The use of a radio frequency tracking system to quantify the external demands of elite wheelchair rugby

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THE USE OF A RADIO FREQUENCY TRACKING SYSTEM TO
QUANTIFY THE EXTERNAL DEMANDS OF ELITE WHEELCHAIR
RUGBY

James Rhodes

A Doctoral Thesis

Submitted in partial fulfilment of the requirements for the award of Doctor of
Philosophy of Loughborough University

September 2015

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Abstract

Within team sports, coaches aim to improve physical preparation by optimising the training process specific to competition. Unfortunately, at the elite level of wheelchair rugby (WCR) evidence-based information to guide this process is currently lacking. The present thesis investigates measures of external load during elite competition and explores whether this can be translated to inform current training practices.

The first study established the suitability of a radio frequency-based, indoor tracking system (ITS) for the collection of movements specific to WCR. Minimal relative distance errors (< 0.2%) were seen across different sampling frequencies. Peak speed displayed the greatest relative error in 4 Hz tags (2%), with significantly lower errors observed in higher frequency tags (< 1%). The ITS was therefore deemed an acceptable tool for quantifying external load specific to WCR using a sampling frequency of 8 or 16 Hz.

The external demands of elite competition were determined in Chapters 4 and 5. Notable differences in the volume of activity were displayed across the International Wheelchair Rugby Federation (IWRF) classification groups. However, the specific positional requirements of low-point (LP) and high-point players (HP) appeared to influence the intensity of external load (Chapter 4). Chapter 5 extended this work and established that peak speed and the ability to perform at high-intensities were best associated with successful mobility performance in WCR, as defined by team rank. This was further shown to be role-dependent, whereby high-ranked HP players achieved greater peak speeds and performed more high-intensity activities (HIA) than respective lower-ranked players.

Comparisons between the current external demands of training were then compared to that of competition (Chapter 6). Conditioning drills were shown to exceed the demands of competition, irrespective of classification. Notable differences in skill-based and game related drills were displayed across player classifications, whereby both were shown to be role-dependent. Although game-simulation drills provided the best representation of competition, the duration appeared important since this factor influenced the results (Chapter 6). When the format of these drills were further modified (Chapter 7), drills containing fewer players increased the volume and intensity of training, specifically in HP. Whilst a 30-second shot-clock elicited no changes in external load, differences were revealed when the shot-clock was further reduced to 15-s. Coaches can therefore modify the external training response by making subtle changes to the format of game-simulation drills.

This thesis revealed that functional classification and positional-role are key factors during competition, and training should therefore be structured with this in mind. Conditioning drills can be used to elicit a progressive overload in the external responses, whilst game-simulation drills can provide the best representation of competition. Given the importance of game-simulation drills, the combination of different formats throughout training sessions are critical in order to maximise the preparation of elite WCR players.

Keywords: Paralympic, external load, functional classification, training, specificity, performance analysis
Acknowledgements

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Through the process of this thesis I could not have asked to have been involved with a more supportive team than the staff and students at the Peter Harrison Centre for Disability Sport. I have received a tremendous amount of support from Tom, John, Terri and Christof and the completion of this PhD would not have been possible without your support. This experience would also not have been the same without the laughs and social events provided by the residents of 10 Adam Dale (past and present!), Fry, Sion and the others in the PhD office. I thank you for all supporting me during this PhD. Finally, I am also indebted to UK Sport, Peter Harrison Foundation and the School of Sport, Exercise and Health Sciences, without your financial support this research could not have taken place.

To the Great Britain Wheelchair Rugby team, I am very grateful for the opportunity to research and work in a practical environment. Not only did I learn many things from this experience that will help me in my future work, but I also appreciate the staff that has assisted me along the way. To Paul and Justin, thank you for incorporating this research into your programme. I wish to also thank Phil for his contribution and always being there to answer Rugby and technical based questions. Lastly, thank you to Lorraine for your support, and to all the players for participating. I wish you all the best in your build up to Rio 2016.

Finally, thanks go to my Mum, Dad and Kimberley for their continued support during these 3 years. You have driven me to challenge and believe in myself, without your support I wouldn't have made it through this process. I am forever grateful for your support.
Dedication

This thesis is dedicated to my family, in particular my Mum, Dad and Amber for always being there for me. Without the opportunities you have provided me with, I would not have discovered my interest in the sports industry.
Preface

An overview of the publications and communications of the research conducted whilst writing this thesis is given below:

Peer reviewed publications

Chapter 3


Chapter 4


Chapter 5


Miscellaneous articles published alongside PhD


Conference communications

Rhodes JM. The validity and reliability of a novel indoor player tracking system for use within wheelchair court sports (Poster). VISTA IPC Paralympic Conference. Bonn, Germany (June 2013)


Rhodes JM. A comparison of external load between training and competition in elite wheelchair rugby players (Poster). School of Sport Exercise and Health Sciences Postgraduate Research Conference. Loughborough University, UK (June 2015).
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List of Abbreviations

Throughout the current thesis, the following abbreviations and units of measurement were used to signify frequently used terms. All abbreviations were defined the first instance they appear in the text:

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<td>AB</td>
<td>Able-bodied</td>
</tr>
<tr>
<td>ANOVA</td>
<td>Analysis of variance</td>
</tr>
<tr>
<td>b·min⁻¹</td>
<td>Beats per minute</td>
</tr>
<tr>
<td>BLa</td>
<td>Blood lactate concentration</td>
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<tr>
<td>CV%</td>
<td>Coefficient of variation</td>
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<tr>
<td>CL</td>
<td>Confidence limits</td>
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<td>ES</td>
<td>Effect size</td>
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<td>GPS</td>
<td>Global positioning system</td>
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<td>HIA</td>
<td>High-intensity activities</td>
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<td>HP</td>
<td>High-point players</td>
</tr>
<tr>
<td>HR</td>
<td>Heart rate</td>
</tr>
<tr>
<td>Hz</td>
<td>Hertz</td>
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<tr>
<td>IPC</td>
<td>International Paralympic Committee</td>
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<td>ITS</td>
<td>Indoor tracking system</td>
</tr>
<tr>
<td>IWRF</td>
<td>International Wheelchair Rugby Federation</td>
</tr>
<tr>
<td>km·h⁻¹</td>
<td>Kilometres per hour</td>
</tr>
<tr>
<td>LOA</td>
<td>Limits of agreement</td>
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<td>LP</td>
<td>Low-point players</td>
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<td>LPM</td>
<td>Local positioning measurement</td>
</tr>
<tr>
<td>m</td>
<td>Metres</td>
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<tr>
<td>m·min⁻¹</td>
<td>Metres per min</td>
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<tr>
<td>m·s⁻¹</td>
<td>Metres per second</td>
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<td>MDL</td>
<td>Miniaturised data logger</td>
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<td>Non-SCI</td>
<td>Non-spinal cord injured</td>
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<td>RPE</td>
<td>Rating of perceived exertion</td>
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<tr>
<td>s</td>
<td>Seconds</td>
</tr>
<tr>
<td>SCI</td>
<td>Spinal cord injury</td>
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<tr>
<td>SWC</td>
<td>Smallest worthwhile change</td>
</tr>
<tr>
<td>TEE</td>
<td>Typical error of the estimate</td>
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<tr>
<td>V̇O₂peak</td>
<td>Peak oxygen uptake (L·min⁻¹)</td>
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<td>Peak speed</td>
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<td>Ultra wide band</td>
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<td>Work-rest ratio</td>
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<td>Wireless ad-hoc system for positioning</td>
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<td>Wheelchair basketball</td>
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<td>WCR</td>
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<td>Wheelchair tennis</td>
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1. Introduction

Throughout elite sport, the quest for success requires practitioners to continuously explore tools to support and improve performance (Carling et al., 2005). There is little doubt that in order to achieve success in sports performance, training strategies must adopt an evidence-based approach. Accordingly, a structured framework for player preparation should entail the development of physical as well as technical capabilities – specific to the demands of competition (Duthie, 2006). Yet, it has only been within the last decade that the potential benefits of the scientific processes in bridging the gap between research and practice have been recognised in the literature (Castellano et al., 2014).

1.1 General introduction

Wheelchair rugby is an intermittent team sport characterised by physical, tactical and technical components. The intermittent movement patterns associated with wheelchair rugby (WCR) necessitates contributions from both the aerobic and anaerobic systems (Goosey-Tolfrey et al., 2006). Therefore, it is important that training strategies used by elite WCR teams are designed to include activities that stress these systems to prepare players to the many facets experienced during competition.

As in all team sports, WCR coaches aim to improve team performance by optimising the training process specific to competition. Training specificity is widely regarded as a fundamental factor in shaping this success, and is related to the degree to which the training resembles actual competition (Gamble, 2010). As such, knowledge of the movement demands of competition is necessary to aid in the design and application of player preparation programmes (Gamble, 2013). This process can be thought of as an ongoing cycle of competition and training (Figure 1.1). The first step of this process is to collate and interpret knowledge regarding the physical demands of the sport and the requirements specific for each
player. This forms the basis for planning and implementation of evidence-based training strategies to improve the specificity of training. Unfortunately, at the elite level of WCR there have been relatively few studies that have provided information about the physical demands of competition, and of those available (Sarro et al., 2010; Sporner et al., 2009), the methodologies employed limit the application to the modern game.

Central to the development of effective training strategies is the periodization of training load throughout the season (Gamble, 2010). This has typically been obtained from other team sports through subtle changes in the volume, intensity and the frequency of training load (Morgans et al., 2014). Monitoring the overall load during training has evolved considerably with advances in technology. At present, there are numerous methods used, including player tracking-based technology (external load), and physiological measures such as heart rate (HR), blood lactate (BLa) and/or rating of perceived exertion (RPE) (internal load). External load can be defined as the work completed by a player (e.g. total distance, peak speed etc.) and is important in understanding the physical load performed (Halson, 2014). Unfortunately, the value of player tracking devices for the assessment of external load in WCR players remains unclear due to the insufficient published research on the validity and reliability of these methods. Alternatively, internal load can be referred to as the physiological stress (e.g. HR, BLa and RPE) imposed on a player (Impellizzeri et al., 2005). However, individuals with tetraplegia typically demonstrate a disrupted autonomic innervation of the heart (further details are provided in section 2.1.2) and as a consequence quantifying the physiological demand, particularly via HR in WCR players may be problematic. Nevertheless, it is imperative that sport scientists use valid and reliable methods to monitor training load to optimise the training process in WCR.
Figure 1.1 - Conceptual model illustrating the on-going cycle of competition and training during AB team sports. Adapted from Carling et al. (2005).
1.2 Aims and objectives of the thesis

The principal aim of the thesis was to examine how the analysis of external load during competition may guide future training strategies to maximise player preparation in WCR. In order to achieve this, the programme of study was applied across a three-year period alongside international WCR tournaments and during the preparation of the Great Britain WCR squad for Rio 2016, whereby four main objectives were formulated:

i) To evaluate the suitability of an indoor tracking system (ITS) for the measurement of wheelchair sport-specific activities.

ii) To quantify the external load during competition and identify the influence of functional classification, in order to establish the activity profiles of elite WCR.

iii) To explore the external load of current training modes used by elite WCR players throughout the competitive phase of the season.

iv) To prescribe training recommendations aimed at optimising training specificity to advance the preparation of elite WCR players.

1.3 Organisation of the thesis and experimental aims

The current thesis was structured into a total of five experimental chapters (Chapters 3-7), with the research questions of each addressed below. Preceding this, a comprehensive literature review (Chapter 2) was conducted. This review focused on the application of player tracking when assessing competition/training and critiqued previous research that has adopted this approach when investigating WCR performance.

The first experimental chapter (Chapter 3) examined the effectiveness of a radio-frequency based ITS. Specifically, this chapter investigated the validity and reliability of the
ITS during on-court movements at speeds specific to WCR. The subsequent results permitted data collection of the following experimental chapters.

**Chapters 4 and 5** were the first studies whereby large cohorts of elite WCR players were monitored during international competition. The first of these two studies (**Chapter 4**) examined the external load of WCR players, acknowledging the influence of the International Wheelchair Rugby Federation (IWRF) classification during competition. **Chapter 4** further assessed external load to identify the influence of fatigue within games. **Chapter 5** extended the analyses to include team rank as an outcome measure of successful performance. The subsequent results were used to determine the most advantageous indicators of physical performance required for successful performance.

The final phase of the PhD programme involved the assessment of current training practices used by elite WCR players (**Chapter 6**) and whether modifications to training could more accurately reflect the external load during competition (**Chapter 7**). **Chapter 6** quantified the external load of current training practices in comparison to the demands of competition identified in **Chapters 4-5**. **Chapter 7**, the final experimental chapter, investigated whether external load was influenced by subtle modifications to the format of game-simulation drills. A general discussion of the key findings, implications and applications of this work are presented in **Chapter 8**.
2. Literature Review

2.1 Wheelchair rugby

2.1.1 The sport

WCR was first introduced as a demonstration event at the Atlanta 1996 Paralympic Games and later included as a full medal sport at the Sydney 2000 Paralympic Games. The sport is an intermittent, court-based mixed team sport played by both male and female players (IWRF, 2012). It consists of 4 x 8-min quarters, played on an indoor wooden sprung surface (15 m x 28 m). A team composes of a maximum of 12 players, with 4 players allowed on-court at any one time. The remaining team members make up an interchangeable substitutes bench and can be frequently rotated on-court as the coach deems necessary. The game-clock is started once a team has possession of the ball, during which they have a total of 40 s to score otherwise they concede possession. The regulations restrict the team in possession to advance from the backcourt to the frontcourt within 12 s and must bounce or pass the ball every 10 s, otherwise possession is conceded. The objective of offensive game-play is to score goals by carrying the ball over the opposing team’s goal line. Alternatively, through the use of strategic ‘picking’ skills (to block and trap an opponent) the objective of defensive game play is to prevent the opponents from scoring by forcing them to commit a time violation or ball-handling error in order to regain possession (Orr & Malone, 2010; Yilla & Sherrill, 1994).

2.1.2 The athletes

Initially, WCR was developed for individuals with tetraplegia due to a spinal cord injury (SCI) at the level of the cervical vertebrae. Tetraplegia refers to impairment or loss of motor and/or sensory function in the cervical segments of the spinal cord, and results in some impairment of the arms as well as typically the trunk, legs and pelvic organs (Kirschblum et al., 2011). Depending on the SCI completeness and level of the lesion, loss of functional muscle mass
and descending sympathetic control attribute to large variations in physical capacity (Goosey-Tolfrey et al., 2006; Janssen et al., 2002; Leicht et al., 2012; West et al., 2014). As such, physiological measures of physical capacity (peak HR and oxygen uptake [$\dot{V}O_{2peak}$]) are inversely related to lesion level - meaning that the higher the level of injury, the lower the peak physiological responses (Leicht et al., 2013; Paulson et al., 2013). The attenuated sympathetic innervation and low levels of physical capacity resulting from a cervical level SCI mean that the use of HR for exercise prescription may be unsuitable for individuals with tetraplegia (Valent et al., 2007). Nevertheless, as the popularity of WCR has increased, individuals with other types of physical impairments (collectively referred to as non-SCI athletes) are now eligible to compete via changes in the International Paralympic Committee (IPC) classification code. Typical impairments include bilateral upper- and lower-extremity limb loss, post-polio disability, neurological disorders (cerebral palsy) and some forms of muscular dystrophy. In contrast to athletes with a SCI, many non-SCI athletes have limited to no trunk and/or leg impairment (Altmann et al., 2013). While trunk function is a prerequisite for improved wheelchair manoeuvrability (Vanlandewijck et al., 2011), non-SCI athletes may be perceived as more dominant over SCI athletes in the same functional class (Altmann et al., 2013). Consequently, the classification process is central to WCR to ensure that a player’s impairment is relevant to performance (Tweedy & Vanlandewijck, 2011).

### 2.1.3 Functional classification in WCR

The many different types and severity of disabilities in Paralympic sports highlight the importance of a system that ensures the fair competition between players with varying disabilities (Tweedy & Vanlandewijck, 2011). Whilst classification in able-bodied (AB) sports typically group players according to sex, age or weight, classification in Paralympic sports assess the disability and functional ability of each player with the aim of minimising the impact of impairment on the outcome of competition (Goosey-Tolfrey & Leicht, 2013).
The classification process in WCR represents a sport-specific approach based on the observations from three individual components. Currently, the three components consist of:

i) Physical assessment – Composed of the bench test and trunk tests to evaluate muscle and trunk function in all planes of movement.

ii) Functional observations - Assesses the functional movement during sport-specific tasks (wheelchair manoeuvrability, resistance pushing, dribbling, catching, ball-pickups and chair transfers).

iii) Observational criteria - On-court observations consisting of the warm-up, training and competition.

The subsequent results are used to classify players into one of seven classification groups based on IWRF guidelines (see Table 2.1) ranging from 0.5 (most impaired) to 3.5 (least impaired). Each team is permitted to field four players at any one time, whereby the total number of points on-court cannot exceed 8.0 points (Molik et al., 2008). For each female player on-court, however, a team is permitted an extra 0.5 points over the 8.0 points (IWRF, 2010).

The wheelchair is also considered a key part of the classification process. There are two general types of chairs (Table 2.1), each designed for the specific requirements of the positional-roles (Keogh, 2011). Typically, the offensive chair, set up with wings between the front bumper and the rear wheels, and spoke guards flush with the push-rim, is designed to prevent players being easily held or ‘picked’ by an opponent. Alternatively, a defensive chair typically sits low with a larger degree of camber and a longer pick bar at the front strategically designed for blocking opponents. High-point players (HP; 2.0-3.5) typically occupy offensive roles on court and as such use an offensive chair, whilst low-point players (LP; 0.5-1.5) naturally occupy defensive roles and utilise a defensive chair (Table 2.1). While a lower seat
height and larger camber improves the manoeuvrability and blocking performance of defensive chairs, this comes at the expense of sprint performance (Mason et al., 2012). Accordingly, functional classification has a large impact on team composition and team tactics (Altmann et al., 2014).

Table 2.1 – Player characteristics in relation to their IWRF classification (IWRF, 2010)

<table>
<thead>
<tr>
<th>Classification</th>
<th>Functional Description</th>
<th>Positional-Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>LP 0.5</td>
<td>Main role as a blocker. Shoulder instability and lack of triceps function causes head bob when pushing. Typical use of forearm on the wheel for starting, turning and stopping the wheelchair. Usually passes the ball using a scoop technique or bats the ball for longer range passing.</td>
<td>Defensive</td>
</tr>
<tr>
<td>1.0</td>
<td>Not a ball handler but may in-bound the ball on occasion. Shoulder and triceps weakness causes a slight head bob when pushing and restricts catching to a forearm catch, followed by a typically weak chest pass.</td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td>Usually an excellent blocker and may also on occasion handle the ball. Increased shoulder strength allows a more efficient pushing technique. Wrist imbalance usually causes limited ball security when passing. Players predominantly have asymmetry in arms and use their stronger arm for chair and ball skills.</td>
<td></td>
</tr>
<tr>
<td>HP 2.0</td>
<td>Typically have very strong and stable shoulders that allow for good pushing and ball-handling capabilities. Effective chest passer with control over moderate distances. Can typically hold the ball with wrist firmly however has limited finger flexion.</td>
<td></td>
</tr>
<tr>
<td>2.5</td>
<td>Main role as a ball-handler and fairly quick playmaker. Good functional grip enabling good functional grip on the pushrim of the wheelchair. Has some trunk control providing good stability in the chair. Usually demonstrate excellent two handed catching ability with the possibility of single handed catches.</td>
<td></td>
</tr>
<tr>
<td>3.0</td>
<td>Excellent ball-handler with the ability to grip the pushrim to generate fast pushing speeds. Functional fingers enable ball control in varying planes of movement.</td>
<td></td>
</tr>
<tr>
<td>3.5</td>
<td>Primary playmaker on the team and demonstrates good trunk function for excellent stability in the wheelchair. The combination of hand and trunk function results in excellent passing and ball security skills.</td>
<td></td>
</tr>
</tbody>
</table>

To date, there is a dearth of research examining functional classification and performance in WCR is available. Even in the few studies conducted the results have often been inconsistent. This is typically explained by issues surrounding the sample used and the
differences in testing equipment. However, the results of such studies provide a limited insight regarding the impact of functional classification in WCR. Malone et al. (2006) examined the skill performance of 80 WCR players during a battery of field tests (20 m sprint, endurance sprint, passing and slalom test). The results identified a significant correlation between functional classification and test performance, whereby players with a higher classification performed better on all tests. The authors therefore concluded that the classification system adequately divides players based on functional ability and performance (Malone et al., 2006). Alternatively, contrasting findings were identified in the anaerobic capacity of WCR players (Morgulec et al., 2005). When grouped according to IWRF classification (group I - 0.5; group II – 1.0-1.5; group III – 2.0-2.5; group IV – 3.0-3.5), a significant difference in peak power was identified in group I players compared to all other player groups, while no differences were found between groups II to IV (Morgulec et al., 2005). Similar findings were also identified in the technical skills of Polish WCR players (Molik et al., 2006). Significant differences in the technical skills performed during competition were observed in group I players compared with groups II to IV, whilst no other differences existed (Molik et al., 2006). Such findings underline the need for a continued examination of the IWRF classification system.

More recently, research examined the aerobic and anaerobic capacity of 30 Polish WCR players with regard to functional classification (Morgulec et al., 2011). Although minimal differences in aerobic capacity ($\dot{V}O_2$peak) were observed, peak power achieved during a Wingate Anaerobic Test (Figure 2.1) was significantly greater in HP (2.0-3.5) compared to LP (0.5-1.5) (Morgulec et al., 2011). Such findings do not support those of Malone et al. (2006), whereby classification was independent of performance (Morgulec et al., 2011). However, this study recruited sub-elite WCR players and therefore performance variability was confounded by the varying levels of player experience, skill and physical capacity (Molik
et al., 2008). Nevertheless, similar trends were identified in game-efficiency patterns, whereby HP were observed to perform the majority of technical skills (points scored, assists, turnovers, steals) during matches from the 2005 WCR European Championships \((n = 105\) players; Molik et al., 2008) and 2008 Paralympic Games \((n = 77\) players; Morgulec et al., 2010). Given that mainly offensive actions were analysed, the close relationship between functional classification and positional-role attribute to such findings (see Table 2.1). LP typically possesses limited shoulder and wrist stability that impede ball-handling capabilities, restricting players to defensive roles. Alternatively, HP generally displays good shoulder and wrist stability, enabling players to perform ball-handling tasks effectively, which sees them occupy offensive duties as previously mentioned.

![Figure 2.1](image-url)  

**Figure 2.1** – Peak power output (Watts) in relation to functional classification in WCR players \((n = 30)\). Data obtained from Morgulec et al. (2011). *Significantly different to group 2.0-2.5. #Significantly different to group 3.0-3.5.

It is evident from the aforementioned literature that 0.5 players present lower aerobic and anaerobic capacity, interspersed with lower game-efficiency patterns in comparison with all other players (Molik et al., 2006; Morgulec et al., 2006: 2011). However, a lack of
differences between 2.0-3.5 players underlines the need for continued examination of the IWRF classification system (Morgulec et al., 2011). Whilst the importance of functional classification in WCR is clear, an understanding of classification and performance, specifically during competition is not well understood. It is therefore important to utilise the large body of knowledge available in AB team sports to assist in furthering the understanding of competition and translating such findings for the application of WCR.

2.2 Quantification of external load during competition

Player tracking techniques provide an objective yet relatively non-invasive method for quantifying the external load of an athlete during competition (Cummins et al., 2013). Such analyses partly indicates the ‘demands’ associated with a given sport and is vital for sport scientists and applied practitioners in order to inform the specificity of conditioning, recovery and a variety of game-specific training strategies (Morgans et al., 2014). While the advent of player tracking techniques has facilitated the ease of collecting external load, the on-going challenge faced by practitioners is the ability to quantify external load both accurately and with minimal interference to the athlete.

2.2.1 Techniques

2.2.1.1 Manual techniques

Early investigations relied on simplistic manual coding techniques as an inexpensive method of providing an insight into the external load of match-play (Hahn et al., 1979; Reilly & Thomas, 1976; Sanderson & Way, 1977). Common practice required the field dimensions to be scaled down onto paper to subsequently track player movement. The definitive study to adopt such techniques was conducted by Reilly and Thomas (1976) and involved the subjective assessment of distances and movement intensity during soccer match-play. While
manual techniques were generally shown to be convenient and inexpensive, they are associated with several recognised limitations. Such techniques are highly dependent on observer experience and rely on subjective interpretations of activity performed (Bloomfield et al., 2004). They are also considerably labour-intensive, time-consuming and therefore limited to a single player at a time (Barris & Button, 2008). These limitations combined with advances in technology eventually led to the development of video-based tracking systems dedicated to the analysis of external load in team sports.

2.2.1.2 Video tracking techniques

With advancements in technology the use of video cameras has enhanced the quality of player tracking techniques (Dawson et al., 2004). This method enabled the observer to record player movement and analyse the information post event with greater accuracy. Using this method, researchers have been able to establish the total distance covered (Dawson et al., 2004; Deutsch et al., 1998), the distances in various speed zones (Burgess et al., 2006; Dawson et al., 2004; Spencer et al., 2004) and the work to rest ratio of individual players (Dawson et al., 2004; Spencer et al., 2004). Unfortunately, this process is again highly labour intensive and does not facilitate real-time analysis (Carling et al., 2008). Furthermore, the reliability of such methods is questionable due to the subjective classification of movement speeds. Observer consistency is considered crucial in establishing the reliability of such techniques where the total time and frequency of movements can exhibit large variations (Barris & Button, 2008). McInnes et al. (1995) investigated the intra-observer reliability by measuring the magnitude of difference (coefficient of variation [CV%]) during basketball match-play. Subsequently, the reliability of such methods decreased as speed of activity increased, whereby low-speed activities were easier to replicate for the observer (4.1-4.9% CV) as opposed to high-speed activities (5.6-8.8% CV). In support of this, Deutsch et al. (1998) reported the error associated
with video tracking techniques increased during the performance of quick lateral movements. More recently, both rugby union and hockey research displayed similar findings (Duthrie et al., 2003; Spencer et al., 2004). Analysis of rugby union displayed good reliability for the frequency of low-intensity movements (4.3-7.2% CV), whereas high-intensity movements such as sprinting (10.9% CV) were harder to replicate (Duthrie et al., 2003). Similarly, analysis from hockey indicated sprinting actions also displayed the greatest observer errors (8.1% CV) (Spencer et al., 2004). Consequently, the reliability of this process can vary depending on a number of factors including observer experience, viewing perspective and player movement speed.

### 2.2.1.3 Automatic tracking techniques

Automatic tracking of players has recently become a preferred approach to the capture and quantification of external load in team sports. Unlike the aforementioned techniques, movement data can be processed using automated analysis more efficiently post-match. Using digital footage obtained from fixed cameras, activity of all participating players are tracked simultaneously using image-processing techniques (Abdelkrim et al., 2007). The use of such sophisticated systems is apparent only within elite sporting contexts, largely due to the associated costs and logistical implications (i.e. setup). Moreover, automatic tracking is difficult to conduct when competitors maintain a close proximity and therefore frequent human intervention may be required (Barros et al., 2007; Di Salvo et al., 2009). Figueroa et al. (2006) further identified issues associated with the specific problems of lighting changes and changes in movement speed, making such techniques difficult with team sports. Whilst such limitations should be recognised, the sampling frequency of automatic tracking systems remains far superior compared to the aforementioned techniques (10-30 Hz).
Despite the increased sampling frequency, automatic tracking techniques still have a number of recognised limitations. Validation studies have revealed significant differences in distance measurements compared to a criterion (trundle wheel) method (Edgecomb & Norton, 2006). Edgecomb & Norton (2006) suggested that large systematic errors were associated with this method, whereby an overestimation of distance occurred (5.8-7.3%). Furthermore, during basketball-specific movements, measurement error was greatest when players performed sprinting (3.6% CV) and high-intensity activities (HIA) (3.9% CV) (Abdelkrim et al., 2007). However, measurement error decreased when players performed low-speed movements such as walking (2.9% CV) and jogging (2.6% CV). Nevertheless, in agreement with the aforementioned techniques, the speed of activity is a key factor in the validation of automatic tracking techniques (Abdelkrim et al., 2007).

