Game-Related Statistics: Comparing and Predicting Winners and Losers in Handball and Beach Handball

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DOCTORAL THESIS

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Mentor:
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SUPERVISORS INFORMATION

Jose M. Saavedra is a sports science researcher who earned his PhD in 2002 in Spain. He has taught at various universities in Spain, Portugal, the United Kingdom, and Iceland for over 25 years. His main scientific interests are divided into two areas: On one hand, sports analysis, particularly performance analysis, and on the other, the effects of exercise on health in populations with certain pathologies. He has participated in over 100 conferences as an invited researcher, presenting oral communications and posters in different countries such as Spain, Portugal, Austria, France, Italy, Croatia, the Czech Republic, the UK, and the USA, among others. He has published more than 110 articles, which have been cited over 4,000 times. He has supervised 8 doctoral theses, over 35 master's theses, and 6 bachelor's theses.

Dr. Damir Sekulić is a tenured professor at the University of Split's Faculty of Kinesiology. Since 2014, he has published over 160 highly cited scientific papers, earning him a prominent reputation in sports science and kinesiology. Professionally, Dr. Sekulić has lectured internationally extensively and received numerous awards for his scientific contributions. He has led significant national research projects as principal investigator, including founded work on the measurement of change of direction speed and reactive agility. Recently, he has collaborated internationally on a research project investigating COVID-19's impact on fitness. A dedicated mentor, Dr. Sekulić has supervised 12 PhD students at several European universities, solidifying his status as a leading expert in kinesiology.

ACKNOWLEDGMENTS

After years of contemplating the implications and benefits of doing a PhD, I was happy to have officially begun this journey in spring 2022, knowing I had fantastic circumstances being a full-time staff member of the **Reykjavik University Sport Science department**. It was essential to have the support and encouragement to continue my professional development from my Head of department **dr. Hafrún Kristjánsdóttir,** for which I am very grateful. To my fellow members of staff, and my friends at the Sport Science department, I´m so lucky to belong to the "A-team." **Kristján Halldórsson, Hjalti Rúnar Oddsson, dr. Ásrún Matthíasdóttir, dr. Ingi Þór Einarsson**, **dr. Hugh Fullagar** and **dr. Peter O´Donoghue**, thank you for all the help and encouragement through the years.

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Thanks to my friends in the handball community, whom I have reached out to for their thoughts and opinions on the work on many occasions throughout the process. The coaching staff of Valur receives a special mention for their time in relation to work on *study 4*.

It was a great fortune for me to learn about and finally enrol in the international PhD program at the **Faculty of Kinesiology at the University of Split**. This program has proven to be a great platform for me to take the next step in my professional development. Having taught within academia for years, this program allowed me to develop my research skills. There are many reasons why I can wholeheartedly recommend the PhD program at Split. The staff at the Faculty of Kinesiology and my fellow PhD candidates have been a real pleasure for me to get acquainted with as they invited a welcoming atmosphere.

Special thanks go to **dr. Damir Sekulic**, my second supervisor, for a great and rewarding collaboration during my studies. Thank you for trusting in me, for the guidance and warm welcome in my visits to Croatia. These visits offered real opportunities to extent my professional network, which I am confident will be fruitful in the future.

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ABSTRACT

This dissertation explores performance indicators differentiating and discriminating winning and losing teams from official sets of game-related statistics in handball and beach handball. The research comprises four primary studies, each contributing to the use of game-related statistics in a specific performance context.

The *Study 1* examined sex-based differences in game-related statistics between winning and losing teams in an amateur (hereafter semi-professional) handball league. Performance indicators were selected by predictive models for males (five variables) and females (two variables) from an entire season of statistics, tested for reliability. The findings suggest that special attention should be given to the goalkeeper's performance and overall shooting efficiency. The sexes differed in terms of moderate effect size (d>0.5), 9 m shot efficiency, red cards, 2-minute exclusions, and technical fouls.

The *Study 2* delved into the final ten minutes of balanced handball games, investigating the factors that discriminate winners from losers during this critical period. The analysis revealed that winning male teams exhibit better shooting efficiency (d=1.114), goalkeepers 9 m saves efficiency (d=1.100), total saves efficiency (d=0.827) and 9 m shots efficiency (d=0.875) with large effect sizes. Results for females identified shots (d=1.414), GB save efficiency (d=1.330), 9 m shot (d=0.933), and GB 9 m save efficiency (d=0.923). The discriminatory model for males selected only technical fouls and 9m shots with 40.4% correct classification. In conclusion, the authors argue that special attention should be paid to 9 m shots in the final minutes due to teams adapting to the high pressure, fatigue, and tactical constraints, possibly by playing more passively.

