Zoë van der Weel

Is there a meaningful relationship between physical and technical performance?

A study on international women's team handball matches

Preface

This year has been all about thinking, playing and breathing handball. I am grateful to be a part of the Norwegian School of Sport Sciences, and I am honoured to be writing a master thesis at this school. I have learned a lot, and most importantly; I want to learn more!

During the year of writing this thesis, I must thank some people that have helped and supported me through this year. And the Oscars go to:

Live S. Luteberget, my idol, and Matt Spencer, my favourite professor at the school. Thank you for being my supervisors and for always having your office doors open and giving me helpful feedback. I hope and dream to call you my colleagues someday. Also, thank you Kenneth Wilsgård, for taking the time out of your inhumane busy schedule to help me.

To my mother, Audrey and my father, Ruud, thank you for inspiring me to be ambitious. To my younger siblings; Yvo, Mats, Rikke and Leah; recent studies suggest that the eldest child also is smartest (Lehmann, Nuevo-Chiquero & Vidal-Fernandes, 2016).

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Without further ado; happy reading!

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Abstract

Team Handball is one of the team sports with the highest speed of play and is characterized by repeated jumps, sprints, changes of direction, body contacts and specific technical movement patterns in response to different tactical situations in the game. The aim of this study is to investigate if there is a relationship between physical and technical performances in international women's team handball matches. Earlier studies report a decrease in physical intensity measured by Player Load^{TM} (PL) and high intensity events (HIE), during the game, however there are no studies that indicate if this is associated with technical performance.

Physical data (PL and HIE) from nine Golden League matches on 15 different female outfield players were analysed, each represented 2-9 times, resulting in a total of 70 match data samples. There was also conducted video analysis using a grading system to extract the technical variables involvements (INV) and points. The INV are a summation of every time points are given to a player, independent of point sum. Points are the sum of all points given combined.

There are high initial periods, with declines in intensity throughout. There is a significant decrease in both PL and INV·min^{-1}, with large and moderate effect sizes respectively, compared to mean in the last bouts of the consecutive field time. INV·min^{-1} in an elite handball game effect PL·min^{-1} and HIE in this study (r = -0.68 & -0.57 respectively), and INV·min^{-1} correlated largely negatively with field time (r = -0.71). There are substantial differences in PL·min^{-1} and HIE·min^{-1}, with the backs showing higher PL·min^{-1} and HIE·min^{-1} than pivots and wings. A higher amount of HIE·min^{-1} is correlated to a higher number of positive points·min^{-1} for backs (r = 0.60) and pivots (r = 0.43).

A high amount of field time has a negative impact on INV·min^{-1}. Thus, appropriate rotation strategies may allow players to enhance the ability to perform at the required level. Furthermore, most technical actions are HIE, suggesting a high pace in elite handball games, and the ability to perform HIE is a quality seen in high-level teams. Developing the grade system should be the main focus for further investigation.

Contents

1.   Introduction

Handball is a team sport in constant development, and the physical and technical demands change with the development of the game's intensity (Michalsik, Aagaard, & Madsen, 2015). Handball is one of the team sports with the highest speed of play, and the sport can be characterized by repeated jumps, sprints, change of directions, body contacts in high speed and specific technical movement patterns in response to different tactical situations in the game (Karcher & Buchheit, 2014). An understanding of the physical and technical demands in handball is required for talent identification, design of specific training drills and the development of position-specific training programmes for each individual athlete (Karcher & Buchheit, 2014).

Published research that has investigated both physical and technical demands in handball matches is limited (Ziv & Lidor, 2009). Due to factors such as unlimited substitutions, a smaller court and high-intensity actions in a small area, studies on handball are more complicated to execute methodically compared to other team sports such as football, rugby and Australian football (Karcher & Buchheit, 2014; Michalsik, Aagaard, & Madsen, 2013; Povoas et al., 2012). Due to methodical variations in different studies, the number of high-intensity actions have most likely been underestimated (Karcher & Buchheit, 2014; Povoas et al., 2012). In addition, most of the literature on this subject are on male handball teams. Further research on the physical and technical demands in handball and on the activity profiles for each individual athlete may lead to a deeper understanding of the sport and the dynamics of the game.

1.1 *Purpose of study*

The aim of this master thesis is to investigate the relationship between physical and technical performance in women's elite team handball. Earlier studies rapport a decrease in intensity during a match using high-intensity activity variables (Wik, Luteberget, & Spencer, 2017; Michalsik, Madsen, & Aagaard, 2014a; Povoas et al., 2014a; Michalsik et al., 2013; Povoas et al., 2012; Chelly et al., 2011), however there is currently no research investigating the relationships with technical performance. To my knowledge, this study is therefore the first to specifically investigate this particular subject. A better understanding of the physical and technical demands will provide handball coaches and support staff more tools when making training programmes, choose training drills and talent identification. The literature found on this subject is mostly based from other team sports such as rugby, football and Australian football. Although these studies can provide a good background of research on this subject, the relevance may be limited due to the specific nature of handball, in relation to other team sports.

2. Theory

2.1   A brief description of handball and the dynamics of the game

Handball is an Olympic team sport that is played all over the world, but is mostly popular in Europe. 207 countries are members of the International Handball Federation (IHF), according to the IHF website. Handball is played professionally in over fifteen countries in Europe (i.e., Germany, Spain, France, Croatia, Serbia and Denmark) with more than 200 players in each elite league (Karcher & Buchheit, 2014).

Handball is a time-dependent invasion game, played between two teams of seven players (including a goal keeper) on an indoor court which is 20-m wide and 40-m long (Volossovitch, 2013). There are unlimited substitutions so players can be substituted freely, and there are normally seven to nine substitutes on the bench depending on the level. The game is played in two times 30 effective minutes, with a 10- to 15-minute break (IHF, 2010). The teams vary between defence and attack phases depending on the ball possession. Each team attempts to score by throwing the ball into opposing team's goal. The ball possession between the teams change approximately every 22-36 s, and the attack phase is defined as both the fast-break phase and the organized attack phase (Rogulj et al., 2011). $88 \pm 6\%$ of the time in ball possession is used to build up an attack (EHF, 2012). The ball possession ends when a team attempts a field shot, when a 7-m throw is not rebounded by the offence (possession continues after an offensive rebound) or in the case of a turnover (Volossovitch, 2013). Handball is a high-scoring game, where the majority of ball possessions end with a shot (Volossovitch, 2013). Most players play both defence and attack, but there are also players who specialize in either defence or attack and they substitute depending on the phase. The teams have specialized players on each player position, and the player positions in handball are goal keepers, wing players, back court players and pivots. Normally each team will have two players in each position; two goalkeepers, two left wings, two right wings, two right backs, two playmakers, two left backs and two pivots.

2.2   *Physical demands*

Today it is common practice to measure the physical activity demands in professional team sports (Aughey, 2010; Bradley et al., 2013; Povoas et al., 2012; Wisbey, Montgomery, Pyne, & Rattray, 2010). This provides valuable information to the coaches, scientists and medical staff. Analysis of games may lead to a better understanding of the physical demands and performance, which can result in improvements in a practical setting and physical development of players (Cunniffe, Proctor, Baker, & Davies, 2009; Di Salvo et al., 2007; Michalsik et al., 2014a). The use of wearable micro sensor technology has greatly increased in recent years. These micro sensor technology units, also called *inertial measurement units* (IMUs), have integrated inertial sensors that consist of accelerometers, gyroscopes and magnetometers, which measure the physical activity demands in team sports (Chambers, Gabbett, Cole, & Beard, 2015; Dellaserra, Gao, & Ransdell, 2014).

The activity demands in team sports are highly complex (Gray & Jenkins, 2010; Karcher & Buchheit, 2014; Stolen, Chamari, Castagna, & Wisloff, 2005). Sports such as football, rugby, basketball and handball are very different in nature, but there is still a major resemblance in their general activity patterns which include their intermittent and multidirectional activity (Holme, 2015).

2.2.1   Measuring physical activity in team sports

Measuring the physical activity in team sports is a challenge. The activities in team sports consist of high-intensity running infused with periods of low intensity or recovery (Cunniffe et al., 2009; Di Salvo et al., 2007; Michalsik et al., 2014a). The activity also involves brief and explosive movement actions and collisions between players, which are sometimes repeated frequently within periods of short duration (Dawson, Hopkinson, Appleby, Stewart, & Roberts, 2004; Gabbett, Jenkins, & Abernethy, 2010; Rampinini, Impellizzeri, Castagna, Coutts, & Wisloff, 2009). Previously, time-motion analysis has been a preferred method to measure activity demands in team sports. This method uses different systems such as notational video analysis, semi-automatic camera systems, global positioning system (GPS) and local positioning system (LPS) to track player movements (Carling, Bloomfield, Nelsen, & Reilly, 2008). These systems have both advantages and disadvantages (Barris & Button, 2008; Carling et al., 2008; Larsson,

2003). Time-motion analysis is mostly known for measurements of displacement, or so called "running based activities". The most researched area in time-motion analysis has been distance or time spent within specific speed bands, with a special interest in the high-speed bands (Bradley et al., 2009; Coutts, Quinn, Hocking, Castagna, & Rampinini, 2010; Mohr, Krustrup, & Bangsbo, 2003). These studies, and other time-motion analysis studies have shown to be reliable in measuring speed and distance in general, but have also reported a decrease in reliability and validity with faster and/or less linear activities, especially if performed in restricted areas (Coutts & Duffield, 2010; Di Salvo, Collins, McNeill, & Marco, 2006; Duffield, Reid, Baker, & Spratford, 2010; Frencken, Lemmink, & Delleman, 2010; Ogris et al., 2012). Time-motion analysis also fails to register important "non-running based activities" such as actions of agility (changes of direction), jumps and player contact (collisions and tackles). This failure of precise measurement may result in an underestimation of the "real" physical demands in team sports. This applies to handball, where these actions are performed frequently (Karcher & Buchheit, 2014). Previously mentioned wearable IMUs have therefore been introduced in team sports to measure the "non-running based activities", and can complement traditional time-motion analysis.

In order to understand how to measure the physical demands in team sports, it is essential to understand how they work. Following is a brief description of the three components in micro sensor technology.

Accelerometers

Accelerometers are motion sensors that detect linear acceleration along one or several axes (Yang & Hsu, 2010). An accelerometer consists of a mass, connected to a frame (accelerometer case) by a beam that can be compared to a damped spring (Aminian & Najafi, 2004). When the case with the mass accelerates, this force is transformed to the spring deformation, which is converted to change of electrical impedance or a charge generation depending on the type of accelerometer (Aminian & Najafi, 2004). The magnitude of this force is proportional to the external acceleration (Kavanagh & Menz, 2008), and can be measured by a specific "sensing chart" within the sensor (Godfrey, Conway, Meagher, & OLaighin, 2008). This "sensing chart" is variable between different accelerometers, which has its advantages and disadvantages (Godfrey et al., 2008, Kavanagh & Menz, 2008). Some accelerometers can for example not detect gravity,

while others cannot separate between applied acceleration in space and the gravitational acceleration (Kavanagh & Menz, 2008).

Gyroscopes

Gyroscopes are motion sensors that detect angular velocity about one or several axes (Yang & Hsu, 2010). They are based on the transfer of energy between two vibration modes and can calculate angular velocity by using the Coriolis effect (Aminian & Najafi, 2004). The Coriolis effect is an apparent force that arises in a rotating reference frame and is proportional to the angular rate of rotation (Aminian & Najafi, 2004). The angular velocity is again measured by a specific "sensing chart", and is also variable between different gyroscopes. A gyroscope can additionally measure a change in orientation by combining the angular velocity (Luinge & Veltink, 2005). Gyroscopes and accelerometers complement each other and are often used together, as they together can provide more precise acceleration data (Luinge & Veltink, 2005).

Magnetometers

A magnetometer, also called an electronic compass, is a sensor that can measure orientation relative to the magnetic north direction, and are used to measure rotations with respect to the earth's magnetic field (Aminian & Najafi, 2004). They are used in combination with accelerometers and gyroscopes to correct the orientation to the gyroscope.

2.2.2   Using micro sensor technology in team sports

IMUs include an integrated GPS sensor and are coupled with heart rate sensors (Chambers et al., 2015, Dellaserra et al., 2014). The devices are very easy to use in a practical setting because they contain a built-in microprocessor that offers automatic feedback in real time via telemetry. Also, the micro sensor technology is usable both indoors and outdoors and is not relying on any stationary receivers or cameras to function (Chambers et al., 2015). Players wear the devices in a custom-made vest, under their match or training gear, where the position of the device is on their upper back (Fig 2.1).

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Figure 2.1: The OptimEye S5 (left) fitted in the pouch of a custom-made vest (right). (pictures borrowed from Wik, 2015).

Player Load^TM

The use of micro sensor technology has allowed for a more detailed quantification of actions and external load. These devices use special algorithms to accurately measure micro movements, movements which would not have been captured during traditional time-motion analysis. The Australian Institute of Sport and Catapult Sports developed Player Load^TM (PL) to account for the "non-running" based work like jumping, tackling, changes of directions and turning, and is used as a measure of physical performance and exertion based on changes in acceleration (Catapult Sports, 2013a). PL can be described as a resultant vector magnitude derived from tri-axial accelerometer data, and combine the "non-running based activities" and the "running based activities". PL has showed high correlations for distance covered in both running sports (Catapult Sports, 2013a; Polglaze, Dawson, Hiscock, & Peeling, 2015) as well as team sports (Gallo, Cormack, Gabbett, Williams, & Lorenzen, 2014; Polglaze et al., 2015). It has also, as previously mentioned, been shown to discriminate between player level (Boyd, Ball, & Aughey, 2013), playing position (Boyd et al., 2013; Gabbett, Jenkins, & Abernethy, 2012; Jones, West, Crewther, Cook, & Kilduff, 2015), period in game (Cormack, Smith, Mooney, Young, & O'Brien, 2014; Jones et al., 2015), training and match (Boyd et al., 2013; Gabbett et al., 2012) and is related to technical performance (Sullivan et al., 2014a). In addition, PL may be a practical way to measure external training load (Gallo et al., 2015, Scott, Lockie, Knight, Clark, & Janse de Jonge, 2013),

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and may be an indicator of muscle damage (Young, Hepner, & Robbins, 2012). PL has been validated as a useful measure of intensity for Australian football (Mooney, Cormack, O'Brien, & Coutts 2013), and Jones et al. (2015) support the use of Player Load^{TM} along with other measures of intensity to monitor performance and fatigue.