2.2.1.4 Global positioning systems

Unlike the aforementioned techniques, the recent development of portable global positioning systems (GPS) has permitted wider application of wearable technology within team sports (Cummins et al., 2013). GPS techniques require each player to wear a receiver, which draws on signals sent from at least three orbiting satellites to determine positional information (Aughey, 2011). These devices permit the real-time analysis of external load and are increasingly used by sport practitioners to provide a comprehensive analysis of competition in certain sports (Cummins et al., 2013). The system automatically stores the external load of individuals and multiple players can be tracked at the same time. Whilst GPS removes the operator errors associated with the manual and computerised systems mentioned previously, issues concerning the validity and reliability of the technology must be considered. There is an abundance of literature examining the validity and reliability of GPS for the measurement of external load specific to team sports (see Aughey, 2011). Initial investigations assessed
GPS devices with a sampling frequency of 1 Hz, which has since progressed to systems capable of sampling up to 15 Hz devices.

The sampling frequency refers to the speed at which GPS devices can collect movement data. The 1 Hz devices are capable of collecting only one positional measurement each second. These devices will therefore be unable to collect data lasting less than 1 s, reducing the ability to accurately detect changes in distance at high speeds. Nevertheless, validity testing of 1 Hz GPS devices has indicated varying results. When compared to timing gates during a linear running protocol, measurement error was greatest during high-speed running (5.6% CV) and lowest during low-speed running (0.7% CV) (Portas et al., 2010). Significant differences between known and estimated distances were also observed with devices typically overestimating distance values by 2.0-4.8% (Coutts & Duffield, 2010; Edgecomb & Norton, 2006). In contrast, Duffield and colleagues (2010) reported that compared to a VICON (Oxford, UK) motion analysis system (100 Hz), the 1 Hz device can underestimate distance by ~40% during movements in confined spaces. Moreover, rapid changes of direction may be underestimated as a sampling frequency of 1 Hz was insufficient for the measurement of speeds in excess of 2.5 m·s⁻¹ (Gray et al., 2010; Jennings et al., 2010; MacLeod et al., 2009).

The accuracy of GPS devices seemingly improve with an increase in sampling frequency. In studies where the assessment of 5 Hz devices were accompanied by a comparison with 1 Hz devices, 5 Hz devices were more valid and reliable in all cases (Petersen et al., 2009; Jennings et al., 2010; Portas et al., 2010). Despite this, 5 Hz devices still displayed limitations. Large differences in movement velocity during linear sprinting over distances of 20, 30 and 40 m were observed (Petersen et al., 2009). The validity of 5 Hz devices during sprinting ranged from 2-13%, with a tendency for reduced accuracy to be
displayed over shorter distances (20 m) when compared with longer sprints (40 m) (Petersen et al., 2009). Similar results were identified during straight line movement over a range of speeds in Australian Football players (Jennings et al., 2010). Across all intensities (walking to sprinting) devices showed greater measurement error over 10 m (21.3-30.9%) compared to longer distances (40 m; 9.8-11.9%). Despite this, the validity decreased as the movement intensity increased from walking (21.3%) to sprinting (30.9%) (Jennings et al., 2010). Consequently, in line with the aforementioned techniques, the validity and reliability of 5 Hz GPS devices are again dependent on the speed of movement.

Of the available literature concerning the validity and reliability of GPS devices, there have been a limited number of investigations using a sampling frequency of 10 Hz and 15 Hz devices (Johnston et al., 2014a). Initial examination of 10 Hz devices has identified errors of 10.9% and 5.1% when examining the distance covered during 15 m and 30 m running, respectively (Castellano et al., 2011a). However, distance covered was only examined using straight line tests and over relatively short distances (15-30 m). Alternatively, Varley et al. (2012) revealed 10 Hz devices were considerably more reliable for measuring constant velocity compared to 5 Hz devices. The 10 Hz devices demonstrated lower CV values of 2.0-5.3% during different starting velocities (1-8 m·s⁻¹) compared to 5 Hz devices (6.3-12.4% CV). Subsequently, the magnitude of measurement error can again be observed to improve with an increase in sampling frequency.

Only recently have increases in sampling rate to 15 Hz occurred. The 15 Hz sampling frequency is calculated by supplementing a 10 Hz device with accelerometer data (Aughey, 2011). In the only available study to address 15 Hz devices, good levels of reliability were found with < 2% error in total distances (Johnston et al., 2014a). This is an improvement on research examining 1 and 5 Hz devices for total distance (Coutts & Duffield 2010; Johnston
et al., 2012). Despite this, the validity of 15 Hz devices revealed contrasting results when compared to criterion measures. Johnston et al. (2014a) reported the error of measuring peak speed was greater in 15 Hz devices (8.1%) as opposed to those previously reported in 1 and 5 Hz devices (2.3-7.2%). Despite this, validation was measured using a pre-determined course, and reported error may have been caused by participants not correctly following the course. Given the relatively sparse research into 15 Hz devices, it is difficult to determine whether these results are representative of the true validity, especially since there is no other research to compare these findings with. Nevertheless, regardless of device validity, a major limitation of GPS technology is its reliance on satellite signals, restricting its use to an outdoor environment only (Larsson, 2003).

2.2.1.5 Wheel-mounted devices

Indoor sports, specifically wheelchair court sports (wheelchair basketball, tennis and rugby) cannot utilise GPS and as a consequence must employ alternate tracking methods. Initial investigations into wheelchair sport-specific movements utilised a velocometer to provide detailed feedback about important aspects of linear performance (Goosey-Tolfrey & Moss, 2005; Moss et al., 2003). Unfortunately, while the device demonstrates good validity (0 ± 0.4% error), a number of practical limitations hinder its application in a competitive environment. Limitations associated with the mass, set-up and calibration time all need to be minimised when working in an elite environment. Hence, the device may be more useful as a research tool than a practical device of competition. More recently, miniaturised data loggers (MDL) have been employed in an attempt to explore the external load of wheelchair court sports. Such devices were originally developed to determine the activity of daily life wheelchair uses (Tolerico et al., 2007) and have recently been implemented into the wheelchair sporting environment (Sindall et al., 2013a,b; Sporner et al., 2009). The MDL, which attaches to the
spokes of a wheelchair wheel, operates via three reed switches at 120° intervals. Distance is calculated by multiplying number of reed switch triggers by 1/3 of the wheel circumference. Average speed can then be calculated by dividing distance by time (Sindall et al., 2013a). The small lightweight devices attach to the axle of the rear wheels, enabling data to be collected and stored over periods of approximately three months (Tolerico et al., 2007). The practical benefits of MDL mean they could be easily attached to a player’s sports wheelchair to record the distances covered and speed profiles during competition (Mason et al., 2014). Sindall et al. (2013a) recently validated the MDL against a motor-driven treadmill. As shown in Figure 2.2, the device provided an accurate and reliable representation of distance and speed < 2.5 m·s⁻¹, yet large variations in these parameters were reported at speeds in excess of 2.5 m·s⁻¹. Additionally, issues surrounding the practicality of the MDL must be considered, whereby the frequent occurrence of wheel changes during WCR competition (e.g. tyre punctures) hinder the suitability of wheel-mounted devices.

Figure 2.2 – Distance and speed assessment for a wheel-mounted device on a motor driven treadmill. Values for the device (solid lines) are reported against the fixed distance and speed (dotted lines). Reproduced from Sindall et al. (2013a).
2.2.1.5 Radio-frequency based techniques

Radio-frequency tracking systems have recently emerged as an alternative form of wearable tracking technology, with both the Local Positioning Measurement (LPM) system (Frencken et al., 2010; Ogris et al., 2012) and the Wireless Ad-hoc System for Positioning (WASP) currently available (Hedley et al., 2010; Sathyan et al., 2011). While such systems gather similar data to GPS, they rely on the distance measurements between fixed base stations positioned around the playing court and subsequently they can function indoors (Ogris et al., 2012). Due to the faster signal speed of radio-frequency systems much higher sampling frequencies are possible. A minor limitation of radio-frequency systems is the requirement of players to wear a tag during competition; however tags are much smaller and lighter compared to typical GPS units (40 x 40 x 10 mm; 25 g vs. 91 x 45 x 21 mm; 85 g) and provide minimal disruption to the players (Sathyan et al., 2011). Unfortunately, these systems are still in their relative infancy, particularly for sporting applications and as a result little is known about their validity and reliability. Initial validation of the LPM system assessed self-regulated walking and sprinting during four soccer-specific courses (Frencken et al., 2010). When sampling at 45 Hz, the LPM system underestimated the known distance for all courses; however, this was under 1.6% on average. The magnitude of this error is smaller compared to the aforementioned techniques of video-tracking (~4.8%) and GPS (~5.8%). Despite this, the average speed recorded by the LPM system was significantly lower compared to actual speed given by timing gates (1.8-3.9% CV), while the magnitude of error increased as the speed of movement increased (Frencken et al., 2010). In support of this, Ogris et al. (2012) confirmed measurement error also increased (10% error) during high-speed movements (> 19.0 km·h⁻¹) when compared to a VICON camera system (50 Hz). Yet the LPM system provided valid speed estimations at low speeds (< 14.1 km·h⁻¹). More recently, validation of the WASP system when sampling at 10 Hz, revealed an overestimation (2.7%) in distance travelled.
during dynamic testing (Sathyan et al., 2012). Unfortunately, the analysis was confined to a basic linear and non-linear course (Figure 2.3) at self-regulated speeds (not defined), which may not adequately reflect movements seen during competition. It is therefore recommended that the future validation of player tracking systems assess movements and intensities specific to the intended activity.

![Figure 2.3](image)

**Figure 2.3** – Linear (horizontal dashed line) and non-linear (dotted line) courses used in the validation of the WASP system. Black dots denote starting points. Reproduced from Sathyan et al. (2012).

### 2.2.2 The application of external load during team sports

The widespread application of player tracking techniques outlined above has permitted data about the external load of match-play activities to help evaluate performance and inform training (Cummins et al., 2013). From its introduction, player tracking techniques were used to measure the basic components of player activity, including the distance covered and the speed of these activities. A multitude of other variables can be further obtained, in which research has moved from general descriptive work to the analysis of the intensity of external load during competition and training.
2.2.2.1 Competition

Broad assessments across the entire match are often the starting point for player tracking research in AB sports. As a result, total distance is the most commonly reported variable in player tracking studies. Australian Football players generally cover the greatest distance (~13000 m) per match (Dawson et al., 2004; Edgecomb & Norton, 2006; Wisbey et al., 2010), while soccer players consistently demonstrate a higher distance (~10000 m) (Barros et al., 2007; Di Salvo et al., 2009; Mohr et al., 2003) than players from both rugby codes (~7000 m) (Austin & Kelly, 2013; Cahill et al., 2013; Cunniffe et al., 2009; Gabbett, 2013). Positional differences were further evident across AB sports (Austin & Kelly, 2014; Cahill et al., 2013; Carling et al., 2008; Di Salvo et al., 2009). Understanding such differences specific to each positional-role is essential when developing sport-specific training programmes. For example in soccer, there are large differences in the external responses between players, attributed to the tactical demands specific to each role. It has been recognised that fullbacks and wide midfielders typically perform the longest distances covered during competition (Bangsbo et al., 1991; Di Salvo et al., 2009; Mohr et al., 2003). Such comparisons present information that can be utilised to prepare players specifically to meet the requirements of their individual role within the team.

It is generally accepted that physical performance declines during AB competition as a consequence of increased fatigue towards the end of the match (Aughey, 2010; Coutts et al., 2010; Gabbett, 2012; Mohr et al., 2003). Several investigations in soccer have observed a reduction in total distance in the second half when compared to the first half (Bangsbo et al., 1991; Mohr et al., 2003). Moreover, analyses of Australian football indicated relative distance was greatest during the first quarter (117 m·min⁻¹), followed by a significant decrease in the second quarter (108 m·min⁻¹). This was maintained in the third quarter (108 m·min⁻¹),
followed by a further decrease in the fourth quarter (103 m·min⁻¹) (Coutts et al., 2010). In effect, this reduction may indicate the development of fatigue in the second half and is important for the design and format of conditioning-based training strategies. Despite this, recent research has suggested the volume of activity (total and relative distance) may not be the best indicator of physical performance across match-play (Di Salvo et al., 2009; Sirotic et al., 2009). Alternatively, measures of HIA may be advocated as better indicators of fatigue over time (Bradley et al., 2009; Mohr et al., 2003).

Whilst, HIA remains central to determining match performance and fatigue (Bradley et al., 2009), there are concerns over the determination of these activities. To date, there are no standardised methods for reporting intensity, and several definitions of what constitutes ‘high-intensity activities’ exist (Dwyer & Gabbett, 2012). Research has typically adopted speed-based thresholds to determine the intensity distribution of external load during AB sports (Di Salvo et al., 2009; Lovell & Abt, 2013; Rampinini et al., 2009). As shown in Table 2.2, speed zone criteria for what constitutes HIA often varied. Likewise, across the reviewed articles there were five alternative rationales for the thresholds used to define movement. Studies commonly provide justification for high-intensity categories based upon dated recommendations that have previously been constructed using timing gates or manual observation methods (Bangsbo et al., 1991; Reilly & Thomas, 1976). Pre-determined speed-based thresholds (i.e. ProZone® and AMISCO Pro®) are also commonly applied to soccer match-play (Bradley et al., 2013; Di Salvo et al., 2009; Rampinini et al., 2007a: 2009). A limitation of this approach is that it fails to account for the individual sprinting capacity of players (Abt & Lovell, 2009), since match speeds can vary considerably across playing positions (Di Salvo et al., 2009; Rampinini et al., 2007a: 2009). Thus, certain players may lack the capacity to reach speeds others are capable of, and in this way their intensity profile will be misrepresented (Cahill et al., 2013). Alternatively, both Cahill et al. (2013) and Venter
et al. (2010) employed an individualised speed threshold design based upon individual peak speeds attained throughout their studies. Such rationale offers an improved specificity in threshold design as it encompasses an individualised approach. Nevertheless, HIA appear to be the most important indicator of successful performance in AB sports (Di Salvo et al., 2009; Gabbett et al., 2013; Mohr et al., 2003).
Table 2.2 - Speed-based threshold design for the upper bands (zones 4-6) utilised in AB team sports.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Sport</th>
<th>Rationale</th>
<th>Speed</th>
<th>Zone 4 Description</th>
<th>Speed</th>
<th>Zone 5 Description</th>
<th>Speed</th>
<th>Zone 6 Description</th>
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</thead>
<tbody>
<tr>
<td>Wisbey et al. (2009)</td>
<td></td>
<td>None stated</td>
<td>16.0-18.0</td>
<td>&gt;18.0</td>
<td></td>
<td>&gt;25.0</td>
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<tr>
<td>Brewer et al. (2010)</td>
<td></td>
<td>None stated</td>
<td>&gt;15.0</td>
<td>High-intensity</td>
<td>20.0-23.0</td>
<td>High-speed</td>
<td>&gt;23.0</td>
<td>Sprint</td>
</tr>
<tr>
<td>Aughey &amp; Falloon (2010)</td>
<td></td>
<td>None stated</td>
<td>15.2-18.0</td>
<td>Jogging</td>
<td>&gt;18.0</td>
<td></td>
<td>&gt;25.0</td>
<td></td>
</tr>
<tr>
<td>Aughey (2010)</td>
<td></td>
<td>Previous research</td>
<td>15.0-36.0</td>
<td>High-intensity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coutts et al. (2010)</td>
<td>Australian Football</td>
<td>Previous research</td>
<td>14.4-20.0</td>
<td>Running</td>
<td>20.0-23.0</td>
<td>Higher-speed</td>
<td>&gt;23.0</td>
<td>Sprint</td>
</tr>
<tr>
<td>Wisbey et al. (2010)</td>
<td></td>
<td>None stated</td>
<td>16.0-18.0</td>
<td></td>
<td>18.0-21.6</td>
<td></td>
<td>&gt;18.0</td>
<td>Sprint</td>
</tr>
<tr>
<td>Aughey (2011)</td>
<td></td>
<td>Previous research</td>
<td>14.4-18.0</td>
<td></td>
<td></td>
<td></td>
<td>&gt;18.0</td>
<td>Sprint</td>
</tr>
<tr>
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<td></td>
<td>Previous research</td>
<td>14.0-19.9</td>
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<td>&gt;20.0</td>
<td>Very high-speed</td>
<td>Sprint</td>
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</tr>
<tr>
<td>Young et al. (2012)</td>
<td></td>
<td>Manufacturer recommendations</td>
<td>14.4.2-1.5</td>
<td>Running</td>
<td>21.6-25.2</td>
<td>Fast running</td>
<td>&gt;25.2</td>
<td>Sprint</td>
</tr>
<tr>
<td>Johnston et al. (2015)</td>
<td></td>
<td>Previous research</td>
<td>14.4.20.0</td>
<td>High-speed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conniffe et al. (2009)</td>
<td>Rugby Union</td>
<td>Previous research</td>
<td>14.0-18.0</td>
<td>Striding</td>
<td>12.0-21.0</td>
<td>Striding</td>
<td>&gt;21.0</td>
<td>Sprint</td>
</tr>
<tr>
<td>Hartwig et al. (2011)</td>
<td></td>
<td>Individualised</td>
<td>7.0-12.0</td>
<td>Jogging</td>
<td>19.8-25.0</td>
<td>High-intensity</td>
<td>&gt;25.0</td>
<td>Sprint</td>
</tr>
<tr>
<td>Ventier et al. (2011)</td>
<td></td>
<td>Individualised</td>
<td>51-80%</td>
<td>Striding</td>
<td>96-100%</td>
<td>Vmax*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cahill et al. (2013)</td>
<td></td>
<td>Individualised</td>
<td>51-80%</td>
<td>Striding</td>
<td>Vmax*</td>
<td>96-100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suarez-Arrones et al. (2014)</td>
<td></td>
<td>Previous research</td>
<td>14.1-18.0</td>
<td>Medium-intensity</td>
<td>18.1-20.0</td>
<td>High-intensity</td>
<td>&gt;20.1</td>
<td>Sprint</td>
</tr>
<tr>
<td>Sykes et al. (2009; 2011)</td>
<td>Rugby League</td>
<td>ProZone</td>
<td>14.4-19.7</td>
<td>Running</td>
<td>19.8-25.0</td>
<td>High-intensity</td>
<td>&gt;25.0</td>
<td>Sprint</td>
</tr>
<tr>
<td>McElhan et al. (2011)</td>
<td></td>
<td>Previous research</td>
<td>14.1-18.0</td>
<td>Striding</td>
<td>19.8-25.0</td>
<td>High-intensity</td>
<td>&gt;25.0</td>
<td>Sprint</td>
</tr>
<tr>
<td>Waldron et al. (2011)</td>
<td></td>
<td>Previous research</td>
<td>14.0-21.0</td>
<td>Moderate</td>
<td>19.1-23.0</td>
<td>High-intensity</td>
<td>&gt;23.0</td>
<td>Sprint</td>
</tr>
<tr>
<td>Gabbett et al. (2012)</td>
<td></td>
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<td>18.0-20.0</td>
<td>High-intensity</td>
<td>20.0-24.0</td>
<td>Sprinting</td>
<td>&gt;24.0</td>
<td>Sprint</td>
</tr>
<tr>
<td>Austin &amp; Kelly (2013)</td>
<td></td>
<td>Previous research</td>
<td></td>
<td>High-intensity</td>
<td></td>
<td></td>
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<td>Johnston et al. (2013)</td>
<td></td>
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<td></td>
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<td>Weaving et al. (2014)</td>
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<td>Bangsbo et al. (1991)</td>
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<td>None stated</td>
<td>15.0</td>
<td>Moderate</td>
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<td>Mohr et al. (2003)</td>
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<td>Previous research</td>
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<td>High-speed</td>
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<td>Sprinting</td>
</tr>
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<td>Barros et al. (2007)</td>
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<td>Previous research</td>
<td>14.0-19.0</td>
<td>Moderate-intensity</td>
<td>19.1-23.0</td>
<td>High-intensity</td>
<td>&gt;23.0</td>
<td>Sprinting</td>
</tr>
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<td>Rampinni et al. (2007; 2009)</td>
<td></td>
<td>ProZone</td>
<td>14.4-19.8</td>
<td>Running</td>
<td>19.8-25.2</td>
<td>High-speed</td>
<td>&gt;25.2</td>
<td>Sprinting</td>
</tr>
<tr>
<td>Bradley et al. (2013; 2014)</td>
<td></td>
<td>ProZone</td>
<td>14.4-19.8</td>
<td>Running</td>
<td>19.8-25.2</td>
<td>High-speed</td>
<td>&gt;25.2</td>
<td>Sprinting</td>
</tr>
</tbody>
</table>

*Note: Values given in km·h⁻¹ unless stated.

*Vmax represents peak speed attained during competition.
The analysis of external load observed during competition may not always provide a fair reflection of a team and individual performance since contextual factors may influence the overall profile (Castellano et al., 2011b). Previous research has advocated the analysis of match-outcome (Castellano et al., 2011b; Lago et al., 2010), team-formation (Bradley et al., 2009, 2011) or team rank during competition (Di Salvo et al., 2009; Gabbett, 2013, 2014; Rampinini et al., 2007). Whilst the influence of match-outcome is well documented in team sports (Bloomfield et al., 2004; Castellano et al., 2011b; Lago et al., 2009), caution must be exercised since score-lines and consequently team dynamics are likely to frequently alternate during competition (Castellano et al., 2014). Alternatively, the analysis of activity in relation to team rank has been used to provide an indication of the extent to which external load can influence the success of teams. Two studies conducted within elite soccer players in England (Di Salvo et al., 2009) and Italy (Rampinini et al., 2009) found an association between external load and team success, as determined by final league position. Interestingly, low-ranked Italian teams were shown to cover greater total distances, whilst performing less HIA compared to high-ranked teams (Rampinini et al., 2009). In contrast, Di Salvo et al. (2009) observed low-ranked English teams performed more HIA than higher ranked teams. However, in agreement with previous research (Castellano et al., 2014), it is vital team rank must be taken at the time of the match rather than final league position, as this incorporates current team performance. From the point of training, coverage of such variables are necessary to increase the understanding of factors potentially affecting external load and to facilitate strategies to maximise player preparation.

### 2.2.2.2 Training

In order to optimally prepare players to undertake the different requirements of competition, training sessions that address the specificity of competition need to be implemented. Training
specificity is widely regarded as a fundamental factor in shaping the success of AB team sports (Gamble, 2010). Subsequently, data obtained through player tracking techniques can be used to enhance training specificity and subsequently improve player preparation. Despite this more systematic approach to training prescription, a considerable disparity between training and competition has been observed (Gabbett, 2012; Hartwig et al., 2011; Higham et al., 2013). Such data conclude that training prescription may be inadequate across the majority of team sports. However, it is important to acknowledge that training is typically sub-divided into a variety of modes designed with a specific objective, e.g. conditioning, skill-based, or game-specific modes (Higham et al., 2013). The need to include a number of components into training would indicate that training strategies should be multi-dimensional (Morgans et al., 2014). Typically, conditioning drills should replicate or exceed the intensity experienced during competition (Peterson et al., 2011). Whilst this was established during netball (Chandler et al., 2014), HIA during conditioning drills were found to be much lower compared to rugby league competition (Gabbett et al., 2012). Alternatively, skill-based drills generally employ highly repetitious low-intensity ball-handling drills where the focus is skill execution with minimal errors (Farrow et al., 2008). Game-specific drills permit the simulation of movement patterns of competition, while maintaining a competitive environment that would not be present during conditioning- and skill-based drills (Gabbett, 2006). In a study of rugby league players, game-specific drills offered the most specific form of training mode, providing comparable high-intensity demands to competition (Gabbett et al., 2012). This detailed understanding of training and competition enables the provision of evidence-based training strategies that accurately reflect the demands of competition (Cummins et al., 2013).

As training intensity is the primary focus of training strategies (Morgans et al., 2014), the analyses of work-rest ratios (W:R) provides a good indication of the intermittent
distribution of training load. Such ratios depict the average recovery time (rest) between bouts of activity (work). The advantage of this approach in relation to training is that optimum recovery periods can be prescribed specific to each training mode. Whilst research has typically defined W:R as the amount of HIA in relation to low-intensity activities (Austin et al., 2011; Cunniffe et al., 2009; McLellan et al., 2011), it is imperative they are defined specific to the intended sport. That said, coaches can influence this intensity through the modification of player numbers (Hill-Haas et al., 2009; Rampinini et al., 2007b; Williams & Owen, 2007), pitch size (Kelly & Drust, 2009) and/or playing regulations (Fanchini et al., 2011; Hill-Haas et al., 2010). In practice, drills with reduced player numbers elicit greater overall load (Hill-Haas et al., 2010) since there are more continual activities that are performed at high-intensities (e.g. sprinting and accelerating) (Morgans et al., 2014; Platt et al., 2005). Changing the duration of training drills has a corresponding effect on the activity of training. For example, when training drills were examined using 2-6 min soccer games, there was a significant increase in the exercise intensity during the 2 and 4 min games compared to the 6 min game (Fanchini et al., 2011). However, it is important to note the manipulation of training duration may also elicit changes in the quality of technical actions as well as external load (Morgans et al., 2014).

In summary, empirical information gleaned from player tracking techniques are considered essential to provide a platform upon which evidence-based training strategies can be made. Unfortunately, this empirical evidence is currently lacking in WCR. Nevertheless, the focus of the next section aims to collate the depth of performance-based research within WCR and how these methods have been applied to determine the physical requirements of WCR.
2.3 External load in wheelchair court sports

As outlined there are significant methodological issues with player tracking techniques that confound the inherent difficulty in collecting competitive data in WCR. Nevertheless, the physical preparation of the elite player has become a vital part of modern WCR teams mainly due to the high physical demands that take place during competition (Malone et al., 2010).

2.3.1 Volume of activity

The general consensus across the literature within WCR suggests that players cover distances ranging from 2000-5000 m during competition (Sarro et al., 2010; Sporner et al., 2009). Initial investigations utilised a wheel-mounted MDL to assess the volume of activity in recreational WCR players (Sporner et al., 2009). Total distance covered across competition was ~2365 m, with a mean speed of 1.33 m·s⁻¹. When automatic tracking systems were first employed these distances were greatly exceeded, with total distances of 4540 m recorded in elite WCR players during 2008 Demolition Derby (Sarro et al., 2010). Subsequently, the physical demands of WCR have increased as the standard of competition has improved. The more refined movement pattern and superior force application seen in experienced wheelchair users would likely contribute to these differences (de Groot et al., 2008; Lenton et al., 2008). Although interesting, this comparison between playing standards was made across two separate studies, which utilised different methodologies, most notably the different player tracking systems (wheel-mounted and automatic tracking). Furthermore, a major limitation of both studies was the failure to account for differences in relative time between individuals. Normalising movement parameters (e.g. total distance) based on playing time are often more effective when comparing between individuals, especially in WCR where continuous roll-on substitutions are permitted.