The *Study 3* focused on performance profiling in handball, using discriminative variables to develop a performance profile for one successful team using the most impactful performance indicators. The profiles were based on the team´s game-related statistics of the previous five years and split according to opponents' quality. The two profiles against other

TOP4 and lower-ranked teams differed, indicating different interactions based on opposition quality. These profiles can aid coaches by identifying current team performance characteristics and areas for improvement.

The *Study 4* shifted the focus to women's beach handball, comparing game-related statistics between winning and losing teams at the elite international level. Although beach handball has unique sports characteristics, the game principles are comparable to indoor handball, which invites a similar approach to game-related statistics. The findings emphasize that the official data was reliable and performance could be discriminated with 80.6% accuracy using the overall valuation index and GB saves efficiency.

The cross-paper synthesis of the findings produced overarching themes related to the steps of using the data. Reliable and valid data collection is fundamental for accurate performance analysis. Selecting appropriate performance indicators based on the context is crucial to inform coaches in developing practical training and match strategies. Creating performance profiles can be a valuable tool to enhance individual and team performance. The dissertation also discusses the limitations of the studies, such as sample size constraints and the variability of game conditions. Future research directions include theoretically guided exploration of the processes behind the game-related statistical events recorded with advanced statistical methods. Moreover, to investigate the applicability of the findings to different levels of competition and other team sports.

In conclusion, this dissertation contributes to understanding of performance analysis in handball and beach handball by identifying key performance indicators and demonstrating their practical applications. The findings provide valuable insights for coaches, analysts, and researchers aiming to improve performance outcomes in these sports.

Keywords: Performance indicators, profiles, ecological dynamics, discriminative analysis, predictive models, situational variables

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Introduction

1.1 Background and motivation

Given how deep the Icelandic handball roots are, it was only natural to an eight-year-old me for Iceland to host the World Championships in 1995. Icelanders closely follow their handball national teams and take great pride in our ability to punch well above our "*per capita*" weight in this sport. The silver medal won at the 2008 Olympics is considered a breakthrough for the following success in team sport in Iceland, instilling a belief that a nation of 350 thousand could reach international success (Halldorsson, 2017). The male team has a strong following in Icelandic society, topping the charts for televised sports in Iceland, with nine out of ten events being international handball matches and up to 50% live viewership (Sigurbjörnsson, 2023). Almost every player selected for the national team has broken through in the Icelandic semi-professional league with outstanding performances before moving abroad. Although the league has elements of amateurism, it will be referred to as semi-professional in this thesis as the author deems it more fitting. The male national team has a long series of consecutive qualifications for major championships. Lately, the females have qualified for the last European championship (2024) and competed at the IHF World Championships (2023). This success can be attributed to a handball community of less than 8000 participants nationwide, male and female, youth and seniors combined (Atlason, 2023).

I have been involved in several roles in the Icelandic handball community for three decades. First, by playing at youth levels with my local club, Fjölnir and then at senior level for 13 years, along with coaching and organizing. I guess there was a shortage of coaches at a critical time in Fjölnir handball that resulted in me, and my friends started coaching 10- and 11-year-old players at the age of 17. Due to our inexperience, the duties of a coach were split between us, as well as the salary.

Lately, I have been taking on new roles as a sporting parent, club board member and finally, as a researcher in handball. Handball can be an attractive sport, for there is always

something new to try, learn and experiment with. Even though the fundamental aim remains the same, the game's dynamics are constantly changing, and so are we. The experience of being immersed in the activity and forgetting all else during training and competition has been a welcomed distraction from everyday work in my life. I am very grateful for my 16 years in senior handball in Iceland, during which time I was able to have a dual career with my studies and later professional teaching. I can honestly say that I have thoroughly enjoyed the ride with my teammates over the years through highs and lows.

I have seen how youngsters can develop and thrive in a semi-professional environment after earning their place in a senior first team. Historically, the Icelandic league has been a stepping stone for promising players who can take the next step in Scandinavia, continental Europe or even the German Bundesliga. Given the sporting context of Iceland, where many handball teams are located within a small radius of the Reykjavik Capital area, international success has been rare given the stiff competition and professional opposition. However, earlier this year, the Valur males' team was crowned EHF´s European Cup champions, the first European title earned by an Icelandic club.