Reliability of physical measuring

The newest research on this subject is unpublished work from our lab (Luteberget, Holme & Spencer). The manuscript, estimating the reliability and sensitivity of OptimEye IMUs to measure physical activity in team handball, included both a lab assessment and a field assessment on twenty-two handball players. Inertial movement analysis (IMA) count was divided into intensity bands where movements in the medium/high (>2.5m·s^{-1}) band were defined as high intensity events (HIE). The results from the lab show that the reliability of IMA count was good. A good reliability for PL and associated variables was evident. The coefficient of variation (CV) of the variables was well below the smallest worthwhile difference (PL = 0.9% CV, HIE = 3.1% CV), suggesting that OptimEye IMU and its software are sensitive for use in team handball.

2.2.3 Physical demands in handball

There are many similarities between handball and other team sports; such as Australian football, rugby and soccer when considering the physical demands. They are all are complex sports with demands in abilities as both an individual player and a team player, including tactical, technical, physical, physiological and social aspects (Michalsik et al., 2013). The demands will vary in terms of playing level, player position, team tactics and different phases in defence and attack (Karcher & Buchheit, 2014; Michalsik et al., 2013; Povoas et al., 2012). Because of this complexity, determining the physical demands are not as obvious as with individual sports (Wik et al., 2017). Previous research has mentioned some physical demands which can be important for handball performance, including aerobic and anaerobic capacity, the ability to perform high-intensity actions and changes of direction repeatedly, coordination, strength, stability, flexibility, ability to sprint, ability to accelerate, ability to decelerate and ability to jump (Karcher & Buchheit, 2014; Manchado, Tortosa-Martinez, Vila, Ferragut, & Platen, 2013a; Michalsik et al., 2013, Povoas et al., 2012). This large spectrum of physical demands emphasizes the sport's complexity, and makes the quantifying of physical demands a challenge.

Match analysis

According to Manchado et al. (2013a) and Michalsik et al. (2014a), female handball players cover approximately 2.9-4.0 km per game with an average speed of approximately 4.2-5.3 km/hour, although these data were reported from traditional video analysis. These results are lower than in other team sports, and is possibly a result from a smaller court, fewer players, a shorter game time, or different tactical organizing (Karcher & Buchheit, 2014). Michalsik et al. (2014a) found that the average speed of female handball players was the same in both defence phases and attack phases.

According to the review of Volossovitch (2013), where all studies that involved performance analysis in handball during the two last decades are analysed independent of level, studies had a tendency to focus on the following issues: throwing performance analysis, goalkeeper performance assessment, activity profiles of handball games and statistical modelling of team's performance. Hierarchical structure of performance in handball can be represented by four groups of performance factors: 1) basic anthropological characteristics; 2) specific abilities and skills of handball players; 3) situation-based parameters of competition activities or playing efficiency; and 4) outcome of a match (Vuleta, Milanović, Sertić, 2003). As mentioned in the introduction, there are large variations between studies and the reason for this may be variations when analysing both during and between games, inconsequent inclusion-criteria, and differences in movement analyses. An example of this is that in some studies, players must have reached a certain amount of playing time on court to be included in the study (Michalsik et al., 2014a; Michalsik et al., 2013) while in other studies there are no inclusion-criteria at all (Povoas et al., 2014a; Povoas et al., 2012). Another example is the definition of high-intensity actions in different studies; some have defined running, sprinting and sideways movement as high-intensity actions, while others have solely defined high-intensity actions as running and sprinting (Michalsik et al., 2014a; Michalsik et al., 2013). Lastly, literature on technical and physical demands between different playing positions is scarce (Karcher & Buchheit, 2014).

High-intensity actions in handball are quite interesting because these actions are likely crucial for the outcome of the game (Thorlund, Michalsik, Madsen & Aagaard, 2007). They require power, strength, large amounts of energy (as they are eccentric-related actions) and can lead to neuromuscular fatigue (Karcher & Buchheit, 2014). Michalsik et al. (2014a) found that female

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handball players had 2.5% of the total number of activity changes in the high intensity category and 0.8% of effective playing time in the high-intensity category. As mentioned previously, high-intensity actions such as accelerations, decelerations and changes of directions have most likely been underreported in previous studies. These actions require a significant amount of energy every time they are executed (Michalsik et al., 2013; Osgnach, Poser, Bernardini, Rinaldo, & di Prampero, 2010; Povoas et al., 2012). Underreporting can thus occur while using the traditional method based on speed-zones in locomotion studies. Osgnach et al. (2010) emphasized this in his football study. They showed that 42% of the total energy-usage was used in the high-intensity category, while only 18% of the distance covered during the game was categorized as high-speed. This shows that previous methods have not been sensitive enough when analysing the maximal or submaximal efforts of a handball player, since these efforts have been in small areas on a small court and this has prevented registration of actions in high speed (Karcher & Buchheit, 2014). In addition, the definition of what a high-intensity action is differs from study to study, making it even more difficult when interpreting these studies. However, micro technology-tools have been introduced lately. Luteberget & Spencer 's (2016) study was the first to use IMUs to measure physical demands in a handball match, extracting PL, changes of direction (CoD), Decelerations (Dec) and Accelerations (Acc), and summarizing the latter three to profile HIE. HIE are defined as all Acc, CoD or Dec > 2.5 m/s^{-1}. They reported an average of HIE combined for all players to be 3.90 ± 1.58 per minute. Backcourt players had the highest values of HIE per minute, followed by line players and wing players. They also found averages for the amount of accelerations combined for all players (0.7 ± 0.4 per minute), change of directions combined for all players (2.3 ± 0.9 per minute) and decelerations combined for all players (1.0 ± 0.4 per minute). Backcourt players and line players also have the highest PL of all the player positions (Luteberget & Spencer, 2016).

2.2.4 Fatigue

Fatigue in a periodically high-intensity sport is defined as a reduction in performance compared to baseline values (Waldron & Highton, 2014). Fatigue is thus characterized as a task-dependent decline in performance, which in team sports can be identified as distance covered or intensity over periods, halves or temporary in a game (Waldron & Highton, 2014). The method to measure fatigue is either to measure throughout the game based on tests before and after the game,

comparing the halves or measuring in the most intense part of the game versus later periods in the game.

There have only been a few studies that have assessed fatigue in handball using time-movement analysis (Michalsik et al., 2014a on women, Danish league; Povoas et al., 2014b on men, Portuguese league; Michalsik et al., 2013 on men, Danish league; Povoas et al., 2012 on men, Portuguese league; Chelly et al., 2011 on young men), and these studies vary between gender and level. Wik et al. (2017) studied women on an international level using IMA-analysis. A repeating result throughout different studies was a decline in high-intensity activity in the second half compared to the first half (Povoas et al., 2012 found this only for defence play and not attack play). Michalsik et al. (2014a) and Michalsik et al. (2013) found significant differences and tendencies towards a decline in average speed between first and second half, but no differences in total distance covered between the halves, while Chelly et al. (2011) found a decline in total distance covered between halves. Low-intensity activity increased in the second half in the study of Michalsik et al., (2014a), while Chelly et al., (2011) reported more walking and less running in the second half. Wik et al. (2017) also found a decline in intensity after periods of high intensity. The studies of Povoas et al., (2012) and Povoas et al., (2014) show fewer stops when preceded by HIE, situations one on one and an increased time between activity-changes in the second half. When assessing periods in the game, Povoas et al., (2012) found the most high-intensity running in the first five minutes of the first half, and the least high-intensity running the first five minutes of the second half. Michalsik et al., (2013) also reported similar results, where the players covered more total- and high-intensity distance the first five minutes in the first half than in the first five minutes in the second half. In addition, there was found a higher total distance covered the first 10 minutes than the last 10 minutes of the first half, but a higher total distance was covered the last five minutes of the second half than the last five minutes in the first half. These observations can indicate that players develop fatigue throughout and towards the end of a handball-game.

2.3   Technical demands

In sport, the concept of technique involves the movements executed by athletes in their sports practice, throughout training or competition (Palao & Morante 2013). There are different concepts of technique, and the way technique is defined influences the understanding of sports performance. Technique is most accurately defined as "the proper pattern of movements to do a specific skill" (Antòn, 1998).

2.3.1   Efficacy and technique

There are several definitions of technical effectiveness. In broad terms, technique is the ability to use certain movements or actions while effectiveness is the power to produce a decided/desired/decisive effect. A movement is effective if the execution achieves the objective(s) of the movement (accuracy, scoring, power, projecting the body as far or as high as possible etc.; Palao & Morante, 2013). In certain sports like athletics for example, the idea of a proper movement pattern involves only movement execution. But in other sports such as team sports, a proper movement pattern also involves perception and decision making. Technique is adapted to accomplish a purpose, so the use of a technique by an athlete involves intention, which is a tactic (Palao & Morante, 2013). In order to properly map the efficacy of the sport technique, the aspects that characterize and define it must be considered: a) is it conditioned by sport rules, b) it seeks efficacy, c) it seeks economy, d) it follows a model and e) it requires adaptation (Morante and Izquierdo, 2008). Sport rules influence the way a sport technique is executed. The rules state the conditions of the sport and the purpose of implementing the technique (e.g. time, distance, goals etc.) in order to properly understand how this effects technique and its efficacy, it is necessary to know the purpose, structure, and the repertoire of technical skills in the given sport. Therefore, the set of movements executed in a sport technique in order to achieve performance in that technique is unique to each sport (Bompa, 1990).

Sport techniques attempt to make use of athletes' functional and motor abilities to solve the situations that sport competitions create. Efficiency can even vary within a sport. For example: the concepts of running in a sprint race cannot be applied to running in a fast break in handball when establishing efficiency (Brechue, 2011). The economy of applying the technique refers to how an athlete effectively manages resources in the best possible way (i.e. energy cost, time,

concentration, etc.). Therefore, this concept refers to the relationship between technical efficiency and the cost involved in its execution. For example, when comparing a marathon runner and a football player, the same concept cannot be applied to establish the economy of running (Brechue, 2011; Kyröläinen, Belli, & Komi, 2001).

Further, the possible movements that can be made by the athlete is determined by the structural characteristics of the human body (Palao & Morante, 2013). The mechanical principles, sport characteristics, and the context of movement execution play a role in the determination of the ideal pattern or model of a movement. Sport technique involves the process of perceiving the situation, making a decision about the movement execution, carrying out the movements, and analysing the execution. Through this process, the athlete tries to respond optimally to the situation that he or she faces. The success of the technique involves the proper execution of the different stages of this process. The analysis of the efficacy of the athlete's technique involves understanding the aspects of this process and the aspects that effect technique efficacy (Bartlett, 2001).

Criteria to establish technique effectiveness
Technique effectiveness can be established in relation to reference criteria; any evaluation of efficiency is based on the comparison of the performance with an ideal technical model. This ideal model establishes how an athlete's technical execution should be carried out for all the parameters of the movement (Morante, 2004). This ideal model is created in regards to the sports' characteristics: efficiency, economy, models of execution, need for adaptation, and outcome.

Team sports rely on a technique where the success of the movement is related to the variability and uncertainty in the athlete's actions by reducing the opponent's chances of anticipating the athlete's movements (Palao & Morante, 2013). Therefore, the psycho-tactical criteria of the technique execution must be mapped to establish its efficacy. Examples of parameters here include cues (i.e., fast breaks), feints, speed of the movements etc. The outcome of the movement provides a reference for the way the movement is done. This has traditionally been the criteria for establishing efficacy in team sports, and it involves establishing the performance level that is achieved by an athlete that changes in relation to the sport and the technique (e.g. points scored, winner-error ratios, success percentages, attempts etc; Palao & Morante, 2013).

2.3.2 Analysing technical performance in team sports

The goals, purposes and rules of the different sports establish the technique repertory and what is considered correct regarding technical effectiveness. However, it must be taken in consideration that not all the actions produced in a sport pursue the same goals. For example, in an invasion sport such as football, the actions executed by the goalkeeper are different from a field player, and for both of these players, the actions and goals change if they are on offense or defence.

In order to make appropriate decisions on court in a team sport, each player and the coach need as much information as possible about the unfolding of game play (Gréhaigne & Godbout, 2013). It would therefore make sense to collect objective data relating to players and their behaviours. When deciding what observation and assessment tools to use, careful thinking is needed on what parameters to observe, the observational methods that ought to be used to collect the data, the way these data will be analysed, and finally the way the assessment results will be presented and used. According to Gréhaigne & Godbout (2013), observational data make it possible to evaluate more precisely, for a given player and/or team, game-play actions in order to: better understand the roles and level of combination of various players within the team, develop a classification of individual and collective behaviours by making comparisons over several competition situations, obtain measurements that will make comparisons possible between players or for the same player over time, determine directions of the evolution of game play and that of players over time, and elaborate play models by taking better account of observed performance/learning levels. In team sports four elements are at play simultaneously: opposition to opponents, cooperation between team-mates, attack on the opponent's goal and defence of own goal. In this opposition relationship, the team must coordinate its actions to score goals and at the same time prevent opponents to score goals. Thus, choices must be made depending on likely costs and benefits, and players must manage varying courses and trajectories of team-mates, opponents, and the ball in conditions of decisional urgency. As decision making is constantly influenced by what is happening on the court (both teammates and opponents), performance analysis in team sports must rely on representational pictures of successive configurations of play. In so doing, performance analysis brings in a qualitative dimension to notational analysis Gréhaigne & Godbout (2013).

In invasion sports, efficacy is measured as the ability of the athlete to put the ball in the opposing team's goal, or the actions that allow or prevent that (offence or defence, respectively). Kempton, Sirotic, Cameron, & Coutts (2013) state that relatively few studies have investigated the effect of fatigue on technical performance in competitive matches in team sports. Research on football using SICS® System (a multi-camera match analysis system) has shown that players have a decline in the number of involvements with the ball, short passes and successful short passes from the first half to the second half (Rampinini et al., 2009). The percentage of successful short passes is on the other hand the same between the halves, which can suggest that match-induced fatigue has a larger impact on a players' ability to involve themselves in the game rather than their technical abilities. On the contrary, one of the few rugby studies that have assessed technical performance using time-movement analysis (Sirotic, Coutts, Knowles, & Catterick, 2009) did not find a decline in the frequency of technical abilities between the first and the second half. Only one study Carling & Dupont, (2011) has used "tracking" of their players to see if a decline in physical performance affects technical performance in professional football-matches. They found that while the distance of running at high speed declined between halves and towards the end of the game, they did not find a decline in technical performance. They also found a decline in high-speed running, but not in technical performance, in the five-minute period after the five-minute period with the highest intensity during the game. They did although find a decline in both parameters the last five minutes of the game. These findings of Carling & Dupont (2011) are a clear contrast to other studies that have used specific technical performance tests and controlled match-simulations for assessing the impact of physical fatigue on technical performance in team sports (Rampinini et al., 2008; Royal et al., 2006).