Sarro et al. (2010) further identified classification-dependent trends in the volume of activity, whereby total distance and mean speed values increased in association with
improved functional ability (Figure 2.4). This was probably closely linked to the tactical role of HP (Table 2.1) as well as their greater physical capacity (Morgulec et al., 2011). Although such findings may be expected, the findings are somewhat limited as not all functional classifications were assessed. Data was also limited to a maximum sample of two players for each classification group. Larger sample sizes for each classification group may reduce the influence of factors such as game-style and team tactics. Nevertheless, these data support the need to understand external load specific to each classification when developing individualised training strategies.

![Graph showing total distance and mean speed during a single elite WCR match](image)

**Figure 2.4** – Total distance (bars) and mean speed (dotted line) values during a single elite WCR match ($n = 8$). Data obtained from Sarro et al. (2010).

Furthermore, recent rule variations in WCR may influence the physical characteristics of competition. Specifically, changes to the timing regulations and the introduction of unlimited substitutions may now affect the speed of the game. This in turn could influence the specific tactics and line-ups used during competition. Under new regulations introduced post 2008, a team in possession has 12 s to advance the ball from the back-court into the front court (15 s according to previous rules). Also, a team in possession now has a total of 40 s to
score or they conceded possession (no time stipulation according to previous rules). Unfortunately, to date no information exists regarding the effect of the new rule changes on external load during WCR competition. Further, it is possible the demands of competition have changed in the seven years since some of these studies were completed.

2.3.2 Match fatigue

The three major international competitions at the elite level of WCR are the Paralympic Games, World Championships and Zonal Championships (Americas/European/Oceania). These tournaments typically consist of a round-robin style tournament. This schedule involves intense periods where teams are required to play up to six matches in four days. With limited time to recover before the next match and an increased importance of match outcomes as the tournament progresses, the ability to maintain physical performance across competition is critical. Published research on the physical demands of elite WCR is limited, especially relating to recent competition and tournament play. Analysis of data derived from WCR competition demonstrated a decline in total distance covered (5.6%) and mean speed (14.5%) across match-halves (Sarro et al., 2010). Consistent with AB findings (Di Salvo et al., 2009; Mohr et al., 2003), this reduction in volume suggests that fatigue occurs towards the end of WCR matches. Whilst, such findings could be attributed to a multitude of factors (e.g. score-line, team tactics etc.) doubts surrounding the practicality of these activity metrics must be addressed. The pragmatic question would be whether a reduction of ~49 m in total distance over 35 min of play is meaningful enough to warrant prescription of additional conditioning training. Furthermore, Sarro et al. (2010) identified such a decline was greater in LP (distance = 9.9%; mean speed = 19.1%) as opposed to HP (distance = 4.2%; mean speed = 10.1%). The general drop-off in volume towards the end of a match may suggest the need for supplementary conditioning programmes tailored to individual classification groups. Despite
this, caution must still be taken when interpreting this information, as only one match was assessed from a small number of athletes ($n = 8$). Advances in technology may enable further evidence-based relationships between external load and fatigue in WCR.

### 2.3.3 Speed characteristics

While sprint performance appears to be an integral part of WCR (Goosey-Tolfrey & Leicht, 2012; Mason et al., 2010; Tweedy & Diaper, 2010; Vanlandewijck et al., 2001), little is known about the speed-based capabilities of WCR players. Through the use of a velocimeter, Mason et al. (2009) reported the peak speed values during a 15 m linear sprint in elite WCR players (see Table 2.3). The velocimeter attached to an individual’s wheelchair to deduce the measurement of speed and improve the depth of information gleaned (Mason et al., 2014). This device was previously used in wheelchair tennis (WCT), whereby ~60% of peak speed was reached in the first 2.5 m during linear sprints (Goosey-Tolfrey & Moss, 2005). Similarly during a sprint test on a wheelchair ergometer, three male wheelchair basketball (WCB) players achieved 61% of their peak speed (4.02 m·s$^{-1}$) during the first push, 73% during the second push and 80% during the third push (Coutts, 1992). The restricted court dimensions of the wheelchair court sports may suggest players seldom reach their maximal speed during match-play. Thus, development of acceleration may be of greater benefit than a focus on improving maximal speed during game-specific training. Unfortunately, such results failed to take into account the speed characteristics specific to competition. Given that speed characteristics specific to competition have been reported to be greater in high-ranked WCT players compared to low-ranked (3.18 m·s$^{-1}$ vs. 2.40 m·s$^{-1}$) (Sindall et al., 2013b), understanding such parameters are of high importance, especially as this could be considered a fundamental contributor to performance in WCR.
Recent observations of the sprint times in sub-elite WCR players are summarised in Table 2.3 (Morgulec et al., 2011). Although it was evident that 0.5 class players achieved slower times over 20 m (10.7 ± 1.3 s) compared to higher functional players (7.7 ± 0.9 s), no differences between classes 1.0-3.5 were found (Morgulec et al., 2011). The considerable limitation in hand function associated with LP negatively influence wheelchair propulsion technique (Table 2.1), as such it would seem plausible that speed capabilities would therefore differ across functional classification groups. Despite this, WCR players appear to exhibit slower speeds across 20 m compared to elite WCB players (Molik et al., 2013; Vanlandewijck et al., 1999; Yilla & Sherill, 1998). As the anaerobic capacity in WCR players is lower than that of WCB players (Goosey-Tolfrey & Leicht, 2013; Haisma et al., 2006), it is therefore unsurprising that speed characteristics differ between the sports. Nevertheless, accurate determination of player speed is an important component of player tracking and can increase the specificity of future player preparation strategies.
Table 2.3 – Summary of previous investigations into the speed characteristics (mean ± SD) of wheelchair court sports.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Participants</th>
<th>Technique</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2.5 m</td>
<td>5 m</td>
</tr>
<tr>
<td>Yilla &amp; Sherill (1998)</td>
<td>Elite WCR</td>
<td>Stopwatch</td>
<td>-</td>
</tr>
<tr>
<td>Mason et al. (2009)</td>
<td>Elite WCR</td>
<td>Veloocometer</td>
<td>-</td>
</tr>
<tr>
<td>Morgulec et al. (2011)</td>
<td>Sub-elite WCR</td>
<td>Timing gates</td>
<td>-</td>
</tr>
<tr>
<td>Vanlandewijck et al. (1999)</td>
<td>Elite WCB</td>
<td>Timing gates</td>
<td>-</td>
</tr>
<tr>
<td>de Groot et al. (2012)</td>
<td>Club WCB</td>
<td>Stopwatch</td>
<td>2.5 ± 0.2</td>
</tr>
<tr>
<td>Chapman et al. (2012)</td>
<td>Elite WCB</td>
<td>Timing gates</td>
<td>-</td>
</tr>
<tr>
<td>Molik et al. (2013)</td>
<td>Elite female WCB</td>
<td>Timing gates</td>
<td>2.1 ± 0.1</td>
</tr>
<tr>
<td>Granados et al. (2015)</td>
<td>Club WCB</td>
<td>Timing gates</td>
<td>1.8 ± 0.1</td>
</tr>
<tr>
<td>Yanci et al. (2015)</td>
<td>Club WCB</td>
<td>Timing gates</td>
<td>1.9 ± 0.2</td>
</tr>
<tr>
<td>Moss et al. (2005)</td>
<td>Elite WCT</td>
<td>Veloocometer</td>
<td>-</td>
</tr>
</tbody>
</table>

Note: WCR – wheelchair rugby, WCB – wheelchair basketball, WCT – wheelchair tennis
Values expressed as seconds unless stated.
2.3.4 Match intensity

The pattern of intensity in WCR is characterised by intermittent periods of intense effort superimposed on a background of aerobic activity (Goosey-Tolfrey et al., 2006). Stoppages account for around 50% of the overall match time in WCR matches, with around 120 to 270 pauses per match (Sarro et al., 2010; Sporner et al., 2009). Despite this, little is known surrounding the intermittent distribution of intensity during competition. Traditionally, internal load, as expressed by HR has typically been employed as an indicator of intensity due to its strong linear relationship in both AB populations (Garber et al., 2011) and individuals with paraplegia (Goosey-Tolfrey & Tolfrey, 2004). Initial investigations revealed WCB players achieved a mean HR value of 148 b·min\(^{-1}\) during competition, with 62% of the match spent performing HIA (defined as time above 140 b·min\(^{-1}\)) (Coutts, 1988). Moreover, Bloxham et al. (2001) identified WCB match-play was played at an intensity that elicited a HR response that exceeded individual HR\(_{\text{peak}}\) for a considerable part of the match duration (e.g. 24% during the first half and 18% during the second half). Furthermore, in WCT, the varying intensity and intermittent nature of competition was identified by values of 69% to 75% HR\(_{\text{peak}}\) reported (Croft et al., 2010; Roy et al., 2006; Sindall et al., 2013b). While competition-specific intensity is currently unknown in WCR, Barfield et al. (2010) revealed players achieve mean HR values of 106 b·min\(^{-1}\) during training. Players were further shown to be capable of maintaining high intensities (above 70% HR\(_{\text{peak}}\)) for prolonged durations during training (Barfield et al., 2010). The ability to sustain high percentages of HR\(_{\text{peak}}\) is not surprising given the blunted HR responses found in individuals with tetraplegia. This is well documented in the literature with reported HR\(_{\text{peak}}\) values of 184 b·min\(^{-1}\) vs. 129 b·min\(^{-1}\) for paraplegics and tetraplegics respectively during standardised wheelchair propulsion laboratory tests (Leicht et al., 2012). For further information regarding the mechanisms behind this the reader is guided to Valent et al. (2007), since it is beyond the scope of this
thesis. As we know, generally internal load provides information regarding the intermittent distribution of intensity during competition, unfortunately the use of HR is unsuitable for individuals with a SCI (Paulson et al., 2013). Consequently, alternative methods are required to address the intensity of competition in WCR players.

As previously alluded to in section 2.2.2, research has typically adopted arbitrary speed thresholds to determine the intensity of external load during competition (Cahill et al., 2013; Di Salvo et al., 2009; Lovell & Abt, 2013; Rampinini et al., 2009). Of the available research, video tracking results from WCB players suggest ~28% of a match was spent performing high-intensity work – namely sprinting and contesting for the ball (Bloxham et al., 2001). Alternatively, low-intensity activities, such as shooting and gliding comprised the majority of the time during WCB competition (~45%). However, caution must be exercised when interpreting this data. The activity categories defined by Bloxham et al. (2001) were based on the authors’ subjective knowledge and lack any objective definition as to what defines a “high-intensity” movement. More recently, Sindall et al. (2015) reported the intermittent distribution of time spent in zones across a speed continuum within elite WCT players. Stationary activity was shown to incorporate 9% of match-play, while low-intensity movements (< 2.5 m·s⁻¹) dominated the overall profile (89%) of WCT (Sindall et al., 2015). Depending on match format, HIA (> 2.5 m·s⁻¹) accounted for 0.5% to 4.5% of the match during singles and doubles matches respectively. While the design of speed-based thresholds are important for the analyses of match intensity, the differences in functional capacity across WCR players pose a logical requirement for classification-specific threshold design in WCR.

2.3.5 Contextual variables

A pertinent coaching issue in wheelchair court sports is to understand the contextual issues of team rank during competition (Vanlandewijck et al., 2004; Molik et al., 2011; Sindall et al.,
Vanlandewijck et al. (2004) described a relationship between functional classification and game efficiency patterns in elite female WCB players. Consistent with findings in WCR, this study indicated that HP WCB players performed better than LP for the majority of variables linked to match performance (Vanlandewijck et al., 2004). In the same context, female WCB players from high-ranked WCB teams in Gold Cup 2006 showed higher levels of game efficiency than low-ranked teams (Molik et al., 2011). When utilising the MDL, Sindall et al. (2013b) revealed high-ranked WCT players (current world ranking ≤ 25) covered greater total distances and maintained higher average speeds than low-ranked players (current world ranking ≥ 350). Furthermore, high-ranked players also achieved higher peak speeds in comparison to their low-ranked counterparts (Sindall et al., 2013b). Such data suggest high-ranked players are more capable of responding to the physiological challenges associated with WCT competition (Sindall et al., 2013b). In a subsequent study, low-ranked WCT players spent more time stationary (12.6% vs. 8.2%) and less time performing high speed activities (2.50-3.49 m·s⁻¹) compared to their high-ranked counterparts (0% vs. 4.4%) (Sindall et al., 2015). However, given the validity of the MDL previously outlined in section 2.2.1.4, caution should be noted with the interpretation of high-speed movements. On the whole, these observations suggest that the intensity of activities may be important in achieving success in wheelchair court sports, and therefore training strategies should be structured with this in mind.

2.3.6 Training in WCR

Annual training strategies are an integral part of elite sport; however WCR teams are far behind AB sports in the development and effective use of such strategies. In order to optimally prepare WCR players to undertake the different functional and positional-role requirements of competition, specific physical, technical and tactical objectives need to be
formulated. Based on the competition schedule the coach should structure the overall training strategy in accordance with the phase of the season (Table 2.4).

Table 2.4 – Structure of an annual training strategy for WCR.

<table>
<thead>
<tr>
<th>Season phase</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-season</td>
<td>Develop high level of physical conditioning. As phase progresses, training becomes more specific and represents a transitional shift toward the competitive season with a focus on ball-specific drills. This includes skill refinement of basic ball-handling drills and the development of teamwork among players.</td>
</tr>
<tr>
<td>Competitive phase</td>
<td>Continuing perfecting technique to enable performance at the highest level. The main focus should be on simulating specific game situations through technical and tactical-specific drills. Training should focus on the refinement of tactical plays with specific strategies developed for upcoming opponents. Physical conditioning should still be maintained. The overall load should be reduced while the intensity is maintained or increased.</td>
</tr>
<tr>
<td>Off-season</td>
<td>Recovery and evaluation of the previous season. Active rest is advised when progressing towards the start of the new season.</td>
</tr>
</tbody>
</table>

Note: Adapted from Malone et al. (2010).

An appropriate training stimulus, to achieve the required physical capabilities during pre-season, has typically been delivered through propulsion-based conditioning training (Orr & Malone, 2010). Consistent with AB research (Chandler et al., 2014), conditioning drills elicited the greatest load during WCR training (Barfield et al., 2010). Across WCR training, a greater mean HR (114 b·min⁻¹) was observed during conditioning-based training compared to skill- (101 b·min⁻¹) and game-specific (104 b·min⁻¹) training drills (Barfield et al., 2010). Furthermore, duration spent above 70% HR reserve was also greatest during conditioning drills (~74%) compared to other training modes (26-50%). Whilst such results would suggest conditioning drills can provide an appropriate training stimulus to increase the overall load, it is particularly important to assess external load to subsequently monitor training specificity.

One of the main differences between conditioning and other wheelchair-specific drills is the presence of a ball to support the development of tactical and technical skills required
during the competitive phase (Table 2.4). Despite this, an inherent part of the competitive phase is that drills adhere to the specificity of competition. The importance of specificity is based on the notion that the transfer of training performance is dependent on the degree to which training replicates competition (Morgans et al., 2014). Unfortunately, during training, WCR coaches cannot currently monitor the intensity level of training, and so it is not clear to what extent training modes have on the specificity of actual competition.

2.4 Summary

As part of the coaching process, information derived from player tracking techniques is considered fundamental to provide a framework upon which objective decisions for training prescription can be made. Having reviewed the previous literature on player tracking techniques that have been used for AB sports, it was clear that numerous factors must be considered to further improve understanding and to make findings applicable to WCR. Previous investigations into WCR competition were collected up to seven years ago and have limited translations that can be applied to current day WCR teams. Methodological limitations and the wide array of functional abilities observed in WCR present a challenging task in developing the required evidence-based framework. The measurement error associated with player tracking devices appears to be unsystematic across sports. Under- and over-estimations have been reported, with errors attributed to the length of movement, sampling frequency, and more importantly, the speed of movement. Therefore, the validity and reliability of a player tracking technology specific to WCR needs to be established. Once this is achieved, data can be used to directly address the particular needs of WCR performance. Subsequently, the IWRF classification system, the influence of match fatigue and the importance of external load in relation to successful performance all need to be considered. Similarly, further reflection regarding data-driven approaches to training prescription and its eventual application to player preparation is also necessary.
3. Study One: The validity and reliability of a novel indoor player tracking system for use within wheelchair court sports

This chapter has been published in slightly modified format in the *Journal of Sports Sciences*:


The following chapter aims to investigate the capability of an ITS to accurately and reliably quantify measures of external load specific to the wheelchair court sports.
3.1 ABSTRACT

Purpose: To investigate the validity and reliability of a radio frequency-based system for accurately tracking athlete movement within wheelchair court sports. Methods: Four wheelchair-specific tests were devised to assess the system during (i) static measurements; (ii) incremental fixed speeds; (iii) peak speeds; and (iv) multi-directional movements. During each test, three sampling frequencies (4, 8 and 16 Hz) were compared to a criterion method for distance, mean speed and peak speeds. Results: Absolute static error remained between 0.19 and 0.32 m across the session. Distance values (test (ii)) showed greatest relative error in 4 Hz tags (1.3%), with significantly lower errors seen in higher frequency tags (< 1.0%). Relative peak speed errors of < 2.0% (test (iii)) were revealed across all sampling frequencies in relation to the criterion (4.00 ± 0.09 m·s⁻¹). Results showed 8 and 16 Hz sampling frequencies displayed the closest-to-criterion values, whilst intra-tag reliability never exceeded 2.0% CV during peak speed detection. Minimal relative distance errors (< 0.2%) were also seen across sampling frequencies during multi-directional movements (test (iv)). Conclusions: The ITS is deemed an acceptable tool for tracking aspects of mobility at speeds specific to the wheelchair court sports using a sampling frequency of 8 or 16 Hz.
3.2 INTRODUCTION

Understanding the movement demands placed upon an athlete during competition is a fundamental requirement for the prescription of specific, individualised training programmes. Player tracking has been extensively used within AB team sports to explore movement demands, with basic notational techniques employed since the mid-1970’s (Reilly & Thomas, 1976; Sanderson & Way, 1977). Advances in technology introduced more objective methods of player tracking, such as manual (Bloomfield et al., 2004; O’Donoghue, 2002) and automatic video tracking techniques (Barros et al., 2007; Figueroa et al., 2006). Currently, the use of GPS has emerged as the most practical method of player tracking to obtain a real time analysis of external load (e.g. distance covered and speed profiles) during team sports (Cummins et al., 2013).

The validity of GPS during high intensity, intermittent sports has been comprehensively examined (section 2.2.1). Investigations suggest that GPS accurately tracks players during low-speed (< 1.8 m·s⁻¹) movements (Portas et al., 2007), with distance and speed errors (5-20%) increasing exponentially during high-speed (> 4 m·s⁻¹) movements (Duffield et al., 2010; Johnston et al., 2012). Recent studies have also revealed that the validity and reliability of GPS improves when higher sampling frequencies (10 Hz) are used, contributing towards the magnitude of these aforementioned errors (Castellano et al., 2011a; Jennings et al., 2010; Varley et al., 2012).

As discussed in the preceding chapter, a major limitation with GPS is its reliance on satellite signals, restricting its use to an outdoor environment only. As a result, indoor team sports such as WCB and WCR cannot utilise GPS. Consequently, image-based processing techniques (Sarro et al., 2010) and wheel-mounted MDL (Sindall et al., 2013a; Sporner et al., 2009) have been employed in an attempt to determine the demands of the wheelchair court.
sports. However, the issues identified in sections 2.2.1.3 and 2.2.1.5 respectively, questions the suitability of existing techniques for use within elite wheelchair court sport applications.

Radio-frequency tracking systems have emerged, which gather similar data to GPS, with both the LPM system (Frencken et al., 2010; Ogris et al., 2012) and the WASP currently available (Hedley et al., 2010; Sathyan et al., 2011). These systems rely on distance measurements between known fixed base stations and mobile tags worn by the athlete, subsequently making the system suitable for indoor use (Leser et al., 2011; Sathyan et al., 2011). Unfortunately, these systems are still in their relative infancy, particularly for sporting applications and as a result little is known about their validity and reliability for such purposes. Initial validation of the LPM system confirmed error values increased during high-speed movements (> 6 km·h⁻¹), yet provided valid speed estimations at low speeds (Frencken et al., 2010; Ogris et al. 2012). Alternatively, validation of the WASP system revealed an overestimation (2.7%) in distance travelled during dynamic testing (Sathyan et al., 2012). Unfortunately, the analysis was confined to a basic linear and non-linear drill at self-regulated speeds (not defined), which may not adequately reflect movements seen during competition.

A new, radio frequency-based ITS has recently been developed, which utilises ultra-wideband (UWB) signals to communicate with compact tags worn by athletes, providing real-time analysis on external load. The additional benefit of the ITS is the incorporation of smaller, lightweight tags (size = 40 x 40 x 10 mm; mass = 25 g), opposed to the larger tags used with the LPM (92 x 57 x 15 mm; mass = 60 g) and WASP (90 x 50 x 25 mm; mass = 50 g) systems. Subsequently, the ITS may be a more practical solution since minimal disruption would be imposed on athletes during competition and training environments. The aims of the current study were: (1) to investigate the validity and reliability of the ITS during movements and speeds specific to the wheelchair court sports and (2) to determine the effect of different sampling frequencies on the system’s measurement accuracy.
3.3 METHODS

3.3.1 Participants
Two physically active, AB males (age: 30.0 ± 2.0 years, mass: 82.5 ± 9.2 kg, height: 1.81 ± 0.04 m) with extensive experience of wheelchair propulsion volunteered to participate in the current investigation. The study was approved by Loughborough University’s local ethical advisory committee, with informed consent gained prior to participation.

3.3.2 Equipment
The ITS (Ubisense, Series 700 IP, Cambridge, UK) is a wired radio-frequency based real-time location system. The system has an overall bandwidth of 137 Hz and is comprised of six sensors that communicate wirelessly with compact tags. The sensors detect UWB signals from the tags, measuring both the angle-of-arrival and the time-difference-of-arrival to generate an accurate tag location. This provides raw data on the positional coordinates of a tag in three dimensions. To mitigate the effect of random noise in UWB positions, raw data was filtered using a 3-pass sliding-average filter with a window width proportional to the tag frequency (Perrat et al., 2015).

The validity and reliability of the ITS was assessed during one session using four separate tests (i) static measurements; (ii) incremental fixed speeds; (iii) peak speeds; (iv) multi-directional movements. Measures of external load calculated by the ITS were derived using software developed specifically for wheelchair court sports at the University of Nottingham. All dynamic tests ((ii), (iii) and (iv)) were performed in a rugby wheelchair (Melrose Wheelchairs, New Zealand: mass = 12.7 kg; wheel size = 0.591 m; tyre pressure = 120 psi; camber = 18º). The criterion measurement for distance (tests (ii) and (iv)) was provided by a laser total station (Leica TS-30, Leica Geosystems, UK), more commonly used within a professional surveying environment. The Leica system utilises high quality angle and
distance measurements with automatic target tracking to produce accurate coordinates (~0.004 m) about the point of interest (Bayoud, 2006). The total station was positioned on a balcony overlooking the entire court, ensuring a consistent, unobstructed view throughout each test. Wireless timing gates (Brower Timing Systems, Draper, UT) were used to record the mean speed (tests (ii) and (iv)), whilst a wireless inertial sensor (Ellul et al., 2011), attached to the right axle of the wheelchair provided the criterion measurement for peak speed (test (iii)). In brief, the inertial sensor is a small, lightweight device (size = 20 x 30 x 17 mm; mass = 10 g) that transmits data wirelessly at a sampling frequency of approximately 50 Hz. This device has previously been validated during linear wheelchair propulsion (Mason et al., 2014), reporting speed errors < 0.9% CV observed across a range of speeds up to 6 m∙s⁻¹.

3.3.3 Procedures

The ITS was set up in an indoor sports hall equipped with wooden sprung flooring to replicate the playing surface used during WCB and WCR. The six sensors were located around the perimeter of a regulation size WCB and WCR court (28 x 15 m). The sensors were positioned at each of the four corners of the court, with two additional sensors positioned at the half-way line. Each sensor was mounted on an extendable tripod, elevated approximately 4 m high. The orientation of each sensor was configured so that the pitch was 40° from the horizontal and the rotation about the perpendicular line from the sensor face was fixed at 0°, maximising court coverage. Prior to data collection the system was calibrated using two reference points of known coordinates, which were calculated by a laser distance measurer (PLR 50, Bosch, Germany). This enabled precise sensor locations to be determined. A static tag placed in another known location was then used to calibrate the system. This procedure takes multiple measurements from the static tag using its known x, y and z coordinates to determine the orientation and offset off each sensor (Mandeljc et al., 2012). During all dynamic tests (tests (ii), (iii) and (iv)) nine tags were monitored, with three tags sampling at a low (4 Hz), medium
(8 Hz), and high (16 Hz) frequency, which were secured to the wheelchair as demonstrated in Figure 3.1.

Figure 3.1 - The location of the nine tags fixed to the wheelchair during dynamic tests. Inset is the sampling frequency for each tag with regards to its location

(i) Static measurements

The accuracy of a motionless tag was assessed by individually placing three tags of different sampling frequency (low, medium and high) in each of the four corners of the court (where known coordinates exist). Based on previous protocols (Frencken et al., 2010; Sathyan et al., 2012) data was collected from each tag for 20 s. This assessment was performed at the beginning of the session (pre) and then repeated 4 h later at the end of the session (post) to determine whether the system was prone to drift over time.

(ii) Incremental fixed speeds

The accuracy of the system for detecting distance measurements was assessed over increasing fixed speeds using a ‘figure of eight’ course (Figure 3.2). One participant completed five laps of the course at three fixed sub-maximal speeds (4, 6, and 8 km·h⁻¹), with five trials conducted
at each speed. The speeds selected are commonly used within previous sub-maximal wheelchair propulsion literature (Mason et al., 2013; Vanlandewijck et al., 1994). This range also covers the speeds typically averaged during previous wheelchair court sports match-play (Sarro et al., 2010; Sporner et al., 2009). The speeds were averaged throughout each trial through using a Raleigh SP-20 speedometer (Raleigh Ltd, Nottingham, UK). The display monitor was secured to the participant’s knee, providing instantaneous feedback about their average speed. The participant was instructed to maintain these speeds, on average, throughout each trial.

**Figure 3.2** - The ‘figure of eight’ drill used to assess distance during incremental fixed speeds. The solid middle horizontal line represents the location of the timing gates and the start/finish of the drill (a = 8 m, b = 12.25 m; lap = 81 m; total distance = 405 m).

(iii) **Peak speeds**

To assess the accuracy of the system for the detection of peak speeds, a 20 m linear wheelchair sprint was performed. One participant completed all ten trials from a standstill. After each maximal effort, sufficient recovery time was permitted before each subsequent sprint.
In order to determine the accuracy of a player tracking system, the experimental design has to satisfy the demands of the activity to which the system will be exposed (Siegle et al., 2013). A multi-directional drill was used to replicate the frequency and intensity of movements performed during wheelchair court sports competition. Two participants performed 4 x 8-min trials in an alternate order to avoid the possibility of fatigue affecting the quality of the trials, resulting in a total of 8 x 8-min trials. The participants were instructed to incorporate numerous changes in speed and direction to replicate the acceleration, agility and sprinting manoeuvres deemed vital to wheelchair court sport athletes (Vanlandewijck et al., 2001). The total distances covered and mean speeds were collected during each trial.

