GRIT was on the playing fields of the professional rugby union team in question. This venue was where they had regular training and matches, so they were familiar with the surroundings and dynamics of the pitch. By having it outdoors allows the unpredictability of randomised movements, such as cutting agility movements, accelerations/ decelerations and contact. These movement patterns and characteristics of rugby performance is of imperative importance, signifying the need to be performed outdoors. With the use of highly advanced microtechnology, GPS devices allows for accurate and reliable outcome measures of simulation performance.

Similar to other simulations GRIT had audio cues in the form of the 2 researchers, the call commander and timekeeper. Their roles were to give audible cues through the GRIT simulation in accordance with Table 6 and Appendix 12. Further investigation is needed to test the reliability of audible cues in the form of call commander and timekeeper rather than an audio cue from a CD signal.

5.3.2 Power Profiling vs other studies

Power Profile scores were used to quantify the performance decrement from the GRIT simulation. There were 3 categories to measure performance, CMJ (lower body and CNS), Bench Press (Upper Body and Power) and Speed Tests (Whole body, CNS).

Baseline scores were used as a comparison against the scores post GRIT simulation.

RLMSP-i examined Neuromuscular function of the knee extensors through an isokinetic dynamometer, with two isometric contractions at varying intensities (50%, 80% and 100%) of their maximal voluntary contraction. The respective results illustrated the high accuracy of results when simulations used with or without a rugby union tackle (Pointon & Duffield, 2012). Such analysis could not be used in the GRIT simulation due to highly specialised and expensive equipment. The rationale and methodology of the equipment used in the power profiling for the GRIT simulation is widely used across professional rugby union clubs and can be altered if it needs performed for more budget researchers. Equipment to test CMJ parameters (height) and speed tests are widely available to most researchers today.

5.3.3 Additional Physiological & Cognitive Markers

Throughout most simulations, external load (measured by GPS devices) was not the only measurement of fatigue. Another measurement of subject difficulty and cognitive perception used was Rating of Perceived Exertion (RPE) (i.e. in BURST, RLMSP-i protocols) and the Stroop test (RLMSP-i). These methods have been well documented to quantify the individualised perception of difficulty/ challenge to sports performance and exercise prescription ((Impellizzeri et al., 2004) (Birk and Birk, 1987). The Stroop test is a neuropsychological test that requires participants to identify the colour of a word as printed on the screen. These words are textual version of colours themselves, e.g. the word yellow is written in blue text. The participant would have to say the colour blue and not the word yellow ('Say the colour, not the word'). This is repeated for a number of different word-colour combinations and the time it takes the participant to complete the test without error is recorded. The outcomes of this test are twofold i) reaction time (s) to complete 80 correct attempts and ii) accuracy of attempts to complete the required 80 questions (number of attempts). RPE (Borg, 1998) uses a scale from 6-20 as a way of measuring an individual's perception of exertion. Using these additional measurements of perceived effort for analysis, in conjunction with power profiling scores, may help illustrate the level of performance decrement from GRIT. Whilst the participants in this study appear to not have been greatly impeded (showing fatigue-resilience) after the GRIT simulation, this was in physical measures only. Additional cognitive measures could be added to more completely capture the idea of fatigue-resilience.

5.4 Strengths and Limitations

This study evaluates a novel approach in the holistic understanding of game demands and replicating this through a simulation protocol in professional rugby union. In addition, power profiles have been created to determine any fatigue-induced performance decrement from pre- and post-values of the GRIT simulation. This holistic and comprehensive approach evaluated which positions displayed differences from the expected vs actual values of GPS metrics from the simulation in accordance with their respective WCS demand for each BIP category (Short, Moderate, Long and Very Long).

Using the same squad and respective players in each position brings to light the robustness of the current study in that the same club and players were used for both the collection of WCS demands (2017-18 season) and the players used for the GRIT simulation (2019-20 season). Previous studies used multiple players from different clubs, but all in the same league to get such availability for each playing position (Cahill et al., 2013; Quarrie et al., 2013). This methodology of the inclusion of players from the same squad and using players from each position will show a true representation of the WCS demands and subsequent fatigue through the power profiling as these demands are specific to the chosen club. If players from different clubs were recruited to the present study, this would not give a true representation of the accuracy of WCS and subsequent fatigue resilience of power profiling from the GRIT simulation. In addition, if there were recruited players from other clubs, the WCS demands may be either too difficult to achieve or too easy to replicate, enhancing the pacing strategy conundrum as previous mentioned. The application of simulation methodology, in a shuttle run fashion, allows the practitioner to know exactly the physiological cost and demand being placed on the participants, through pre-determined distances covered and organised contact elements. However, the high specificity and organisation can lead to robotic movements from the participants due to a learned effect. This gives power to the stochastic ordering methodology.

Robotic movements from the pre-determined performance targets of the GRIT simulation could potentially lead to pacing strategies. This could question to reliability of the simulation, is the GRIT simulation truly fatigue inducing when performing the

WCS? To counteract this potential limitation, participants could have been instructed to perform the simulation alone as shown in other studies (Mullen, Highton and Twist., 2015). The researchers for the current study chose the participants to perform the simulation together as a whole. This was due to feasibility and time constraints as the simulation was performed in season, with the S&C coaches not wanting the simulation to be performed on multiple occasions due to the performance calendar, the participants professional rugby commitments to training and selection for games. Not to mention, the increased risk of injury as the simulation targets the WCS for each position. However, the researchers acknowledged that the methodology of all participants performing the simulation at the same time could be a limitation. Research has shown that pacing strategies can be indicative for energy preservation when the participants know high intensity activity activities are due to occur and for greater execution of fundamental tasks. However, with this knowledge, this was taken into consideration by the current researchers. Appendix 11 illustrates the analysis taken to analyse if the simulation was fatigue inducing or was a pacing strategy noticed throughout.

Scatterplots were used determine if there was evidence of a pacing or fatigue effect across the GRIT simulation. Differences in actual and expected output, throughout the simulation, were plotted across the duration of the simulation. Appendix 11 demonstrates the BIP Period number as a continuous variable (x-axis) against the differences in the expected vs actual values for the 5 GPS-metrics. The performance metrics Total Distance (A), Moderate Acceleration (B), Hard Acceleration (C), High Speed Running (D) and Sprint Distance (E) were plotted for each BIP category (Short, Moderate, Long and Very Long). This was to determine if the difference in what players actually completed versus what was expected of them based on the simulation, and if it reduced or increased as the simulation progressed.

A line of no change (line of identity observed) gave a reference line to determine where there were no differences between the expected and actual values for each metric. A linear regression line (solid line observed) illustrated the relationship between the BIP number (x-axis) and the difference of the specific GPS-Performance metric (y-axis). This exemplified the trend of differences from the expected and actual values for the performance metrics, as the GRIT simulation progressed from the first BIP period to the last BIP period. The differences between the expected and actual values needed to be analysed to see if there was a fatiguing/ pacing effect. As the differences from the continuous x-axis are consistent, the researcher analysed if the BIP category was accountable for the differences.

The present study aims to test the feasibility in creating a simulation to replicate the WCS match play demands using BIP times. GRIT aims to create a simulation's methodology which is feasible in any environment and not needing highly specialised equipment such as NMT and dynamometers. A weakness of the GRIT simulation is that it lacks reliability as it was only performed twice to the playing group and subsequent analysis does not show the levels of replicability. Future research is therefore warranted for the continuation of the GRIT lifecycle, to test the reliability, validity and repeatability.

5.5 Practical Implications & Future Research

The GRIT simulation provides a novel approach in bringing together the data and practical application, which can easily get lost in translation and practical relevance. The current GRIT simulation requires a full-sized rugby union pitch, but upon further refinement, this could be reduced to smaller sized areas in order to reduce the differences seen from the expected vs actual values. Most notably, future research requires the simulation to enable an increase in acceleration distances (over both Moderate and Hard magnitudes) and decrease in amount of HSR distance. This could potentially be achieved by the reduction in pitch size/ testing area, as it potentially creates greater opportunity for acceleration style movements and less distance covered in HSR distance. A refinement in the acceleration zone would potentially help decrease the differences expected and actual.