The fact that the results from these studies differ from one another can mean that there are differences in the methods used when considering technical performance and the ability to replicate match-related fatigue in a controlled simulation. An example is a study on rugby which reported that fatigue affected the technical performance (Gabbett, 2008). By using a standardized training-drill, they demonstrate that the tackling technique declines progressively in a state of fatigue. More research was needed to investigate the technical performance in real rugby-matches, and Kempton et al., 2013 subsequently reported that elite rugby players experience a reduction in both physical and technical performance during a game, and they found a significant

reduction in technical performances and the amount of involvements towards the end of the game.

2.3.3 Measuring technical performance in team sports

Quantitative measures are a way to express technique effectiveness, and quantitative analysis involves description through quantifiable data. Quantitative analysis involves the numerical description of motion. The most common ways to monitor efficacy are occurrence (number of shots in a game), average, strike rate (between goal/miss), totals (positive + negative actions), involvements (independent of outcome), relative involvements (dependent of outcome), ratio (goals vs shots) percentages (success rate) and coefficients (efficacy from zero to highest value of category). Once the technical effectiveness is measured, it might be an advantage to normalize the data and have reference values to interpret the data (Bartlett, 2001).

2.3.4 Technical performance in handball

The most recent championship for women in handball was the Women's European Championship in Sweden in December 2016 (WECH 2016). The four best teams from WECH 2016 (Norway, Holland, France and Denmark) performed the best in the following important elements of handball: scored goals, shots from 9m, shots from 6m, fast breaks, breakthrough's, turn overs, conceded goals and goal keeper performance. The best 6 teams conceded the fewest goals. Table 2.1 illustrates the technical averages for WECH 2016, comparisons to the European championships from 2014 (WECH 2014) and the best nation(s) for each variable from WECH 2016 (Kovacs, 2016). Offence efficiency is explained as amount of attacks that result in a goal.

Table 2.1: Technical variables for WECH 2014, WECH 2016 and best nation from WECH 2016 in each variable. All numbers are displayed as averages.

	WECH 2014	WECH 2016	Best nation(s) 2016
Number of scored goals/shots	54%	55%	
Offence: most scored goals			NED: 29
Offence: efficiency			NOR: 61%
9-m shots	36%	39%	CZE: 8.5/21
Wing shots	51%	56%	SRB: 7/11
Pivot shots 6-m	61%	66%	DEN: 6/9
Fast breaks	74%	75%	NED
Breakthrough's	70%	71%	ESP, FRA, NED
Penalty shots 7-m	80%	71%	ROU, SWE
Turnovers & technical mistakes	13/ team/match	13/ team/match	Most: ESP, SRB
			Fewest: CZE
Conceded goals	25	25	FRA: 20
GK	33%	33%	NOR: 39%
2 min. suspensions	3.5/team/game	3.5/team/game	DEN: 5
Blocked shots	Blocked: 2.5	Blocked: 2	
Interceptions	Steals: 4	Steals: 3	

Table 2.2: goal distribution by position

	WECH 2014	WECH 2016	Difference
9-m shots	23%	26%	+3
6-m centre	19%	16%	-3
Wing shots	17%	22%	+5
Breakthrough's	12.5%	10%	-2.5
Fast breaks	13%	12%	-1
7-m shots	14%	12%	-2

A summary of the technical analysis Kovacs (2016) made after WECH 2016 show conclusions and trends of the game of top international handball today compared to earlier years. For example: the number of goals increased by 5% from the wing position and 3% from 9m position, while the number of goals decreased for the line players position by 3%, compared to 2014 (table 2.2). When comparing these results to the WECH 2006 (10 years ago), where the goal distribution was 17.9% for wings, 34.5% for 9m shots and 18.2% for pivots, it may seem like wing players do more shooting and have more responsibility during championships in the recent years (Aagaard, 2006). Furthermore, the amount of 9m shots have dropped with almost 10% the last 8-10 years (Aagaard, 2006). Scoring-efficiencies for all positions, including fast breaks and breakthrough's were better than in 2014. The number of fast breaks decreased from 2014, but having obtained the ball, the teams tried to shoot goals quickly, leading to little uneventful time and faster games. The attacks have become even simpler and the attack efficiency was determined by good individual performances. It seemed, with a few exceptions, that the best scorers also were the best assisting players, assist meaning passing the ball to the player who scores. The goal keepers for the best teams in WECH 2016 were high above the average performance. The average number for technical mistakes was the same in 2016 as it was in 2014. This average (13 mistakes on average in 2016) is getting close to the average score for the men in

2016 (11 mistakes). Because of more flexible interchange rules, the number of goals scored with player inferiority has doubled since 2010 (Kovacs, 2016).

It seems that some players are more involved in intense contacts and duels than others, and these players will execute more technical actions such as shots and passes than other players. These actions vary and are dependent on technical roles, player position and defence/attack phases (Karcher & Buchheit, 2014). Karcher & Buchheit (2014)'s study is the first review article of its kind to deliver a comprehensive analysis of different technical and physical demands on the court related to player positions. According to these authors, data on goal keepers is scarce, and more specific research is needed because of their distinctive activity pattern. They summarised that line players cover the least amount of area on court, but they maintain a relatively high intensity due to the high amount of body contact they are exposed to. Wing players perform the highest amount of high-intensity runs and are least exposed to body contact. Back court players are exposed less to body contact than line players, but more than wing players. They however perform a great deal more technical actions such as shots and passes than the two other playing positions. The conclusion in this study is that the players who perform the most technical actions need specific physical preparations concerning game demands.

Michalsik et al. (2015) later completed a study looking at both male and female league-games throughout a season in Denmark. The findings of this study describe the differences between the playing positions according to the physical demands and their involvement in the game, and confirm the findings in Karcher & Buchheit (2014)'s review of the literature. In the male study, findings suggest that there are signs of fatigue because the number of technical actions declined in the second half. In the female study, they reported no signs of fatigue, as the number of technical actions were similar in the second half.

2.3.5 Reliability

According to O'Donoghue (2010), formulating methods in performance analysis often requires the development of a computerised system to gather performance data. First, a system has to be developed and tested, and secondly the system has to be used in the main study of the research project. The system should be specifically developed to be used within the study. The

development of the system requires pilot work, operator training and reliability testing. The ease or difficulty of using the system to analyse a performance determines the number of performances that can be analysed within the research project under the time constraints that apply.

Computerised systems have the ability to automatically generate values that may be of use, in this matter it is a computerised system called Interplay. The order in which data about an event is entered should map the operator's mental model of the event. This mental model is a sequence of event details that is built up by the observer while observing the event (i.e. shot/goal, distance, body-contact). This sequence information can be put in a multiple match analysis facility that produces a spreadsheet of variables.

2.4   Summary

To summarize, handball has various physical demands which differentiate between playing positions and phases of the game. Average intensities and total distances are lower than in other team sports and much of the time/distance is spent in low and moderate intensity, yet short and energy-demanding movements such as accelerations, decelerations, changes of direction and one-on-one duels make the sport physical demanding (Wik et al, 2017). The fact that the sport is so periodic results in another physiological and metabolic response than in other team sports (Wik et al, 2017).

It is obvious that more research is needed in handball before we can conclude if the physical performance can affect the technical performance in team handball matches. Studies that already have been conducted in other team sports have different methodologies and it is difficult to find a common denominator. For example, it is hard to compare studies with game simulations and studies with actual competitive games. It is also difficult to compare handball and other team sports as teams can substitute freely, compared to for example football where most players play 90 minutes.

Because of the limitations of measuring sports indoors, mostly video based time-movement analysis has been done in handball. These results have found a decline in movement variables like high-intensity activities between halves and in periods of the game. Normally the highest

intensity is found in the first periods of the game with declines throughout the game. This indicates match-related fatigue. Some studies find a decline in technical performance because of this match-related fatigue, while other studies find a decline in the players' will to involve themselves in the game.

The studies that find a decline in technical performance in the second half can be misunderstood in the way of interpretation. A less amount of technical actions performed by each player in the second half compared to the first half is not necessarily negative, it might just be a decline in match tempo in the second half (Michalsik et al., 2014a; Michalsik et al.,2013). If a game-profile is slower in the second half, it can mean that players are less willing to involve themselves in the game because of fatigue, but there can also be other reasons, for example that the opponent team lowers their tempo. It can therefore be an advantage to look at the total fatigue-profile of the whole team instead of the players' individual fatigue-profile, or a combination of these two.

3. Method

3.1 Subjects

This is an observational study. The subjects in this study are twenty female Norwegian national team players (mean ± SD; age 25.1 ± 4.2 y, stature 173.9 ± 5.0 cm) from the most-winning national team in the world since 1986 (EHF, 2017). They have been World and Olympic champions in 2015, are current European champions in the women's European handball championship in December 2016 (EHF, 2017). Players were divided into three playing positions; back (left back, playmaker and right back are merged together), wing (left wing and right wing merged together) and line player. Goal keepers are not included because of their obvious differences from other playing positions: they play in a dedicated zone on court and are only involved in the defence play (Povoas et al., 2012). This project is approved by the Norwegian Social Science Data Service.

The data that is analysed is collected from 9 international games from three Golden League tournaments in the 2014/2015 season. The Golden League tournament is a collaboration between Norway, Denmark and France where the handball federations in these three countries have organized three events of televised handball matches per season (NHF, 2017). All players included in the study were familiarized with the data collection procedures in training sessions prior to games to ensure minimal effect on match performance. Apart from players wearing the device, the study did not intervene with the match or match preparation. All of the physical tracking data used in this study has been presented in previous studies (Wik, 2015; Luteberget & Spencer, 2016, Wik et al., 2016) and is therefore already collected. The team experienced four losses and five wins during the nine matches, with a mean goal difference of 5.2 ± 3.7 (Luteberget & Spencer, 2016). From the nine Golden League matches 15 different female outfield players were analysed, each represented 2-9 times (4.7 ± 2.9), resulting in a total of 70 match data samples (backs: n=39, pivots: n=11, wings: n=20). The players participated voluntarily, and the Norwegian Social Science Data Service approved the data storage.

3.2   *Methodology physical analysis*

The players wore micro sensors called IMUs (OptimEye S5, Catapurt Sports, Australia). The IMUs contain an accelerometer, a gyroscope and a magnetometer that sample at 100 Hz. This technology makes it possible to register data such as changes of direction, accelerations, decelerations and body contact with high frequencies. It also combines the data for a total PL, which is an accelerometer-based measurement of external physical loading of team sport athletes. IMU register and create a timeline for each player that records when they execute high intensity actions and how demanding each high-intensity action was. The unit is localized between the player's shoulder blades in a vest under their playing kit (Catapult Sports, Australia, 2014). The data collection was monitored in real-time using the Catapult Sprint (version 5.1.4, Catapult Sports, 2014) software. Substitutions were manually tracked using this software to ensure that only time on the court was included in the analysis. All players were inactivated during time-outs. The substitution area was video-recorded to correct eventual errors. Two physical variables became of interest during the analysing of the data; PL, PL·min^{-1}, HIE and HIE·min^{-1}. As previously mentioned, HIE are defined as all Acc, CoD or Dec > 2.5 m/s^{-1}.

3.2.1   Data processing of the physical analysis

The physical data was already collected from previous research; Luteberget & Spencer (2016) and Wik, Luteberget & Spencer (2016). Match data was downloaded from the Catapult devices using Catapult Sprint (2013b), and organized into 5-min periods, as well as halves, to analyse transient and temporal patterns in match activity (Wik, 2015). Match and IMA output data were exported to Microsoft® Excel®, and calculations of averages, r-values and correlations were conducted. 5-min periods were calculated for each player with the inclusion criteria of minimal 3 minutes played in each 5-min, and in addition they had to concede with at least one more 5-min period (Wik, Luteberget & Spencer, 2016). All data is given as per-minute, and only on-field time was included in the study.

3.3   *Methodology Technical Analysis*

The same 9 games were video-recorded by the Norwegian national team's game analysis team. The main focus of this study is to compare the physical output with technical performance on both team level and individual level. This was done by a grading system where both positive and

negative performances are given points. For example; if a player makes a bad pass to a team mate, and the pass is intercepted by an opponent player which results in a fast break goal, this will result in a low minus score. If a player on the other hand makes a good breakthrough in attack and scores a goal, this player will be rewarded with a high plus score. At the end of a game, each player will have a total score.