3.3.4 Statistical analyses

Data analyses were performed using the Statistical Package for the Social Sciences (SPSS version 19, Chicago, IL). Normality and homogeneity of variance were confirmed by Shapiro-Wilk and Levene’s tests, respectively. Criterion validity of external load measured by the ITS were analysed using 95% limits of agreement (LOA), displaying the systematic bias ± random error demonstrated for each variable (Bland & Altman, 1986). During test (ii), validity was also compared to criterion measures using the typical error of the estimate (TEE) and expressed in raw units (± 95% confidence limits (CL)). A one-way repeated measures analysis of variance (ANOVA) was used to examine the mean differences in performance variables within and between each of the three different sampling frequencies compared to criterion measures across all tests. Statistical significance was accepted when $P < 0.05$. Effect sizes (ES) were calculated to determine the meaningfulness of any differences, whereby ES < 0.2 reflected a trivial effect (Batterham & Hopkins, 2006), with 95% confidence intervals for
differences (95% CI) also presented. Intra-tag reliability was reported as a CV% between the tags for each specific test.

3.4 RESULTS

(i) Static measurements

The mean absolute error during pre-session measurements did not significantly differ between low (0.24 ± 0.27 m), medium (0.26 ± 0.25 m) and high (0.32 ± 0.25 m) frequency tags ($P \geq 0.72$; $ES \leq 0.1$), as demonstrated in Figure 3.3. No significant differences in post session values were revealed between low (0.26 ± 0.24 m), medium (0.26 ± 0.24 m) or high frequency (0.19 ± 0.20 m) tags ($P \geq 0.92$; $ES \leq 0.2$). No significant differences between pre and post session measurements were found at any sampling frequency ($P \geq 0.15$; $ES \leq 0.2$). Intra-tag reliability results revealed that sampling frequency had no effect on reliability with a 1.0% CV demonstrated across all frequencies during pre- and post-session measurements.

Figure 3.3 - Plot of mean static error for each sampling frequency during pre-session and post-session. Error bars represent SD.
(ii) Incremental fixed speeds

The TEE for distance revealed that minimal errors existed during high and medium fixed speeds (0.98-1.09 m), however values increased during low fixed speed (1.85-2.11 m) as displayed in Table 3.1. A significant difference existed between criterion measures and low ($P = 0.0005$; 95% CI = 7.3 to 10.4; ES = 0.9), medium ($P = 0.005$; 95% CI = 6.2 to 8.2; ES = 0.8), and high ($P = 0.005$; 95% CI = 4.5 to 6.6; ES = 0.8) sampling frequencies during low fixed speeds. However, no significant differences were observed during the medium and high fixed speeds ($P \geq 0.12$; ES $\leq 0.7$). Typical error of the estimate values for mean speed demonstrate the ITS to be consistent (0.01 m·s⁻¹) across all sampling frequencies at each fixed speed. Although low frequency tags displayed the greatest absolute differences to criterion values (Table 3.1), no statistically significant difference was observed between sampling frequencies for mean speed ($P \geq 0.15$; ES $\leq 0.4$). Intra-tag reliability results indicated that the error range across fixed speeds to be greatest within low frequency tags (0.1-0.6% CV). This error range decreased at both medium (0.2-0.4% CV) and high (0.2-0.3% CV) sampling frequencies.

(iii) Peak speeds

Mean criterion values were found to be 4.00 ± 0.09 m·s⁻¹ during maximal sprint trials. In comparison, mean tag values for each sampling frequency were 4.07 ± 0.14 m·s⁻¹ (low), 4.05 ± 0.15 m·s⁻¹ (medium), and 4.00 ± 0.12 m·s⁻¹ (high). A significant difference was revealed between both low ($P = 0.001$; 95% CI = -0.17 to -0.01; ES = 0.3) and medium ($P = 0.005$; 95% CI = -0.19 to -0.03; ES = 0.2) sampling frequencies in relation to the criterion measure, with positive systematic bias ± random errors of 0.08 ± 0.17 m·s⁻¹ and 0.05 ± 0.10 m·s⁻¹ respectively (Figure 3.4). Intra-tag reliability was greater within low frequency tags (2.7% CV), and improved as sampling frequency increased (medium = 2.0% CV; high = 1.6% CV).
Table 3.1 - Distance and mean speed values during movement at incremental fixed speeds (test ii)

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Low Freq</th>
<th>TEE</th>
<th>Med Freq</th>
<th>TEE</th>
<th>High Freq</th>
<th>TEE</th>
<th>Mean Speed (m·s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>395</td>
<td>404 (399-409)</td>
<td>1.96</td>
<td>402 (399-406)</td>
<td>1.85</td>
<td>400 (398-404)</td>
<td>2.11</td>
<td>1.14 (1.15-1.19)</td>
</tr>
<tr>
<td>394</td>
<td>398 (397-399)</td>
<td>1.03</td>
<td>398 (396-400)</td>
<td>1.04</td>
<td>396 (394-398)</td>
<td>1.09</td>
<td>1.55 (1.52-1.60)</td>
</tr>
<tr>
<td>394</td>
<td>397 (394-400)</td>
<td>1.06</td>
<td>397 (395-401)</td>
<td>1.00</td>
<td>396 (394-399)</td>
<td>0.98</td>
<td>2.01 (1.97-2.07)</td>
</tr>
</tbody>
</table>

Note: Data expressed as mean values (95% CL). TEE expressed as raw unit.
Figure 3.4 - Plot of mean error (bias) for each frequency during maximal sprint tests (m·s⁻¹). Error bars represent 95% LOA. * represents a significant difference between sampling frequency and criterion.

(iv) Multi-directional movements

Mean criterion distance measurements were 999 ± 65 m during the multi-directional test. In comparison, mean distance values for each sampling frequency were 997 ± 63 m (low), 999 ± 63 m (medium) and 998 ± 62 m (high). Criterion values for mean speed were 2.08 ± 0.14 m·s⁻¹. Alternatively, ITS mean speed values showed 2.08 ± 0.13 m·s⁻¹ (low), 2.08 ± 0.13 m·s⁻¹ (medium), and 2.07 ± 0.13 m·s⁻¹ (high). Systematic bias and random error values for distance and mean speed during the 8-min multi-directional test are illustrated in Figure 3.5. Distance results show the low and medium frequency tags to demonstrate similar systematic bias ± random error (5 ± 10 m), which were improved in the high frequency tags (3 ± 6 m). Yet, no significant difference was observed between any tag frequency and the criterion measure for distance covered (P ≥ 0.54; ES ≤ 0.1). Systematic bias ± random error results for
mean speed remained consistent across all sampling frequencies (0.01 ± 0.02 m·s⁻¹). Again, no significant differences were identified between all sampling frequencies and the criterion measure for mean speed \( (P ≥ 0.71; \ ES ≤ 0.1) \). Intra-tag reliability results revealed 0.5% CV for both distance and mean speed in low and medium frequency tags. High frequency tags revealed values of 0.2% CV and 0.4% CV for distance and mean speed respectively.

**Figure 3.5** - Plot of mean error (bias) for distance (m) and mean speed (m·s⁻¹) during the multi-directional test. Error bars represent 95% LOA.

### 3.5 DISCUSSION

The aim of the current study was to investigate the validity and reliability of a radio frequency-based system for accurately quantifying measures of external load specific to wheelchair court sport athletes. The results confirmed that the ITS was a suitable system for determining both static and dynamic measurements specific to wheelchair court sports. It was also revealed that sampling frequency influenced validity, particularly at high speeds, which has implications on optimal tag frequency selection for wheelchair court sports applications.
The ITS elicited raw static errors ranging between 0.19-0.32 m and were not found to be influenced by tag sampling frequency. These values are higher than those previously reported for the LPM (0.02 m) and WASP (0.12-0.18 m) radio frequency systems (Frencken et al., 2010; Sathyan et al., 2011). However, such differences may be attributed to the fact these measurements were raw unfiltered coordinates. Given that UWB positions are subject to random noise, accuracy is therefore likely to improve when coordinates are filtered, as this will mitigate the effect of random noise (Perrat et al., 2015). Despite this, the current investigation repeated the static measurements at the end of the testing session and importantly revealed that error did not significantly drift over a 4 h time period. From a practical perspective, this demonstrates that the ITS is capable of working effectively for the duration of WCB (~90 min) and WCR (~60 min) match-play. In addition, the ITS can also be used during prolonged periods, such as multiple tournament games (3-4 matches per day) and training camps, without the concern of measurement drift.

Under controlled testing at incremental fixed speeds (test (ii)) the ITS demonstrated extremely low errors for the assessment of distance covered. As expected, these errors were influenced by movement speed. However, it was observed that the magnitude of error was reduced at the higher speed, which contradicts the patterns observed by previous GPS (Gray et al., 2010; Peterson et al., 2009), radio-frequency (Frencken et al., 2010; Ogris et al., 2012), and MDL literature (Sindall et al., 2013a). These differences may be attributed to the filtering process used by the ITS, as if a small error exists in a specific court location, the filtering process used may exacerbate the error at low speeds, where more data points are collected for a given area. Since LP (< 1.5) exhibit mean speeds of 0.78-1.12 m·s⁻¹ during competition (Sarro et al., 2010; Sporner et al., 2009), it is imperative that the system works effectively at these lower speeds. However, despite the fact the distance error was greater at low speeds it
must be reinforced, that these errors were still extremely small (1.96-2.11 m TEE) and are therefore deemed acceptable for the proposed application.

The influence of sampling frequency can also be seen during this drill (test ii), with low-frequency tags demonstrating the greatest relative distance error values (1.3%), with significantly lower relative errors seen in medium- (1.0%) and high-frequency tags (0.8%). In agreement with this, mean speed results also revealed low-frequency tags to display the greatest relative differences during fixed speed testing (1.4%), with significantly lower relative errors seen in medium- (0.7%) and high-frequency tags (0.5%). Nevertheless, TEE values for mean speed were minimal (0.01) and remained consistent across all fixed speeds regardless of sampling frequency.

The current study revealed that during maximal sprinting, the ITS displayed relative errors < 2.0% in peak speeds. This compares favourably to the greater relative error of approximately 20% for GPS (Duffield et al., 2010), 10% in radio frequency (Ogris et al., 2012) and 10% for MDL (Sindall et al., 2013a). Previous research has discussed the importance of accurately quantifying HIA to facilitate the design of athlete training programmes (Dwyer & Gabbett, 2012). Recent studies have implemented the use of speed zones relative to an individual’s peak speed in order to monitor performance and prescribe training programmes (Cahill et al., 2013; Venter et al., 2011). In order for this approach to be effective, the system must be capable of accurately quantifying peak speeds in the first instance, which the present results have confirmed.

It was also clear that tag frequency played a critical role in accurately identifying peak speeds. Higher tag frequencies (8 and 16 Hz) demonstrated a reduction in random error (< 0.10 m·s⁻¹) compared to low frequency tags (0.17 m·s⁻¹). Given the peak speed values obtainable by WCB (4.45-4.53 m·s⁻¹) and WCR (3.56-3.69 m·s⁻¹) players during maximal
sprinting (Mason et al., 2009; 2012), coupled with the frequency with which HIA are likely to be performed (Vanlandewijck et al., 2001), low sampling frequency tags were therefore not deemed suitable for the current application.

An advantage of the current investigation was the inclusion of a test which assessed the ITS during the type and intensity of movements that the system was intended to be used for (Siegle et al., 2013) i.e. wheelchair court sports. Distance errors revealed when performing multi-directional movements were very low, with absolute errors < 2 m across sampling frequencies, resulting in relative errors < 0.2%. The magnitude of error for the ITS was much smaller than the relative distance errors of 5.8% associated with GPS (Duffield et al., 2010), 4.8% with video tracking techniques (Edgecomb & Norton, 2006) and 1.6-2.7% found in radio-frequency systems (Frencken et al., 2010; Ogris et al., 2012) during sport specific movements.

During this drill (test (iv)), minimal absolute differences in distance (1-2 m) were seen when comparing sampling frequencies. Additionally, similar findings were observed in the mean speed results, with relative errors consistent (< 0.3%) irrespective of sampling frequency. Clearly, the influence of sampling frequency seems to be more prevalent during the incremental fixed speed and peak speed test than the current test. In line with previous research, this suggests that the validity of distance measures improves with longer duration activities (Cummins et al., 2013; Jennings et al., 2011). Accordingly, the selection of sampling frequency for the assessment of distance and mean speed may be less important during wheelchair court sport competition. Despite this, optimal sampling frequency must be considered for an accurate detection of peak speeds during this application.

3.5.1 Practical applications
Determining the optimal tag sampling frequency depends on both the overall bandwidth of the system and the nature of the sport. The likelihood of competition testing during wheelchair court sports consists of monitoring 8-10 players at a given time, yet given the overall bandwidth of the system (137 Hz), high frequency tags (16 Hz) would not be feasible for all players. Subsequently, the favourable results of the 8 Hz tags were deemed acceptable for wheelchair court sports competition.

A limitation of the current study was the use of linear 20 m sprints to assess HIA, since these movements are often multidirectional and interspersed in between lower-intensity movements in wheelchair sports (Vanlandewijck et al., 2001). However, owing to limitations with the availability of equipment to act as a valid and reliable criterion measure this was not possible. Previous research has also discussed the importance of quantifying external load into relative and arbitrary speed thresholds to facilitate training programme development (Cahill et al., 2013; Dwyer & Gabbett, 2012). It could be argued that an assessment of these parameters may have been beneficial in the context of the current investigation. However, given the favourable performance in the detection of peak speeds, it is anticipated that the ITS should adequately determine these parameters. Given the validity and reliability of the ITS in a wheelchair court sport setting, future investigations are recommended to utilise the system to quantify the demands of these sports. This would facilitate the current need to understand physical capacity differences by means of comparing athletes with respect to their classification.

3.6 CONCLUSIONS
The results of the present study revealed that a novel radio frequency ITS provided an accurate and reliable quantification of the external load specific to the wheelchair court sports. Given the greater degree of accuracy for detecting peak speeds, a high sampling frequency (≥ 8 Hz) was recommended for use within wheelchair court sports.
4. Study Two: Activity profiles of elite wheelchair rugby players during competition

This chapter has been published in a slightly modified format in the *International Journal of Sports Physiology & Performance*:


Chapter 3 demonstrated that an ITS was capable of accurately and reliably quantifying measures of external load specific to the wheelchair court sports.

The following chapter seeks to investigate the use of the ITS and to describe the external load of elite WCR competition and to determine whether differences exist across IWRF classifications. Moreover, Chapter 4 aims to establish classification-specific speed zones to provide a holistic overview of WCR competition.
4.1 ABSTRACT

Purpose: To quantify the activity profiles of elite WCR players and establish classification-specific speed zones. Additionally, indicators of fatigue during full matches were explored.

Methods: Seventy-five elite WCR players (male: n = 75; female: n = 1) from eleven national teams were monitored using a radio-frequency based, ITS across two international tournaments. Players who participated in complete quarters (n = 75) and full matches (n = 25) were included and grouped by their IWRF functional classification: group I (0-0.5), II (1.0-1.5), III (2.0-2.5) and IV (3.0-3.5). Results: During a typical quarter, significant increases in total distance (m), relative distance (m·min⁻¹), and mean speed (m·s⁻¹) were associated with an increase in classification group (P < 0.001), with the exception of group III and IV. However, group IV players achieved significantly higher peak speeds (3.82 ± 0.31 m·s⁻¹) than groups I (2.99 ± 0.28 m·s⁻¹), II (3.44 ± 0.26 m·s⁻¹) and III (3.67 ± 0.32 m·s⁻¹). Groups I and II differed significantly in match intensity during very low/low speed zones and the number of HIA in comparison with groups III and IV (P < 0.001). Irrespective of classification, full match analysis revealed that activity profiles did not differ significantly between quarters.

Conclusions: Notable differences in the volume of activity were displayed across the functional classification groups. However, the specific on-court requirements of defensive (I and II) and offensive (III and IV) positional-roles appeared to influence the intensity of match activities and consequently training prescription should be structured accordingly.
4.2 INTRODUCTION

Quantifying the activity profiles of elite athletes during competition facilitates the prescription of training programmes specific to the demands of the sport, which can optimise performance and minimise injury risk for individuals (Gabbett et al., 2008). Typically, automatic video tracking techniques and GPS have been used to identify external load within AB team sports (Bradley et al., 2010; Di Salvo et al., 2009; McLellan et al., 2011; Rampinini et al., 2007a; Waldron et al., 2011). Unfortunately, owing largely to technological limitations, an accurate quantification of the external load during indoor sports such as WCR remains relatively unknown.

A limited number of studies have previously investigated the external load of WCR (Sarro et al., 2010; Sporner et al., 2009). Sporner et al. (2009) revealed that WCR players typically covered $2364 \pm 956$ m at a mean speed of $1.33 \pm 0.25$ m∙s$^{-1}$ during competition. Unfortunately, this information was derived using a MDL, which has been associated with inaccuracies during high-speed movements (see Section 2.2.1.5). Moreover, the analysis was confined to recreational players and was therefore not representative of an elite population. Through the use of image-based processing techniques, Sarro et al. (2010) reported that elite WCR players covered greater distances ($4540 \pm 817$ m) at a mean speed of $1.14 \pm 0.21$ m∙s$^{-1}$. However, as a result of the time consuming analysis procedures involved using this method, the results were restricted to a small sample size ($n = 8$).

Whilst only limited information regarding the volume of activity performed has been addressed in WCR, little is also known about the impact of functional classification on external load. As discussed in section 2.2.3, previous research has shown classification-dependent trends in performance, with higher game-efficiency patterns (Molik et al., 2008), and greater total distance and mean speed values (Sarro et al., 2010) associated with higher functional classifications. Moreover, Sarro et al. (2010) also suggested that fatigue was more
prominent in LP, due to a greater decrease in distance and mean speed values across match-halves. Despite this, previous research has demonstrated total distance to be a weak indicator of fatigue across competition in AB sports such as soccer (Bangsbo et al., 1994; Mohr et al., 2003). Alternatively, relative distance (Austin et al., 2014), peak speeds (McLellan et al., 2011) and HIA (Bradley et al., 2010) have been advocated as better indicators of fatigue over time.

To further quantify the intensity of exercise during competition and training, activities have commonly been categorised into pre-determined arbitrary speed zones (Bangsbo et al., 1994; Rampinini et al., 2007). Arbitrary speed zones facilitate the longitudinal assessment of an athlete’s performance over time. However, given that sprint performance has been shown to be dependent on functional classification in WCR (Morgulec et al., 2011), the use of arbitrary speed zones for all classification groups is likely to misrepresent match-play intensity. Subsequently, recent studies have improved the specificity by relativizing speed zone design through the use of an individual’s peak speed (Cahill et al., 2013; Venter et al., 2011). Whilst technological limitations have previously prevented the analysis of such variables in WCR, the recent development and validation of a radio frequency-based ITS (described in Chapter 3) has enabled a broader assessment of elite WCR competition to be possible. Therefore, through the use of the ITS the aims of the current study were to: (1) quantify the physical demands of WCR between classification groups and to establish arbitrary speed zones specific to each classification; and (2) to explore any changes in activity profiles across full matches to establish external indicators of fatigue in WCR.
4.3 METHODS

4.3.1 Participants

A total of 11 national WCR teams participated in the study with data collected across 21 competitive matches during two international tournaments (2013 European and Americas Zonal Championships). Approval for the study was obtained from the IWRF and the organising committee of each tournament in addition to Loughborough University’s local ethical advisory committee. Written informed consent was provided by each player prior to data collection. Data was collected from all consenting teams and players (age = 32 ± 7 years); however, data was only presented for players who completed full quarters \( (n = 75) \) or full matches \( (n = 25) \). Players were categorised into four groups according to their IWRF classification, based on previous guidelines (Morgulec et al., 2010; 2011). The breakdown of data collected from each group is presented in Table 4.1.

Table 4.1 - A breakdown of classification profiles, datasets and sample size.

<table>
<thead>
<tr>
<th>Group</th>
<th>IWRF Classification</th>
<th>Full Quarters</th>
<th>Participants ( (n) )</th>
<th>Range</th>
<th>Full Matches</th>
<th>Participants ( (n) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>0.5</td>
<td>38</td>
<td>12</td>
<td>3-11</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>II</td>
<td>1.0-1.5</td>
<td>138</td>
<td>22</td>
<td>3-18</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>III</td>
<td>2.0-2.5</td>
<td>122</td>
<td>28</td>
<td>5-15</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>IV</td>
<td>3.0-3.5</td>
<td>108</td>
<td>13</td>
<td>4-18</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>406</td>
<td>75</td>
<td>-</td>
<td>35</td>
<td>25</td>
<td></td>
</tr>
</tbody>
</table>

4.3.2 Procedures

The ITS, as described in Chapter 3 was installed on the main court of each tournament venue and data were collected from a total of 30 matches. Each participating team was monitored whenever they played on the main court (minimum of 3 matches, range 3-6), with data
collected during pool \((n = 20)\), crossover \((n = 4)\) and placement \((n = 6)\) matches. Each match involving a participating team was included for data collection with each team member equipped with a radio-frequency tag, fixed to the foot-strap of the wheelchair. Up to 24 players (12 players from each team) wore a tag during any given match, all players were familiarised with the tags during training sessions prior to the start of the competitions. Tags sampled at 8 Hz, which has previously been confirmed as an acceptable sampling frequency for the collection of movement parameters specific to WCR (Chapter 3). Data collection commenced at the beginning of each quarter and terminated at the end of the quarter. Collection was only paused during any periods of extended stoppages (time-outs, equipment calls) throughout each quarter since WCR players also remain active during the stopped game clock (Sarro et al., 2010). This resulted in a mean collection time of 15.1 (± 1.4) min per quarter. Raw data files were exported using software developed specifically for WCR (Nottingham, UK).

4.3.3 Measures
Total distance (m) and relative distance covered \((m \cdot \text{min}^{-1}; \text{relative to time spent on court})\), mean and peak speed \((m \cdot s^{-1})\) was determined for each player during complete quarters of WCR. Using an approach similar to Cahill et al. (2013) and Venter et al. (2011), five arbitrary speed zones were established specific to each classification. Using the ‘mean’ peak speed \((V_{\text{max}})\) of each classification group the following five speed zones, relative to \(V_{\text{max}}\) were calculated: very low \((\leq 20\% \ V_{\text{max}})\), low \((21-50\% \ V_{\text{max}})\), moderate \((51-80\% \ V_{\text{max}})\), high \((81-95\% \ V_{\text{max}})\), and very high \((> 95\% \ V_{\text{max}})\). The time spent in each of the arbitrary speed zones was then calculated for each classification. Analyses of HIA (high and very high speed zones) were extended to include the total number of HIA performed and both the mean and maximum duration and distance of these activities.
To assess the influence of fatigue across full matches of WCR, total distance (m), relative distance (m·min⁻¹), mean speed, peak speed (m·s⁻¹), and HIA were explored. Only full match datasets (all 4 quarters completed by an individual) were analysed, with external load compared between quarters and halves.

### 4.3.4 Statistical Analyses

Data analyses were performed using the Statistical Package for the Social Sciences (SPSS version 21, Chicago, IL). Descriptive statistics (mean ± SD) were calculated for each participant for all measures of external load. Normality and homogeneity of variance was confirmed by Shapiro-Wilk’s and Levene’s tests respectively. Since players differed in the number of repeated quarters they participated in and the varying sample sizes between classification groups, mixed linear modelling was applied to account for the unbalanced design (Cnaan et al., 1997). Interactions between classification and quarter were also analysed using the full match datasets. Main effects and interactions were accepted as statistically significant whereby \( P \leq 0.05 \). Pairwise comparisons were utilised to explore any significant main effects between classification groups (I, II, III and IV), with a Bonferroni-corrected alpha level used to account for multiple contrasts \( (P = 0.008) \). ES, estimated from the ratio of the mean difference to the pooled standard deviation were also calculated. The magnitude of the ES was classed as trivial \((< 0.2)\), small \((≥ 0.2-0.6)\), moderate \((≥ 0.6-1.2)\), large \((≥ 1.2-2.0)\), and very large \((≥ 2.0)\) based on previous guidelines (Batterham & Hopkins, 2006).

### 4.4 RESULTS

#### 4.4.1 Activity profiles during complete quarters of WCR

Functional classification significantly influenced the total distance, relative distance, mean speed and peak speed achieved during complete quarters of WCR \((P < 0.001)\). As
demonstrated in Table 4.2, significant increases in total distance, relative distance and mean speed were revealed with an increase in functional classification, except for groups III and IV ($P \geq 0.704; \text{ES} \leq 0.1$). Peak speed was significantly higher as classification increased across all groups (Table 4.2).
Table 4.2 - Descriptive statistics (mean ± SD) for measures of external load during a typical WCR quarter.

<table>
<thead>
<tr>
<th>Variables</th>
<th>I (n = 38)</th>
<th>II (n = 138)</th>
<th>III (n = 122)</th>
<th>IV (n = 108)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Total distance (m)</td>
<td>881*#†</td>
<td>137</td>
<td>1011#†</td>
<td>142</td>
</tr>
<tr>
<td>Relative distance (m·min⁻¹)</td>
<td>59.9*#†</td>
<td>6.5</td>
<td>69.7#†</td>
<td>8.4</td>
</tr>
<tr>
<td>Mean speed (m·s⁻¹)</td>
<td>1.01*#†</td>
<td>0.11</td>
<td>1.15#†</td>
<td>0.13</td>
</tr>
<tr>
<td>Peak speed (m·s⁻¹)</td>
<td>2.99*#†</td>
<td>0.28</td>
<td>3.44#†</td>
<td>0.26</td>
</tr>
</tbody>
</table>

Note: number of datasets per classification group. *Significantly different to group II (P < 0.05); #Significantly different to group III (P < 0.05); †Significantly different to group IV (P < 0.05).
### 4.4.1.1 Arbitrary speed zones

The ‘mean’ peak speed values displayed (Table 4.2) established arbitrary speed zones specific to each classification group (Table 4.3). In general, WCR players spent 31% of a typical quarter in the very low speed zone, with the majority of time spent in the low speed zone (47%). The moderate speed zone accounted for 20% of the quarter duration, with 1.5% and 0.5% spent in the high and very high zones, respectively. As illustrated in Figure 4.1, classification had no significant effect on the times spent in the moderate ($P = 0.099$), high ($P = 0.081$) and very high ($P = 0.636$) speed zones. However the time spent in the very low and low speed zones was influenced by classification ($P < 0.001$). Groups I and II spent a significantly greater time in the very low speed zone than groups III and IV ($P < 0.001$; ES = 0.7 - 1.1). Alternatively, groups III and IV spent a significantly greater time in the low speed zone, compared to groups I and II ($P < 0.001$; ES = 0.8 - 1.4).