In 2014, I became a permanent staff member at Reykjavik University, working in parallel with a secondary school teacher/project manager of a sports academy program at Borgarholtsskóli. The Sport Science department grew in academic strength with added research emphasis underscored by the recruitment of my to-be supervisor and the establishment of the PAPESH (Physical Activity, Physical Education, Health and Sport Research Centre) research center. It aligned well with my intentions to do a PhD and take part in publishing papers in collaboration with my colleagues. I have worked on several studies in the field of handball and performance analysis concerning handedness (Laxdal et al., 2023; Laxdal, Ivarsson, Thorgeirsson, et al., 2022) and game-related statistics from the Olympics (Saavedra et al., 2017; Saavedra, Þorgeirsson, Chang, et al., 2018). In addition to handball performance analysis

topics, other papers include training load (Saavedra, Þorgeirsson, Kristjánsdóttir, et al., 2018), physical performance and anthropometry (Saavedra, Kristjánsdóttir, et al., 2018).

My role as a handball researcher officially began on the 1st of April 2022 by starting my PhD studies. The decision regarding the doctoral study was easy to make once the opportunity came for the PhD. The program at Split University was presented to me by my colleague and mentor, dr. Jose Saavedra. In the years leading up to my enrolment in the Split PhD program, I had been teaching courses in motor learning and development. While preparing for teaching, I became interested in the ecological dynamics framework. I realized the value and potential of the ecological approach and theories of dynamic systems in explaining human movement and behaviour. This led me to explore this further and dive profoundly into the existing literature regarding this framework, as it required me to renew my understanding of the nature of human movement, accompanied by new theoretical concepts and vocabulary. This work has deeply influenced my thinking and certainly relates directly to the field of performance analysis.

1.2 General study objectives

This research has provided valuable insights into the local handball community by focusing on Icelandic semi-professional handball. A considerable statistical strength comes from analysing whole seasons of male and female league play. The beach handball is an emerging sport with growing research interest. Generally, this research will present findings using discriminative analysis methods, presenting a novelty in semi-professional handball. These statistical methods have been used in several papers before in sports science (Escalante et al., 2012; Vaz et al., 2011), although limited in handball and even less in beach handball (Lemos et al., 2020).

1.2.1 PhD. study objectives

The objectives of this PhD thesis were to:

i) Analyse differences, and discriminative factors behind winning teams compared to losers for males and females in semi-professional handball and beach handball

ii) Analyse differences between the match play of males and females in game-related statistics

1.3 Individual study objectives

1.3.1 Study 1

The objectives of *study 1* were to:

i) to compare handball game-related statistics by match result (winning and losing teams) for the men's and women's teams in an amateur league

ii) to compare handball game-related statistics by gender

iii) to identify characteristics that discriminated performance in amateur men's and women's handball leagues.

1.3.2 Study 2

The objectives of *study 2* were to:

i) Analyse statistical differences between winners and losers in male and female top Icelandic handball leagues

ii) Calculate a discriminating model for performance variables for both male and female top Icelandic handball leagues.

1.3.3 Study 3

The objectives of *study 3* were to:

i) Create a performance profile of one selected team's performances (TEAM) based on performance indicators from a discriminative analysis. Specifically, by analysing the performance of one successful female team using discriminative analysis of the game-related statistics from five successive seasons (2018/19 - 2022/23).

1.3.4 Study 4

The objectives of *study 4* were to:

i) to compare beach handball game-related statistics by a match outcome (winning and losing teams)

ii) to identify characteristics that discriminate performances in a match.

1.4 Significance of the study

Performance analysis represents a field in sports science that coaches and players are familiar with and recognize to be helpful if cost and time barriers can be broken. Today, most of the research in performance analysis in handball is in the context of elite and international levels. This is perhaps the result of the availability of resources that accompany high-performance sports as opposed to lower levels. However, amateur and semi-professional sports are the grassroots for professional and international sports like handball and beach handball. Therefore, it is relevant to research this performance level to learn how the play differs across performance levels. With abundant outcome statistics available, semi-professional coaches could gain insights from research into which variables are the most important at their respective levels. This research aims to provide the practitioners of handball coaching and users of game-related statistics with several approaches for using statistics. These studies establish some of the first published works on a locally significant sport and performance level, providing baseline, validation, and unique perspectives about the use and limitations of game-related statistics. The studies can collectively inform coaches about the current statistics collected with several applications while discussing its limitations.