The analysis method is developed in collaboration with the Norwegian women's national head coach. Due to the complexity of the environment, temporal and spatial characteristics of player's locations and movements, as well as those of the ball, game play must be analysed in a very systematic way if one wishes to obtain dependable, reliable, and useful information (Grèhaigne & Godbout 2013). The goal of this technical analysis is to establish a good system that will cover all possible actions in the game and grade them appropriately.
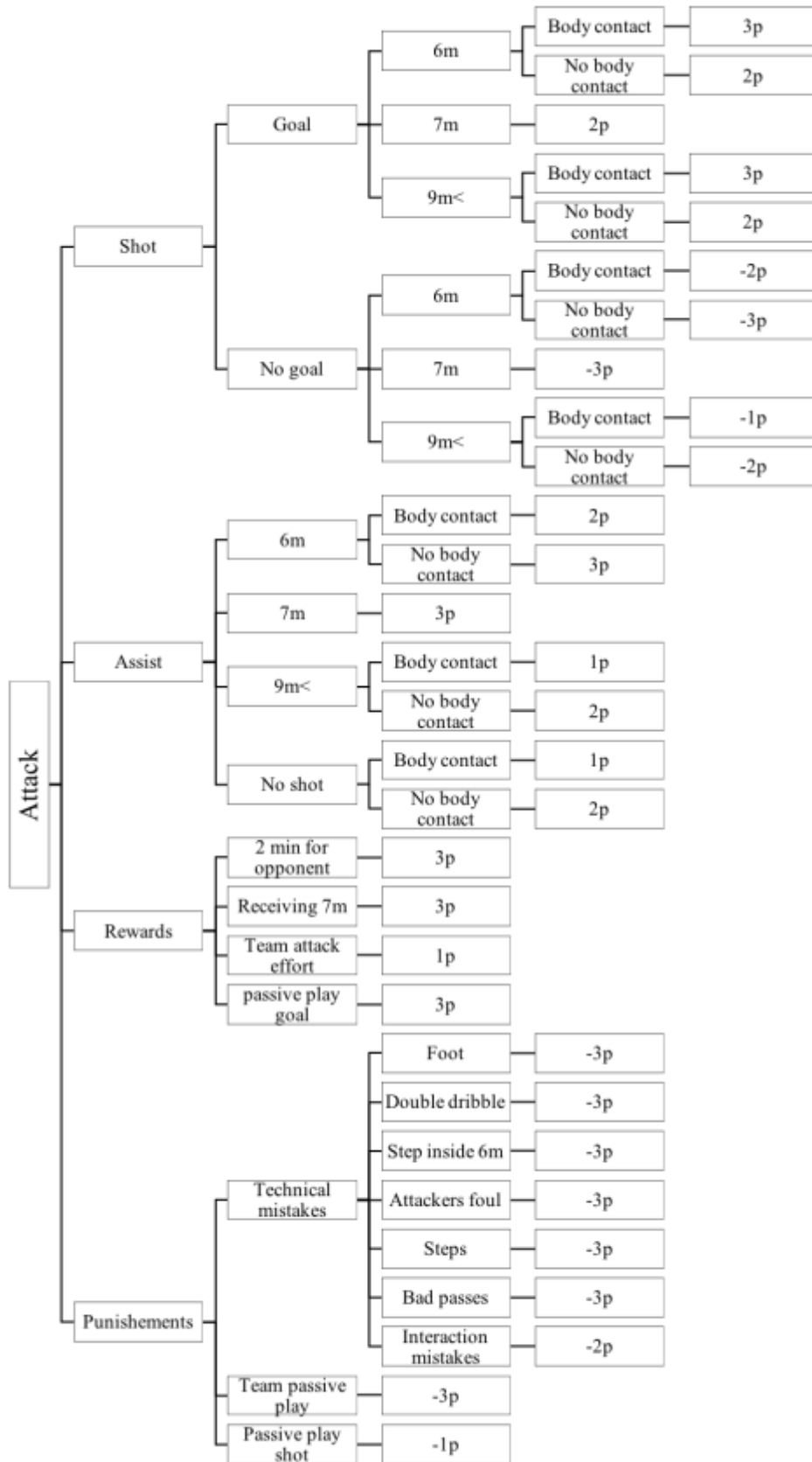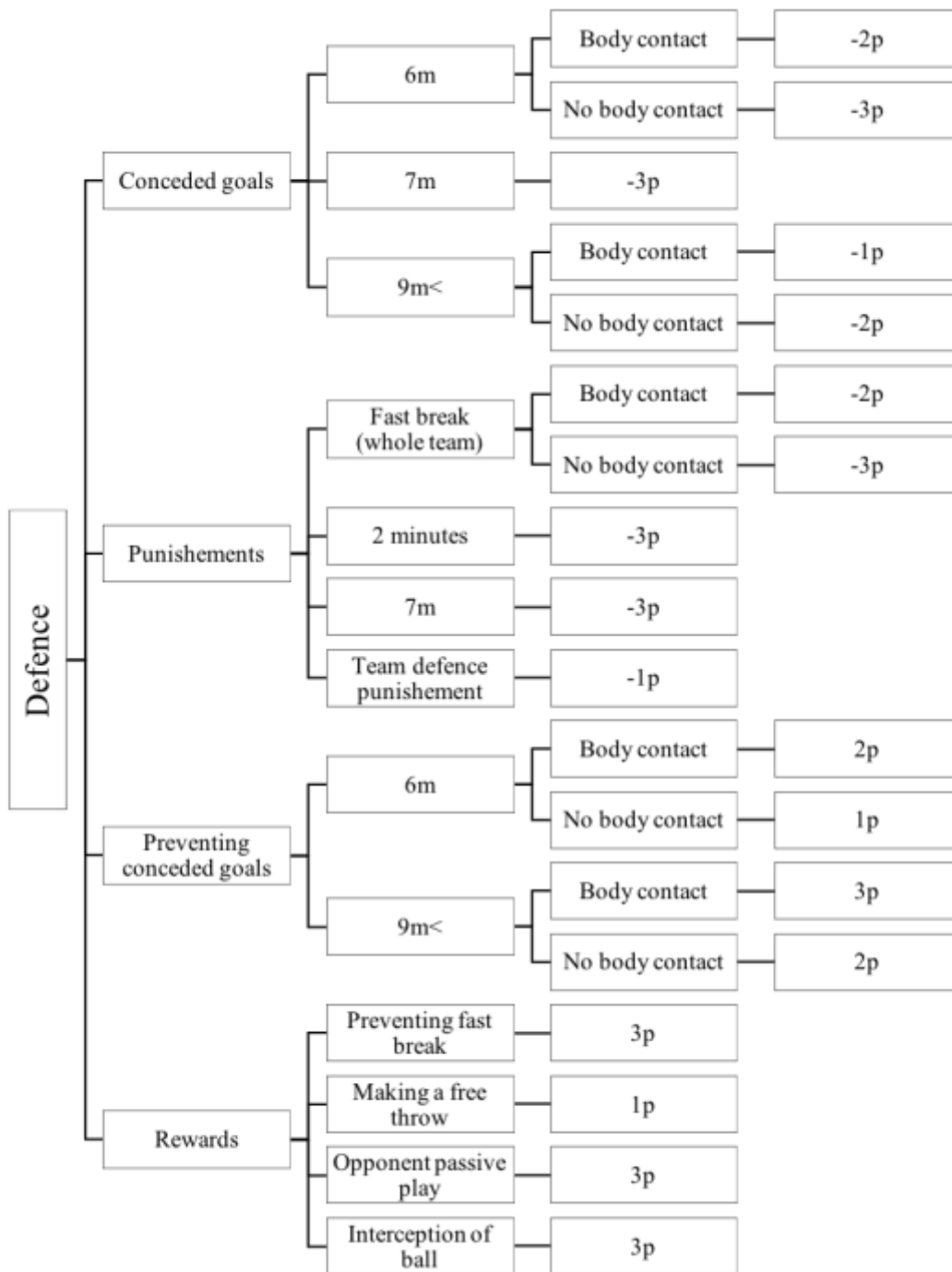
- **Attack**
  - **Shot**
    - **Goal**
      - **6m**
        - Body contact — 3p
        - No body contact — 2p
      - **7m** — 2p
      - **9m<**
        - Body contact — 3p
        - No body contact — 2p
    - **No goal**
      - **6m**
        - Body contact — -2p
        - No body contact — -3p
      - **7m** — -3p
      - **9m<**
        - Body contact — -1p
        - No body contact — -2p
  - **Assist**
    - **6m**
      - Body contact — 2p
      - No body contact — 3p
    - **7m** — 3p
    - **9m<**
      - Body contact — 1p
      - No body contact — 2p
    - **No shot**
      - Body contact — 1p
      - No body contact — 2p
  - **Rewards**
    - 2 min for opponent — 3p
    - Receiving 7m — 3p
    - Team attack effort — 1p
    - passive play goal — 3p
  - **Punishements**
    - **Technical mistakes**
      - Foot — -3p
      - Double dribble — -3p
      - Step inside 6m — -3p
      - Attackers foul — -3p
      - Steps — -3p
      - Bad passes — -3p
      - Interaction mistakes — -2p
    - Team passive play — -3p
    - Passive play shot — -1p

Figure 3.1: Point system for attack

Figure 3.2: Point system for defence

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The actions leading up to a shot towards the goal is mainly distinguished by the help of three main categories (fig 3.1): distance, if there was body-contact or not and goal or no goal. The player who passes the ball to the player who ends the attack, called an assist, will also be registered independent of the result of the shot (fig 3.1). The rest of the team is rewarded with one point if the end of the attack results in a goal ("team attack effort", fig 3.1). If the end result is a miss on goal, only the assist and shooter are registered.

A 100% chance is a shot at 6-m without body contact from the opponent. An assist will get the most points if this player is able to "play free" his/her team-mate to a 100% chance. In defence, players will be punished the hardest if they let the opponent shoot on goal with a 100% chance. The defence will also be punished if the opponent misses a 100% goal as this is an exceptionally good save from the goalkeeper and is still a bad performance of the defence as a collective unit.
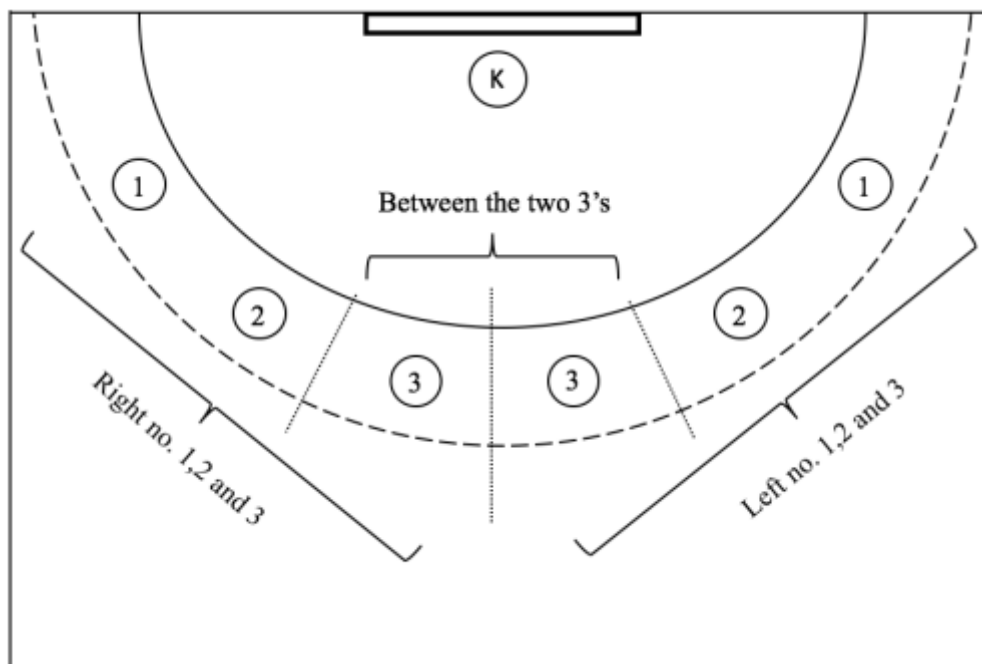
Figure 3.3: Zones in defence. K=goalkeeper

There are some difficulties concerning point-registration in defence because of the complexity of the defence with players working together as a unit, so the choice was made to divide into sections on the court (fig 3.3). The left "three", "two" and "one" are one section, and the right "three", "two" and "one" are another section, shown in fig 3.3. If something happens between the number "three's", only these two players will be rewarded/punished. An important point is that the zones are not divided in certain areas of the court but divided according to the players and their playing position. If the opponent executes an action on the left side and fails, all three players in this section will be rewarded. The same is true for the right side or the two "three's" in the middle. If the opponent scores a goal, all players on court will be punished, but the players standing in the section the goal was made will be punished more than the other players. Again, the same is true for an event that occurs between the two "three's". These sections don't count when the opponent undertakes a fast-break.

The opponent's actions leading up to a shot, at what distance, and if there was any body contact will be registered (fig 3.2). The objective for a good defence is mainly to pressure the opponent to take a low percentage shot since most defences end with a shot on goal, and by registering these different actions we are able to distinguish between bad defence (a 100% chance for the opponent) and good defence (a pressured shot from 11 meters with body-contact). If the opponent scores a goal, the whole team on court will be registered with minus 1 point for letting in a goal ("team defence punishment", fig 3.2). If a player in defence makes a free throw it is seen as a good action as it breaks up the opponent's attack and is registered (fig 3.2). Free throws for the team in attack are not registered.

2-minute suspensions and penalty shots both for and against the team are registered. In addition, technical mistakes such as bad passes, steps, double-dribble, if the ball touches the players foot, attackers-foul and being inside the 6m area are registered. Bad passes are even more specific in the way they are registered; bad pass to a team-mate, bad pass to an opponent, bad pass over the side-line or goal-line and bad pass inside 6 meters (a pass inside 6-meters often results in a quick fast break as the goal keeper has quick access to the ball to pass a fast break pass; fig 3.1).

When the opponents play until passive play, it is a good action of the defence. If the opponent plays until the passive signal is whistled or they shoot without scoring a goal, the team will

receive plus points (fig 3.2). If the opponents still score during passive play, it is seen as highly negative. In attack, if the team play until passive play, it can be both positive and negative (fig 3.1). On one hand, a long attack is a good attack, but on the other hand passive play is only signalled when players do not approach the goal. Players who shoot during passive play and miss will not get as many negative points as usual, as it is a forced ending of the attack and that player took responsibility. If the whole team is whistled for passive play in attack, the whole team will receive negative points for not taking responsibility (more than with "team punishments", fig 3.1). If a player scores during passive play, they will receive a very good score for making a goal in a pressured situation.

Not all players are wearing the IMU, so only the players wearing a IMU are registered and analysed. With that said, when there was a two-minute suspension for a player without a IMU, a "blank" registration is made because it effects the rest of the team, but this information was not used further in the analysis.

3.3.1 Interplay©

Interplay© is a professional video analysis system developed for coaches, players and teams. In this study, it was used as a post-analysis tool with the 9 games imported as video files. It has an ability to analyse two teams simultaneously, and in this study the same team was put in twice, to analyse both attack and defence. The variables were designed especially for this study (fig 3.4 and fig 3.5). The variables were organized in groups for attack types, shots, grades, technical/tactical and multi variables (Interplay, 2017). Figure 3.5 shows a more detailed overview.