The equipment to complete GRIT is readily accessible and does not require specialised apparatus, such as NMT. This is useful when future researchers are seeking an exercise protocol for the WCS demands of all rugby union playing positions. As such, it is evidently important for participants to complete a period of habituation in addition to keep the contact element controlled.

One thing that "match day" provides in which no other setting can replicate is the match-day emotion. This brings to light the psychological elements to replicate the feelings on game day: e.g., the feeling of preparedness and fighting for your club and team-mates against any opposition. Match day routines and rituals are highly individual and a personal process for a player to be prepared in the best light as possible. In order to replicate such playing conditions and emotions, future simulations may wish to include a competitive edge. Although previous research has gone against this idea (Mullen, Highton and Twist, 2015) as it leads to pacing strategies, a points system could be on offer for how well (i.e. how close to the required content) the athlete completes the simulation. Such actions could be points given if the player complete the targeted distance at the correct time, as opposed to achieving the targeted distance too quick and/ or too slow. Either of the two latter outcomes would have a detrimental effect on the intended stimulus for each BIP category. With regards to the contact element, a competitive edge may be utilised by going 1 on 1s with positions battling against each other, such as replicating a ruck or scrum contact element. This inclusion of rugby specific elements enhances relatedness and perhaps the engagement towards the simulation. Anecdotally, the players who participated in the GRIT simulation referred to the demands like match play rather than traditional training, however lacked the competitive edge that is paramount in professional sport, not just professional rugby union.

Positive outcomes from the GRIT simulation include the players being not overly fatigued (colloquially referred to as 'smashed') and were able to complete power profiling post the simulation, as well as a further rugby skills session that same training day. This illustrated that the players who did not experience a performance decrement in the Power Profiling were physically prepared for match-like intensity through i) their ability to reproduce of explosive and power movements from testing and ii) be able to continue the rest of the day's training sessions. This also leads to the question if there were any pacing strategies throughout the simulation. Secondly, should the testing players have the feeling of being 'smashed' when completing the WCS of rugby union in a single half?

There were only performance decrements in the power profiling scores for the elements that truly fatigued each position. Future research in rugby union simulations could refine the implementation of acceleration and sprint metrics for the BIP categories as they were the hardest metrics to achieve in line with what was expected (e.g. marked out acceleration zones), whilst HSR was always above the intended target and super compensated. This could be targeted through colour-coded speed zones, in which the participants can achieve the intended HSR metres and Sprint Distance. Another technique could be to decrease the distance of each shuttle run to limit the opportunity to accumulate high metres of HSR, hence a reduction in the testing area/ pitch size.

Future practitioners need to be able to justify their use and application of appropriate speed bands (relative vs absolute) to make future simulations comparable for inter/ intra comparisons. If the practitioner is using absolute terms, then ensure all of the participants are able to achieve the bands set. i.e., all participants have a maximum velocity of at least 28km/h and able to achieve metres of Sprint Distance.

Future research is required to test the reliability and validity of GRIT simulation once the testing area/ pitch size, acceleration and sprint zones have been refined to meet the intended WCS value. Performing the GRIT simulation, whilst wearing GPS device, on 2 separate occasions will allow for the GPS metrics to be compared between 1st and 2nd run of the GRIT simulation. Player's GPS metrics can be compared between the 2 runs and no GPS metric should produce any difference between the 1st and 2nd run. Intra-player comparison will determine reliability. Completing testing in more than 1 player of the same position grouping would also be useful. This would allow for inter-player (position- specific) comparison. This would shed some light into how repeatable GRIT is in i) a professional rugby union environment with a large population and ii) an amateur environment where there is less opportunity for specialised equipment and apparatus.

This brings to light the differences between the sample size shown in Table 14, ranging from n=272 (short BIP category) to n=48 (very long BIP category). Ideally, the comparative sizes would be similar for a fair comparison. However, this is what was recorded as the number of occurrences for each respective BIP category (short = 272, moderate = 192, long = 112 and very long = 48). The small sample size, particularly for the very long BIP category, was due to the data collection period taken from a single season (2017-18), with no opportunity to increase the number of very long BIP occurrences (n=48). To increase the sample size number, the GRIT simulation needs to be repeated on more occasions. This will increase the sample size number in an attempt to increase the statistical power. 95% CI were included in the analysis to increase statistical rigour and show a range of credible values.

5.6 Conclusion

This study was the first of its kind to report the WCS playing demands for every position in elite rugby union, across different durations of BIP periods. This was then accumulated together in the formation of GRIT simulation. Data collection was across a full playing season (2017-18) in professional club level rugby union. The GRIT simulation shows promising application in any phase of rugby playing level, from grassroots to elite professional, with the rugby specific content and limited amount of specialised kit being required. This is also novel research in its attempt to implement this into a match specific BIP simulation to replicate the WCS match demands. This allows for a deeper understanding in the physical demands imposed on elite club level rugby union, in which there are now standards set, per position, to supersede previous training thresholds. The increase in specific relevant physical load helps practitioners and S&C coaches to reduce the amount of unnecessary physical load being placed during training, which may in turn help to balance the management of fatigue and risk of injury. This knowledge, coupled with increased synchronisation of technical and tactical game applications, allows greater scope of precision to execute decision making skills superseding their previous training thresholds, now mimicking match intensities, which will ultimately avail in future improved match day performances.

Future work is needed to refine the GRIT simulation in order to meet more closely the required elements, such as acceleration and sprint zone markings alongside future reliability and validity studies for further replications.

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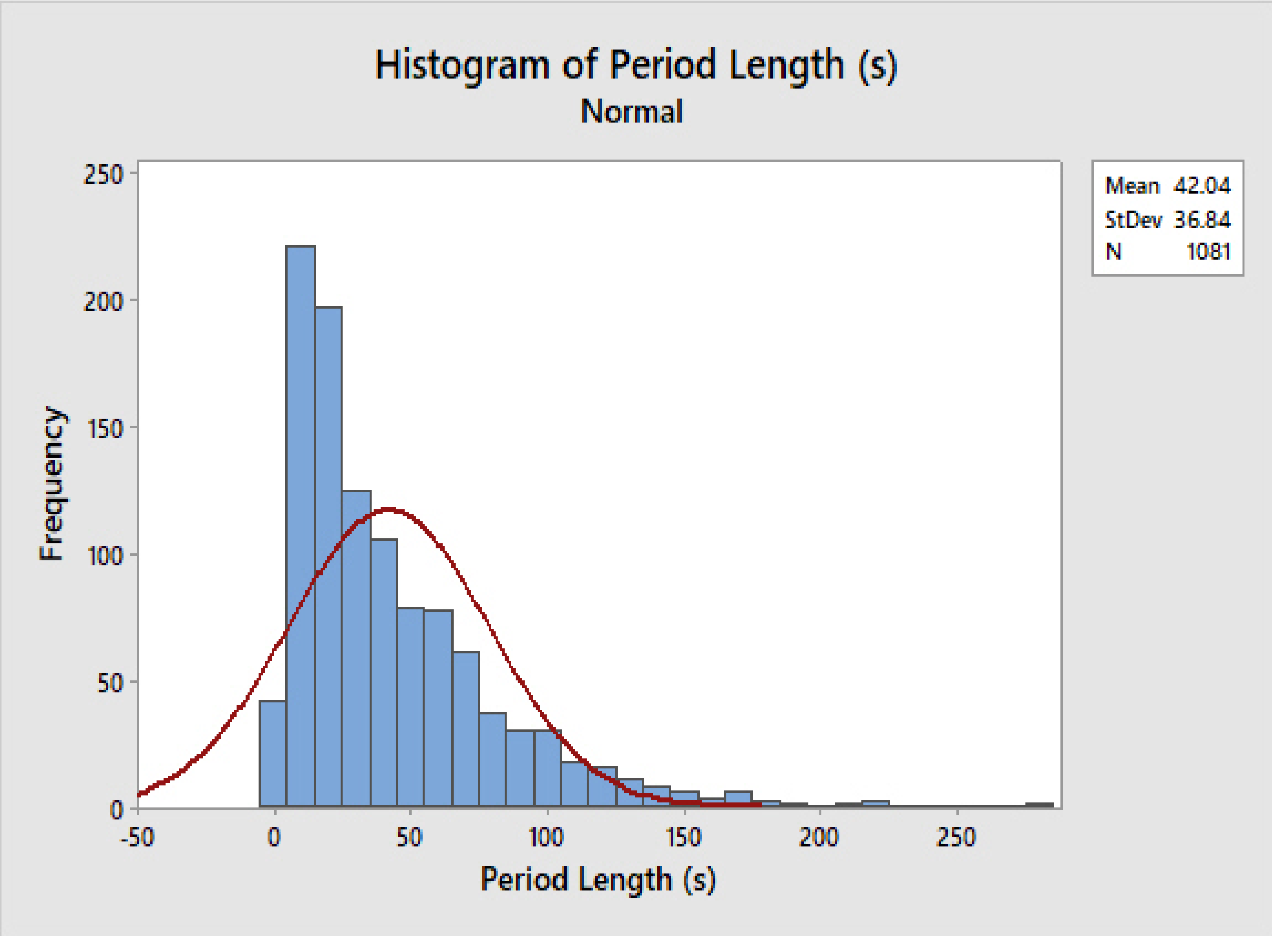
7. Appendices