Study 1 provided an external review of the reliability of the statistics, further comparing the differences and producing discriminatory models for winning and losing teams of male and female and sexes differences. *Study 2* attempted to investigate the final minutes of balanced games at the semi-professional level, providing another set of variables discriminatory for

males but, unfortunately, not females. *Study 3* capitalized on the five years of accumulated data to create the first performance profile in female handball using discriminatory analysis for one successful team. Finally, *study 4* was the first to the author's knowledge to analyse performance using the discriminative analysis method in beach handball at the elite level with data from the 2018 World Championship.

2 Literature review

2.1 Handball and beach handball

2.1.1 Modern handball and the beach handball spin-off

Handball

With origins dating back centuries, the modern 7-a-side indoor team handball [handball] was developed in Germany and Denmark in the early 1900s. Handball became a competitive event for males in 1972 in Munich, and in 1976 in Montreal for females, and it has been featured in every game since. Beach handball was developed in south Italy in the 1980s due to the lack of indoor sports halls for handball, with its first official tournament in 1992. In 1994, beach handball was recognised and adopted by the International Handball Federation (IHF), the world's governing federation for handball, established in 1946 (*IHF | The International Handball Federation – Timeline of Milestones*, 2020).

Beach handball

In the last few decades, handball and beach handball rules have been modified to entertain spectators with the game pace while protecting players' health. The rules of the game undergo regular revision and changes by the governing bodies. Drawing on the similarities between handball and beach handball, the main objective is scoring goals by throwing the ball into a goal past the opposition defense and goalkeeper. Most notably the time playing format (playing time and the number of on-field players), the playing surface (sand vs. indoor) and the scoring system (1-2 points vs one goal) (*IX. Rules of the Game a) Indoor Handball*, 2022; *IX. Rules of the Game b) Beach Handball*, 2021; *IX. Rules of the Game b) Beach Handball*, 2021).

In handball, two rule changes have stood out since the millennia, and they have arguably changed the sport at a fundamental level. The rapid restart increased the game tempo, allowing teams to charge into attack right after conceding a goal. Second was when the obligation to identify a goalkeeper was removed in 2014. This resulted in many teams adopting

the empty net tactic at the risk of conceding a goal from across the court by playing with the goalkeeper as an extra offense player. This tactic has been used during equal numbers and 2-minute suspensions to support the team's attack phase. In beach handball, suspensions are directed against the individual player, so the total number of players remains balanced on the court. However, the goalkeeper is especially incentivised to join the offense as the *"specialist*" scoring counts for two points. The other players score one point per goal, unless it is a spin shot goal or an in-flight goal rewarding two points each (*IX. Rules of the Game b) (Beach Handball*, 2021).

Both sports have received growing research interest in recent years. The state of handball research was discussed in an editorial of a special issue about research in handball in the Journal of Human Kinetics. In 2018, the all-time number of studies with handball as the primary topic was 629, roughly 40% of the total in the previous five years, indicating a rise in interest (Saavedra, 2018). Almost 13% of these papers were related to performance analysis. Beach handball literature is minor in comparison, with no similar review articles available to date to the author's knowledge.

2.1.2 Characteristics of play

Handball

At a highly competitive level, handball players must possess specific physical characteristics to take full advantage of the intermittent, dynamic, fast game play featured in handball and beach handball. Physical, tactical and technical attributes are sport and position-specific and constrained by sex, highlighting the specificity of each position in both sports within the team dynamics. There is consensus that handball performance is multifactorial and, therefore, deserves a multifactorial approach (Massuça & Fragoso, 2013) at individual and team levels with subtopics including coordination, stamina, strength and mental factors (Wagner et al., 2014). Similarly, the main physical demands observed in beach handball include sprinting,

jumping and changes of direction (Gómez-Carmona et al., 2020). In handball, players switch rapidly between four phases of play with different sub-objectives in organised offense and defense and the transition to offense and back to defense (Fasold, 2021). Within this fast rhythm of back-and-forth possession, teams can build scoring momentum, fuelled by turnovers (Mortimer & Burt, 2014), where the predicted scoring chances of elite teams can range between 0% and 100% (Russomanno et al., 2021). A similar model has been suggested for beach handball with alternating defenses in numerical inferiority transitioning to offenses in numerical superiority (Modolo et al., 2022).