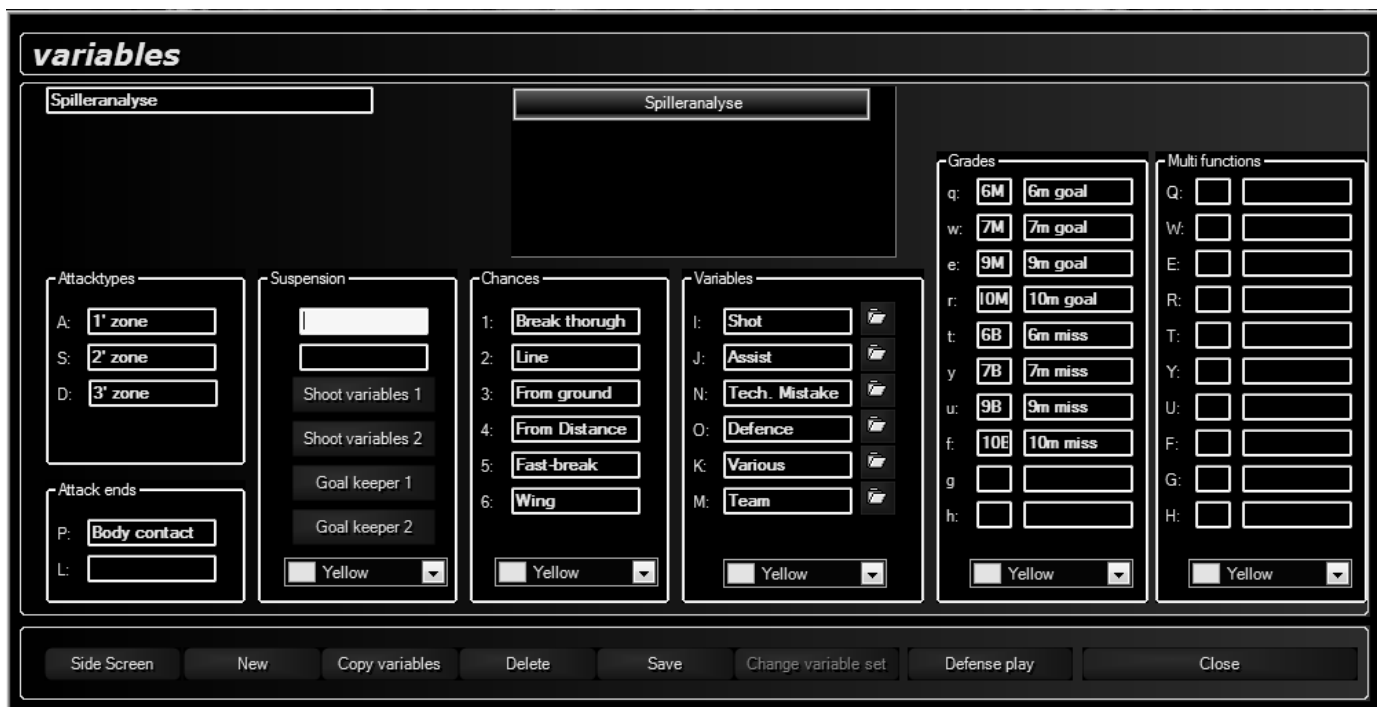*Figure 3.4: The analysing window in Interplay*

Figure 3.5: The different variables in interplay. Attack ends = body contact, Chances = position,
Variables = main variables, grades = distance.

Two technical variables became of interest during the analysing of the data; Involvements (INV)·min^{-1} and points·min^{-1}. The INV are a summation of every time points are given to a player, independent of point sum. Points are the sum of all points given combined. Technical output data were exported to Microsoft® Excel®, and calculations of averages, r-values and correlations were conducted.

3.4   Validity and reliability

Validity is of great importance when collecting data for research purposes, and if the test(s) actually measure what we are trying to measure is the main question concerning validity. A test cannot be valid, if it is not reliable. Reliability involves the credibility and accuracy of a test result, in other words, to evaluate the consistency with which a method can be used. To quantify the reliability of a test, it is common to take a test re-test and identify the typical error of measurement (Thomas, Nelson, & Silverman, 2011). In this study, there was firstly conducted a pilot test, and later there was conducted an intra-operator reliability test, meaning the same person did the test re-test. The pilot test was done on game no. 5, while the test re-test was done on game no. 1,2 and 3. The durance between test and re-test was approximately 1 week. When a human operator is part of the system used to measure performance variables, there will always be an element of subjective judgement when classifying the performance on court. According to McGarry & Franks (1994), the main factor responsible for variation is the quality of opposition.

The reliability-data from these analyses were: 72% correct, 16% 1 point off, 9% 2 points of, 2% 3 points off (this is including registrations that did not match with each other when comparing the test with the retest). The reliability with a Spearman's rho (ρ) = 0.90. With "error" registrations excluded, the results were: 80% correct, 12 % 1 point off, 6% 2 points off, 1% 3 points off. Reliability for each technical variable is shown in fig 3.1 below.

Table 3.1: Reliability scores for the different variables when comparing test with retest.

	Difference in total points	Zone	Body contact (yes/no)	Main variables	Side variables	Distance	Position
Total sum of registrations	790	790	790	790	790	790	790
Sum of identical registrations	635	706	697	778	752	705	717
Percent	80.4 %	89.4 %	88.2 %	98.5 %	95.2 %	89.2 %	90.8 %

3.5 Statistical analyses

Data for changes are presented as mean ± SD. Differences between playing position and between winning and losing were found using Cohens Effects size (ES) statistics on log-transformed data. ES's of <0.2, 0.2 to 0.6, 0.6 to 1.2, 1.2 to 2.0, and >2.0 were considered trivial, small, moderate, large, and very large, respectively (Hopkins, Marshall, Batterham, & Hanin, 2009). Cohen's effect size is calculated using the following equation:

$$d = \frac{\overline{X_1} - \overline{X_2}}{s}$$

where $\overline{X_1}$ is the mean for one population, $\overline{X_2}$ is the mean for the other population, and s is the standard deviation of the pre-test (for both populations, when calculating differences between groups). The percentage likelihood of a difference between groups was calculated and considered almost certainly not (<0.5 %), very unlikely (>0.5-25 %), unlikely (<25 %), possibly (25-75 %),

likely (>75 %), very likely (>95 %), or almost certainly (>99.5 %). A percentage likelihood of difference <75% was considered a substantial magnitude. Threshold chances of 5 % for substantial magnitudes were used, meaning if a likelihood of >5 % in both a positive and negative direction was observed, it was considered an unclear difference. Correlations were assessed by Pearson product- moment correlation coefficient. Magnitude of effect for the correlations were based on the following scale: <0.10 trivial, 0.10-1.29 small, 0.30-0.49 moderate, 0.50-0.69 large, 0.70-0.89 very large, and >0.89 nearly perfect (Hopkins et al., 2009). All calculations were performed in Microsoft® Excel for Mac® (2001). For calculations of ES, 90 % confidence limits, log transformation and calculations of likelihood, pre-made excel spreadsheets (Hopkins, 2006, 2007) was used.

4.   Results

The mean match duration was 71 ± 2.4 min, meaning an additional 11.9 min was added to the official match time. The mean on-field time for the individual players was 31.18 ± 15.02 min. The range of playing time was between 4.45 min and 62.53 min. Pivots had the highest mean on-field time (33.69 ± 15.36 min), however there were no clear differences when compared to wings (31.50 ± 14.42 min) and backs (30.30 ± 15.52 min).

4.1   Effect of exercise duration

The registrations of players with two consecutive periods (n=78), three consecutive periods (n=57), four consecutive periods (n=37), five consecutive periods (n=27), six consecutive periods (n=12) and seven consecutive periods (n=5), and the effect of these consecutive periods of play on percentages of $PL \cdot min^{-1}$ and $INV \cdot min^{-1}$ and Points (not in percent) are shown in figure 4.1. The error bars in fig 4.1 represent the standard deviation for each consecutive period.

4.2   Team correlations

The results range from trivial to perfect, with $INV \cdot min^{-1}$ correlating highly with $PL \cdot min^{-1}$ (r= -0.68) and HIE (r= -0.57), and moderately with $HIE \cdot min^{-1}$ (r= 0.36). P-values for the team as a total are shown in table 4.1. The values range from -0.71 to 0.96.
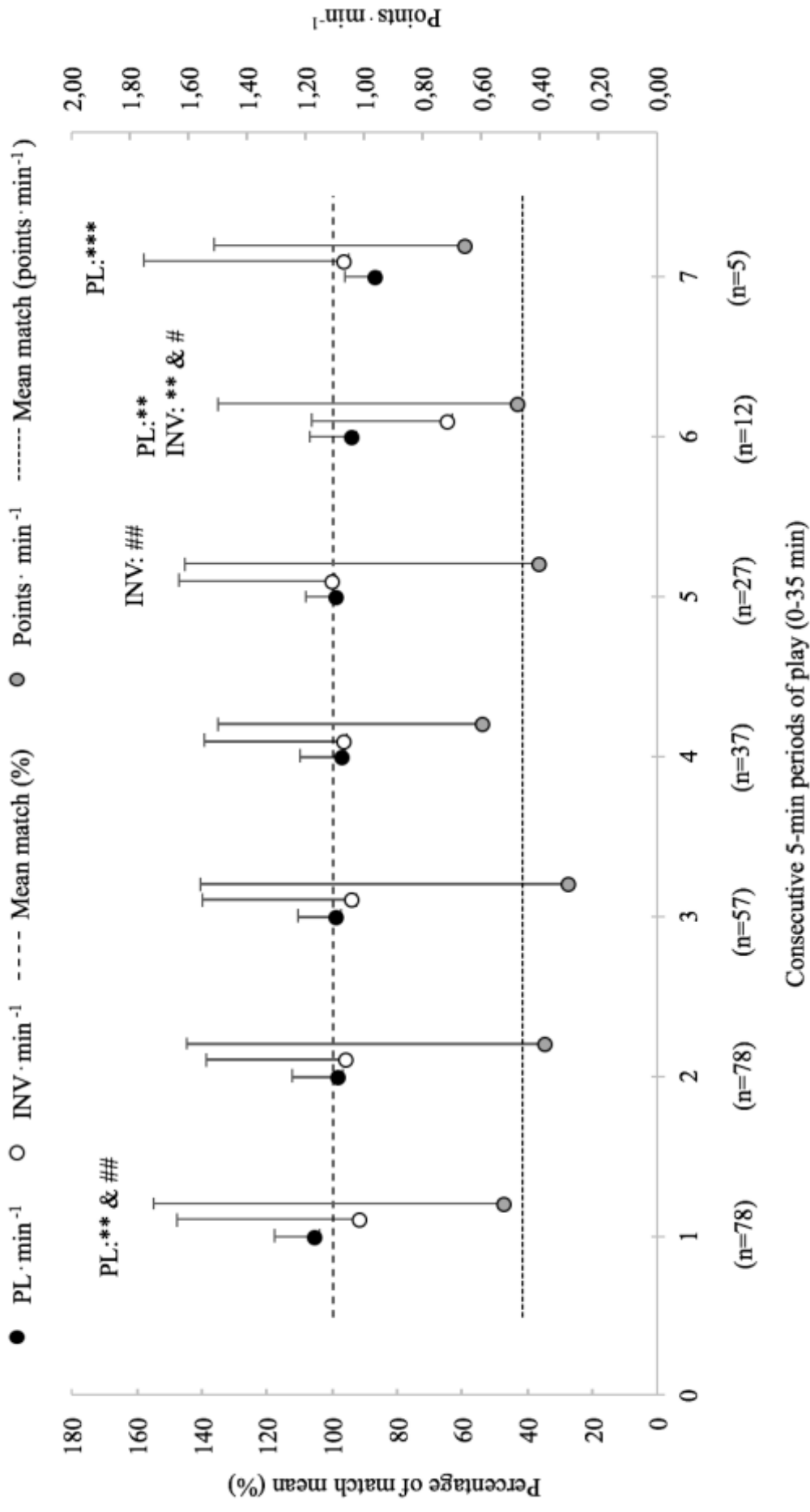
Figure 4.1: Percentage of match mean (%) and consecutive 5-minute periods for Player Load[TM]·min^{-1}, involvements·min^{-1} on field for all players. points are also shown (not %). There are 7 possible consecutive 5-min periods with on-field time, which total 35 min.

* = Different compared to mean # = Different compared to following period. Effect size (ES) between different periods is indicated by the stated symbols and are marked by variable name. Number of symbols represent the effect size. Only ES with a substantial likelihood of difference (>75%) are shown. * = small, ** moderate, *** large, **** very large. INV = involvements, PL = Player Load[TM]

Table 4.1: P-values for PL, PL·min^{-1}, HIE, HIE·min^{-1}, INV, INV·min^{-1}, Points, Points·min^{-1}, and field time for all players n=70. PL = Player Load^{TM}, HIE = high intensity events, INV = involvements.

	PL	PL·min^{-1}	HIE	HIE·min^{-1}	INV	INV·min^{-1}	Points	Points·min^{-1}	Field time
PL	1.00								
PL·min^{-1}	0.01	1.00							
HIE	0.87	0.07	1.00						
HIE·min^{-1}	-0.26	0.56	0.14	1.00					
INV	0.07	0.06	0.13	0.10	1.00				
INV·min^{-1}	-0.68	0.20	-0.57	0.36	0.39	1.00			
Points	0.13	0.23	0.11	0.08	0.32	0.15	1.00		
Points·min^{-1}	-0.12	0.33	-0.10	0.20	0.20	0.39	0.71	1.00	
Field time	0.97	-0.19	0.83	-0.36	0.06	-0.71	0.07	-0.15	1.00

4.3   Values and differences between playing positions

The mean for all players, when combining all PL·min^{-1} was 9.61 ± 1.16. The backs had the highest values of PL·min^{-1}, followed by wings and pivots (table 4.2). The range in PL·min^{-1} for all players was 8.15 to 12.96. The mean for all players, when combining all HIE·min^{-1} was 4.39 ± 1.35. The backs also had the highest values of HIE·min^{-1} followed by pivots and wings (table 4.2), with the range for all players being 2.05 to 9.24 HIE·min^{-1}.

Table 4.2: The physical variables; Player Load^{TM} (PL)·min⁻¹ and high intensity events (HIE)·min⁻¹ with comparisons between playing positions and magnitude of differences.

		Mean ± SD		Magnitude of differences	
				Effect size	Rating
PL·min^{-1}					
	Back	9.99 ± 1.38			
			vs pivot	0.80	Very likely
			vs wing	0.76	Very likely
	Pivot	9.10 ± 0.58			
			vs wing	0.11	Unclear
	Wing	9.16 ± 0.56			
HIE·min^{-1}					
	Back	5.13 ± 1.13			
			vs pivot	0.87	Very likely
			vs wing	2.57	Most likely
	Pivot	4.24 ± 1.05			
			vs wing	1.46	Most likely
	Wing	3.03 ± 0.65			

The mean for all players, when combining INV·min^{-1} was 1.85 ± 1.55. The pivots had the highest values of INV·min^{-1}, followed by backs and wings (table 4.3). The range for INV·min^{-1} for all players was from 0.21 to 12.22. Lastly, the mean for all players, when combining all points·min^{-1} was +0.26 ± 0.97. The backs had the highest values of points·min^{-1}, followed by pivots and wings (table 4.3). The range for points·min^{-1} was -2.2 to +3.92.

Table 4.3: The technical variables; Involvements (INV)·min⁻¹ and Points·min⁻¹ with comparisons between playing positions and magnitude of differences.