Appendix 1: *Systematic Review of Studies*

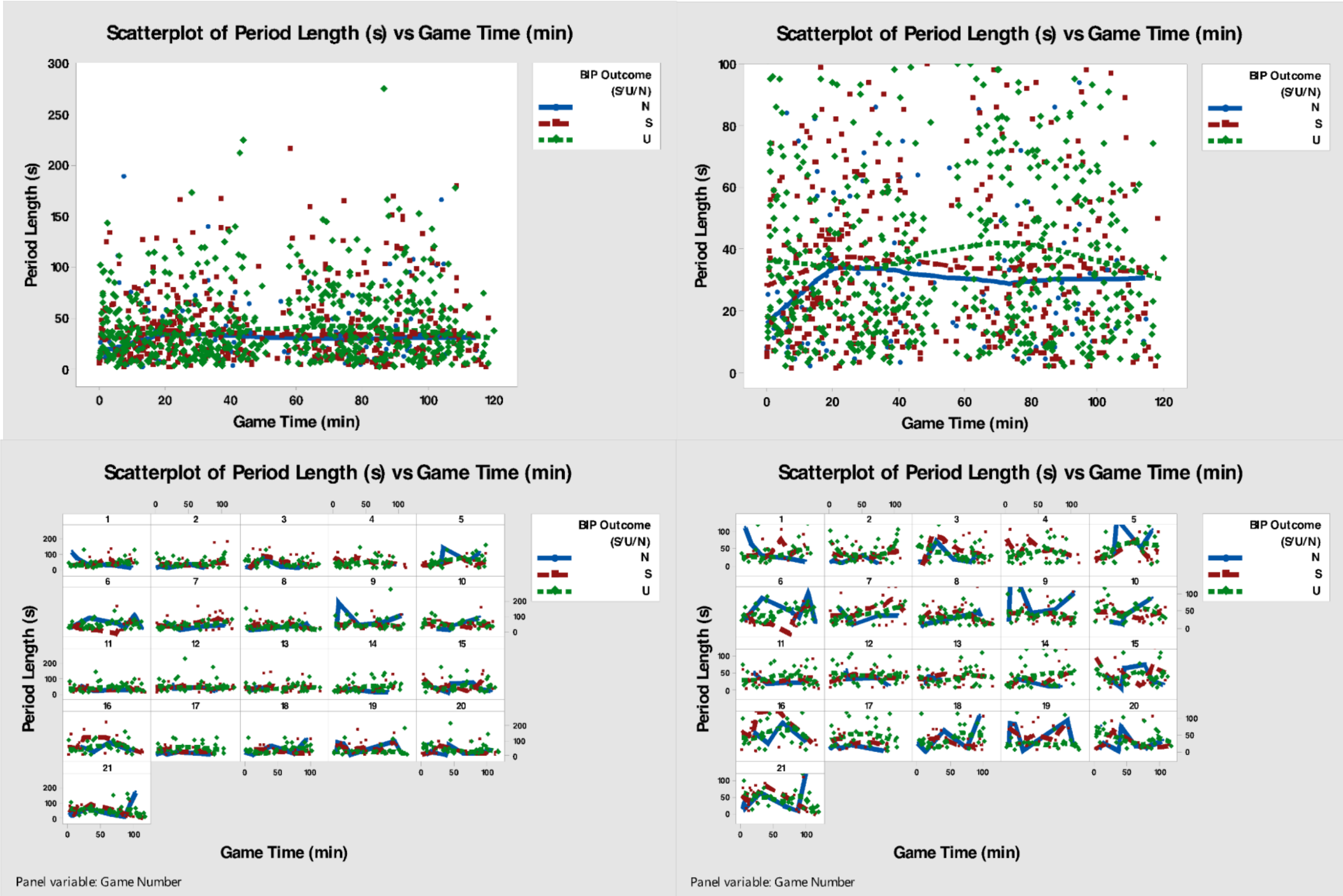
Reference	Subjects	Tests	Procedures	Findings	Conclusion
Dobbin et al., 2018	N = 36 (academy n= 20, university = 16) (rugby league)	Prone YoYo Intermittent Test (YoYo-IR1) RLMSP-i	YoYo-IR1: 40m shuttle (as many as possible) with 10 seconds active recovery. Directed by audio signal RLMSP-i (2x23 minute rugby league movement simulation protocol)	YoYo-IR1 distance associated with RLMSP-i running performance to maintain peak and repeated sprint speeds. It is related to player's internal/ external and perceptual response. RLMSP-i can be used to assess rugby specific High Intensity activity	Accurately simulated demands of rugby league.
Stone et al., 2014	N = 8 (Division 1 soccer)	Soccer Simulation Protocol	Match play specific timings (6x 16-minute sets with 3 minutes rest between sets). x8 cycles and 1 repeated sprint (6x15m sprint every 18s) block between cycles 4 and 5.	Playing surface did not affect pattern of play and recovery, although sprint performance was affected.	Accurately measured soccer match play demands.
Mullen, Twist and Highton (2019)	N = 20 (university rugby league)	MSFT (estimate VO_{2max} pretesting) RLMSP-i	RLMSP-i (2x23 minute rugby league movement simulation protocol) designed to replicate mean movement speed, distance and playing times of interchanged rugby league players. Players ran alone and followed instructions from an audio cue.	Movements tested and subsequent metrics: low intensity activity, high intensity activity, high speed running, peak speed, sprint into contact, PlayerLoad and time spent at High metabolic power >20W/kg (s).	Stochastic movement characteristics had no detrimental effect on reliability of HSR.
Greig and Siegler (2009)	N = 10 (professional male soccer)	Soccer-specific intermittent treadmill protocol	Aim: Replicate the average activity profile of soccer match play. Totalled 90 minutes of activity with 15 minutes passive interval for half time.	Used to demonstrate mechanical demands of intermittent running, replicating short duration bouts and valid frequency of speed change. Maximum treadmill acceleration limited to	Accurately simulated the activity profile of soccer. Did not take into account random sport specific actions but as cuts,

				2m/s/s. Constant 2% gradient used to account for energetic cost of outdoor running.	accelerations and decelerations.
Kunz et al., 2019	N = 11 (youth soccer)	Simulated soccer match	Baseline and post-tests intersected by 2x40 minute soccer match simulation Tests: CMJ (height), 30s skipping, blood Creatine Kinase concentration, Maximal Voluntary contraction and Questionnaires (ARSS, VAS and RPE)	When compared with actual match play data, this simulation lead to pacing strategies to maintain performance and prevent premature fatigue. U-shaped pattern results for agility and speed tests.	Pacing strategies revealed during both halves may have resulted from learned effect of the familiarisation period.
Aldous et al., 2014	N = 12 (university soccer)	Intermittent Soccer Performance Test (iSPT)	2x45 minute halves with 15minute interval for half time. Each half had 3x15 minute blocks consisting of stand, walk, jog, run and fast run. Instructed via audio and visual cue.	iSPT had low CV values for test-retest and therefore can be easily reproduced. Audio and visual cues given to dictate the target speed against the current speed.	iSPT does not take into account multidirectional movements – change of direction.