### Table 4.3 - Arbitrary speed zones (m·s⁻¹) as proposed for use within WCR classification groups.

<table>
<thead>
<tr>
<th>Zones</th>
<th>I ($n = 38$)</th>
<th>II ($n = 138$)</th>
<th>III ($n = 122$)</th>
<th>IV ($n = 108$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very low</td>
<td>≤ 0.60</td>
<td>≤ 0.69</td>
<td>≤ 0.73</td>
<td>≤ 0.76</td>
</tr>
<tr>
<td>Low</td>
<td>0.61-1.50</td>
<td>0.70-1.72</td>
<td>0.74-1.84</td>
<td>0.77-1.91</td>
</tr>
<tr>
<td>Moderate</td>
<td>1.51-2.39</td>
<td>1.73-2.75</td>
<td>1.85-2.94</td>
<td>1.92-3.06</td>
</tr>
<tr>
<td>High</td>
<td>2.40-2.84</td>
<td>2.76-3.27</td>
<td>2.95-3.49</td>
<td>3.07-3.63</td>
</tr>
<tr>
<td>Very High</td>
<td>&gt; 2.84</td>
<td>&gt; 3.27</td>
<td>&gt; 3.49</td>
<td>&gt; 3.63</td>
</tr>
</tbody>
</table>

**Note:** Very low = ≤ 20% Vmax; Low = 21-50% Vmax; Moderate = 51-80% Vmax; High = 81-95%; Very high = >95%
Figure 4.1 – Time spent (min) within five arbitrary speed zones between classification groups during a typical WCR quarter. *Significantly different to group III. †Significantly different to group IV. Data presented as means ± SD.

4.4.1.2 High-intensity activities

The number of HIA differed between classifications ($P = 0.005$). As highlighted in Table 4.4, group I performed more HIA than groups III ($P = 0.005; \text{ES} = 0.6$) and IV ($P = 0.004; \text{ES} = 0.6$). Classification had no significant effect on the mean ($P = 0.347$) and maximum ($P = 0.629$) duration of HIA. However a significant main effect for the mean ($P < 0.001$) and maximum ($P = 0.031$) distance of each HIA was revealed. The mean distance of each HIA was significantly greater for groups III and IV compared to I and II (Table 4.4). Despite this, pairwise comparisons failed to reach statistical significance between all classification groups for maximum distance ($P \geq 0.009; \text{ES} \leq 0.5$).
Table 4.4 - Descriptive statistics (mean ± SD) for HIA performed during a typical WCR quarter.

<table>
<thead>
<tr>
<th></th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n = 38)</td>
<td>(n = 138)</td>
<td>(n = 122)</td>
<td>(n = 108)</td>
</tr>
<tr>
<td>Number</td>
<td>13*†</td>
<td>11</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Mean duration (s)</td>
<td>1.7</td>
<td>1.7</td>
<td>1.8</td>
<td>1.9</td>
</tr>
<tr>
<td>Max duration (s)</td>
<td>4.3</td>
<td>4.2</td>
<td>4.4</td>
<td>4.0</td>
</tr>
<tr>
<td>Mean distance (m)</td>
<td>4.7*†</td>
<td>5.4*†</td>
<td>6.3</td>
<td>6.4</td>
</tr>
<tr>
<td>Max distance (m)</td>
<td>11.7</td>
<td>13.5</td>
<td>15.4</td>
<td>14.8</td>
</tr>
</tbody>
</table>

Note: *Significantly different to group III (P < 0.05); †Significantly different to group IV (P < 0.05).
4.4.2 Activity profiles during full matches of WCR

Total distance ($P \geq 0.827$), relative distance ($P \geq 0.963$), mean speed ($P \geq 0.946$) and peak speed ($P \geq 0.944$) did not differ across quarters or halves (Figure 4.2). No significant changes in the number ($P \geq 0.964$), mean duration ($P \geq 0.990$) maximum duration ($P \geq 0.641$), mean distance ($P \geq 0.998$) or maximum distance ($P \geq 0.592$) of HIA performed were identified across quarters and halves. Moreover, no interactions existed for any movement parameter between classification group and neither match quarters nor match-halves ($P \geq 0.545$).
Figure 4.2 – Total distance (a), relative distance (b), mean speed (c) and peak speed (d) values of each classification group during each of the four quarters in full matches of WCR. Data presented as means ± SD.
4.5 DISCUSSION

The results of the current study revealed that functional classification is closely associated with the volume of activity elicited over typical quarters of WCR competition. In addition, the ability to perform greater peak speeds increased with functional classification. Whilst the current study was the first to establish arbitrary speed zones for WCR, results revealed that match-play intensity was also influenced by functional classification, particularly during low-speeds, which has practical implications on classification-specific training prescription. Furthermore, measures of external load across full WCR matches indicated no deterioration of physical performance was evident, regardless of functional classification.

The present study demonstrated that total distance, relative distance and mean speed values increased in association with higher functional classification across a typical quarter, yet no significant difference between classification groups III (2.0-2.5) and IV (3.0-3.5) was observed. Such findings are consistent with previous WCR research, in which game efficiency patterns did not significantly differ between these classification groups (Morgulec et al., 2010). Practical implications of these findings may impact upon team selection, in which group III players (2.0-2.5) do not seemingly restrict the functional ability of the team, whilst subsequently reducing the total on-court classification points (8.0 points permitted at any one time). This could partially explain why the present study observed a wider number of participants within group III \((n = 28)\) than in group IV \((n = 13)\). Despite this, sprint performance differed across all classification groups, with group IV capable of reaching significantly higher peak speeds \((3.82 \pm 0.31 \text{ m·s}^{-1})\) than groups I \((2.99 \pm 0.28 \text{ m·s}^{-1})\), II \((3.44 \pm 0.26 \text{ m·s}^{-1})\), and III \((3.67 \pm 0.32 \text{ m·s}^{-1})\). This could, however, be attributed to the superior trunk function associated with higher classification groups (Vanlandewijck et al., 2001). While the ability to apply force effectively to the hand-rim is a prerequisite for successful sprint performance, trunk function has previously been established as an important
determinant of hand-rim force application (Goosey-Tolfrey et al., 2012; Vanlandewijck et al., 2011). Subsequently, improved trunk function was likely to attribute to an increase in applied hand-rim force and, as such, greater peak speeds can be expected in higher functional players (Vanlandewijck et al., 2011). Nevertheless, the volume of activity along with the peak speeds performed during WCR competition advocates the need for classification-specific training drills.

Given that peak speeds are influenced by functional classification, the use of arbitrary speed zones for all classification groups was likely to misrepresent individual intensity profiles. Thus, the creation of arbitrary zones specific to each classification group was an important outcome of the current study. Accordingly, the data suggested that elite WCR competition is typically played at low speeds, with at least 75% of a typical quarter spent within the very low and low speed zones (≤ 50% Vmax) regardless of functional classification. Specifically, groups I and II spent a significantly greater amount of time within the very low zone compared to groups III and IV. Such a finding may be attributed to the varying on-court roles, in which groups I and II (0-1.5) have previously been identified as LP who predominantly occupy defensive roles, whereas groups III and IV (2.0-3.5) have been identified as HP occupying offensive roles (Mason et al., 2009; Orr & Malone, 2012). These positional-roles require LP to pick the opposition, which may account for the longer durations of static/very low speed activity. Alternatively, groups III and IV spent significantly more time within the low speed zone, equating to 54% and 52% of the total quarter duration respectively, as opposed to groups I (39%) and II (41%). These findings indicate the contrasting intermittent match intensities between LP and HP, suggesting the need for role-specific training drills.

The present data also indicated that HIA were influenced by positional-role during a typical WCR quarter. The significantly greater number of HIA exhibited by LP compared to
HP indicates that this is a key requirement for the defensive on-court role. The rationale for such a finding may be attributed to the fact that LP do not possess the physical function of HP (Orr & Malone, 2012) and therefore must perform HIA more frequently to compete with more functionally able opponents. Furthermore, typical HIA durations of 1.7 to 1.9 s were observed, with no significant differences across classification groups. This could be partly attributed to opposing players and court dimensions, preventing the capacity to generate prolonged durations of HIA. Despite this, the higher speeds attained by HP are likely to have attributed to the significant differences found in the mean distance of HIA. Nevertheless, these findings further emphasize that positional-roles seem to dictate the intensity of activity in WCR, highlighting the necessity for role-specific training drills, in addition to classification-specific drills required for the volume of activity.

As part of the largest study to monitor external load across full WCR matches, our results revealed elite WCR players covered approximately 4213 ± 626 m at a mean speed of 1.17 ± 0.14 m·s⁻¹. These results were in accordance with the total distance (4540 ± 817 m) and mean speed values (1.14 ± 0.21 m·s⁻¹) previously reported by Sarro et al. (2010). Interestingly, the addition of rule changes (post 2008) in WCR has seemingly had no effect on the overall demands of the sport. That said, the present study revealed that external load did not seem to deviate significantly across full WCR matches, suggesting current match-play activity was not influenced by fatigue which is in contrast to Sarro et al., (2010). This would appear to suggest that the addition of continuous roll-on substitutions may partly explain these contrasting findings. Indeed, if activity was perceived to be deteriorating then the likelihood is that player would be substituted. Despite this, future analysis of technical skills and physiological measures across full matches may further contribute to the current understandings of fatigue during WCR competition.
4.5.1 Practical applications
In order to facilitate the development of WCR training programmes a better understanding of the demands of competition are required to improve the key training principles; specificity and individualisation of training. The current findings suggest that training programmes should be classification-specific when related to activity volume, and designed to elicit the levels of aerobic demands sufficient to cope with match distances of up to ~4,600 m, combined with the anaerobic demands required for ~38 high-intensity efforts per match. Such programmes should also be extended to accommodate the various intensities attributed to the specific positional-roles of LP and HP.

A limitation of the current study was the inability to examine the individual physiological responses in relation to the determination of speed zones. However, in elite athletes with tetraplegia, HR response is generally reduced (Goosey-Tolfrey & Leicht, 2013), consequently the collection of HR in WCR players is therefore questionable and methods such as RPE may be better advocated. Future work utilising individualised physiological measures (e.g. Bla) alongside the traditional arbitrary approach is therefore recommended (Hunter et al., 2015). Nevertheless, normalising speed zones based on match-play sprinting capacity may reflect an ecologically valid approach to between-player and rank comparisons. Furthermore, the ability to accelerate from a standstill is a key indicator of performance in WCR (Mason et al., 2010; Vanlandewijck et al., 2001). Yet owing to the sensitivity of the ITS when sampling at 8 Hz, a limitation of the current technology was the inability to accurately measure acceleration values. Further work utilising the ITS alongside accelerometry technology may provide a more in-depth insight into the external load during WCR competition. However, acceleration efforts are unlikely to have registered as HIA within the present study, and as a consequent the true HIA seen during competition may be underestimated. Whilst the dynamic nature of WCR competition has been explored in the
present study, it is recommended that future research investigates the effect of situational variables (e.g. team rank, match outcome) on external load as seen in AB sports (Di Salvo et al., 2009; Rampinini et al., 2007a; Taylor et al., 2008) to establish which external measures of performance are associated with successful performance.

4.6 CONCLUSIONS
The present investigation demonstrated notable differences in the volume of activity across functional classification during elite WCR competition. Additionally, the use of individualised peak speeds in determining arbitrary speed zones provided new insights into the classification-specific differences in match-play intensity. However, these differences were exacerbated between groups I and II (0.5-1.5) compared with groups III and IV (2.0-3.5). Such differences can be attributed to the varying positional-roles of defensive (I and II) and offensive (III and IV) players. Furthermore, as opposed to previous reports, the measures of external load monitored in the current study were not shown to be associated with a physical decline across full WCR matches. The current results highlight the importance of both classification and role-specific training drills in WCR.
5. Study Three: Effect of team rank and player classification on activity profiles of elite wheelchair rugby players

This chapter has been published in a slightly modified format in the *Journal of Sports Sciences*:


Chapter 4 has provided first insights into the external load responses during elite WCR competition, and highlighted the impact of functional classification.

Chapter 5 will extend these measures in relation to successful performance as determined by team rank.
5.1 ABSTRACT

Purpose: To establish which measures of external load are associated with successful WCR performance and to determine whether these measures differed across classification groups.

Methods: Data were collected from 11 international teams during 30 matches (353 match observations) using a radio-frequency based, ITS across two tournaments. Players \((n = 111)\) were first grouped by team rank as determined by their team’s final IWRF world ranking (LOW, MID, HIGH) and then into one of four groups based on their IWRF classification: group I (0.5), II (1.0-1.5), III (2.0-2.5), IV (3.0-3.5). Results: The volume of activity (relative distance and mean speed), peak speed, and time spent within classification-specific arbitrary speed zones were calculated for each individual. Although no differences were identified in the volume of activity, playing time (min:s) was significantly reduced in LOW \((34:51 \pm 8:35)\) compared to MID \((48:54 \pm 0:51)\) and HIGH \((45:38 \pm 9:53)\), which was further supported by the greater number of substitutions performed by LOW. HIGH achieved greater peak speeds \((3.55 \pm 0.40 \text{ m} \cdot \text{s}^{-1})\) than LOW \((3.27 \pm 0.42 \text{ m} \cdot \text{s}^{-1})\) and MID \((3.45 \pm 0.41 \text{ m} \cdot \text{s}^{-1})\). Peak speed was further shown to be classification-dependent \((P \leq 0.005)\), whereby HIGH groups III and IV players achieved greater peak speeds than LOW and MID. The time spent performing HIA was also greater in HIGH compared to LOW and MID, whilst further influenced by classification \((P \leq 0.0005)\). Conclusions: Peak speed and the ability to perform a greater number of HIA were associated with successful performance in WCR.
5.2 INTRODUCTION

Only recently have the characteristics of elite WCR competition received scientific attention (Molik et al., 2008; Morgulec et al., 2010; Chapter 4). Early notational analysis data suggested that HP generally perform better than LP in most of the ball-handling match activities such as points scored, interceptions, passes made and passes caught (Molik et al., 2008; Morgulec et al., 2010). The close relationship between functional classification and positional-role outlined in section 2.2.2 may partially explain such findings.

Through recent developments in technology (Chapter 3), information regarding external load during WCR competition have been described (Chapter 4). During competition, elite WCR players typically cover distances between 3500-4600 m (Sarro, et al., 2010), with a mean peak speed of $3.48 \pm 0.36 \text{ m} \cdot \text{s}^{-1}$ (Chapter 4). Competition has been further characterised by prolonged low-intensity activities ($\leq 50\%$ peak speed) interspersed with frequent periods of short (1.7-1.9 s) HIA (Chapter 4). Classification-dependent trends in match performance were further highlighted; whereby greater total distance, mean speed (Sarro et al., 2010) and peak speed values (Chapter 4) were reported as functional ability increased. Furthermore, when grouped by positional-role, notable trends in the intensity of match-play activity were also evident. As documented in Chapter 4, defensive players spent a significantly greater amount of time performing very low speed activities compared to offensive players, whilst, a greater number of high-intensity efforts were exhibited by defensive players (~13) compared to offensive players (~9). Such results may be attributed to the key requirements for the varying positional-roles. These roles require defensive players to block and trap opponents resulting in longer durations of very low speed activity, yet must perform HIA more frequently to compete with more functionally able opponents. However, an understanding of which aspects of external load are associated with successful performance is required to further the evidence-based approach of future training strategies in WCR.
Whilst key indicators of successful performance have been explored using team rank in AB sports, no such information exists for WCR. In the only study to investigate the influence of successful performance within an elite wheelchair sporting application, greater peak speeds were reported in high-ranked WCT players (Sindall et al., 2013b). While high peak speeds may be advantageous for WCT performance, it is important to acknowledge the classification and tactical roles associated with individuals in WCR that could influence this relationship. Therefore, the aim of the current study was to establish which aspects of external load were associated with successful performance as determined by team rank during elite WCR. A secondary aim was to determine whether the impact of external load on performance was further influenced by functional classification.

5.3 METHODS

5.3.1 Participants

All National teams competing in the 2013 European and Americas Zonal Championships were invited to participate in the current study. Out of the 15 competing teams, 11 agreed to participate giving a sample of 111 elite International WCR players (male: \(n = 110\); female: \(n = 1\); age: 32 ± 7 years). Players were subdivided into the following three groups according to their IWRF world ranking after the end of the final competition: the top 3 ranked teams (HIGH); middle 5 ranked teams (MID); and the lowest 3 ranked teams (LOW) according to the approach used in AB soccer (Di Salvo et al., 2009; Rampinini et al., 2007). Team ranking was taken after the final competition to account for current team performance (Castellano et al., 2014) and did not change between competitions. Each player was assigned into one of four groups according to the preceding chapter. LP were categorised as groups I (0.5) and II (1.0-1.5), whilst HP as groups III (2.0-2.5) and IV (3.0-3.5). Approval for the study was
obtained from the IWRF and the organising committee of each tournament in addition to Loughborough University’s local ethical advisory committee. All participants provided their written informed consent to participate in the current investigation.

5.3.2 Procedures

Full details of the data collection procedures were outlined in Chapter 4. A match observation was characterised for each individual by the accumulation of activity collected during the respective four quarters of that match (353 match observations). Measures of external load were then presented as the mean of all match observations as grouped by each individual’s team rank and functional classification. Additionally, as continuous roll-on substitutions are common features of competition, observations from substituted players were also included for analysis. Collection was only paused during any periods of extended stoppages (time-outs, equipment calls etc.) since players also remain active during the stopped game-clock (Sarro et al., 2010).

5.3.3 Measures

Full details for the measures of external load analysed in the current chapter are documented in Chapter 4 (section 4.3.3). All equipment, data collection and analysis procedures were replicated.

5.3.4 Statistical Analyses

Data analysis was performed using the Statistical Package for the Social Sciences (SPSS version 21, Chicago, IL). Descriptive statistics (mean ± SD) were calculated for each participant for all measures of external load. Normality and homogeneity of variance was confirmed by Shapiro-Wilk and Levene’s tests respectively. Since players differed in the number of match observations they participated in and the varying sample sizes between team
ranks and classification groups, mixed linear modelling was applied to account for the unbalanced design (Cnaan et al., 1997). Main effects and interactions were accepted as statistically significant whereby \( P \leq 0.05 \). Pairwise comparisons were utilised to explore any significant interactions between team ranks and classification groups, with 95% CI for differences also presented. ES were calculated as the ratio of the mean difference to the pooled standard deviation of the difference. The magnitude of the ES were classed as trivial (< 0.2), small (0.2-0.6), moderate (0.6-1.2), large (1.2-2.0), and very large (\( \geq 2.0 \)) based on previous guidelines (Batterham & Hopkins, 2006).

5.4 RESULTS

No significant effect of team rank was observed for relative distance (Figure 5.1a; \( P = 0.532 \)) and mean speed (Figure 5.1b; \( P = 0.538 \)). However, there was a significant influence of team rank on mean playing time (min:s) \( (P \leq 0.0005) \), which was significantly reduced in LOW (34:51 ± 8:35) compared to MID (48:54 ± 0:51; \( P \leq 0.0005; 95\%\ CI = -245.7\ to\ -157.8;\ ES = 1.7) and HIGH (45:38 ± 9:53; \( P \leq 0.0005; 95\%\ CI = -136.1\ to\ -44.0;\ ES = 1.2). The number of substitutions performed was also shown to be influenced by team rank \( (P \leq 0.0005) \). LOW performed a greater number of substitutions per match (12 ± 4) than both MID (4 ± 3; \( P \leq 0.0005; 95\%\ CI = 4.7\ to\ 10.6;\ ES > 2.0) and HIGH (5 ± 3; \( P \leq 0.0005; 95\%\ CI = 2.9\ to\ 9.8;\ ES = 1.7).
Figure 5.1 - Relative distance (a), mean speed (b), and peak speed (c) in relation to team rank during match-play. Data presented as means ± SD. *Significantly different to MID. #Significantly different to HIGH.
Peak speed was significantly affected by team rank \((P = 0.002)\). As illustrated in Figure 5.1c, HIGH achieved greater peak speeds \((3.56 \pm 0.40 \text{ m·s}^{-1})\) compared to LOW \((3.27 \pm 0.42 \text{ m·s}^{-1}; P \leq 0.0005; 95\% \text{ CI} = -0.4 \text{ to } -0.1; \text{ ES} = 0.7)\) and MID \((3.45 \pm 0.41 \text{ m·s}^{-1}; P = 0.003; 95\% \text{ CI} = 0.1 \text{ to } 0.2; \text{ ES} = 0.3)\). The relative time spent within low, high and very high speed zones were also significantly influenced by team rank \((P \leq 0.0005)\). Figure 5.2 reveals LOW \((52.3 \pm 7.0\%)\) spent more time in the low speed zone compared to MID \((46.7 \pm 7.9\%; P \leq 0.0005; 95\% \text{ CI} = 3.0 \text{ to } 8.1; \text{ ES} = 0.7)\) and HIGH \((46.8 \pm 7.6\%; P \leq 0.0005; 95\% \text{ CI} = 2.9 \text{ to } 8.1; \text{ ES} = 0.8)\). However, HIGH spent greater time within high \((2.9 \pm 1.6\%)\) and very high \((0.7 \pm 0.8\%)\) speed zones compared to LOW \((1.5 \pm 1.1\% \text{ and } 0 \pm 0.4\%; P \leq 0.0005; \text{ ES} = 0.9-1.0)\) and MID \((2.0 \pm 1.3\% \text{ and } 0.3 \pm 0.5\%; P \leq 0.025; \text{ ES} = 0.6)\). HIA were also significantly influenced by team rank \((P \leq 0.0005)\). As shown in Table 5.1, HIGH performed a greater number of relative HIA compared to LOW \((P \leq 0.0005; 95\% \text{ CI} = -0.5 \text{ to } -0.2; \text{ ES} = 1.4)\) and MID \((P = 0.006; 95\% \text{ CI} = -0.3 \text{ to } -0.04; \text{ ES} = 0.8)\). Whilst HIGH also covered greater mean \((P \leq 0.001; \text{ ES} = 0.5-0.8)\) and max distances \((P \leq 0.006; \text{ ES} = 0.6-1.1)\), for a longer mean \((P \leq 0.0005; \text{ ES} = 0.8-1.0)\) and max duration \((P \leq 0.008; \text{ ES} = 0.5-1.1)\) at high-intensities compared to both LOW and MID.
Figure 5.2 – Match intensity in relation to team rank during a typical match. Data presented as mean ± SD. *Significantly different to MID. #Significantly different to HIGH.

Table 5.1 - HIA (mean ± SD) during a typical WCR match in relation to team rank.

<table>
<thead>
<tr>
<th>HIA</th>
<th>Team Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LOW (n = 79)</td>
</tr>
<tr>
<td>Relative Number</td>
<td>0.4 ± 0.3*#</td>
</tr>
<tr>
<td>Mean Distance (m)</td>
<td>4.5 ± 2.8*#</td>
</tr>
<tr>
<td>Max Distance (m)</td>
<td>7.7 ± 5.2*#</td>
</tr>
<tr>
<td>Mean Duration (s)</td>
<td>1.4 ± 0.8*#</td>
</tr>
<tr>
<td>Max Duration (s)</td>
<td>2.4 ± 1.6**#</td>
</tr>
</tbody>
</table>

Note: n = number of match observations. *Significantly different to MID. #Significantly different to HIGH.
No significant interaction was observed between team rank and classification group for relative distance \((P = 0.141)\) or mean speed \((P = 0.102)\). However, classification group was shown to influence peak speed values across team rank \((P = 0.008)\). Table 5.2 reveals HIGH achieved significantly greater peak speeds compared to LOW across all classification groups \((P \leq 0.001; \text{ES} = 0.6-1.5)\), whilst HIGH groups III and IV players achieved greater peak speeds compared to respective MID players \((P \leq 0.005; \text{ES} = 0.7-0.8)\). A significant interaction was observed across low \((P = 0.009)\), high \((P \leq 0.0005)\) and very high \((P \leq 0.0005)\) speed zones, whilst a significant interaction also existed for the HIA performed during competition \((P \leq 0.0005)\). Post hoc analyses revealed:

- **Group I**: LOW spent significantly greater time within the low speed zone compared to MID \((P \leq 0.0005; 95\% \text{ CI} = 3.0 \text{ to } 12.3; \text{ES} = 1.4)\) and HIGH \((P \leq 0.0005; 95\% \text{ CI} = 2.1 \text{ to } 11.2; \text{ES} = 1.3)\). Whilst LOW and MID spent significantly less time in the high \((P \leq 0.0005; \text{ES} = 1.0-1.3)\) and very high speed zones \((P \leq 0.029; \text{ES} = 1.1-1.4)\) compared to HIGH. LOW were significantly different to HIGH for all measures of HIA \((P \leq 0.005; \text{ES} = 1.0-1.5)\), whilst the relative number \((P = 0.002; 95\% \text{ CI} = -0.5 \text{ to } -0.1; \text{ES} = 0.7)\), max distance \((P = 0.027; 95\% \text{ CI} = -7.8 \text{ to } -0.9; \text{ES} = 0.9)\) and max duration \((P = 0.038; 95\% \text{ CI} = 0.5 \text{ to } 1.8; \text{ES} = 0.9)\) of HIA significantly differed between LOW and MID. MID performed significantly less HIA compared to HIGH \((P \leq 0.008; \text{ES} = 0.6-1.0)\).

- **Group II**: LOW players spent significantly less time in high and very high speed zones as opposed to MID \((P = 0.006; \text{ES} = 0.6-0.8)\) and HIGH \((P = 0.07; \text{ES} = 0.8-1.0)\), whilst MID spent significantly less time in the high speed zone than HIGH \((P = 0.003; 95\% \text{ CI} = 0.3 \text{ to } 1.3; \text{ES} = 0.5)\). LOW were shown to perform a significantly fewer relative number of HIA compared to MID \((P = 0.004; 95\% \text{ CI} = -0.7 \text{ to } -0.1; \text{ES} = 1.1)\) and HIGH \((P \leq 0.0005; 95\% \text{ CI} = -0.9 \text{ to } -0.3; \text{ES} = 1.7)\).
• Group III: LOW and MID players were found to spend significantly less time in high speed zones ($P \leq 0.023; \text{ES} = 0.7-0.8$) and very high speed zones ($P \leq 0.026; \text{ES} = 1.1-1.2$) as opposed to HIGH. All parameters of HIA were also shown to be significantly lower in LOW ($P \leq 0.001; \text{ES} = 0.5-0.8$) and MID ($P \leq 0.006; \text{ES} = 0.4-0.8$) compared to HIGH.

• Group IV: MID were shown to spend significantly less time within high speed zones ($P = 0.022; \text{95\% CI} = 0.2 \text{ to } 2.0; \text{ES} = 0.9$) compared to HIGH. Although the relative number of HIA did not differ between team ranks ($P \geq 0.174; \text{ES} \leq 0.2$), LOW and MID were found to cover less mean ($P \leq 0.005; \text{ES} = 1.1-2.0$) and max distances ($P \leq 0.001; \text{ES} = 1.0-2.0$), for lower mean ($P \leq 0.0005; \text{ES} = 1.3-2.0$) and max durations at high-intensities ($P \leq 0.001; \text{ES} = 1.0-2.0$) compared to HIGH.
<table>
<thead>
<tr>
<th>Team Rank</th>
<th>LOW</th>
<th>MID</th>
<th>HIGH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LP</td>
<td>II</td>
<td>III</td>
</tr>
<tr>
<td>I</td>
<td>60.1 ± 5.2</td>
<td>66.0 ± 3.9</td>
<td>74.9 ± 15.0</td>
</tr>
<tr>
<td>II</td>
<td>1.00 ± 0.09</td>
<td>1.10 ± 0.07</td>
<td>1.25 ± 0.25</td>
</tr>
<tr>
<td>III</td>
<td>2.60 ± 0.15*</td>
<td>3.13 ± 0.27*</td>
<td>3.45 ± 0.30*</td>
</tr>
</tbody>
</table>

**Note:** *Significantly different to MID. #Significantly different to HIGH.*
5.5 DISCUSSION

The current study was the first to examine the influence of team rank on the external load of elite WCR during competition to establish which aspects of external load are critical to successful performance. Although the volume of activity was largely uninfluenced by team rank, peak speeds and the capacity to perform at high intensities were both found to be associated with successful performance in WCR. External load were further influenced by classification and positional-role, as demonstrated by the significantly higher peak speed values observed for HIGH HP. HIA were also shown to be important and classification-dependent, with greater time spent within very-high speed zones observed in HIGH group I and HP. Such results demonstrate which aspects of external load were most associated with successful performance in WCR, which may have implications on future training prescription and performance monitoring.