		Mean ± SD		Magnitude of differences	
				Effect size	Rating
INV·min^{-1}					
	Back	1.54 ± 0.86			
			vs pivot	0.23	Unclear
			vs wing	0.14	Unclear
	Pivot	1.83 ± 1.33			
			vs wing	0.37	Unclear
	Wing	1.37 ± 0.54			
Points·min^{-1}					
	Back	0.37 ± 0.74			
			vs pivot	0.04	Unclear
			vs wing	0.70	Likely
	Pivot	0.02 ± 0.56			
			vs wing	0.87	Likely
	Wing	-0.19 ± 0.76			

There were no substantial differences in the results when comparing the team's wins and losses. The only result that was not unclear was INV·min^{-1} with a possible difference and an effect size of 0.25. INV, points, points·min^{-1}, HIE·min^{-1} and PL·min^{-1} were all unclear with effect sizes ranging from -0.05 to 0.30 when comparing wins and losses.

4.4   Comparisons between playing positions

Ranges for the different playing positions in PL·min^{-1} are 9.19 to 12.96 for backs, 8.24 to 9.96 for pivots and 8.15 to 10.20 for wings. For HIE·min^{-1} the ranges are between 3.18 to 9.24 for backs, 3.01 to 6.52 for pivots and 2.05 to 5.06 for wings. Ranges in INV·min^{-1} are 0.59 to 5.07 for backs, 0.81 to 5.40 for pivots and 0.80 to 3.17 for wings. Lastly, the range for points·min^{-1} are -0.91 to +2.51 for backs, -0.82 to +0.90 for pivots and -2.9 to +0.67 for wings. INV·min^{-1} compared with both PL·min^{-1} and HIE·min^{-1} are shown in figure 4.2 and 4.3, respectively. Points·min^{-1} compared with PL·min^{-1} and HIE·min^{-1} are shown in figure 4.4 and 4.5, respectively.
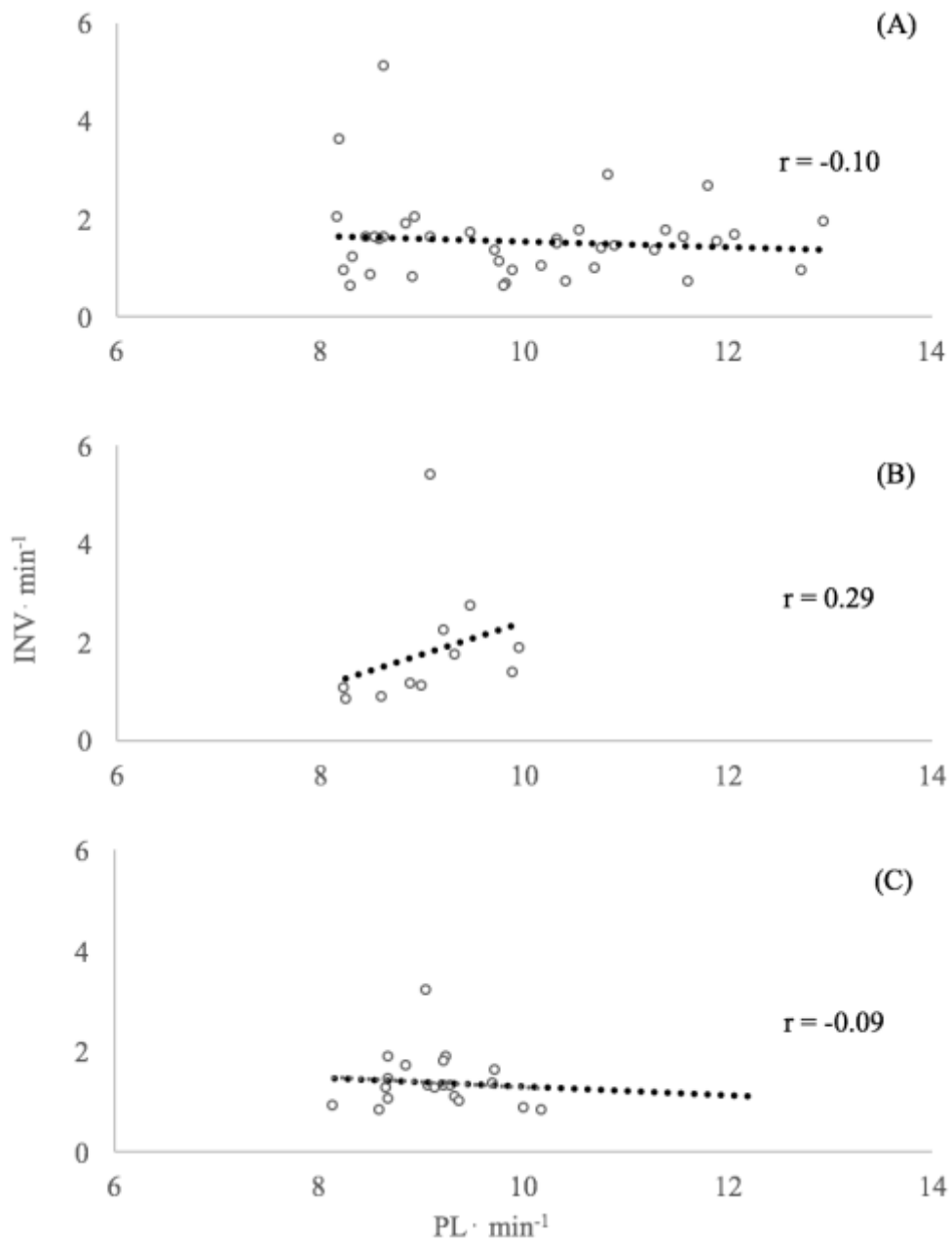
Figure 4.2: The relationship between involvements·min⁻¹ and Player Load·min⁻¹ for backs n=39 (A), pivots n=11 (B) and wings n=20 (C) and r-values respectively. PL=player load^TM, INV=involvements.
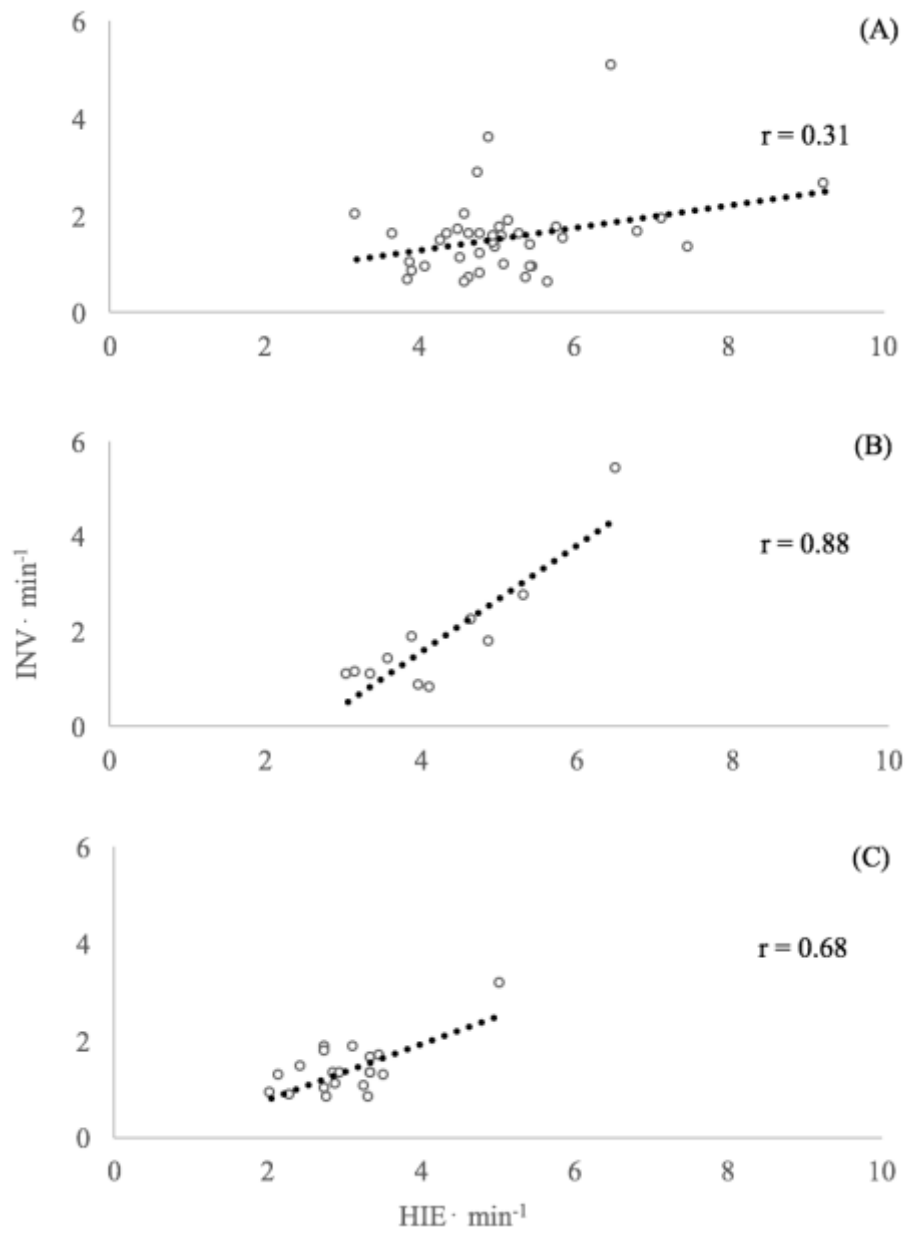
Figure 4.3: The relationship between involvements·min⁻¹ and high intensity events·min⁻¹ for backs n=39 (A), pivots n=11 (B) and wings n=20 (C) and r-values respectively. INV=involvements, HIE=high intensity events
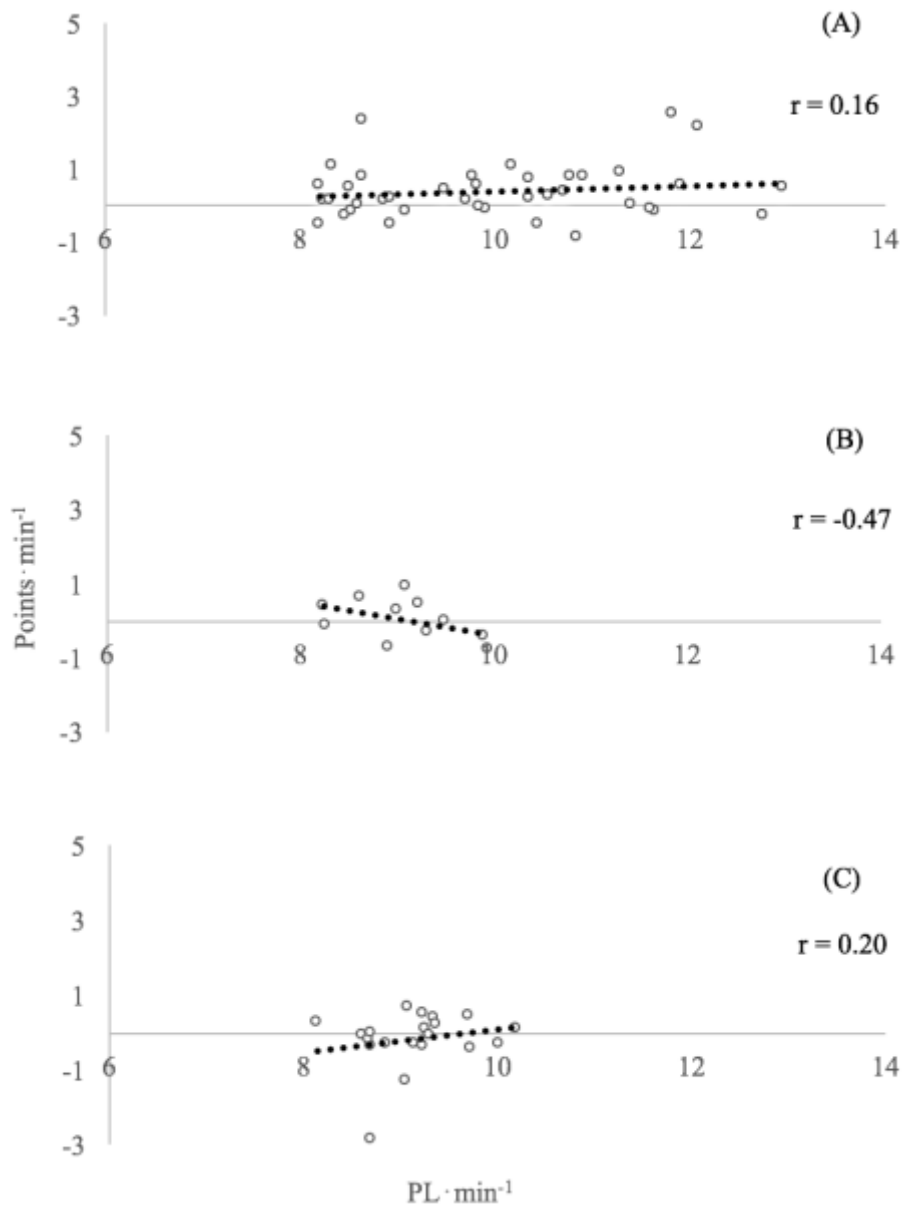
Figure 4.4: The relationship between Points·min⁻¹ and Player Load·min⁻¹ for backs n=39 (A), pivots n=11 (B) and wings n=20 (C) and r-values respectively. PL=Player Load™
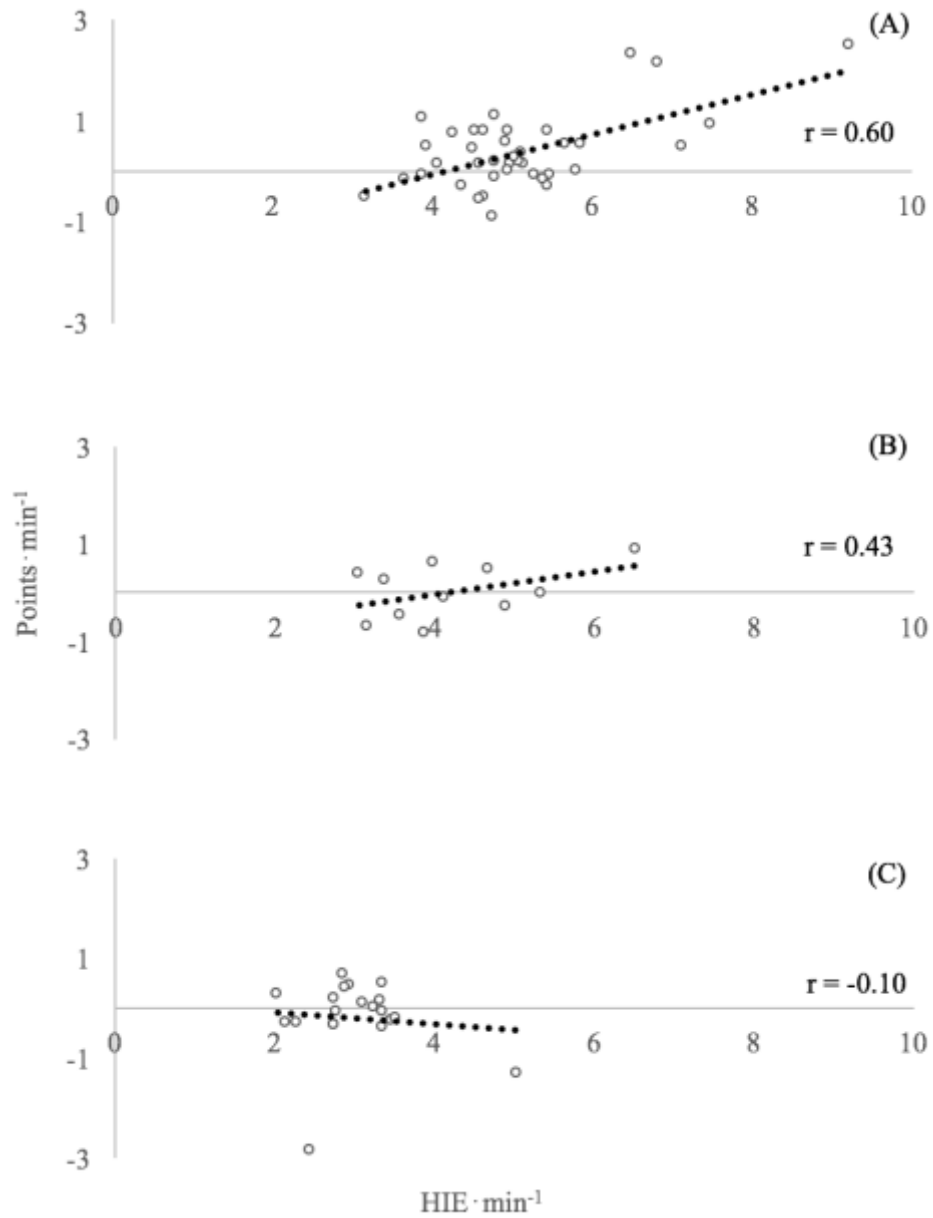
Figure 4.5: The relationship between points·min⁻¹ and high intensity events·min⁻¹ for backs n=39 (A), pivots n=11 (B) and wings n=20 (C) and r-values respectively. HIE = high intensity events.