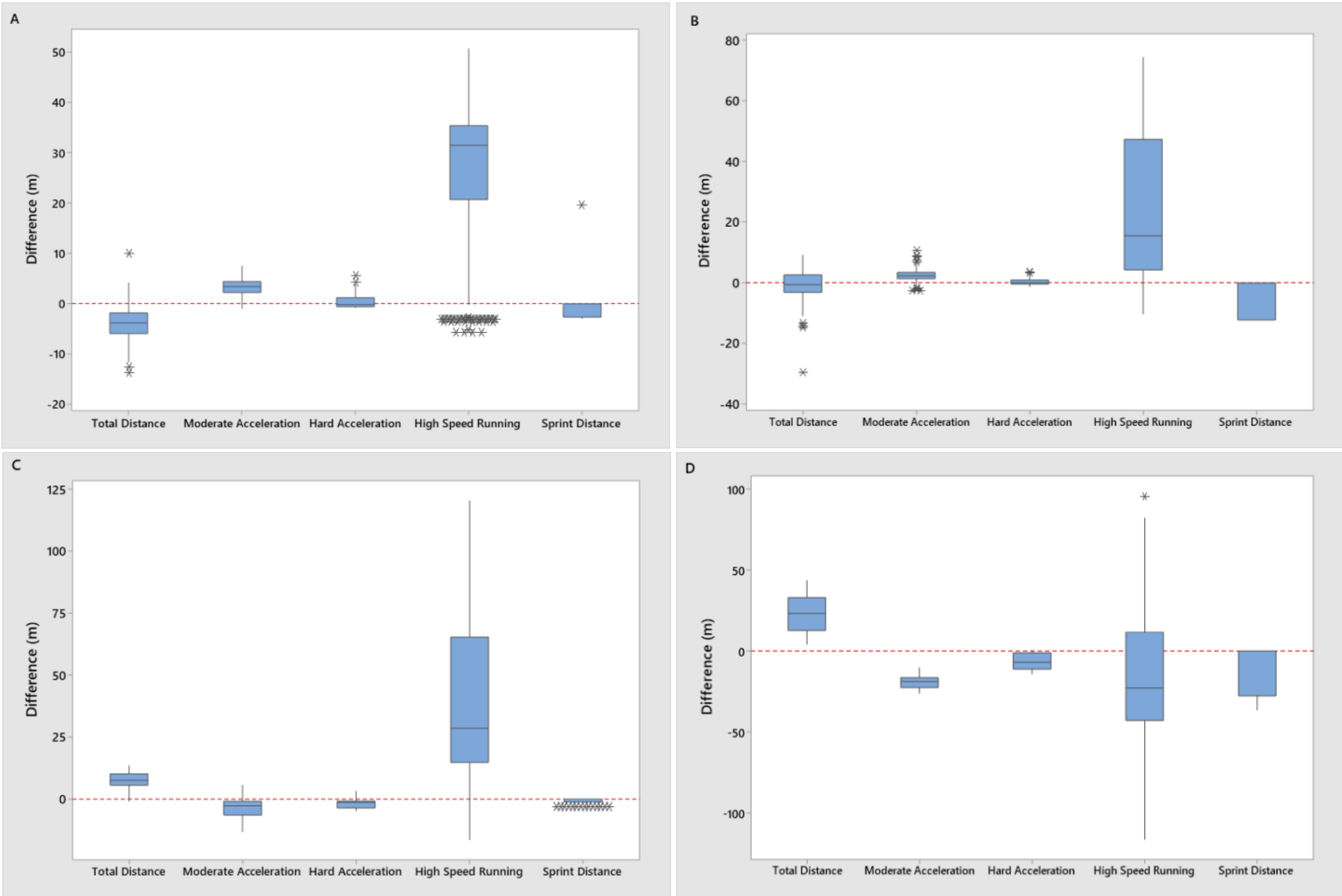
Appendix 2: *Histogram illustrating the normality curve of the BIP durations against frequency of occurrences.*



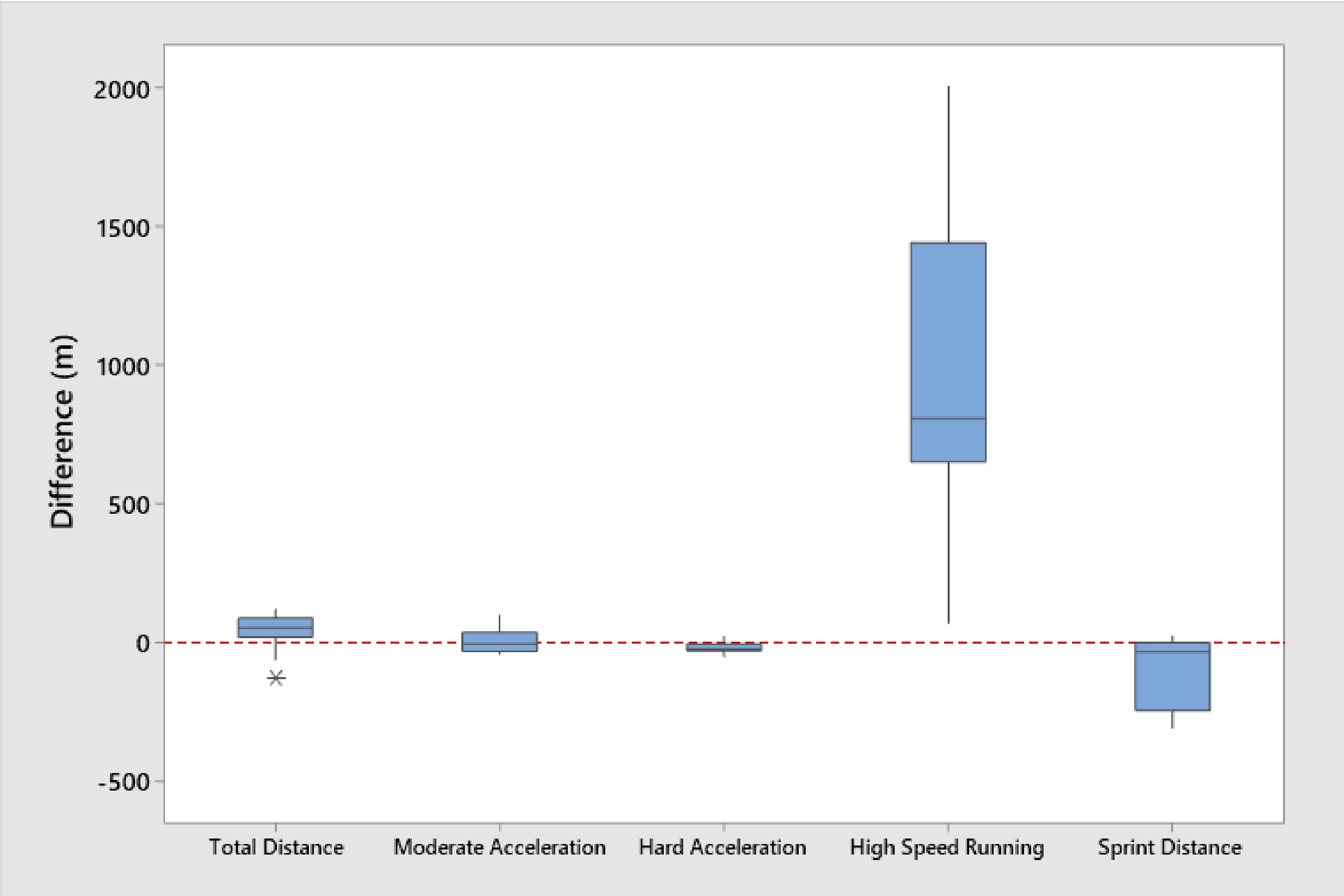
Appendix 3: *Scatterplots illustrating the BIP period length (s) against game time (mins) with varying Period Length (s) axis.*