The current study revealed large differences in playing time between team ranks. The shorter playing time of LOW suggests that players may lack the physical capacity to maintain performance over prolonged durations, which was further supported by the greater number of substitutions performed by LOW. Consequently, coaching strategies designed to maximise physical capacity may improve the match performance of lower-ranked teams. Nevertheless, the relative distance covered, along with mean speed were not significantly different between MID and HIGH. Therefore, it appeared that successful performance in WCR was not influenced by the volume of activity performed. Even when categorised by functional classification, the volume of activity performed was largely unaffected by team rank. The comparable activity volume of all players across team ranks reported here suggests association to successful performance is negligible. Despite this, the performance of Paralympic court-based sport players has previously been shown to be highly dependent upon
aerobic fitness (Bernardi et al., 2010). Therefore, elite WCR players should be sufficiently prepared so that they can meet the external demands (3500-4600 m) required for competition (Chapter 4; Sarro et al., 2010).

Since opponents can dictate a player’s movement on-court, it was anticipated that the ability to frequently reach high speeds and sustain HIA would be restricted. Previous research has suggested that sprinting performance and the ability to reach high peak speeds to be less of a priority in WCR compared to acceleration and manoeuvrability performance (Mason et al., 2010). That said, our study found HIGH achieved greater peak speeds (3.59 ± 0.44 m·s⁻¹) than both LOW (3.31 ± 0.49 m·s⁻¹) and MID (3.46 ± 0.43 m·s⁻¹). This supports and extends previous knowledge gleaned from WCT (Sindall et al., 2013b). Furthermore, although the majority of activity during WCR is spent at low intensities (~75%) (Chapter 4), the current study established that players from HIGH spent a greater proportion of time performing HIA compared to players from lower ranked teams. One likely explanation that is difficult to quantify from the current data is that HIGH prevented the opposition from achieving high peak speeds and sustaining HIA by adopting full-court press tactics. Such tactics work by pressurising the ball-handler and reducing the on-court space using ‘trapping’ techniques (Malone & Orr, 2010). On the other hand, it is possible that HIGH players may be more capable of creating court space in order to perform higher peak speeds and a greater number of HIA. Although team efficiency and playing style may account for some differences between team ranks, future notational analysis techniques are required to establish this information with regard to positional transitions, ball possession, and court zones etc. Irrespective of what the explanations may be, the current findings reveal that success in WCR can be characterised by a player’s ability to consistently reach high peak speeds, whilst performing at high-intensities and therefore training and game patterns should be structured to promote this.
Our findings were able to distinguish differences between HP and LP and highlight the increased importance of peak speed for offensive players. As such, HIGH offensive players achieved greater peak speeds than respective MID players, whilst no differences existed between MID and HIGH defensive players. Previous research has demonstrated that the majority of points (~88%) are scored by HP in WCR (Molik et al., 2008; Morgulec et al., 2010). Subsequently the capacity to achieve superior peak speeds could prove pivotal to perform this role effectively and influence team success. Alternatively, peak speed may be less important for LP, whereby tactical aspects of performance may be more of a necessity. Such findings therefore further reiterate the suggestion of role-specific training acknowledged in the previous chapter, and also identify this parameter as one of the key performance indicators, which may be of use for talent identification purposes (Carling, 2013).

The magnitude of differences in HIA was found to be classification-dependent, whereby HIGH group I and HP spent significantly greater time within very high speed zones and were able to sustain these activities for longer compared to respective MID players. It could be suggested that players at the highest level of WCR have the physical capacity to maintain repeated HIA during competition. Additionally, it is plausible that like peak speeds, HIGH players are more capable of finding court space in order to reach HIA repeatedly. Subsequently, training strategies aimed at sustaining HIA under the pressure of opponents may be beneficial for HP. Alternatively, the time spent within the very high speed zone and the ability to sustain HIA were not shown to differ in group II players between MID and HIGH. Subsequently, given that previous research identified no differences in ball-handling patterns between groups I and II (Morgulec et al., 2010), such results may imply that the external load characteristics of group I players could be more critical to successful team performance than group II players, whilst subsequently reducing the total on-court classification points (8.0 points permitted at any one time). Nevertheless, a technical analysis
of WCR is further required to supplement the external load currently presented to gain a holistic appraisal of the sport.

5.5.1 Practical applications

Team line-up is an additional factor that may influence the external load during competition. The current data would suggest LOW and HIGH teams generally utilised group III players, as opposed to MID teams that typically employed more group II and IV players during competition. It is recommended however that future research investigates the effect of different line-up strategies (i.e. mid-point vs. high- and low-point line-ups) on external load and performance in WCR. Moreover, the categorising of movement into speed zones could further be used to identify individual W:R. Such information would provide coaches with important information that could be implemented into future training strategies and is subsequently worthy of further investigation.

5.6 CONCLUSIONS

The current study provides new insights into the possible influence of successful performance on external load and highlights the impact of functional classification. The capacity to reach higher peak speeds and to perform increased activities at high-intensities was associated with successful performance in WCR. These variables were further influenced by functional classification, specifically in group I and HP. Although the volume of activity appeared uninfluenced by team rank, physical conditioning appeared important since LOW performed more substitutions and consequently averaged shorter playing durations.
6. Study Four: A comparison of external load between training and competition in elite wheelchair rugby players.

Chapters 4 and 5 provided evidence that functional classification influenced measures of external load during competition. The importance of peak speed and HIA was further highlighted in Chapter 5.

The following chapter investigates measures of external load drawn from competition to examine how closely training reflects the external demands of competition in elite WCR players.
6.1 ABSTRACT

**Purpose:** To investigate the external load of individual training modes and compare with WCR competition. Additionally, examine the impact of player classification on external load during training. **Methods:** Fifteen international WCR players were monitored using a radio-frequency based, ITS across training sessions \((n = 464)\) and international competition \((n = 34)\). Training was classified into one of four modes: conditioning \((n = 71)\), skill-based \((n = 133)\), game related \((n = 151)\) and game-simulation drills \((n = 109)\). Game-simulation drills were further categorised by their duration, which were 3-min game-clock \((n = 44)\), 8-min game-clock \((n = 39)\), and 10-min running-clock \((n = 26)\). Players were grouped by their IWRF classification as either LP \((\leq 1.5; n = 8)\) or HP \((\geq 2.0; n = 7)\). **Results:** Conditioning drills were shown to exceed the demands of competition, irrespective of classification \((P \leq 0.005; \text{ES} = 0.6-2.0)\). Neither skill-based nor game related drills replicated the external load of competition \((P \leq 0.005; \text{ES} = 0.5-1.1)\) and were further shown to be classification-dependent. Compared to competition, no significant main effect was identified with respect to game-simulation drills. The volume of activity and W:R were significantly lower during 3- and 8-min game-clock durations in relation to competition \((P \leq 0.039; \text{ES} = 0.5-0.7)\). However, no significant main effects were identified between the 10-min running-clock and competition. **Conclusions:** Although game-simulation drills provided the best representation of competition, the structured duration appeared important since the 10-min running-clock increased training specificity.
6.2 INTRODUCTION
Knowledge of the demands of competition is necessary to aid in the format and application of competition-specific training strategies. Yet only a few studies have examined the demands of WCR competition (Chapters 4 & 5; Sarro et al., 2010). While the initial investigation conducted by Sarro et al. (2010) provided an important starting point, the analyses of total distance and mean speed are unlikely to completely inform the prescription of training. More recently, the results of Chapter 4 revealed activities at lower levels of intensity dominated the external load of competition. While HIA contribute to only a small part of competition (~5%), players perform between 36-52 high-intensity efforts per match, each lasting between 1.7-1.9 s (Chapter 4). However, classification-specific requirements varied considerably during competition, with these mainly attributed to the tactical demands specific to each classification. Subsequent work in Chapter 5 was able to distinguish between player classifications and highlight the increased importance of peak speed and HIA for successful performance. The specific requirements across player classifications have important implications for adopting a more individualised approach to the prescription of training.

External load drawn from competition has previously been employed to aid the development of sports-specific training approaches in a variety of AB team sports (Chandler et al., 2014; Gabbett, 2012; Hartwig et al., 2011; Higham et al., 2013; Peterson et al., 2011). In the available literature, a considerable disparity between training and competition has been observed, whereby training failed to replicate the external load associated with competition (Gabbett et al., 2009; Gabbett, 2012; Hartwig et al., 2011). However, it is important to acknowledge that training is typically composed of a number of individual modes depending on their primary objectives and can be classed as either conditioning, skill-based, or game-specific drills. Typically, conditioning drills are prescribed as continuous pushing drills to improve the physical capabilities of players and should replicate or exceed the load.
experienced during competition (Peterson et al., 2011). Skill-based drills generally employ structured ball-handling tasks that are performed at a low-intensity aimed to improve technical aspects (Farrow et al., 2008). Alternatively, game-specific drills are based on the ‘specificity of practice principle’ where competition-specific scenarios are prescribed and the greatest training adaptations occur when the external load replicates the multi-faceted demands of competition (Gabbett, 2006; Farrow et al., 2008). Simply, coaches must balance the development of physical, technical, and tactical requirements to aid in the preparation of players.

Unfortunately, the research examining training in WCR is limited to a single study (Barfield et al., 2010). Barfield et al. (2010) monitored the internal responses of tetraplegic WCR players \((n = 9)\) to an un-prescribed external load during different training modes. Conditioning drills elicited a greater HR response \((114 \pm 13.2 \text{ b.min}^{-1})\) compared to skill-based \((101 \pm 13.7 \text{ b.min}^{-1})\) and game-simulation training \((104 \pm 17.8 \text{ b.min}^{-1})\). A limitation of this study was not only the omission of external load but also that the analysis of training could not be compared to competition. Moreover, there appears to be large variations in the peak HR across players, which can be attributed to compromised HR response previously mentioned in this thesis (see Section 2.1.3).

Despite recent competition-based investigations, a major challenge in WCR is the lack of research that examines the specificity of training. With this in mind, the purpose of the current study was to investigate the external load of individual training modes and compare these with competition. Additionally, this study also aimed to examine the impact of player classification on external load during WCR training.
6.3 METHODS

6.3.1 Participants

Fifteen international WCR players (male: \( n = 14 \); female: \( n = 1 \); age: 28.8 ± 6.5 years; mass: 60.7 ± 9.8 kg) provided written informed consent and volunteered to participate in the current study. Approval for the study was obtained by Loughborough University’s local ethical advisory committee. Players were grouped based on their IWRF classification as either LP (≤ 1.5; \( n = 8 \)) or HP (≥ 2.0; \( n = 7 \)).

6.3.2 Experimental design

Training was monitored over a 3-month period during the competitive phase of the season. Data were collected from a total of 21 individual training drills (\( n = 464 \) observations; See appendices) developed by the coaching staff and classified into one of four modes of training, based on the primary purpose of the drill:

- Conditioning drills (\( n = 71 \) observations) – continuous pushing drills used to improve the physical capabilities of players.
- Skill-based drills (\( n = 133 \) observations) - structured ball-handling tasks with the aim of minimising handling errors.
- Game related drills (\( n = 151 \) observations) - designed to practice game-specific tactical plays and included coach interaction.
- Game-simulation drills (\( n = 109 \) observations) - intended to replicate competition conditions (i.e. 4 vs. 4 structure and typical game regulations).

A key manipulation to game-simulation drills was the structured duration of the drills. Subsequently, these were further categorised into the different variations used, which were 3-min game-clock (\( n = 44 \) observations), 8-min game-clock (\( n = 39 \) observations), and 10-min
running-clock \((n = 26\) observations). During game-clock variations, timing was stopped when a goal was scored, the ball was out of bounds, or a foul/violation was committed. Whereas during the running-clock variation, timing continued throughout the allotted time (10-min). Before each training session, players performed a 20-min standardised warm-up involving moderate- to high-intensity continuous pushing, dynamic stretching and maximal linear sprints. Warm-up activity was not included in any training session analyses.

Training activities were compared with the external load collected during 5 competitive matches over an international tournament on the same group of players \((n = 34\) match observations). A match observation was characterised for each individual by the accumulation of activity collected during the respective four quarters of that match. External load was therefore presented as the mean of all match observations for each individual player.

6.3.3 Measures

The following variables were collected and analysed during both the training and competition environment: relative distance covered \((m \cdot \text{min}^{-1};\) relative to time spent on court), mean and peak speed \((m \cdot s^{-1})\) was determined for each player. Relative time was quantified into five arbitrary speed zones, which were based upon the percentage of each player’s mean peak speed attained during game-simulation drills played throughout the collection period. The percentage thresholds as previously used in team sports (Cahill et al., 2012), were: very low \((\leq 20\%\), low \((21-50\%\), moderate \((51-80\%\), high \((81-95\%\) and very high \((> 95\%\)). These thresholds were subsequently used to calculate the ratio of time spent performing work (moderate, high and very high speed zones) in relation to rest (very low and low speed zones) to determine the W:R. Further analysis of the combined time spent in high and very high speed zones and were extended to include the relative number of HIA performed and both the mean and maximum duration and distance of these activities.
6.3.4 Statistical analyses

Data analyses were performed using the Statistical Package for the Social Sciences (SPSS version 21, Chicago, IL). Descriptive statistics (mean ± SD) were calculated for each participant for all parameters. Normality and homogeneity of variance was confirmed by Shapiro-Wilk and Levene’s tests respectively. Mixed linear modelling was applied to account for the unbalanced design (Cnaan et al., 1997). Main effects and interactions were accepted as statistically significant whereby \( P \leq 0.05 \). Pairwise comparisons were utilised to explore any significant interactions between training mode and competition across player classifications. ES were calculated as the ratio of the mean difference to the pooled standard deviation of the difference. The magnitude of ES was classed as trivial (< 0.2), small (0.2-0.6), moderate (0.6-1.2), large (1.2-2.0), and very large (≥ 2.0) based on previous guidelines (Batterham & Hopkins et al., 2006).

6.4 RESULTS

Within group variability was 1.2% CV and 1.8% CV for LP and HP, respectively. Table 6.1 demonstrates the differences in external load during the individual training modes in comparison to competition.
6.4.1 Conditioning drills

Relative distance, mean speed and W:R of conditioning drills significantly ($P \leq 0.0005$; ES = 1.2-1.5) exceeded competition (Table 6.1). Less time was spent performing low speed activities ($P \leq 0.0005$; ES = 1.7), whilst greater time was spent in moderate to very high speed zones ($P \leq 0.0005$; ES = 1.4-2.0). The relative number, maximum distance and duration of HIA were also greater than during competition ($P \leq 0.0005$; ES = 0.6-2.0). Furthermore, a significant interaction was identified for the maximum distance ($P \leq 0.0005$; ES = 0.8) and duration of HIA ($P \leq 0.0005$; ES = 0.9), which only exceeded competition for HP.

6.4.2 Skill-based drills

Relative distance, mean speed, peak speed and W:R were all significantly lower during skill-based drills ($P \leq 0.0005$; ES = 0.6-2.0) compared to competition (Table 6.1). Time spent at very low speeds were greater ($P \leq 0.0005$; ES = 1.1), while low ($P \leq 0.0005$; ES = 1.1) and high-speed activities were lower ($P = 0.009$; ES = 0.5) than observed in competition. HIA were all significantly lower than competition ($P \leq 0.027$; ES = 0.6-1.2). A significant interaction was identified for relative distance and mean speed, whereby HP achieved significantly lower values compared to competition ($P \leq 0.002$; ES = 1.3). Compared to competition, HP spent a greater time performing very low ($P \leq 0.0005$; ES = 2.0), with less time performing low ($P \leq 0.0005$; ES = 1.9) and high speed activities ($P \leq 0.002$; ES = 0.7). The relative number of HIA were comparable to competition in LP, yet significantly lower in HP ($P \leq 0.0005$; ES = 1.4).

6.4.3 Game related drills

Relative distance, mean speed, peak speed and W:R were all significantly lower compared to competition ($P \leq 0.0005$; ES = 0.8-1.4). Differences were also identified in the time spent
within all speed zones compared to competition ($P \leq 0.007$; $ES = 0.8\text{-}1.4$). All HIA were significantly lower in relation to competition ($P \leq 0.0005$; $ES = 1.0\text{-}1.4$). A significant interaction between classification and competition was identified for high ($P = 0.002$; $ES = 1.0$) and very high speed activities ($P = 0.039$; $ES = 0.9$), whereby LP spent less time in these zones in relation to competition.

### 6.4.4 Game-simulation drills

Although no main effect was identified with respect to competition (Table 6.1), a significant interaction was observed for peak speed ($P = 0.023$; $ES = 0.7$) and W:R ($P = 0.002$; $ES = 0.9$). Compared to competition, HP spent greater time in very low speed zones ($P \leq 0.0005$; $ES = 0.9$) and less time in low ($P = 0.002$; $ES = 0.6$) and moderate speed zones ($P = 0.005$; $ES = 0.9$). Alternatively, LP spent significantly less time performing high ($P = 0.039$; $ES = 0.7$) and very high speed activities ($P = 0.039$; $ES = 0.6$). The relative number of HIA were comparable to competition for HP, but significantly lower in LP ($P = 0.032$; $ES = 1.0$).
Table 6.1 - External load (mean ± SD) during individual training modes in relation to player classification

<table>
<thead>
<tr>
<th>Activities</th>
<th>Conditioning</th>
<th>Skill-based</th>
<th>Game Related</th>
<th>Game Simulation</th>
<th>International Competition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LP (n = 24)</td>
<td>HP (n = 47)</td>
<td>LP (n = 60)</td>
<td>HP (n = 73)</td>
<td>LP (n = 49)</td>
</tr>
<tr>
<td>Relative Distance (m min⁻¹)</td>
<td>79.2 ± 29.3†️</td>
<td>118.6 ± 37.7*</td>
<td>61.2 ± 21.6 #</td>
<td>59.7 ± 21.8#</td>
<td>43.6 ± 15.7*</td>
</tr>
<tr>
<td>Mean Speed (m s⁻¹)</td>
<td>1.32 ± 0.46*</td>
<td>1.98 ± 0.63*</td>
<td>1.02 ± 0.36 #</td>
<td>0.99 ± 0.36#</td>
<td>0.72 ± 0.26*</td>
</tr>
<tr>
<td>Peak Speed (m s⁻¹)</td>
<td>3.22 ± 0.76</td>
<td>3.90 ± 0.62</td>
<td>2.44 ± 0.58*</td>
<td>2.60 ± 0.76#</td>
<td>2.82 ± 0.46*</td>
</tr>
<tr>
<td>Work-rest Ratio (W:R)</td>
<td>1:2.4</td>
<td>1:1.5†️</td>
<td>1:7.5#</td>
<td>1:11.2*</td>
<td>1:17.2*</td>
</tr>
<tr>
<td>Intensity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very Low (%)</td>
<td>32.5 ± 19.1</td>
<td>20.1 ± 16.3</td>
<td>43.9 ± 18.2 #</td>
<td>51.0 ± 17.3#</td>
<td>56.3 ± 19.0*</td>
</tr>
<tr>
<td>Low (%)</td>
<td>29.0 ± 13.7*</td>
<td>21.4 ± 16.5#</td>
<td>31.7 ± 18.6 #</td>
<td>31.8 ± 15.1#</td>
<td>33.1 ± 13.0*</td>
</tr>
<tr>
<td>Moderate (%)</td>
<td>29.0 ± 19.4†️</td>
<td>35.8 ± 16.0#</td>
<td>21.7 ± 19.8</td>
<td>15.4 ± 18.3</td>
<td>9.3 ± 7.3*</td>
</tr>
<tr>
<td>High (%)</td>
<td>7.6 ± 3.6*</td>
<td>18.0 ± 13.0#</td>
<td>2.0 ± 3.9 #</td>
<td>1.1 ± 2.5*</td>
<td>0.9 ± 1.4#</td>
</tr>
<tr>
<td>Very High (%)</td>
<td>1.9 ± 3.3†️</td>
<td>4.3 ± 4.1†️</td>
<td>0.5 ± 1.9</td>
<td>0.4 ± 1.3</td>
<td>0.2 ± 0.6#</td>
</tr>
<tr>
<td>HIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative Number (n min⁻¹)</td>
<td>2.2 ± 1.1#</td>
<td>3.6 ± 2.4†️</td>
<td>0.6 ± 1.2 #</td>
<td>0.2 ± 0.5#</td>
<td>0.2 ± 0.4#</td>
</tr>
<tr>
<td>Mean Distance (m)</td>
<td>6.3 ± 3.2</td>
<td>8.5 ± 4.9</td>
<td>2.0 ± 1.4 #</td>
<td>2.4 ± 6.1#</td>
<td>2.2 ± 2.7#</td>
</tr>
<tr>
<td>Max Distance (m)</td>
<td>15.1 ± 10.4 #†️</td>
<td>27.8 ± 19.9#</td>
<td>4.4 ± 3.3#</td>
<td>4.5 ± 10.8#</td>
<td>3.8 ± 5.4#</td>
</tr>
<tr>
<td>Mean Duration (s)</td>
<td>2.4 ± 1.1</td>
<td>2.7 ± 1.7</td>
<td>0.7 ± 0.5#</td>
<td>0.7 ± 1.7#</td>
<td>0.8 ± 0.9#</td>
</tr>
<tr>
<td>Max Duration (s)</td>
<td>5.1 ± 4.6 #†️</td>
<td>8.1 ± 5.8#</td>
<td>1.5 ± 3.4#</td>
<td>1.3 ± 3.1*</td>
<td>1.3 ± 1.8#</td>
</tr>
</tbody>
</table>

*Note: # = significant main effect between training mode and competition. † = significant interaction between player classification and competition. * = significant difference to competition
Table 6.2 demonstrates the differences in external load during the different structured durations of game-simulation drills compared to competition.

6.4.4.1 3-min variation

Relative distance, mean speed, peak speed and W:R were significantly lower ($P \leq 0.039$; ES = 0.5-0.6) in relation to competition (Table 6.2). Compared to competition, less time was spent performing moderate ($P = 0.017$; ES = 0.6) and high speed activities ($P = 0.007$; ES = 0.7). HIA were all significantly lower than competition ($P \leq 0.005$; ES = 0.7-0.8). HP performed significantly lower relative distance and mean speed values compared to competition ($P \leq 0.0005$; ES = 0.9-1.0). LP failed to replicate the peak speeds observed during competition ($P \leq 0.0005$; ES = 1.3). Further interactions were observed in very low, moderate and high speed zones ($P \leq 0.003$; ES = 0.8-1.1).

6.4.4.2 8-min variation

Relative distance, mean speed, W:R and the number of HIA were lower compared to competition ($P \leq 0.039$; ES = 0.6-0.7). Significant interactions were identified between classification and competition for the time spent within very low, moderate, high and very speed zones ($P \leq 0.027$; ES = 0.7-1.2). Finally, the relative number of HIA were comparable to competition for HP, but significantly lower in LP ($P = 0.007$; ES = 1.1).

6.4.4.3 10-min variation

No significant main effects were identified between the 10-min game-simulation drills and competition (Table 6.2). Significant interactions revealed differences were identified between HP and competition for relative distance ($P = 0.008$; ES = 0.9), mean speed ($P = 0.008$; ES = 0.8), and the time spent performing very low ($P = 0.012$; ES = 0.9) and moderate speed activities ($P = 0.018$; ES = 0.8).
Table 6.2 - External load (mean ± SD) during game-simulation manipulations in relation to player classification.

<table>
<thead>
<tr>
<th>Activities</th>
<th>3-minute</th>
<th>8-minute</th>
<th>10-minute</th>
<th>International Competition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LP (n = 48)</td>
<td>HP (n = 77)</td>
<td>LP (n = 43)</td>
<td>HP (n = 59)</td>
</tr>
<tr>
<td>Duration (min)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-minute</td>
<td>6.15 ± 0.15</td>
<td></td>
<td>15.05 ± 1.28</td>
<td></td>
</tr>
<tr>
<td>8-minute</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10-minute</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work-rest Ratio (W:R)</td>
<td>1:4.5*</td>
<td>#</td>
<td>1:4.4*</td>
<td>#</td>
</tr>
<tr>
<td>Intensity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very Low (%)</td>
<td>39.3 ± 7.4</td>
<td></td>
<td>42.5 ± 7.4</td>
<td></td>
</tr>
<tr>
<td>Low (%)</td>
<td>41.2 ± 5.2</td>
<td></td>
<td>39.3 ± 5.4</td>
<td></td>
</tr>
<tr>
<td>Moderate (%)</td>
<td>17.1 ± 4.1</td>
<td></td>
<td>15.5 ± 2.0</td>
<td></td>
</tr>
<tr>
<td>High (%)</td>
<td>1.9 ± 1.3*</td>
<td></td>
<td>2.3 ± 1.2*</td>
<td></td>
</tr>
<tr>
<td>Very High (%)</td>
<td>0.3 ± 0.5*</td>
<td></td>
<td>0.4 ± 0.4*</td>
<td></td>
</tr>
<tr>
<td>HIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative Number (n·min⁻¹)</td>
<td>0.4 ± 0.4*</td>
<td>#</td>
<td>0.5 ± 0.3*</td>
<td>#</td>
</tr>
<tr>
<td>Mean Distance (m)</td>
<td>4.2 ± 2.8*</td>
<td></td>
<td>5.9 ± 2.0</td>
<td></td>
</tr>
<tr>
<td>Max Distance (m)</td>
<td>7.3 ± 5.3*</td>
<td></td>
<td>12.6 ± 4.1</td>
<td></td>
</tr>
<tr>
<td>Mean Duration (s)</td>
<td>1.4 ± 1.0*</td>
<td></td>
<td>2.0 ± 0.6</td>
<td></td>
</tr>
<tr>
<td>Max Duration (s)</td>
<td>2.5 ± 1.8*</td>
<td></td>
<td>4.2 ± 1.2</td>
<td></td>
</tr>
</tbody>
</table>

Note: # = significant main effect between duration manipulation and competition. † = significant interaction between player classification and competition. * = significant difference to competition.
6.5 DISCUSSION

The current study indicated conditioning drills were shown to exceed the demands of competition whereas neither skill-based nor game related drills replicated the external load of competition. Game-simulation drills offered the closest representation of competition, as evidenced by a comparable external load. However, this was dependent on the structured duration of the drill, as the 10-min running-clock modification more closely reflected the external demands of competition than other drill modifications. Finally, classification-specific differences were identified during individual training modes, specifically skill-based and game related drills further emphasising the need for role-specific training.