5.   Discussion

The aim of this study was to investigate if there is a meaningful relationship between the physical output and technical performance in elite handball matches. This is, to my knowledge, one of the first studies to investigate this relationship, and is a new method of evaluating player performance in elite handball. The primary measure of physical output in this study are the variables $PL \cdot min^{-1}$ and $HIE \cdot min^{-1}$, while the primary measure of technical output are the variables $INV \cdot min^{-1}$ and $points \cdot min^{-1}$. The majority of the discussion will therefore concern these variables. The main findings in this study are high initial intensities, declines throughout consecutive periods and lowest bouts of intensity in the end periods. There was found a decline in player INV in last periods. The results show a good relationship between player INV in the game and the physical variables. Also, there are differences in activity load and $HIE \cdot min^{-1}$ between playing positions, while there are unclear relationships between technical variables and player positions. Lastly, there are position specific differences when comparing physical with technical variables.

This study has had a wider inclusion criteria concerning on-field time compared to other studies (Michalsik et al., 2013; Povoas et al., 2012; Povoas et al., 2014a; Sibila, Vuleta Pori, 2004; Michalsik et al., 2014a; Michalsik, Madsen, Aagaard, 2014b). Previous studies have excluded players with field times $\leq 70\%$ to elucidate the demands of full-time players. In this study, all players who had on-field time and received points are included, making it possible to investigate a larger number of the different variables.

5.1   Team analysis

5.1.1   Physical effects of exercise duration

Initial intensity in periods

The initial 5-min period was observed to be substantially elevated in $PL \cdot min^{-1}$ compared to the following period (fig 4.1). This is compatible with previous research on high-initial activity rates in handball (Povoas et al., 2012; Michalsik et al., 2013), and other team sports (Bradley & Noakes, 2013; Jones et al., 2015; Sykes, Twist, Nicholas, & Lamb, 2011; Waldron et al., 2015, Mooney et al., 2013; Aughey, 2010 Polley, Cormack, Gabbett, & Polglaze, 2015; Cormack et al.,

2014). According to Michalsik et al. (2013), this may indicate temporary fatigue already in the first half, especially for full time players.

Akenhead, Hayes, Thompson, & French (2013) proposes that possible reasons for elevated opening intensities in soccer might be tactical input from coaches, or the preceding rest period after the warm-up where players have optimal conditions of force production and full energy stores. Kempton, Sirotic & Coutts (2015) suggests that, in opening phases, rugby players might experience better physiological conditions for high workloads. It is also suggested that motivational factors is a reason for high initial periods, wanting to get a good start to the game, contributing to a chaotic start before the game slows down and finds it's rhythm (Akenhead et al., 2013; Bradley & Noakes, 2013). From a tactical point of view, starting the game with a high intensity might be advantageous, as having a lead from start will put pressure on the opponents. This may consequently lead to players fatiguing earlier, as shown in previous studies, where declines in activity levels are related to high work rates in previous periods of matches (Bradley & Noakes, 2013; Coutts et al., 2010; Rampinini et al., 2007). Pacing during the game might also be a reason, as intensity might be regulated after a high activity period in order to maintain pacing strategies (Edwards & Noakes, 2009).

Findings of initial periods having longer time of "ball in play" in soccer and rugby league games may indicate that players get the chance to work more, suggesting that game dynamics also plays a role other than physical capacity (Carling & Dupont, 2011; Kempton et al., 2015). However, in the current study the initial period is not necessarily the first period of the game, indicating that longer "ball in play"-time might not be a plausible explanation for the elevated intensity, at least not in team handball. The fact that the initial period for the players could be at any point in the game, may suggest that players are more motivated and active, wanting to make an impact as soon as they are introduced into the game. If players generally play more intensely in their first period of play, this can be used as a tactic by coaches by introducing rested players for an impact in selected periods of the game in order to raise intensity (Waldron, Highton, Daniels & Twist, 2013).

Intensity across periods

The decline in PL·min^{-1} across the periods (fig 4.1) may be associated with the physical deterioration of players (i.e. changes in muscle structure and glycogen depletion), and inability to work at the desired rate. This theory has support from findings for soccer games (Krustrup et al., 2006), however the comparisons to handball is questionable. A game of handball is in fact shorter than soccer, have lower mean speeds during games (Karcher & Buchheit, 2014) and have unlimited interchanges, which means more frequent periods for rest. Studies also show that impairments in physical capacity are associated with lower team activity in handball games (Michalsik et al., 2013; Povoas et al., 2014a). Lastly, the decline in intensity could also be caused by an imbalance between physical capacity and game demands (Cormack et al., 2014; Johnston, Gabbett, & Jenkins, 2015), where players start at an intensity that is difficult to maintain through the match. This might be relevant especially for national teams, where players might have less experience with game demands at a higher level (Ronglan, Raastad, & Borgesen, 2006). Knowledge of energy demands and previous experience are important factors for players when setting a good pacing strategy (Edwards & Noakes, 2009).

Intensity in final periods

The final two periods (fig 4.1), in the consecutive 5-min periods analysis, were substantially lower in PL·min^{-1} compared to mean. The last period was also large in effect size. Previous studies have found an increase in PL·min^{-1} in the final period (Wik et al., 2017; Michalsik et al., 2013), explained by an "end spurt" phenomenon (Waldron & Highton, 2014) where increased motivation and "energy saving" for the "end spurt" might be present, either consciously or subconsciously. However, because the final period in the current study is not necessarily the final period in the game, our findings are not comparable. Also, 12 out of 78 individual player samples met the inclusion criteria for period six, while only 5 out of 78 samples met the inclusion criteria in seven consecutive periods (fig 4.1). This suggests that the players in the final two periods have played either the whole half or the whole game, and the explanation for the decrease is fatigue (Waldron & Highton, 2014). Findings in Australian football suggest that a high amount of interchanges was good for maintaining m·min^{-1} and high speed running (Mooney et al., 2013), and substitute or interchange players generally work more intensely than whole-game players (Black & Gabbett, 2014; Bradley & Noakes, 2013; Carling, Le Gall, & Dupont, 2012, Mohr et

al., 2003). Therefore, appropriate player rotations may allow players to maintain an optimal physical performance level or, at least, limit a possible drop in physical/playing efficiency (Karcher & Buchheit, 2014). The findings of a decline in intensity in final periods also show that team activity profiles do not necessarily show individual fatigue in players, but is a good indication of whole-team physical performance (Wik, 2015).

5.1.2 Technical effects of exercise duration

Physical performance is not necessarily crucial for the match outcome, as players can compensate with other skills. Higher work rates are reported in the less successful soccer teams compared to more successful teams (Di Salvo et al., 2009; Rampinini, Coutts, Castagna, Sassi, & Impellizzeri, 2007; Rampinini et al., 2009). Also, studies of Australian football have suggested that the ability to get involved in the game is more important than physical levels (Johnston et al., 2012, Sullivan et al., 2014a).

There was a substantial decline in the amount of INV·min^{-1} in the last periods (period six and seven) compared to period five (fig 4.1). Duarte, Batalha, Folgado, & Sampaio (2009) showed that technical skills in futsal changed when modifying the duration of the exercise. The amount of successive contacts with the ball, the number of dribbles and the number of tackles were increased with the shorter bouts of exercise than the longer bouts of exercise. The results showed that by extending the duration of exercise, the players tend to solve the game problems with less help of individual solutions. Also, the development of successive contacts with the ball, dribbles, and tackles reduce significantly throughout the longer bout of exercise, supporting the element of technical fatigue. Recent research in female handball, performed by Michalsik et al. (2015), did on the other hand not find any signs of technical fatigue when comparing the first half to the second half in regards to amount of intense technical playing actions. This study shows that, although no signs of technical fatigue were found between halves in Michalsik et al. (2015)'s study, technical fatigue may still exist during halves. Furthermore, these findings substantiate another hypothesis mentioned; players might be less willing to involve themselves at the end of the half or the end of the game because of fatigue (Michalsik et al., 2014a; Michalsik et al.,2013).

5.1.3 Range dispersion

The consecutive 5-min periods show extensive range in both of the technical variables (INV·min^{-1} and points·min^{-1}) between the players (fig 4.1). This may be because of the wide inclusion criteria. As mentioned, all players are included, also one-way players. Luteberget & Spencer (2016) showed large differences between one- and two-way players in terms of intensity. One-way players are located in a higher range in both HIE and PL compared to two-way players, which means that they seem to work at higher intensities when on court, and have time to recover off court. Differences in physical conditions and body anthropometry may be a contributing factor to the variation as well. Furthermore, the range can also be explained by the fact that players' offensive role may differ from their defensive role. In this study, no specific analysis of one- and two-way players was undertaken.

5.1.4 Team comparisons between physical and technical performance

A small correlation was found between INV·min^{-1} and PL·min^{-1}, while there was a moderate correlation between INV·min^{-1} and HIE·min^{-1} in this study (table 4.1). This suggests a relationship between the technical INV and physical variables researched in this study. This could imply that physical performance in fact affects technical performance.

INV·min^{-1} has a large negative correlation with both PL and HIE, which could propose that a higher workload leads to less INV in the game. However, the total amount of PL and HIE are highly affected by the time spent on field, shown by a nearly perfect (PL) and very largely (HIE) correlation to field time. Furthermore, there is a very large negative correlation between INV·min^{-1} and field time, meaning that a high amount of field time has a negative impact on the technical INV during the game. Appropriate player rotation strategies might enhance the ability to perform at the required level when on court. Most actions like shooting, blocking and tackling require strength and power, and high demands of these actions in elite games suggest fatigue will prevent chances of performing at the required level (Ronglan et al., 2006). From these findings, it might be likely to conclude that high physical levels are mandatory for executing technical performances at the required level.

The correlation between points·min^{-1} and HIE·min^{-1} is small positive, while the correlation between points·min^{-1} and PL·min^{-1} is moderately positive. This might indicate that players, although having a high PL and a high amount of HIE, mostly undertake actions with a positive outcome. Points·min^{-1} do not have the same very large negative correlation with field time as INV·min^{-1}. This might suggest that players with more field time have a lower INV·min^{-1}, and the lack of correlation between field time and points might suggest that the ratio between positive and negative INV is equal. One might therefore speculate that the outcome of the INV done with more field time are equivocal, but this is not for certain since points as previously mentioned do not correlate with the amount spent on court.

5.1.5 Outcome in game

There was no substantial difference in variables when comparing winning and losing games. Firstly, not all players were investigated, which might be a factor to why the findings are unclear. The players not investigated might be the ones strongly contributing to the win or loss. Secondly, match results in handball can quite possibly be decided already early in the second half, and as such, goal difference could influence the pacing strategies of players, in the way of reducing effort because a comfortable lead or an anticipated loss. Score line has in fact been suggested to affect physical performance and pacing strategies in other team sports (Bradley & Noakes, 2013; Black & Gabbett, 2014). Furthermore, as the Golden League is a friendly tournament, there might have been more interchanges in games to try out new players or new tactics. This might have been a conscious choice made by the coaches to focus on the development of the team, rather than the outcome of the game.

5.2 Comparisons between playing positions

5.2.1 Physical variables

The differences in overall intensity (PL·min^{-1}) are substantial between playing positions, with backs displaying higher values than pivots and wings (table 4.2). The difference in PL·min^{-1} between pivots and wings is unclear. There are substantial differences between the playing

positions in HIE·min^{-1} with wings and pivots showing largely lower values than backs (table 4.2). The wings also showed lower values than pivots. This suggests that wing players have a steadier activity profile (i.e. running at a steady pace) with a relatively greater number of lower-intensity events than backs and pivots. This is in agreement with earlier studies on female handball players showing a higher total distance covered by wings compared to backs (Michalsik et al., 2014a). However, earlier studies on male handball players show that backs cover the greatest distance compared to other playing positions (Povoas et al., 2012; Michalsik et al., 2014a). Wings also perform the most fast breaks out of the playing positions, and cover more distance at speeds defined as sprints (Povoas et al., 2012). This suggests that wing players require specialized physical training programmes to meet the demands of match play.