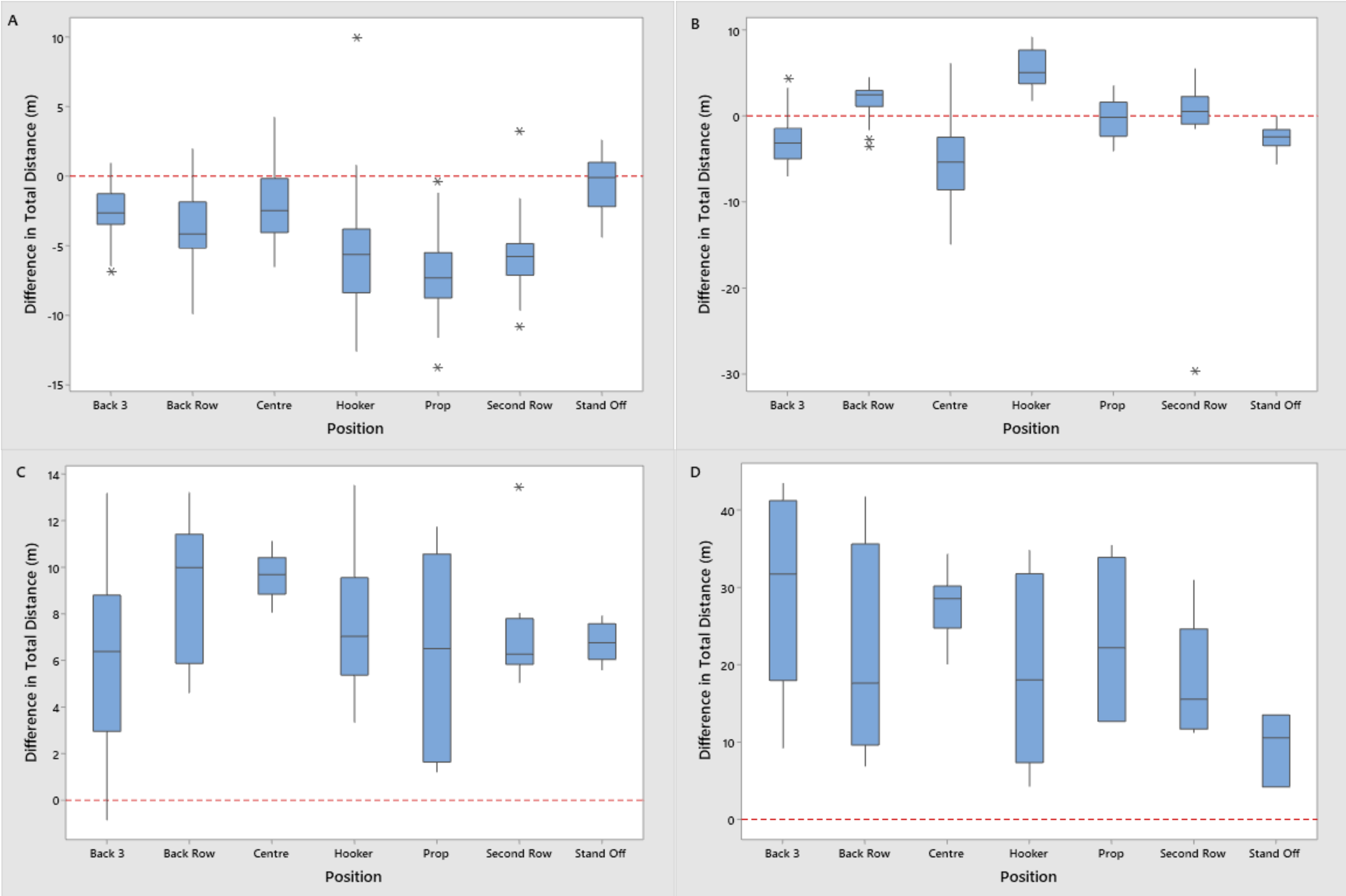
Appendix 4: *Boxplots illustrating the absolute difference (m) for each GPS derived metric with the respective BIP Category (A = Short, B = Moderate, C = Long and D = Very Long duration). A line of equality (identity line) is used to show that there is no change from expected minus actual values.*



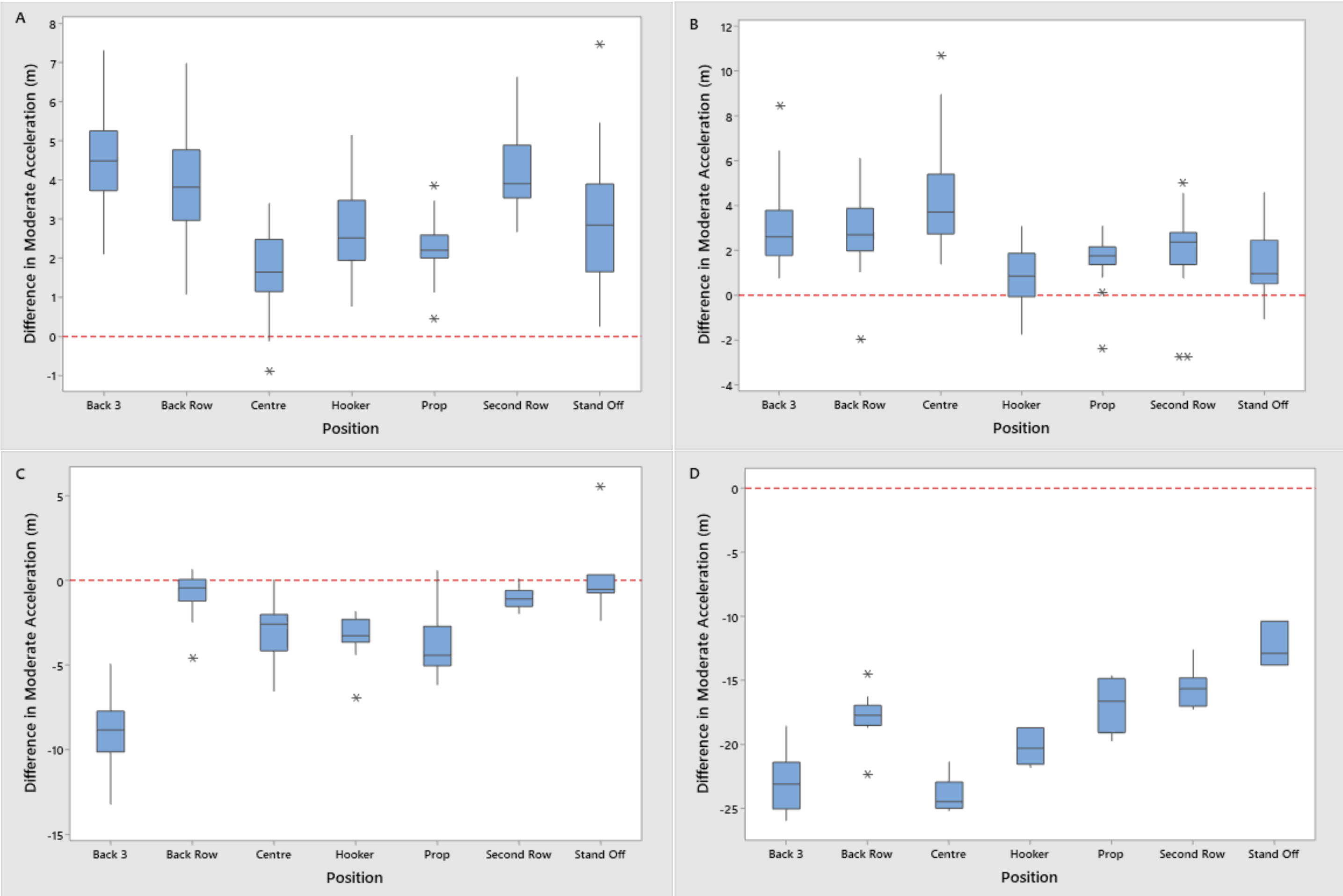
Appendix 5: *Boxplot illustrating the session analysis for the differences in 5 GPS-Performance metrics across the whole GRIT simulation.*