Conditioning drills were found to replicate, if not on most occasions exceed competition for all parameters irrespective of player classification. Consistent with observations in AB team sports (Chandler et al., 2014; Peterson et al., 2011), the goal of conditioning drills was to place a large emphasis on the volume of activity (105 m·min$^{-1}$ vs. 71 m·min$^{-1}$) and the time spent performing HIA in relation to competition (18% vs. 4%). The current data illustrate that conditioning drills can provide an appropriate training stimulus to increase the overall load of training. Incorporating longer conditioning periods into the training session will apply a progressive overload and thereby enhance training load. However, coaches must be aware of the balance between physical improvement and injury risk when prescribing training load (Gabbett et al., 2012). Although increases in training load have previously been associated with overreaching (Halson & Jeukendrup, 2004; Le Meur et al., 2013) and injury (Viljoen et al., 2009) in AB sports, little is known surrounding the optimum prescription of training load during WCR training. Nevertheless, the demands of competition, specifically ball-handling and player interaction, are notably absent from conditioning drills. Therefore, additional means are required that prepares players for the technical and tactical elements of competition.
Although skill-based drills do place an emphasis on ball-handling and interaction with team-mates, the current study found a reduced W:R combined with lower peak speeds and HIA in relation to competition. The reduced W:R can be explained by the ‘closed’ nature of such drills (Farrow et al., 2008), which typically focus on one discreet skill at a time. As such, skill-based drills permit additional recovery time while players wait for their turn to perform a task, resulting in prolonged static periods. Furthermore, the comparably low peak speeds and reduction in HIA most likely reflect the size of the playing area of these drills, with players unlikely to sustain such activities within the relatively small court dimensions. Differences in skill-based drills may be better reflected by quantifying the technical requirements (e.g. ball-handling) rather than the external load alone.

The comparably low external load elicited during skill-based drills was not specific to all players. Despite the lower peak speed values, LP accumulated a comparable amount of HIA in relation to competition. Such results may be attributed to the fact that players perform these drills collectively as a squad. Consequently, the demands of skill-based training may be greater for LP who must work harder to keep up with their functionally more able team-mates. Although it may be undesirable for skill-based drills to reproduce the external loads of competition, additional training modes are required to provide the added stimulus of competition-specific training in HP.

Game related drills provide an additional means for exposing players to competition-specific scenarios that are not present in closed, skill-based drills (Farrow et al., 2008). However, compared with competition, game related drills were characterised by more time spent performing very low-speed activities and considerably less HIA. This may partially be explained by the intermittent breaks during game related drills for coaching intervention. Such breaks were included in the current analyses to reflect the actual demands experienced by the players for that training mode. In addition, our findings were able to distinguish
classification-specific differences during game related training. Compared to competition, HP were observed to spend comparable time performing high and very high intensity activities with lower values observed for LP. The positional-roles specific to WCR may be attributed to such results, as outlined in Chapters 4 and 5 WCR players typically occupy defensive (LP) and offensive (HP) positions, which are also evident during game related drills. Subsequently, these drills typically overemphasize positional-roles, as HP are continuously required to perform offensive actions (e.g. attacking the key) whilst LP typically maintain static blocking positions to simulate a key defensive duty. Although game related drills provide a focus on the tactical aspects of competition, it was clear that these drills do not reproduce the external load specific to competition especially for LP.

Game-simulation training offered the closest representation of competition, as players performed similar volumes of activity in relation to competition, and completed a comparable number of HIA. Collectively, game-simulation drills promote the physical adaptations that adequately meet the demands of WCR competition. Although specific training objectives alter throughout the season, the ultimate goal of the competitive phase should be to induce similar load to that encountered during competition (Farrow et al., 2008; Gabbett et al., 2012; Higham et al., 2013). Hence, the reason why the main focus of training within the current study appeared to be centred on game-simulation drills (43.3% of total training time). Again, classification-specific differences were identified. LP were observed to achieve significantly lower peak speeds and spend less time performing high and very high intensity activities in relation to competition. Given the importance of game-simulation drills in developing all facets of competition, current drills may fail to adequately prepare all players for the highest level of competition.

The manipulation of duration distinguished large differences between game-simulation drills. Irrespective of player classification, reducing the duration to 3-min
variations restricted the opportunity to replicate the W:R and HIA of competition. In addition, the volume of activity and peak speed values were found to be lower compared to competition in HP and LP, respectively. Although the mean and maximum duration of HIA were similar between 8-min quarters and competition, these HIA were performed less frequently compared to competition. Nevertheless, the 10-min manipulation led to an observed improvement in training specificity. Such findings could be attributed to the addition of a running-clock as opposed to a game-clock used in the 3- and 8-min variations. The stopped time during a game-clock typically represents approximately 50% of the total duration, which equates to ~120 interruptions in play (Sarro et al., 2010). Consequently, the period of recovery is likely to be longer during a game-clock format, as players are more likely to stop or ‘coast’ during these paused periods. From a practical perspective, coaches could therefore increase the specificity of game-simulation drills by the inclusion of a running-clock format as this was shown to provide comparable external responses in relation to competition.

6.5.1 Practical applications

The findings of this study highlight the potential to improve the training specificity of WCR players. Our results showed the progressive overload required to improve physical conditioning in WCR players is provided by conditioning drills. Coaches should be aware that the external load of skill-based and game related drills are substantially lower than competition, although the tactical benefits of these drills should not be underestimated. Future work is required to alter the conditions, design, or complexity of game-simulation drills to provide an appropriate training stimulus for WCR. The data presented here illustrate the addition of a running-clock time stipulation can assist in advancing training specificity by providing a comparable external load to competition.

The present data is only representative of the international squad that were investigated. As these training patterns are a consequence of the coaching staff, it is likely that
each individual squad will have a contrasting training strategy. With this in mind, the current findings may not be representative of the WCR population. Therefore, more information is required to quantify a definitive training load, specifically across different phases of the season.

6.6 CONCLUSIONS

Conditioning drills exceeded these demands, irrespective of classification. Yet both skill-based and game related drills were shown to be classification-dependent, attributed to the varying positional-roles of defensive and offensive players. Although game-simulation drills provided the closest representation of competition, the structured duration appeared important since the 10-min running-clock increased training specificity from an external perspective.
7. Study Five: External load characteristics of game-simulation drills in elite wheelchair rugby players: Effect of player number and duration changes

The preceding chapter (Chapter 6) outlined the importance of game-simulation drills in the preparation of elite WCR players. However, further information is required on how game-simulation drills can best be utilised during WCR training so after consultation with the Head Coach and Sport Scientist this chapter seeks to examine measures of external load during further manipulations to this mode of training.
7.1 ABSTRACT

**Purpose:** To examine the external load of elite WCR players during game-simulation drills of differing player number and shot-clock regulations. Additionally, determine whether the response was further influenced by functional classification. **Methods:** Eight elite WCR players (LP = 3; HP = 5) were monitored using an ITS during the squad’s training sessions over a 5-month period throughout the competitive phase of the season. External load was collected from three separate variations of game-simulation drills: i) 3 vs. 3 drills ($n = 8$ observations); ii) 30-s shot-clock ($n = 24$ observations) and iii) 15-s shot-clock ($n = 16$ observations). These modified drills were compared with the external load collected during regular game-simulation drills (4 vs. 4; $n = 16$ observations). **Results:** Compared to regular game-simulation drills, the 3 vs. 3 drills elicited a moderate increase in the volume (6.3%; ES = 0.7) and number of HIA (44.1%; ES = 1.1). Moderate to large increases in all measures were observed during the 15-s shot-clock drills. Classification-specific differences were further identified, with increases observed in LP and HP during the 15-s shot-clock and 3 vs. 3 drills respectively. **Conclusions:** Game-simulation drills containing fewer players can increase the volume and intensity of training, specifically in HP. While employing a 30-s shot-clock elicited no observed differences, changes in external load were found when the shot-clock was reduced to 15-s, especially in LP. Coaches can therefore modify the training response by making subtle changes to the format of game-simulation drills.
7.2 INTRODUCTION

Game-simulation drills are a popular training modality with coaches because they enable a combination of technical, tactical and physical elements of performance to be developed under sport specific conditions. Results from the preceding chapter signified the importance of game-simulation drills, since they accounted for 43% of total WCR training time and offered the closest external representation of competition. Furthermore, a corresponding effect on external load was found when the structured duration of these drills were manipulated. In practice, reducing the duration to a 3-min game-clock restricted the opportunity to replicate competition-specific peak speeds and HIA. Alternatively, while an 8-min game-clock was sufficient to provide the high-intensity requirements of competition in HP, this was not evident for LP. However, a 10-min running-clock led to an observed increase in competition-specific movements irrespective of functional classification (Chapter 6). Such findings were attributed to the addition of a running-clock as opposed to using a game-clock format. While the results of Chapter 6 provided an insight into current WCR training practice, it is currently unclear how game-simulation drills can best be utilised to prepare elite WCR players.

At present, there is relatively little information regarding the prescription of game-simulation drills during elite WCR training. Previous AB research has revealed that modifications to the format of game-simulation training drills can affect the external load experienced by players during training (Casamichana & Castellano, 2010; Hill-Haas et al., 2010; Kennett et al., 2012; Owen et al., 2014; Rampinini et al., 2007b). These studies have frequently investigated the impact of manipulating the number of players on court during game-simulation drills (Hill-Haas et al., 2010; Kennett et al., 2012; Rampinini et al., 2007b). By reducing player numbers athletes have been shown to spend more time performing HIA during soccer- (Morgans et al., 2014) and rugby-specific drills (Kennett et al., 2012). Additionally, coaches quite often modify playing regulations in game-simulation drills to
achieve greater intensity (Hill-Haas et al., 2011). Hill-Haas et al. (2010) identified that changes in technical regulations (e.g. each player allowed a maximum of one touch on the ball) can alter the training response in elite soccer players. Coaches can use this information for designing drills that are either more intense than competition to overload players, or lower than competition when recovery strategies are the primary objective.

Unfortunately, no studies have examined the effects of the number of players or the playing regulations on the training response of WCR players. Understanding these training variables would allow a better integration of game-simulation drills within the whole training process and would facilitate the prescription of future WCR-specific training strategies. Therefore, the aim of this study was to examine the external load of elite WCR players during WCR-specific game-simulation drills of differing player number and shot-clock regulations. A secondary aim was to determine whether these responses were further influenced by functional classification.

7.3 METHODS

7.3.1 Participants
Eight elite male WCR players (age: 27.3 ± 5.3 years; mass: 60.9 ± 10.2 kg) provided written informed consent and volunteered to participate in this study. Players were grouped by their IWRF classification as either LP (n = 3) or HP (n = 5). Data were only reported for players free from injury and illness during training activities. Approval for the study was obtained by Loughborough University’s ethical advisory committee.

7.3.2 Procedures
Data were collected using the ITS as previously detailed in Chapter 3, during the team’s training sessions over a 5-month period throughout the competitive phase of the season (January to May). Data collection procedures (i.e. tag location) were replicated as explained
in the preceding chapters. Players were instructed to maintain normal fluid intake and cooling strategies, and no additional dietary interventions were undertaken once training commenced. All players were familiar with the ITS and its operational procedures.

7.3.3 Experimental design

Players were allocated by the Head Coach into balanced teams for each drill according to their IWRF classification, ensuring that 8.0 points on court was not exceeded at any time. The court size (15 m x 28 m), clock format (running-clock) and the overall duration (4 x 10-min quarters) were strictly controlled based on findings from the previous chapter (Chapter 6). In consultation with the Head Coach and Sport Scientist, three separate variations of game-simulation drills were developed, whereby the number of players and shot-clock regulations were modified. These incorporated modification of player numbers by including 1) 3 vs. 3 game formats (n = 8 observations) and modification of the shot-clock regulations to evaluate 2) 30-s shot-clock (4 vs. 4; n = 24 observations) and 3) 15-s shot-clock (4 vs. 4; n = 16 observations). The shot-clock was started once a team were in possession of the ball, of which they had the stipulated time to score otherwise, they conceded possession. These modified drills were compared with the external load collected during regular game-simulation drill (10-min running-clock format; 40-s shot-clock) over the data collection period on the same group of players (n = 16 observations). The order of play in which the drills were performed were randomly allocated across the collection period, with a training observation characterised for each individual by the accumulation of activity collected during the respective four quarters of that drill. External load for game-simulation drills were therefore presented as the mean of all training observations for each individual player. Game-simulation drills were preceded by a 20-min standardised warm-up involving moderate- to high-intensity continuous pushing, dynamic stretching and maximal linear sprints. Coaches
verbally encouraged the players throughout the drills and scoring was recorded to maintain motivation and further sports specificity.

7.3.4 Measures

The following measures of external load were collected and analysed during the aforementioned training sessions for each player: Relative distance covered (m·min⁻¹; relative to time spent on court), mean and peak speeds (m·s⁻¹). As described in the preceding Chapter, the W:R was categorised into the ratio of time spent performing work (moderate, high and very high speed zones) in relation to rest (very low and low speed zones) according to the relative time spent in five speed zones (Chapter 6). These speed zones were based upon the percentage of each player’s mean peak speed attained during the regular game-simulation drills played throughout the collection period. Further analysis of the combined time spent in high and very high speed zones was extended to include the time spent (%), relative number (n·min⁻¹), and the mean distance (m) and duration (s) of HIA.

7.3.5 Statistical analyses

External load data were processed and analysed using a customised Excel spreadsheet (Microsoft, Redmond, USA). Raw data are presented as mean ± SD for each parameter. Between-observation variability of the measures were calculated from the regular game-simulation drills (10-min running-clock) from a larger cohort of athletes (n = 26 observations; LP = 10 observations; HP = 16 observations; Chapter 6) and were expressed using the CV (%) and presented with 95% CL as markers of uncertainty of the estimates. Data were interpreted using the ES statistic with 95% confidence intervals (± CI) and percentage change to determine the magnitude of effects, classified as trivial < 0.2; small 0.2 to 0.6; moderate 0.6 to 1.2; large 1.2 to 2.0; and very large > 2.0 (Hopkins, 2006). The smallest worthwhile change (SWC %) in external load was defined as 0.2 multiplied by the between subject standard
deviation (Hopkins et al., 2009). The SWC in measures were again calculated from the larger cohort (Chapter 6), and can be used to interpret the magnitude of effects reported here. This statistical approach was utilised to identify worthwhile changes in performance while accounting for the variability of measurement.

7.4 RESULTS

Within group variability were 2.5% CV and 1.9% CV for LP and HP, respectively. The between-observation variability and SWC in measures of external load are reported in Table 7.1. Overall, variability was greatest for the time spent performing HIA (22.4% CV) and the relative number of HIA performed (16.0% CV). Lowest variability was observed for the volume of activity performed (1.9% CV) and peak speed (2.4% CV). Between-observation variability was also shown to be greater in LP compared to HP for all measures of external load (Table 7.1).
Table 7.1 - Between-observation variability (CV ± 95% CL) and the smallest worthwhile change (%) required for external load measures.

<table>
<thead>
<tr>
<th></th>
<th>Overall</th>
<th>LP</th>
<th>HP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CV%</td>
<td>SWC (%)</td>
<td>CV%</td>
</tr>
<tr>
<td>Activities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative distance (m·min⁻¹)</td>
<td>1.9 ± 0.1</td>
<td>2.6</td>
<td>2.5 ± 0.1</td>
</tr>
<tr>
<td>Mean speed (m·s⁻¹)</td>
<td>1.9 ± 0.1</td>
<td>2.6</td>
<td>2.5 ± 0.1</td>
</tr>
<tr>
<td>Peak speed (m·s⁻¹)</td>
<td>2.4 ± 0.2</td>
<td>2.3</td>
<td>2.9 ± 0.1</td>
</tr>
<tr>
<td>Work-rest ratio (W:R)</td>
<td>6.8 ± 0.3</td>
<td>4.4</td>
<td>6.8 ± 0.7</td>
</tr>
<tr>
<td>HIA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time spent (%)</td>
<td>22.4 ± 0.5</td>
<td>8.9</td>
<td>38.8 ± 0.9</td>
</tr>
<tr>
<td>Relative Number (n min⁻¹)</td>
<td>16.0 ± 0.1</td>
<td>6.3</td>
<td>23.9 ± 0.2</td>
</tr>
<tr>
<td>Mean distance (m)</td>
<td>6.6 ± 0.9</td>
<td>6.2</td>
<td>20.5 ± 1.6</td>
</tr>
<tr>
<td>Mean duration (s)</td>
<td>4.5 ± 0.2</td>
<td>4.7</td>
<td>12.5 ± 0.4</td>
</tr>
</tbody>
</table>

Note: CV – Coefficient of variation; CL – Confidence limits.
Table 7.2 shows the comparison of external load for the modified drills in relation to regular game-simulation drills. Compared to regular game-simulation drills, the 3 vs. 3 drills elicited a moderate increase in the relative distance, mean speed (6.3%; ES = 0.7; 95% CI 0.6 to 0.8), the W:R (15.1%; ES = 0.8; 95% CI 0.6 to 0.9), time spent performing HIA (44.1%; ES = 1.1; 95% CI 1.0 to 1.8) and the relative number of HIA (43.5%; ES = 1.0; 95% CI 0.8 to 1.2) (Figure 7.1). Only trivial to small increases were observed for all measures of external load during the 30-s shot-clock compared to regular game-simulation drills (Figure 7.1). The greatest increase in external load occurred during the 15-s shot-clock, where large increases were observed in the relative distance, mean speed (12.9%; ES = 1.5; 95% CI 1.4 to 1.8), peak speed (8.8%; ES = 1.2; 95% CI 1.1 to 1.3) and the relative number of HIA performed (57.1%; ES = 1.3; 95% CI 1.2 to 1.4). Finally, moderate increases in the W:R (15.1%; ES = 0.6; 95% CI 0.3 to 1.0) and the time spent performing HIA (27.1%; ES = 0.8; 95% CI 0.5 to 1.2) were also observed during the 15-s shot-clock (Figure 7.1).
Table 7.2 – Descriptive statistics (mean ± SD) for modified drills in comparison to regular game-simulation drills.

<table>
<thead>
<tr>
<th></th>
<th>Modified Drills</th>
<th></th>
<th></th>
<th>Regular</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>3 vs. 3</td>
<td>30-s shot-clock</td>
<td>15-s shot-clock</td>
</tr>
<tr>
<td><strong>Activities</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative Distance (m·min⁻¹)</td>
<td></td>
<td>78.6 ± 8.0</td>
<td>76.3 ± 4.8</td>
<td>83.6 ± 6.3</td>
</tr>
<tr>
<td>Mean Speed (m·s⁻¹)</td>
<td></td>
<td>1.31 ± 0.13</td>
<td>1.27 ± 0.08</td>
<td>1.41 ± 0.11</td>
</tr>
<tr>
<td>Peak Speed (m·s⁻¹)</td>
<td></td>
<td>3.79 ± 0.33</td>
<td>3.72 ± 0.34</td>
<td>3.98 ± 0.24</td>
</tr>
<tr>
<td>W:R</td>
<td></td>
<td>1:3.1</td>
<td>1:3.7</td>
<td>1:2.9</td>
</tr>
<tr>
<td><strong>HIA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time Spent (%)</td>
<td></td>
<td>4.1 ± 1.4</td>
<td>2.8 ± 0.8</td>
<td>3.6 ± 1.1</td>
</tr>
<tr>
<td>Relative Number ( n·min⁻¹)</td>
<td></td>
<td>1.0 ± 0.4</td>
<td>0.7 ± 0.2</td>
<td>1.1 ± 0.4</td>
</tr>
<tr>
<td>Mean Distance (m)</td>
<td></td>
<td>7.1 ± 1.1</td>
<td>6.6 ± 1.8</td>
<td>6.0 ± 2.2</td>
</tr>
<tr>
<td>Mean Duration (s)</td>
<td></td>
<td>2.2 ± 0.3</td>
<td>2.0 ± 0.5</td>
<td>1.6 ± 0.3</td>
</tr>
</tbody>
</table>
**Figure 7.1** - Magnitude of change in activities (a) and HIA (b) during modified game-simulation drills in relation to regular game-simulation drills. Error bars represent 95% CI.
7.4.1 Functional classification

Table 7.3 shows the descriptive statistics from the modified drills in relation to functional classification when compared to regular game-simulation drills. When categorised by functional classification, the 3 vs. 3 drills elicited large increases in the relative distance, mean speed (10.1%; ES = 1.6; 95% CI 1.6 to 1.7) and the W:R (18.4%; ES = 1.2; 95% CI 0.8 to 1.5) in HP (Figure 7.2). A moderate increase in the relative number of HIA performed (25.0%; ES = 1.0; 95% CI 0.9 to 1.2) was also observed in HP. During drills with a 30-s shot-clock, moderate decreases in peak speed (1.7%; ES = 0.7; 95% CI 0.7 to 0.8) and the mean distance (21.0%; ES = 1.1; 95% CI 0.7 to 1.8) and duration (22.9%; ES = 1.1; 95% CI 1.0 to 1.4) of HIA were observed compared to regular game-simulation drills in LP (Figure 7.2). A large decrease was further witnessed in the time spent performing HIA in LP (22.6%; ES = 1.4; 95% CI 1.2 to 1.7). Alternatively, the 15-s shot-clock drills elicited large to very large increases in the relative distance, mean speed (19.7%; ES = 2.0; 95% CI 1.9 to 2.1), peak speed (11.9%; ES = 1.8; 95% CI 1.5 to 2.0), W:R (40.9%; ES = 2.3; 95% CI 1.9 to 3.3), the time spent performing HIA (41.9%; ES = 1.4; 95% CI 1.4 to 2.4) and the relative number of HIA (62.5%; ES = 1.4; 95% CI 1.4 to 1.8) in LP (Figure 7.2). In HP, large increases were observed in the relative distance, mean speed (10.0%; ES = 1.2; 95% CI 1.1 to 1.3), peak speed (7.4%; ES = 1.3; 95% CI 1.1 to 1.4) and relative number of HIA performed (50.0%; ES = 1.2; 95% CI 1.1 to 1.5).
Table 7.3 – Descriptive statistics (mean ± SD) of modified drills in LP and HP compared to regular game-simulation drills.

<table>
<thead>
<tr>
<th>Modified Drills</th>
<th>3 vs. 3</th>
<th>30-second shot-clock</th>
<th>15-second shot-clock</th>
<th>Regular</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LP</td>
<td>HP</td>
<td>LP</td>
<td>HP</td>
</tr>
<tr>
<td>Activities</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative Distance (m·min⁻¹)</td>
<td>71.4 ± 7.8</td>
<td>83.0 ± 4.2</td>
<td>72.0 ± 1.9</td>
<td>77.8 ± 5.0</td>
</tr>
<tr>
<td>Mean Speed (m·s⁻¹)</td>
<td>1.19 ± 0.13</td>
<td>1.38 ± 0.07</td>
<td>1.20 ± 0.03</td>
<td>1.30 ± 0.08</td>
</tr>
<tr>
<td>Peak Speed (m·s⁻¹)</td>
<td>3.50 ± 0.27</td>
<td>3.97 ± 0.23</td>
<td>3.39 ± 0.09</td>
<td>3.90 ± 0.18</td>
</tr>
<tr>
<td>Work-rest Ratio (W:R)</td>
<td>1:2.9</td>
<td>1:3.1</td>
<td>1:3.2</td>
<td>1:4.1</td>
</tr>
<tr>
<td>HIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time spent (%)</td>
<td>5.3 ± 0.8</td>
<td>3.4 ± 1.1</td>
<td>2.4 ± 0.5</td>
<td>2.8 ± 0.8</td>
</tr>
<tr>
<td>Relative Number (n·min⁻¹)</td>
<td>1.2 ± 0.5</td>
<td>0.8 ± 0.2</td>
<td>0.8 ± 0.1</td>
<td>0.7 ± 0.1</td>
</tr>
<tr>
<td>Mean Distance (m)</td>
<td>6.8 ± 1.5</td>
<td>7.3 ± 0.9</td>
<td>4.9 ± 0.9</td>
<td>7.6 ± 1.8</td>
</tr>
<tr>
<td>Mean Duration (s)</td>
<td>2.2 ± 0.4</td>
<td>2.2 ± 0.3</td>
<td>1.6 ± 0.3</td>
<td>2.2 ± 0.5</td>
</tr>
</tbody>
</table>
**Figure 7.2** - Magnitude of change in activities (a) and HIA (b) for LP (black) and HP (grey) during modified game-simulation drills in relation to regular game-simulation drills. Error bars represent 95% CI.
7.5 DISCUSSION

This study was the first to examine the external load response to various game-simulation drills in WCR. Our data indicated that changes in the number of players and shot-clock regulations appeared to have an influence on the externally measured load during game-simulation drills. Furthermore, classification-specific differences were identified for all the drills, more notably with differences between LP and HP particularly during the 3 vs. 3 and 15-s shot-clock drills respectively. These findings extend our current knowledge with ideas of how to develop competition-specific training strategies when preparing for elite competition.

The present study also quantified the variability of external load during WCR training to assist with establishing meaningful differences in outcome measures. The volume of activity performed and the peak speeds reached appeared to be the most stable measures of external load during WCR game-simulation drills. Similar findings have previously been reported in match-play variation for soccer (2.4% CV; Rampinini et al., 2007a), rugby league (3.6% CV; Kempton et al., 2014) and Australian football (5.3% CV; Kempton et al., 2015). In contrast, the variability in HIA observed in the current study was slightly greater than that previously reported (18-20% CV). Such findings are likely to be explained by the complexity of WCR, whereby notable discrepancies in functional classifications, positional-roles (Chapters 4 & 5) and physical capacity between players (Morgulec et al., 2011) may influence this variability. Despite the small cohort of players, descriptive data in relation to functional classification also showed clear differences between LP and HP. It was envisaged that HP would demonstrate the largest variations in measures since they are typically more involved in the game play than LP (Morgulec et al., 2010). Interestingly, this was not the case for the current population, since the largest variations were observed in LP. While difficult to provide explanation, the diverse tactical roles of LP may partly explain these results. Defensive players may therefore be most susceptible to differences in the tactics employed during game-
simulation drills. Nevertheless, regardless of functional classification, these findings suggest caution is required when using HIA for interpreting changes in an individual’s external load.

Reducing the number of players on court from 4 vs. 4 to 3 vs. 3 had a substantial effect on the external load during game-simulation drills. The relative number of HIA performed during the 3 vs. 3 drills increased with a moderate effect compared to regular game-simulation drills. Even though this measure had a high variability (16.0% CV), the magnitude of change detected during the 3 vs. 3 drills were twice the CV%, and several orders of magnitude larger than the SWC for this parameters. Therefore, there can be confidence that this was a true reflection of the increased demands of this drill modification.

The greater available court area per player ratio during the 3 vs. 3 drills (70.0 m² vs. 52.5 m²) was likely to be responsible for the increased external load. This is supported by previous AB research, whereby significant correlations between relative pitch area and increases in external load have been reported (Casamichana & Castellano, 2010; Kennett et al., 2012; Owen et al., 2014). The specifics of the aforementioned changes were further dependent on the functional requirements of WCR players. While results were comparable in LP, HP were observed to demonstrate large increases in the volume of activity and the W:R compared to regular game-simulation drills. This increased load observed in HP is likely due to the positional requirements during these drills. HP who typically fulfil offensive roles on court are responsible for distributing the ball and are typically more involved in the play than LP who tend to adopt defensive strategies (Chapter 5). Consequently, the reduced passing options during small-sided drills rely on HP to continually create space to receive the ball, resulting in a greater response in external load. These findings suggest that small-sided drills may provide good exposure for HP due to the increased offensive activity during these drills. Collectively, such results suggest that 3 vs. 3 drills can provide a training response in excess of regular
game-simulation drills and may therefore be a practical method for stressing aerobic and anaerobic capabilities for WCR players.