The physical output of the different playing positions can also be affected by different tactical aspects and roles. Backs and pivots are more involved in the tactical play in both attack and defence compared to wings, and will therefore possibly have a higher amount of HIE·min^{-1}. Pivots also perform a high amount of isometric actions (screenings for example) that are not intercepted by the IMU-units, so an underestimation in intensity may be present. As mentioned, the wider inclusion criteria may be responsible for the wide range of intensities shown in this study. It may be difficult to compare this current study to other previous studies that have investigated physical demands in team handball. Despite this, there appears to be little doubt that HIE are an important element for physical performance in both female (Manchado et al., 2013a; Michalsik et al., 2015) and male (Povoas et al., 2014a; Michalsik et al., 2014b) team handball.

5.2.2 Technical variables

There are unclear differences for INV·min^{-1} between all playing positions (table 4.3). As previously mentioned, backs and pivots are more involved in the tactical game play than wings, so a greater difference was expected. A possible reason for this outcome is the element of "team registrations". We added these "team registration" points for the reason that all players in theory are involved every time the team scored a goal or conceded a goal, so the whole team would be graded and be marked as involved, although only maximum three players would be involved in the actual situation. This makes the number of INV between playing positions more even, and will possibly influence and impair the results.

The difference in points·min^{-1} between backs and pivots is unclear, but the differences between backs and wings, and pivots and wings, are moderate (table 4.3). Wings have a lower value of points·min^{-1} than both backs and pivots, meaning that they might receive less points per INV. A possible explanation may be a larger number of misses on goal due to a narrower shooting angle compared to the rest of the playing positions (scoring percentage from wing: 56%, Kovacs, 2016). Another explanation may be less involvement in the game both in defence and attack, meaning that the majority of points the wings receive are either from shooting themselves or team registrations.

5.2.3 Position-specific comparisons on performance

Backs and wings have a small negative relationship, while pivots have a moderately positive relationship when comparing INV·min^{-1} with PL·min^{-1} (fig 4.2). Pivots and wings had a nearly perfect and very large correlations respectively, between INV·min^{-1} and HIE·min^{-1} (fig 4.3). Backs had a moderately positive relationship. This indicates that a high amount of INV·min^{-1} executed by all playing positions probably indicates a high amount of HIE·min^{-1}. Thus, players execute high-intensity actions when they are involved in the game, suggesting the pace in elite handball matches is high because all technical actions are high-intensity events (CoD, Acc, Dec). The difference in correlation between the pivots and wings compared to backs can be explained by the position demands for each playing position. According to Michalsik et al. (2015), both wings and pivots execute more high-intensity running than backs, due to a larger number of fast breaks. Although backs perform less high-intensity running in total, they cover a relatively large total distance due to their central position in the offense, where they perform large amounts of intermittent sideway movements (Michalsik et al., 2015). Furthermore, wings and pivots cover a greater total distance than backs in defence, with wing players performing intense retreats and pivots performing a high number of physical confrontations with opponents due to their middle defence position (Michalsik et al, 2015).

For pivots, a moderate negative correlation between in Points·min^{-1} and PL·min^{-1} was found, while a small positive correlation was evident for backs and wings (fig 4.4). This may be explained by a few following theories: most pivots are largely involved in the game in defence since they often play a key role as a "number 3" in defence. "Tactically, it would pay off for

opponents to shoot in the middle of the defence rather than in the side-sector, so most shots will come over the 3'positions" (quotation: V. Holmeset). This means they are involved in two sectors of defence play, unlike other player positions, and get "punished" for double as many defences with conceded goals. Furthermore, according to Michalsik et al. (2015), pivots are the heaviest, and tallest (together with backs). Great muscle strength and rate of force development potentially are important abilities in elite pivots. Consequently, a large body mass (likely associated with a large muscle mass) is therefore expected to have significant impact on a pivots success during duelling/wrestling with players, but will potentially also be negative for endurance abilities (Manchado et al., 2013b). This can mean their fatigue impacts their INV negatively during the game. Furthermore, in attack, they are mostly only graded when they are passed the ball, meaning they most often get points when they score or miss, but screenings are also an important part of being a pivot and is in addition an isometric high intensity action (Luteberget & Spencer, 2016). Screenings seem to be of large importance for nearly each attack play, since the screenings help with making spaces in the opponents' defence. These actions are unfortunately not included in this analysis because of analytical difficulties since screenings are difficult to detect while conducting the technical analysis.

Backs and pivots have a large and moderate positive relationship in Points·min^{-1} vs HIE·min^{-1}, respectively (fig 4.5). Thus, HIE might be more important for points than PL. Conversely, this does not seem to be the same case for wing players, with a small negative correlation between points·min^{-1} and HIE·min^{-1}. This indicates that the different playing positions might have different physical factors influencing their performance. According to Karcher & Buchheit (2014), wings perform the greatest amount of high-intensity runs (in line with Povoas et al., 2012), but receive and give the least number of contacts, and show the lowest physiological demands. Backs and pivots might be more dependent on HIE to be able to execute their position demands (feints, contacts etc.), while wings performance might be less dependent on such actions.

5.3 Methodological limitations and directions for further studies

5.3.1 Subjects and matches

Golden League matches are often played as weekend tournaments with a congested schedule. Previous research indicates that even 48 hours' rest is not sufficient to fully recover from intense team handball play (Ronglan et al., 2006), meaning that results in this study may not fully represent a championship match. The effect of fatigue from previous matches on both physical- and technical outcome is therefore unclear. For example, in the 2016 European championship, Norway's national women's team played 8 games in 13 days (EHF, 2017). Further studies on player- and team activity during intense match periods may be beneficial for improving PL management and performance in the course of tournaments. Also, since the Golden League is a friendly tournament, the team might substitute players more frequently than in a championship such as the European, World or Olympic championships.

5.3.2 Physical aspects

There were no measures performed for internal load, and a combination with external load would provide a more sensitive measure of demands (Carling, 2013; Dellaserra et al., 2014). Also, there were no measures performed for underlying mechanisms for fatigue.

As mentioned, the first 5-min period in this study is not necessarily the first period of the game. Consequently, finding high initial periods in this study does not necessarily translate to high initial periods at the start of a game, but it does possibly mean that players want to make an impact when entering the game. This is similar for the last 5-min periods; these periods might not be at the end of the second half, showing full game fatigue profiles, but can also be at the end of the first half, showing fatigue within halves. The fact that consecutive periods did not include the half time break is also a strength in this study, unlike previous studies where bouts of consecutive periods in the first and second half were combined (Wik, 2015). Also, the inclusion criteria of minimal 3 minutes playing time on court per 5-minute period, theoretically allows for 2 min rest time in each period, opposing fatigue. Lastly, players with one to seven periods of playing time were combined, hiding potential differences in pacing strategies. It would be interesting to investigate differences between halves in points and INV (physical outcome between halves has

already been investigated, Wik et al., 2016). Also, the conceding 5 min periods are collected independently of half. This might affect the results, since Wik et al. (2016) showed there are lower intensities in second half periods, compared to the corresponding periods in first half.

As mentioned, fatigue from previous matches would be relevant for practical application of the current results, since in international championships, games are played every other day. Players in junior rugby league have shown to pace their effort in order to enhance performance in a four-day tournament (Johnston et al., 2015), highlighting this issue.

5.3.3 Technical aspects

A major advantage in this study compared to other previous studies on handball is the addition of performance-related measures by the quantification of technical performance. As there previously have been no definitions of a threshold when fatigue affects performance, this study, and the grading system established, can provide a tool for assisting coaches when players might have reached that threshold. However, there are several modifications that would be advantageous to assess for further research: The reliability test showed good reliability for the main variables, except for the body-contact variable, meaning it was difficult to determine this variable during the technical analysis. A possibility for further analysis is to eliminate the body-contact points to obtain a better reliability score.

There are some issues concerning the grading system that have to be addressed. Mainly, the grading system measures indicators of performance but not performance itself. For example: Some playing positions are more involved in the game than others, and will potentially receive more positive or negative points than others. The question to be asked then is: does the system reward players that get by on just the "team registration" points rather than being involved in the game? And does this system reward players who don't shoot? Because if you don't shoot, you don't miss either, and players can collect positive points for assists and team points. For example, from some coaching perspectives, players should be rewarded for trying and taking responsibility in the game independent of outcome. Different coaching perspectives could result in different grading systems.

There are also some player-favouring factors involved. For example; pivots will almost never get assist points but they do screens to help team-mates in almost every attack. Also, players who hypothetically get a penalty shot in attack and take the penalty themselves will end up with the large total of five points after one attack. The main point is that the grading system should not try to compare between positions, but within positions or within individuals as game data over time.

Giving/receiving 2-min suspensions were graded for the individual player responsible, but the periods with a player up/down were not investigated further. This is something to consider for the future since the players on court will quite possibly be affected by the player deficit/abundance and their performance will possibly be worse or better. It would for example be interesting to investigate, if intensity increases due to the larger ratio of area per player (mainly in defence) when receiving a 2-min suspension, does the technical performance decrease in line with Duarte et al. (2009)'s study.

The results could alternatively be adjusted to the current scoring percentages for different playing positions in the technical analysis. Currently, in this study, a 6m shot is in fact a 6m shot independently if it is from the wing or from the middle of the 6m line. Most will argue that shooting from the wing is more difficult than shooting from the middle (Kovacs, 2016), resulting in the wings getting unfairly "punished" for missing a shot on goal, and not receiving the points they deserve when scoring a goal. The same goes for a fast-break 6m goal without body-contact compared to a 6m break-through goal in attack, where the latter incident requires much more technique by fainting past a defender and, making it even more difficult, most certainly having body contact.

The main goal for further investigation after this thesis could be to use the grading system to establish a threshold required for handball players to maintain overall performance, as it can be used as a tool for coaches to make tactical decisions based on real-time data, or for analysis after the game. This will create the ability to look for patterns on whole-team performance and individual performance.

6. Conclusion

In this study, physical and technical variables were examined, investigating for comparisons between these two types of variables. The following question was asked: is there a relationship between physical performance and technical performance in elite female handball players?

The findings in this study of high initial periods might suggest that players enter the game wanting to make an impact, and the fact that the intensity declines throughout might be due to pacing strategies. In the last bouts however, there is a decrease in both intensity and INV in the game compared to mean. This might suggest, although other studies suggest the opposite, that fatigue may affect technical performance during a half/game. It might also suggest that players might not involve themselves as much at the end of a half/game because of fatigue. The comparison on team levels between technical and physical variables suggest that technical INV in an elite handball game effect the physical variables ($PL \cdot min^{-1}$, HIE) in this study. Thus, appropriate rotation strategies may allow players to enhance the ability to perform at the required level when on court since $INV \cdot min^{-1}$ correlated largely negatively with field time.

There are differences between playing positions in the physical variables ($PL \cdot min^{-1}$ & $HIE \cdot min^{-1}$), with the backs showing higher $PL \cdot min^{-1}$ and $HIE \cdot min^{-1}$ than pivots and wings. The results between playing positions and technical differences are on the other hand unclear and requires more investigation. When comparing physical and technical performances for each playing position, the results show that, for all playing positions, most technical actions are HIE, suggesting a high pace in elite handball games. A higher amount of $HIE \cdot min^{-1}$ is correlated to a higher number of positive $points \cdot min^{-1}$ for backs and pivots, which may imply that the ability to perform high-intensity actions is a quality seen in high-level teams. Pivot players do much unappreciated work in attack in regards to the grading system, which must be considered for further studies.

The main focus for further investigation on this subject might be developing the grade system further, so that it can become a tool on technical performance for coaches in the future, either on real-time data or after-game analysis.

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Table summary

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Abbreviations

IMU/IMUs	Inertial Measurement Units
IMA	Inertial movement analysis
PL	Player Load^{TM}
HIE	High intensity events
INV	Involvements
Acc	Accelerations
Dec	Decelerations
CoD	Changes of direction
WECH	Women's European Championship Handball
7-m	7-meter penalty shot
6-m	6-meter shot
9-m	9-meter shot
ES	Effect size
CV	Confidence limits

Appendix

I   Approval of data storage

Norsk samfunnsvitenskapelig datatjeneste AS
NORWEGIAN SOCIAL SCIENCE DATA SERVICES

Matthew Spencer
Seksjon for fysisk prestasjonsevne Norges idrettshøgskole
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Vår dato: 02.09.2014   Vår ref: 39602 / 3 / LT   Deres dato: Deres ref:

TILBAKEMELDING PÅ MELDING OM BEHANDLING AV PERSONOPPLYSNINGER

Vi viser til melding om behandling av personopplysninger, mottatt 28.08.2014. Meldingen gjelder prosjektet:

39602	*Arbeidskravsanalyse av håndballspillere på nasjonalt/internasjonalt nivå - fysiske krav og taktiske profiler*
Behandlingsansvarlig	*Norges idrettshøgskole, ved institusjonens øverste leder*
Daglig ansvarlig	*Matthew Spencer*

Personvernombudet har vurdert prosjektet og finner at behandlingen av personopplysninger er meldepliktig i henhold til personopplysningsloven § 31. Behandlingen tilfredsstiller kravene i personopplysningsloven.

Personvernombudets vurdering forutsetter at prosjektet gjennomføres i tråd med opplysningene gitt i meldeskjemaet, korrespondanse med ombudet, ombudets kommentarer samt personopplysningsloven og helseregisterloven med forskrifter. Behandlingen av personopplysninger kan settes i gang.

Det gjøres oppmerksom på at det skal gis ny melding dersom behandlingen endres i forhold til de opplysninger som ligger til grunn for personvernombudets vurdering. Endringsmeldinger gis via et eget skjema, http://www.nsd.uib.no/personvern/meldeplikt/skjema.html. Det skal også gis melding etter tre år dersom prosjektet fortsatt pågår. Meldinger skal skje skriftlig til ombudet.

Personvernombudet har lagt ut opplysninger om prosjektet i en offentlig database, http://pvo.nsd.no/prosjekt.

Personvernombudet vil ved prosjektets avslutning, 31.12.2018, rette en henvendelse angående status for behandlingen av personopplysninger.

Vennlig hilsen

Katrine Utaaker Segadal

Lis Tenold

Kontaktperson: Lis Tenold tlf: 55 58 33 77
Vedlegg: Prosjektvurdering