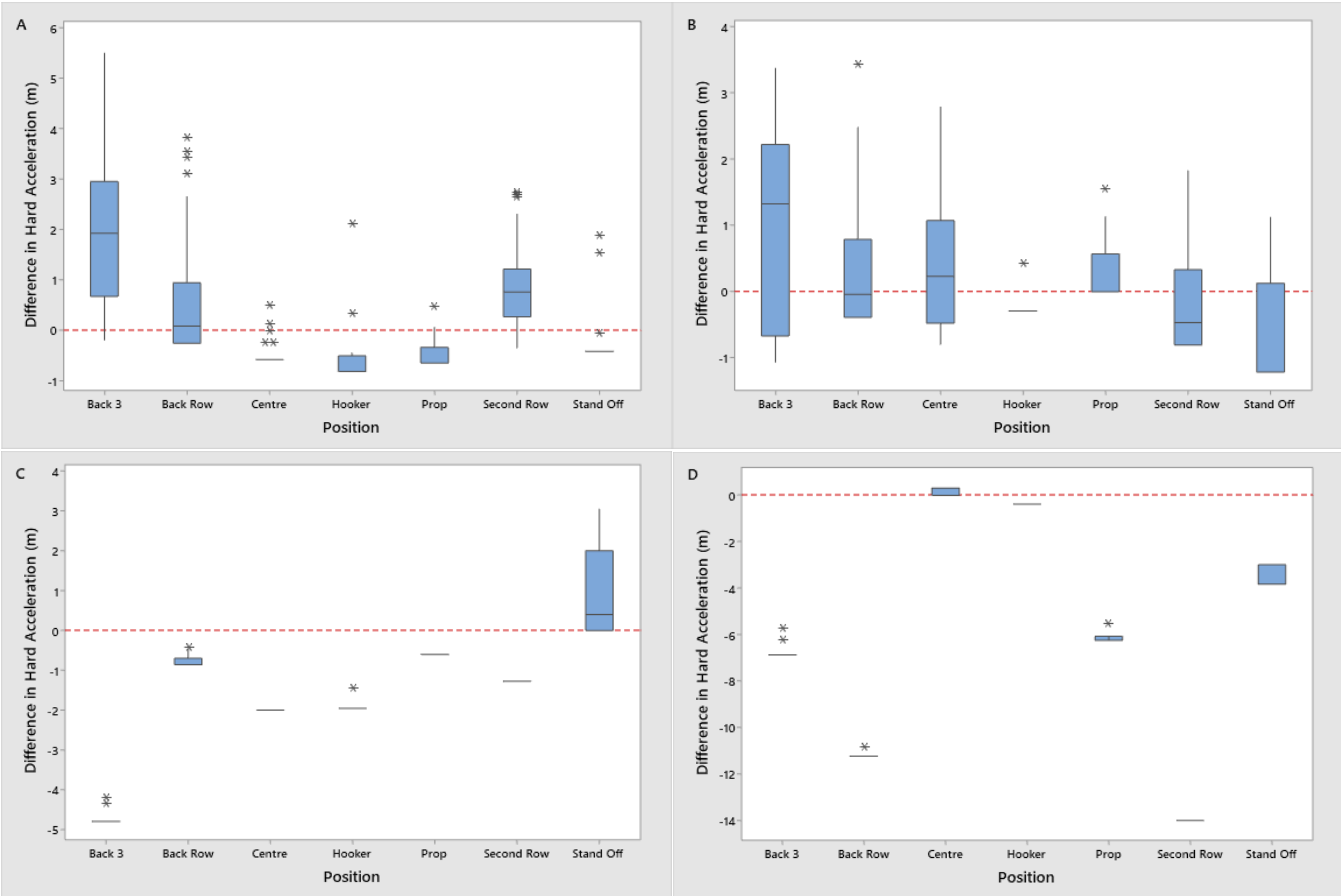
Appendix 6: *Boxplot illustrating the differences between expected and actual values for the Total Distance metric, represented by a line of no change (line of identity observed). Ball-in-Play (BIP) categories are described as Short (A), Moderate (B), Long (C) and Very Long (D) duration.*



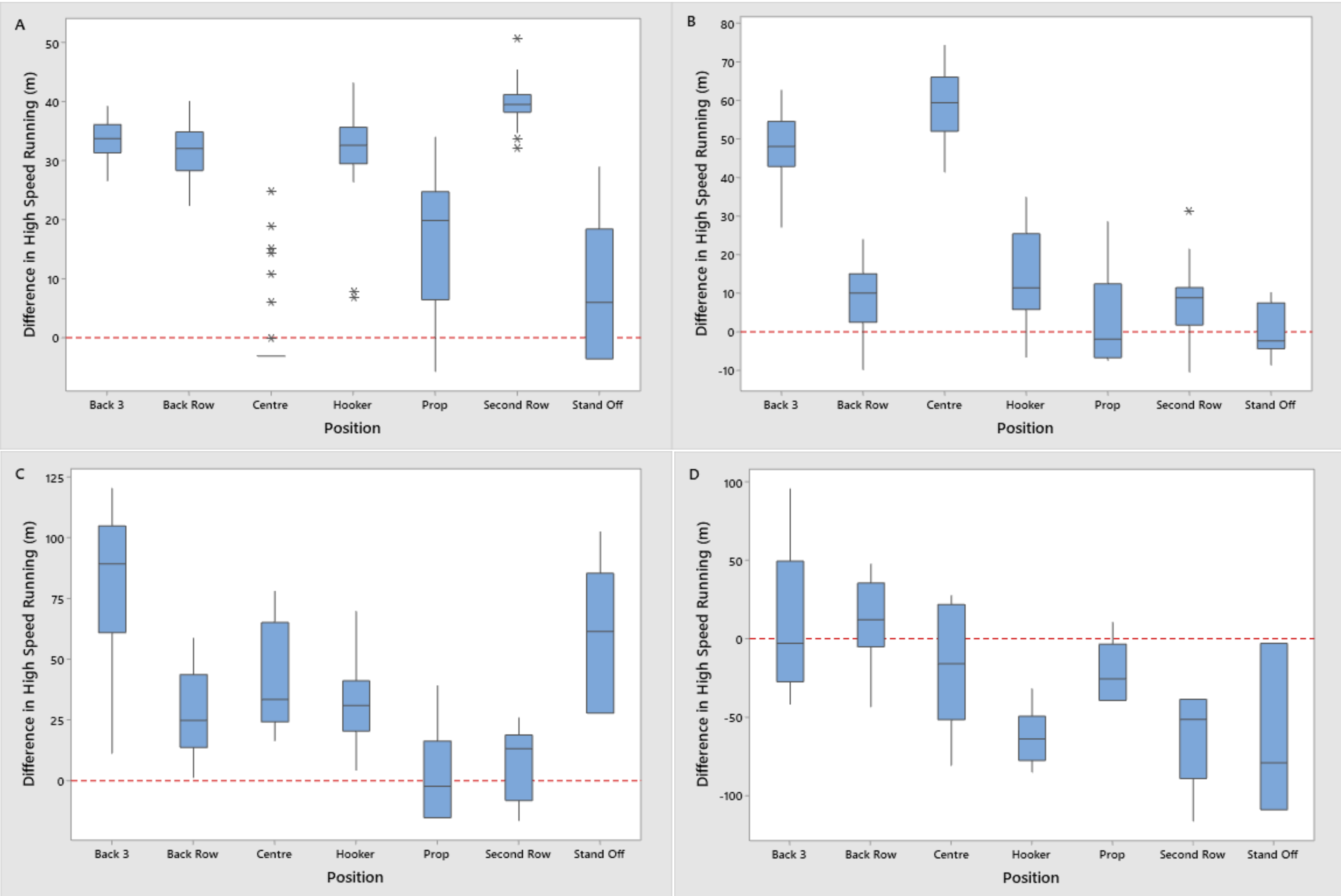
Appendix 7: *Boxplot illustrating the differences between expected and actual values for the Moderate Acceleration metric, represented by a line of no change (line of identity observed). Ball-in-Play (BIP) categories are described as Short (A), Moderate (B), Long (C) and Very Long (D) duration.*