In this study, reducing the shot-clock duration from 40- to 30-s had a limited influence on the external load in WCR players. Compared to regular game-simulation drills (40-s shot-clock), the 30-s shot-clock resulted in a ~3% increase in both relative distance and mean speed values. Although it appears this drill type increased the volume of activity, such changes may have a relatively minor influence on training adaption. Even though measures of relative distance and mean speeds have a low variability (1.9% CV), the magnitude of change detected during these drills was not large enough to interpret as a worthwhile change. Accordingly, it is important that coaches and practitioners interpret changes in the context of the magnitude of change, rather than simply on the basis of a statistical assessment. Nevertheless, the comparable results may be attributed to the fact that in general, the average time of each offensive-play during competition is typically less than 30-s (~23 s; unpublished observations). So by reducing the shot-clock to 30-s, no perceived change in activity is achieved. Despite this, the comparable external load elicited during the 30-s shot-clock drill was not specific to LP. A 22.6% decrease in the time spent performing HIA resulted in a large change in LP. While such a change was larger than the SWC, the magnitude of change detected here was marginally greater than the CV for this parameter. Therefore, it is unclear whether this was a true reflection of the demands of this training drill. However, the related tactical benefit of such drills must be considered. During a 30-s shot-clock, it can be suggested that LP spend more time performing low-intensity defending strategies to prevent the opposition from scoring quick goals, subsequently reducing the amount of HIA performed. That said, these findings are important from a methodological point and therefore the tactical benefits of this drill must be taken into account when prescribing training strategies. While collectively the inclusion of a 30-s shot-clock offers no additional training stimulus compared
to regular game-simulation drills, such drills may be useful for tapering strategies during the WCR season because of their lower external responses.

The greatest increase in measures of external load was observed when the shot-clock was further reduced to 15-s. Very large to large increases in the volume of activity and peak speed values, respectively occurred during this drill. This meant that not only did players push further, but they also had to push faster compared to regular game-simulation drills. Furthermore, the players in the current study performed ~57% more HIA during 15-s shot-clock drills (1.1 per min) compared to the regular game-simulation drills (0.7 per min). This also compares favourably with the relative number of HIA previously reported in Chapter 5 for successful WCR teams (0.9 per min). Nevertheless, the magnitude of change detected during the 15-s shot-clock drill was again more than double the between-observation variability. However, because of the high variability of the number of HIA observed in the current study, individual responses should be monitored to ensure that all players receive the intended training stimulus (Kennett et al., 2012). Moreover, LP achieved a comparable relative distance (85.7 m·min⁻¹) and W:R (1:2.2) to values previously observed during WCR-specific conditioning drills (79.2 m·min⁻¹; 1:2.4) (Chapter 6). Coaches may therefore achieve the desired conditioning qualities in LP, whilst also maintaining the sport specific element during the 15-s shot-clock drill. Indeed, the practical benefits of game-simulation drills are thought to increase player compliance and motivation, since these drills are perceived to be sport specific. However, increasing the load of training drills may also elicit changes in the quality of technical actions (Morgans et al., 2014). It is plausible to suggest players may not be able to consistently sustain the technical skills to achieve and maintain the required level; as such, training may become counterproductive in terms of technical performance. Unfortunately, this has not been empirically examined and was outside the scope of this study. Nevertheless, collectively these results suggest that 15-s shot-clock drills may be useful for
7.5.1 Practical applications

Although specific training objectives alter throughout the season, the ultimate goal of the competitive phase should be to induce similar responses to that encountered during competition (Chapter 6). Therefore, given the importance of game-simulation drills for training specificity, the combination of different formats throughout training sessions are critical in order to maximise the preparation of players and reduce the monotony of training. The data presented provided evidence that subtle changes in the design of game-simulation drills can influence the external load in elite WCR players. For example, reducing the number of players on court can be used to impose a greater external training load on elite HP. This study provided new information about the effectiveness of using game-simulation drills as a training stimulus in WCR. Coaches can use such information for choosing variations that are either more intense than competition to overload players (15-s shot-clock), or lower when tactical requirements are an associated goal of training (30-s shot clock).

The relevance of game-simulation drills can be attributed to the fact that they offer a multifunctional training benefit by simultaneously addressing physical, tactical and technical qualities (Dellal et al., 2012). Although the current study investigated the physical aspects of game-simulation drills, as determined by external load, the technical qualities were not examined in this study. Future research is required to understand the influence of modified game-simulation drills on the technical capabilities that may be executed performing these drills. Increases in external load may be unfavourable if at the expense of technical efficiency as this would result in a counterproductive stimulus (Morgans et al., 2014). Nevertheless, it is
clear that coaching staff can successfully manipulate training to prepare players for increases in external load during the competitive phase of the season.

It is important to note that the current data was drawn from a single team over a specific phase of the season. A longitudinal assessment across all phases of WCR training would be desirable to gain a holistic appraisal of WCR training. Furthermore, the comparatively small sample size in this investigation presents an additional limitation and future studies with larger sample sizes are required to provide a better estimate of the change in external load during WCR training. However, the statistical method used requires fewer participants than more traditional statistical approaches (Batterham & Hopkins, 2006), and thus the effect of this limitation has been minimised.

7.6 CONCLUSIONS

Game-simulation drills containing fewer players can influence the volume and intensity of external load during training (e.g. specifically for HP). Whilst a 30-s shot-clock elicited no observed differences in the training response, changes in external load were found when the shot-clock was further reduced to 15-s, especially in LP. Coaches can therefore modify the training response by making subtle changes to the design of game-simulation drills. Finally while global measures of external load such as relative distance and mean speeds are relatively stable, measures of high-intensity exhibit a large degree of variability. It is therefore recommended that multiple observations obtained from many training sessions are necessary to accurately examine the changes in HIA.
8. General Discussion

The aim of the current thesis was to examine how the analysis of external load during competition may guide future training strategies to maximise player preparation in WCR. As outlined in section 1.2, four main objectives were developed:

i) To evaluate the suitability of an ITS for the measurement of wheelchair sport-specific activities.

ii) To quantify the external load during competition and identify the influence of functional classification, in order to establish the activity profiles of elite WCR.

iii) To explore the external load of current training modes used by elite WCR players throughout the competitive phase of the season.

iv) To prescribe training recommendations aimed at optimising training specificity to advance the preparation of elite WCR players.

8.1 Overview

The aim of the current chapter was to discuss the outcomes of the experimental chapters and to integrate these findings in the context of the overall aim of the thesis. Initially, the first experimental chapter was conducted to determine the suitability of a player tracking system in WCR. The following two experimental chapters then utilised the aforementioned system to examine the competition-specific responses of elite WCR players. In the final two chapters of this thesis, the information gleaned from competition was utilised to examine current training practices (Chapter 6) and to optimise the preparation of elite WCR players (Chapter 7). Such findings help shape a holistic framework of the training process in elite WCR (Figure 8.1). Figure 8.1 was adapted from the conceptual model originally developed for AB sports (Figure 1.1) to illustrate the factors that influence the training process in WCR and highlight those that have been considered throughout the current thesis.
Figure 8.1 - Conceptual model adapted from Figure 1.1 illustrating the specific factors that may influence the physical training process within WCR. Superscript numbers represent the relevant experimental chapter during which each factor was addressed.
8.2 Integration of player tracking system suitable for WCR

It was evident from Chapter 2 there are significant methodological issues with player tracking techniques that confound the inherent difficulty in accurately and practically quantifying external load during elite competition. The application of player tracking systems to determine external load in AB sports are influenced by a number of factors including the type and speed of the movement, along with the sampling frequency of the system. Although these considerations were drawn from literature conducted in AB team sports, it was necessary to develop an understanding of such key issues when utilising a WCR-specific tracking system (Chapter 3).

The use of a tracking system to quantify a variety of movements specific to WCR is, at present, limited. Therefore, a key advantage of Chapter 3 was the inclusion of a test which exposed the ITS to the typical movements and speeds performed during WCR competition. Unfortunately, owing to the overall bandwidth of the system (137 Hz), the ITS is not capable of accurately quantifying intense activities such as accelerations and decelerations (see section 8.6.1). However, given the importance of peak speed to WCR competition (Chapter 5) and for developing individualised speed zones (Chapter 4), the capability of accurately detecting peak speeds was an important feature of the ITS and Chapter 3. That said, concurrently measuring 20 m sprint performance using both the ITS and an inertial sensor, resulted in relative errors less than 2%. This compares favourably to the relative error of ~20% for GPS (Duffield et al., 2010), 10% in radio-frequency (Ogris et al., 2012) and 10% for MDL devices (Sindall et al., 2013a). Despite this, larger errors in peak speed were found with the ITS when sampling at 4 Hz, indicating that high sampling frequencies of ≥ 8 Hz were necessary. Again because of the overall bandwidth, high-frequency tags (16 Hz) would not be practically feasible for WCR. Nevertheless, 8 Hz tags were deemed appropriate for tasks specific to elite WCR and served as the criteria for the ensuing experimental chapters.
8.3 Examination of external load during elite WCR competition

Prior to this thesis, few studies had investigated measures of external load during WCR competition (Sarro et al., 2010; Sporner et al., 2009). Unfortunately, when attempting to ascertain an evidence-based framework relating to WCR competition, more detailed information is required about the physical demands of competition and hence the rationale for the research conducted throughout the current thesis. As proposed in Figure 8.1, a detailed understanding of the physical demands of competition is essential for the design of specific training strategies. Therefore, the analyses of competition encapsulated factors such as match fatigue (Chapter 4) and indicators of successful performance (Chapter 5) with reference to functional classification and positional-role.

8.3.1 Functional classification

Through Chapters 4 and 5, it appeared that distinct differences in measures of external load exist between player classifications. This would suggest that classification-specific training strategies should be considered. In respect of this, the volume of activity increased in association with higher functional ability in players (Chapter 4). However, it was purported that functional classification had no effect on the volume of activity between classification groups III (2.0-2.5) and IV (3.0-3.5). This replicated the diversity in findings that have been established from the limited performance-based research in the area of game efficiency patterns (Molik et al., 2008; Morgulec et al., 2010) and anaerobic capacity (Morgulec et al., 2011). Furthermore, initial findings suggested that fatigue during competition subsequently reduced a player’s ability to maintain the volume of activity in the later stages of the match (Sarro et al., 2010). The findings of Chapter 4 do not support this, as it was clear that measures of external load did not deviate across full WCR matches irrespective of functional classification. Whilst the volume of activity lacked the sensitivity to discern between players
of higher and lower ability in the context of successful mobility performance (Chapter 5), coaches should be aware that players need to be sufficiently prepared so that they can meet the general demands (3500-4600 m) of competition (Chapter 4; Sarro et al., 2010).

The assessment of peak speeds during competition showed a significant increase in association with functional classification. It was also apparent the capacity to repeat these speeds were crucial since the success of these actions played a critical role in the outcome of competition (Chapter 5). Therefore, practitioners should consider ways in which to develop the peak speed capabilities of players, and may also use this facet of performance to contribute to the identification of potential talent in WCR. Moreover, the fact that peak speed achieved by elite WCR players increased significantly across classification groups, reiterated the merit in individualising speed zones for each classification group (Chapter 4). Thus, the creation of fixed arbitrary speed zones specific to each classification group was an important outcome of the current thesis, since these zones can facilitate a longitudinal assessment of an athlete’s performance over time. The speed zones enabled an insight into the varying intensities of elite WCR, which had previously been speculated about (Goosey-Tolfrey et al., 2006). As a whole, results revealed that WCR is largely composed of low-intensity activities interspersed with short, frequent bouts of HIA. Substantial differences were however revealed in the intensity profiles of elite WCR between players of different classification, which were attributed to a player’s positional-role.

8.3.2 Positional-role

Key outcomes of the current thesis were the observations that certain measures, particularly the intensity of competition, were influenced by positional-role. As previously described, positional-role is closely related to an individual’s functional classification, whereby HP typically occupy offensive roles on court, whilst LP occupy defensive roles (see Table 2.1).
Therefore, the significantly greater number of HIA exhibited by LP compared to HP indicates that this is a key requirement for defensive players (Chapter 4). The high-intensity capabilities of defensive players are of a greater importance than their peak speed, as the defensive requirements of competition render it unnecessary to attain maximal speeds (Chapter 5). Improving the sustainability of high-intensity efforts may therefore facilitate defensive players in the positional aspects of their game. Despite this, the impact of high-intensity efforts to the whole team cannot be over-emphasised, as HIA may be the most appropriate means of evaluating and interpreting successful performance in WCR (Chapter 5). While such findings advocate the need for role-specific training drills, it must be noted that a large majority of WCR training (~92% of total training time) was performed collectively as a squad (Chapter 6). Only conditioning drills were observed to be classification-specific during training, suggesting a greater emphasis should be afforded to both classification- and role-specific training.

8.4 Examination of external load during WCR training

The purpose of training is to prepare players physically, technically and tactically for the subsequent demands of competition (Figure 8.1). Given the multi-faceted demands of WCR competition highlighted above, it could be argued that an individualised approach is required. With this in mind, coaches are required to structure training in a way that prepares all players for optimal training adaption and recovery (Muijka, 2010). The training process drawn from AB sports advocates the manipulation of training volume and intensity, which inevitably will influence an individual’s internal and external training response (Morgans et al., 2014). However, when a training load is consistently excessive or sub-optimal, overreaching or detraining can occur and could negatively influence an individual’s preparation (Gamble, 2010). Therefore, given the findings identified in Chapters 4 and 5, it is crucial that the
correct training mode is applied in context to competition and the requirements of a player’s function.

**8.4.1 Training mode**

As proposed in Figure 8.1, the data generated from training (Chapter 6) allows measures of external load to be ascertained in relation to competition (Chapters 4 & 5). In general, individual modes within the competitive training phase showed considerable differences when compared to competition. Conditioning drills generated the greatest external load amongst WCR players, particularly relating to HIA. By incorporating longer conditioning sessions, coaches can therefore provide a progressive overload in the intensity of training. While it was suggested low-ranked teams lack the physical capacity to maintain performance during prolonged periods (Chapter 5), this observation should encourage WCR coaches to prescribe conditioning-based training strategies, at least among low-ranked teams. Despite this, conditioning drills are generally utilised to prepare players during the pre-season phase and additional modes are required to advance the technical (skill-based) and tactical (game-related) elements of competition (see Table 2.4). Competition-specific training sessions were therefore the priority in the competitive season (~75% of total training time) and took precedent over conditioning-based training (~8% of total training time), as demonstrated in Chapter 6.

The fact that game-simulation drills incorporate the physical, technical and tactical elements of competition, reiterated the importance of these drills. While regular game-simulation drills provide the best representation of competition (Chapter 6), modifications in the design of these drills appear to have a greater influence on the specificity of training (Chapters 6 & 7). The increased load observed during a running-clock format was likely the result of stoppages in play during the game-clock formats (Sarro et al., 2010), whereby players were more likely to stop or ‘coast’ during these paused periods (Chapter 6). Marked
increases in training load, particularly HIA were further evident when modifications to the player number (3 vs. 3) and shot-clock duration (15-s shot-clock) were made (Chapter 7). Even though measures of HIA demonstrated the greatest variability, the magnitude of change detected during these drills was twice the CV%, and several orders of magnitude larger than the SWC for this parameter (Chapter 7). Therefore, there can be a greater degree of certainty that this was a true reflection of the increased demands of these drill modifications. During the competitive phase, coaches can use these findings for prescribing drills that are either more intense than competition to overload players (3 vs. 3; 15-s shot-clock), or lower when recovery strategies are the goal of training (3-min and 8-min games).

As suggested above, the management of training intensity is critical during the competitive phase for the enhancement of training-induced adaptions (Mujika, 2010). That said, HIA have previously been defined using fixed arbitrary speed zones specific to each classification in WCR (Chapters 4 & 5). Whilst this method provides a stable approach for longitudinal monitoring, when working with a smaller group of individuals (as in Chapters 6 & 7) this approach fails to account for the individual capacity of players. Therefore, individualising speed zones expressed relative to a players’ own peak speed was a key feature of Chapters 6 and 7, and provided a more sensitive method for quantifying changes in HIA. However, given the recommendation of classification and role-specific training outlined previously (Chapter 4), it is necessary that the individual responses are further considered.

8.4.2 Functional classification

No studies have directly investigated the individual external responses of WCR training. Therefore, at present there are no practical guidelines on training prescription relating to functional classification in elite WCR. This may be a vital consideration since both skill-based and game-related drills were found to be role-dependent (Chapter 6). While it may be
undesirable for skill-based drills to reproduce the external loads of competition (Farrow et al., 2008), LP were seemingly exposed to an unfavourably high training stimulus during these drills. These effects were likely the result of the fact that players perform these drills collectively as a squad and therefore must work harder to keep up with HP. Alternatively, game-related drills typically overemphasize positional-roles, as HP are continuously required to perform offensive actions whilst LP typically maintain static defensive positions (Chapter 6). While game-related drills supplement the tactical aspects of competition in HP, coaches should be aware that when training as a collective squad, skill-based drills may increase the risk of overtraining and/or injury in LP if the additional load is not acknowledged for these individuals.

As mentioned previously, a favourable feature of game-simulation drills are that they enable aspects of physical, technical and tactical performance to be stressed during fatiguing conditions, much like competition. However, it was revealed that these drills did not reproduce the physical demands, particularly HIA required for competition in LP. Given that LP in the most successful teams perform more HIA compared to respective players in less successful teams (Chapter 5), reiterates the importance of HIA for their positional requirements and therefore should be developed. A way to alter the intensity of these drills is by modifying the format such as playing duration (Chapter 6), number of players and shot-clock regulations (Chapter 7). Subsequently, similar physical gains were made in LP with a 15-s shot-clock drill as was previously achieved with the traditional conditioning drills (Chapter 6). These players also performed ~57% more HIA during these drills compared to successful LP observed in Chapter 5. Whilst the largest variations in measures of HIA were observed in LP (Chapter 7), the magnitude of change detected was again more than double the between-observation variability during these drills. Coaches may therefore promote
conditioning adaptations in LP, whilst also maintaining the sport specific element during the 15-s shot-clock drill.

The specific ‘offensive’ match requirements of HP (Chapters 4 & 5) were further exceeded during game-simulation drills containing fewer players (Chapter 7). Consequently, it was hypothesised that the reduced passing options and greater space on court during 3 vs. 3 drills placed more of an emphasis on HP, as they continually created space to receive the ball. Coaches can therefore use small-sided drills to provide increased offensive exposure for HP. Subsequently, the current evidence provides information to improve coach awareness about the external responses to subtle changes in the design of WCR-specific training drills. The challenge for coaches however, is to establish the most appropriate mode for preparing WCR players that best associate with the correct phase of the season.

8.5 Application of research findings

The research presented in the current thesis has highlighted the following practical applications:

- The use of 8 Hz tags are deemed appropriate for tasks specific to elite WCR
- Functional classification and subsequently positional-role has a substantial influence on the external responses during WCR competition.
- HIA may be the most appropriate means of evaluating and interpreting successful performance in WCR, but care is needed with the interpretation due to the variability of this parameter.
- The results of this thesis imply that game-simulation drills are extremely important and should be used when preparing elite WCR players to the external demands of competition. Moreover, the format of these drills could be modified to improve the specificity of training.

In conclusion, the studies presented in this thesis will considerably add to the body of research in the area. Unfortunately, when attempting to fully understand the training process in WCR,
more information is required and hence the reason for future research to be conducted in WCR.

**8.6 Future directions**

The findings of the current thesis provide coaches with evidence to help inform practice by providing a greater understanding of the demands of both competition and training in elite WCR. That said, as shown in Figure 8.1 a number of further research areas require attention.

**8.6.1 Player tracking technology: Accelerometry**

The ability to accelerate from a standstill is considered a key indicator of performance in WCR (Mason et al., 2010; Vanlandewijck et al., 2001). Unfortunately, owing to the overall bandwidth of the ITS system, intense activities such as accelerations and decelerations were not collected in the current thesis, and therefore the true HIA seen during WCR competition may be slightly underestimated. Future research is therefore likely to focus on additional technological tools as previously described in wheelchair sport (Mason et al., 2014; van der Slikke et al., 2015). This involves the inclusion of accelerometry technology (accelerometer, magnetometer and gyroscope) that permits directional analysis across anatomical planes. The increased sampling frequency of accelerometry measurements (~100 Hz) offers more precise assessments of short high-intensity accelerations during competition. Further analysis within each individual plane of the accelerometer may also assist in profiling the multi-directional rigours of WCR competition. Once validated, it is important to understand how acceleration data may be transferred across competition/training and integrated into the current analyses.

**8.6.2 Internal load**

While the current thesis has provided evidence relating to the external responses during training, further research concerning the internal responses are required to fully understand an individual’s adaption to training. The large heterogeneity in athlete impairment and function
within WCR players can lead to large variations in internal load resulting from a prescribed external load (Leicht et al., 2013). Understanding individual internal loads within the team training environment is therefore vital to reduce the risk of over-training or detraining and optimise individual preparation. As identified in Chapter 2, a large portion of WCR players have a cervical level SCI resulting in impaired autonomic function, therefore the use of HR is ineffective for prescribing training in this population (Paulson et al., 2013; Valent et al., 2007). Alternatively, session RPE may be advocated as a more appropriate method to determine internal load in WCR players. Unfortunately, little is currently known about the relationship between internal and external load in WCR players and as such should be a priority for future research.

8.6.3 Technical analysis

As discussed throughout Chapters 6 and 7, coaches are increasingly trying to simulate the specific demands of competition during the training environment, from both a physical and technical aspect. Although the current thesis addressed the physical requirements of WCR competition, the technical aspects were beyond the scope of this thesis. The incorporation of technical information alongside these measures of external load would provide a greater and more comprehensive analysis of WCR. An integrated approach combining the ITS and video-based analysis may facilitate this process in the future. This information would further enhance the ability of coaches and practitioners to devise positional-specific training drills which involve appropriate external loads, as well as ball-handling and tactical activity patterns.
8.6.4 Tactical analysis

Recent rule changes (post Beijing 2008) surrounding unlimited substitutions may have markedly altered the tactical and apparent physical requirements of competition. Coaches are continually searching for the ideal substitution strategy to maximise and maintain the intensity of the team, while still allowing for the tactical aspects to be applied. Subsequently, a more individualised substitution strategy, appropriately matched to the physical capacity of the squad, could increase the intensity levels and consequently the likelihood of team success. Therefore, future studies should examine the relationship between player substitution and external load in WCR competition. Practice matches with a reference team adopting a specific substitution strategy would enable this type of analysis to be completed. Comparisons could be made between player tracking data of specific periods where the subsequent strategies are employed.

8.6.5 Sample of participants: Athlete impairment

At present an increasing number of individuals with a non-SCI resulting from health conditions such as congenital or acquired limb deficiencies and cerebral palsy now participate in the sport of WCR. In contrast to athletes with a cervical SCI, many non-SCI athletes have partial to no impairment in muscle strength, coordination and trunk strength (Altmann et al., 2015). Whilst such factors are prerequisites for wheelchair manoeuvrability and propulsion speed, non-SCI athletes may therefore be perceived as more dominant over SCI athletes in the same functional class (Altmann et al., 2013). Unfortunately, no literature has been conducted on measures of external load in relation to athlete impairment and severity. Only with this information, an evidence-based classification policy as defined in the IPC position stand can be achieved (Altmann et al., 2015). Therefore, additional research utilising the ITS is
necessary to determine if athlete impairment is relevant to competition-specific performance in WCR.

The experimental chapters conducted throughout the present thesis have attempted to increase the understanding of the match and training activity profiles of elite WCR players. Key match-play information has been derived to assist coaches with understanding the physical demands of WCR competition. The use of individualised arbitrary speed zones provided novel insights into the classification- and positional-specific differences in match-play activity. It was apparent the capacity to reach high match intensities was associated with successful performance in WCR and therefore training should be structured with this in mind. Although game-simulation drills provided the best representation of match-play intensity, subtle changes in the design of these drills can increase the external responses in elite WCR players. That said there is still much potential for researchers and practitioners to extend the evidence-base presented in the current thesis by exploring some of the remaining areas identified above and ultimately improve the performance of elite WCR players.
References


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Appendices

The sample of training drills used in Chapter 6 are detailed below.

**Purpose:** Conditioning drills

- **Suicides Drill** – This drill is set up with cones placed 5 meters apart in a straight line along the court. Players line up on the baseline and sprint to the nearest cone, then turn and sprint back to the baseline, then onto the next cone and back to the baseline and so on. A single set is completed when the player has returned to the baseline from the furthest cone. This is completed a total of three sets.

- **Gauntlet** – This drill is set up with three 5 m x 5 m squares parallel to each other. A single player occupies each of the three squares. The player completing the drill lines up on the baseline and then must push their way through the three squares, whilst the opposing player must prevent the player from getting to the next square using blocking strategies. A single set is completed when the player completes all three squares twice. This is completed a total of two sets.

- **Layup (2 variations)** – Players split into two evenly numbered lines around the half-way line. For the first variation, players slalom around cones in a zig-zag pattern and then race towards a coned area on the baseline. In the second variation, players race from the half-court to the baseline. Players then join the back of the opposite line to go again. This is a continuous drill and players should not be waiting for their turn.

- **Bulldog** – Players line up along the baseline and two players take up a position in the centre of the court. The aim is for players to get from the baseline to the far baseline without getting ‘trapped’ by the two players in the middle of the court. Players that are trapped then take up a position in the centre of court also. The last remaining player is then judged to have ‘won’ the drill. Two sets of this drill are performed.

**Purpose:** Skill-based drills

- **Caterpillar Drill** – The players split into two evenly numbered groups and line up facing one another. One ball starts with the player closest to the baseline. After the player has passed the ball to the player opposite, they spin to the outside and join the end of the line on their side. This continues until both lines reach the opposite end of the court.
• **Flat Nose** – Players split into four evenly numbered lines around the centre circle. The first player in the two adjacent lines has a ball. The player’s with the ball will push to the centre circle and pass the ball to the player in the line to their right. The receiving player will then do the same. Players then moves to the back of the opposite line. Variations in this drill can be made with the type of pass used. This can vary between chest pass, overhead pass, bounce pass etc.

• **Passing Through the Gates** – The players split into two lines, a passing line and receiving line. The players start at half-court. As the receiver advances closer to the baseline, the passer throws the ball to the receiver by leading them towards the baseline. After catching the ball the receiver pushes through the coned area on the baseline, and then returns to the back of the opposite line.

• **3-Player Weave (2 variations)** – There is two variations of this drill, a narrow and a wide weave. For a wide weave, players line up at three different positions along the baseline, one in the centre and one at either sideline. For a narrow weave, all three players line up along the centre of the baseline. The three players then make a weaving pattern, maintaining their distance apart, to the far end of the court and back. This is completed a total of three sets.

**Purpose:** Game-related drills

• **Press Breaks** – This drill aims to simulate the breaking the press element of competition. Defensive players are set up in and around the key to prevent the opposition from passing to the baseline. The offensive players must then try and break this defence and get the ball over the baseline. A number of variations can be added, including timing regulations and player number.

• **Key Attacks** - This drill aims to simulate the attacking element of competition. Shot-clock of 40-s is used and the offensive team must score a goal within this time.

• **Last Goal** – This drill aims to simulate the last goal scenario of competition and concerns clock management skills. Clock duration of one-min is used and the team in possession must score a goal and then defend their goal area to prevent the opposition from scoring. Variations of this drill include using different stop-clock durations to manage.

• **Half-court Drills (5 variations)** – Half-court drills aim to simulate match scenarios using a variety of different variations. These variations are typically surrounding the
player number, which alternate between different line-ups of 4 vs. 3, 2 vs. 2, 3 vs. 3, 5 vs. 5 and 2 vs. 4.

**Purpose:** Game-simulation drills

- **4 vs. 4 Drills (3 variations)** – This is a simulation of a normal game scenario, with standard regulations, scoring and a referee. The different variations used are a 3-minute game-clock, a 10-minute game-clock and a regular 8-minute game-clock.