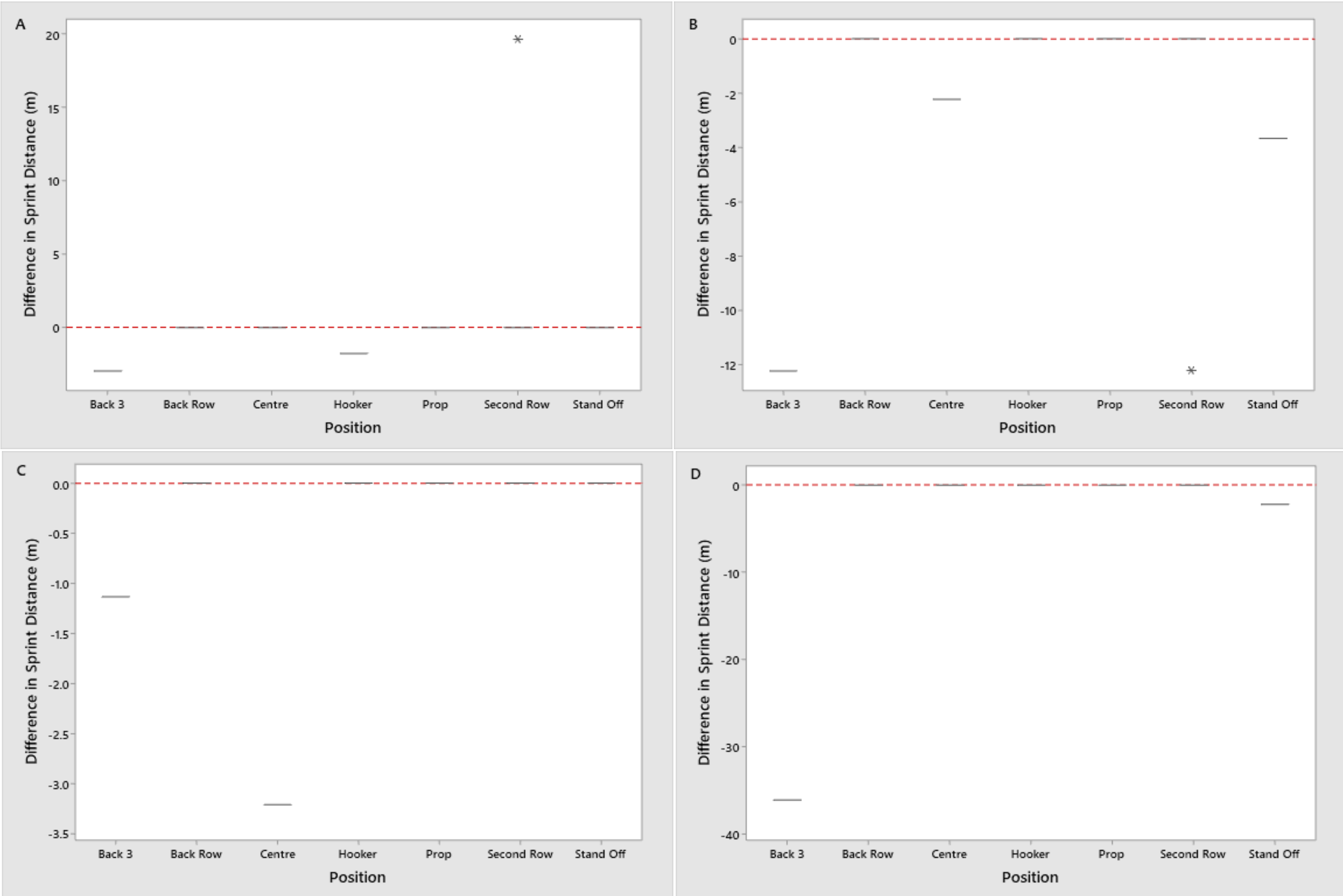
Appendix 8: *Boxplot illustrating the differences between expected and actual values for the Hard Acceleration metric, represented by a line of no change (line of identity observed). Ball-in-Play (BIP) categories are described as Short (A), Moderate (B), Long (C) and Very Long (D) duration.*



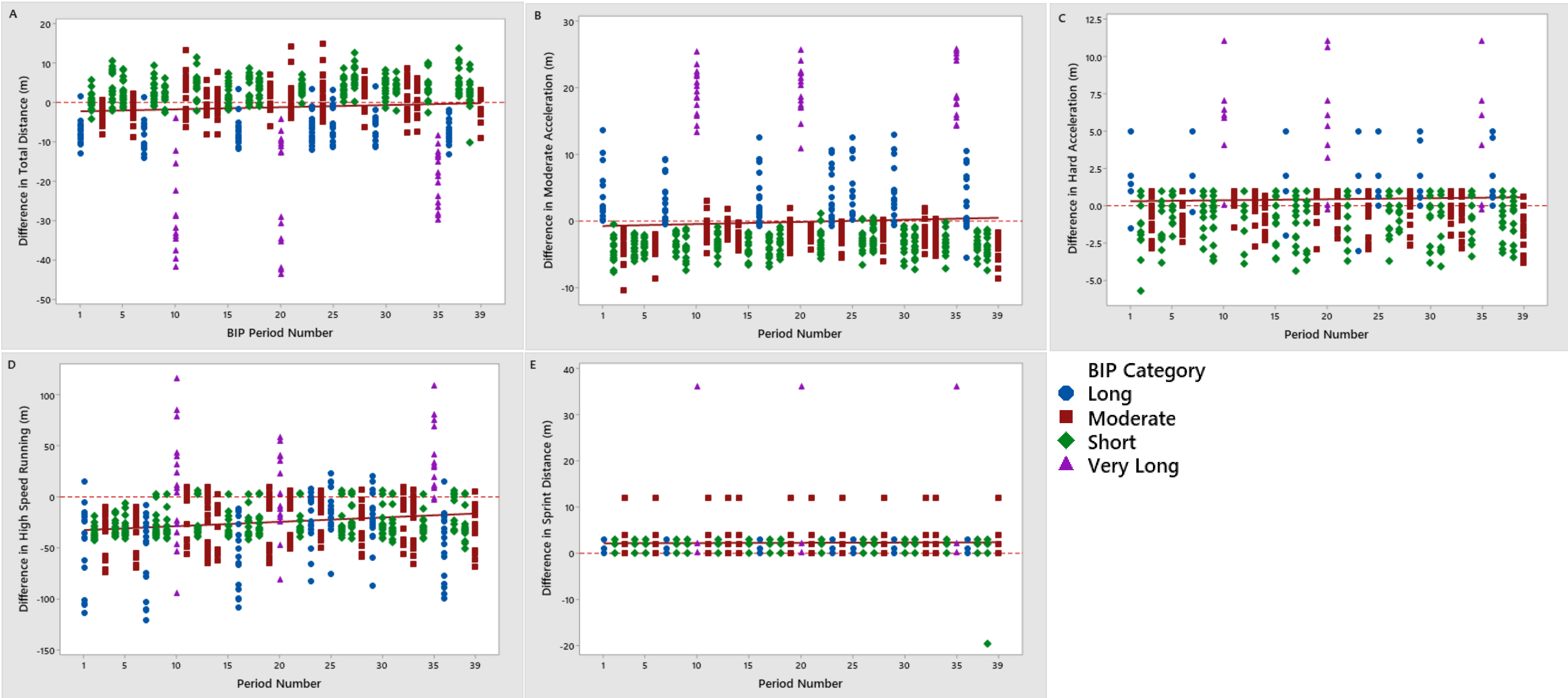
Appendix 9: *Boxplot illustrating the differences between expected and actual values for the High Speed Running metric, represented by a line of no change (line of identity observed). Ball-in-Play (BIP) categories are described as Short (A), Moderate (B), Long (C) and Very Long (D) duration.*



Appendix 10: *Boxplot illustrating the differences between expected and actual values for the Sprint Distance metric, represented by a line of no change (line of identity observed). Ball-in-Play (BIP) categories are described as Short (A), Moderate (B), Long (C) and Very Long (D) duration.*



Appendix 11: *Scatterplot illustrating the differences between expected vs actual values according to the respective GPS-Performance metrics Total Distance (A), Moderate Acceleration (B), Hard Acceleration (C), High Speed Running (D) and Sprint Distance (E) and based categorically according to the BIP Category*. A line of identity illustrates a line of equality (dashed) in addition to a linear regression line (solid) illustrating the relationship between BIP number (progressively from the first BIP (number 1) to the last BIP (number 39) and the specific performance metric.



Appendix 12: *The order of play card used for the GRIT simulation. This displays the BIP category, respective description of the call commands, number of collisions required and start/ end time for each BIP period and time accumulation till the termination of GRIT simulation.*

GRIT ORDER OF SIMULATION

Power Profile Tests PRE - Simulation

Number	BIP Category	BIP/ BOP	Length (s)	Description	Contact	Start Time	End Time
1	long	bip	40	Start Line --> Yellow Cone --> Start Line	All = 1	00:00	00:00:40
2	moderate	bop	40	Active Recovery		00:00:40	00:01:20
3	short	bip	10	Start Line --> Blue Cone	All = 0	00:01:20	00:01:30
4	long	bop	54	Active Recovery - Walk back to try line.		00:01:30	00:02:24
5	moderate	bip	20	Start Line --> Green Cone --> Start Line	Only Hooker = 1	00:02:24	00:02:44
6	short	bop	15	Active Recovery		00:02:44	00:02:59
7	short	bip	10	Start Line --> Blue Cone	All = 0	00:02:59	00:03:09
8	short	bop	15	Active Recovery		00:03:09	00:03:24
9	short	bip	10	Blue Cone --> Start Line	All = 0	00:03:24	00:03:34
10	very long	bop	85	Active Recovery		00:03:34	00:04:59
11	moderate	bip	20	Start Line --> Green Cone --> Start Line	Only Hooker = 1	00:04:59	00:05:19
12	moderate	bop	40	Active Recovery		00:05:19	00:05:59
13	long	bip	40	Start Line --> Yellow Cone --> Start Line	All = 1	00:05:59	00:06:39
14	short	bop	15	Active Recovery		00:06:39	00:06:54
15	short	bip	10	Start Line --> Blue Cone	All = 0	00:06:54	00:07:04
16	moderate	bop	40	Active Recovery		00:07:04	00:07:44
17	short	bip	10	Blue Cone --> Start Line	All = 0	00:07:44	00:07:54
18	short	bop	15	Active Recovery		00:07:54	00:08:09
19	very long	bip	90	Start Line --> Far try line --> Start line --> Red Cone.	LOOK AT TABLE	00:08:09	00:09:39
20	short	bop	15	Active Recovery to green cone.		00:09:39	00:09:54
21	moderate	bip	20	Green Cone --> start line --> Green Cone	Only Hooker = 1	00:09:54	00:10:14
22	moderate	bop	40	Active Recovery to blue cone		00:10:14	00:10:54
23	short	bip	10	Blue Cone --> start line	All = 0	00:10:54	00:11:04
24	short	bop	15	Active Recovery		00:11:04	00:11:19
25	moderate	bip	20	Start Line --> Green Cone --> Start Line	Only Hooker = 1	00:11:19	00:11:39
26	long	bop	54	Active Recovery		00:11:39	00:12:33
27	moderate	bip	20	Start Line --> Green Cone --> Start Line	Only Hooker = 1	00:12:33	00:12:53
28	moderate	bop	40	Active Recovery		00:12:53	00:13:33
29	short	bip	10	Start line --> Blue Cone	All = 0	00:13:33	00:13:43
30	long	bop	54	Active Recovery to start line		00:13:43	00:14:37
31	long	bip	40	Start Line --> Yellow Cone --> Start Line	All = 1	00:14:37	00:15:17
32	moderate	bop	40	Active Recovery		00:15:17	00:15:57
33	short	bip	10	Start Line --> Blue Cone	All = 0	00:15:57	00:16:07
34	short	bop	15	Active Recovery		00:16:07	00:16:22
35	short	bip	10	Blue Cone --> start line	All = 0	00:16:22	00:16:32
36	short	bop	15	Active Recovery		00:16:32	00:16:47
37	moderate	bip	20	Start Line --> Green Cone --> Start Line	Only Hooker = 1	00:16:47	00:17:07
38	moderate	bop	40	Active Recovery		00:17:07	00:17:47
39	very long	bip	90	Start Line --> Far try line --> Start line --> Red Cone.	LOOK AT TABLE	00:17:47	00:19:17
40	short	bop	15	Active Recovery to green cone.		00:19:17	00:19:32
41	moderate	bip	20	Green Cone --> start line --> Green Cone	Only Hooker = 1	00:19:32	00:19:52
42	long	bop	54	Active Recovery to blue cone		00:19:52	00:20:46
43	short	bip	10	Blue Cone --> start line	All = 0	00:20:46	00:20:56
44	short	bop	15	Active Recovery		00:20:56	00:21:11
45	long	bip	40	Start Line --> Yellow Cone --> Start Line	All = 1	00:21:11	00:21:51
46	long	bop	54	Active Recovery		00:21:51	00:22:45
47	moderate	bip	20	Start Line --> Green Cone --> Start Line	Only Hooker = 1	00:22:45	00:23:05
48	short	bop	15	Active Recovery		00:23:05	00:23:20
49	long	bip	40	Start Line --> Yellow Cone --> Start Line	All = 1	00:23:20	00:24:00
50	moderate	bop	40	Active Recovery		00:24:00	00:24:40
51	short	bip	10	Start line --> Blue Cone	All = 0	00:24:40	00:24:50
52	short	bop	15	Active Recovery		00:24:50	00:25:05
53	short	bip	10	Blue Cone --> start line	All = 0	00:25:05	00:25:15
54	very long	bop	85	Active Recovery		00:25:15	00:26:40
55	moderate	bip	20	Start Line --> Green Cone --> Start Line	Only Hooker = 1	00:26:40	00:27:00
56	short	bop	15	Active Recovery		00:27:00	00:27:15
57	long	bip	40	Start Line --> Yellow Cone --> Start Line	All = 1	00:27:15	00:27:55
58	long	bop	54	Active Recovery		00:27:55	00:28:49
59	short	bip	10	Start line --> Blue Cone	All = 0	00:28:49	00:28:59
60	moderate	bop	40	Active Recovery		00:28:59	00:29:39
61	short	bip	10	Blue Cone --> start line	All = 0	00:29:39	00:29:49
62	short	bop	15	Active Recovery		00:29:49	00:30:04
63	moderate	bip	20	Start Line --> Green Cone --> Start Line	Only Hooker = 1	00:30:04	00:30:24
64	moderate	bop	40	Active Recovery		00:30:24	00:31:04
65	moderate	bip	20	Start Line --> Green Cone --> Start Line	Only Hooker = 1	00:31:04	00:31:24
66	long	bop	54	Active Recovery		00:31:24	00:32:18
67	short	bip	10	Start Line --> Blue Cone	All = 0	00:32:18	00:32:28
68	short	bop	15	Active Recovery to red cone		00:32:28	00:32:43
69	very long	bip	90	Red Cone --> Start Line --> Far Try Line --> Start Line	LOOK AT TABLE	00:32:43	00:34:13
70	very long	bop	85	Active Recovery		00:34:13	00:35:38
71	long	bip	40	Start Line --> Yellow Cone --> Start Line	All = 1	00:35:38	00:36:18
72	short	bop	15	Active Recovery		00:36:18	00:36:33
73	short	bip	10	Start Line --> Blue Cone	All = 0	00:36:33	00:36:43
74	moderate	bop	40	Active Recovery		00:36:43	00:37:23
75	short	bip	10	Blue Cone --> start line	All = 0	00:37:23	00:37:33
76	moderate	bop	40	Active Recovery		00:37:33	00:38:13
77	moderate	bip	20	Start Line --> Green Cone --> Start Line	Only Hooker = 1	00:38:13	00:38:33
78	short	bop	15	FINISHED!!!		00:38:33	00:38:48

Power Profile Tests POST - Simulation