Throwing hard, jumping high and running fast are among the top physical qualities of a handball player. Success is, however, determined by many more factors, ranging from individual skills and psychological qualities to team coordination and adaptability (Wagner et al., 2014). Players have their individual anthropometrical and physical capacities that predispose them to selection into different roles within the team and subsequently to receive position-specific training stimuli (Hermassi et al., 2019). Endurance capacity has been especially highlighted as a discriminating variable between positions and performance levels (Massuca et al., 2015), along with experience (Almeida et al., 2020; Granados et al., 2013) and age (Saavedra, Kristjánsdóttir, et al., 2018), especially for international female competitions (Granados et al., 2013; Manchado et al., 2013). On the court, the best teams have taller players with better 9m and wing shot efficiency and more blocks by the defense (Almeida et al., 2020). Furthermore, elite players are taller and leaner, which gives them an advantage in full-body contact sports such as handball. In preparation for competition, strength and power training is recommended to facilitate throwing and sprint performance (Manchado et al., 2013), which has also been shown to discriminate between performance levels and more sport-specific movement skills (Čavala & Katić, 2010). According to a recent review of 17 studies, primarily male (89%), players cover greater distances in national competitions than in international (García-Sánchez et al., 2023).

Beach handball

Beach handball requires specific training to induce sport-specific adaptation, preferably on the sand (de Villarreal et al., 2023). Compared to indoor handball, beach handball is less physically demanding per game due to smaller court size, softer playing surface, and fewer players involved (Mancha-Triguero et al., 2020). However, in other studies, beach handball players have exhibited similar grip strength and higher throwing velocity than team handball players (Ortega Becerra et al., 2018). Major championships in handball take about three weeks with playoffs and rest days, while beach handball tournaments are shorter and scheduled without rest days with up to two matches on the same day (*IX. Rules of the Game a) Indoor Handball*, 2022; *IX. Rules of the Game b) Beach Handball*, 2021).

The decisive game actions are performed intermittently with moderate to high intensity on the sandy surface during the match, with extended periods of lower intensity in between (Pueo et al., 2017). It has been underscored in recent research that superior performance in long jump ability and sport-specific skill throwing discriminate elite from sub-elite for both sexes (Lemos et al., 2020). However, another recent research has reported mixed results from physical testing of sprinting and throwing, which might indicate that throwing hard and jumping high might not indicate elite status (Sánchez-Malia et al., 2022). Similar to other intermittent sports, female beach handball players have been found to cover about half of the total distance at low speed (1.5-5 km/h), while 30% is performed at high speed (9-13 km/h) resulting in a high internal load (>80% of HR max) for more than 62% of the time (Sánchez-Sáez et al., 2021). Similar results have been recorded for males for distance covered and internal load. While moving about the court, players can expect to accelerate every 23 s and 27 s (male and female players) (Pueo et al., 2017). However, the distance covered per minute of play is about the same between the sports (Pueo et al., 2017).

2.1.3 Position specific requirements

Handball

The handball position-specific physical requirements have been established in several researches generally showing differences by performance levels (Hermassi et al., 2019), anthropometric (Vila et al., 2012), physical (Krüger et al., 2014) and sport-specific skill performance (Foretic et al., 2022). Overall, sex differences in physical performance and the need for specialized training have been advocated (Karcher & Buchheit, 2014) but also challenged (Bøgild et al., 2020). The back players are on the left and right of the goal, with one center in the middle. Backs and wings cover longer distances and more meters per second during games than pivots and are more occupied in body contact. Backs throw more than pivots, and wings, in turn, perform more fast breaks than backs (García-Sánchez et al., 2023). At the elite international club level, male wing players performed more high intense actions in offense and center-backs in defense (Manchado et al., 2020). The left and right wings play close to the sideline and usually stay deep during positional offense, close to the end line. Wings tend to be the fastest players sprinting (Čavala & Katić, 2010), lowest in stature (Sporiš et al., 2010) and the lightest (Krüger et al., 2014). Pivots play inside the opponent's defense, fighting more duels and contacts than other positions (Michalsik et al., 2011). They are generally taller and heavier than wings and backs (Krüger et al., 2014), which can be beneficial given their role in creating space inside and through the defense for their teammates.

Goalkeepers perform a unique role of guarding the goal inside the 6m goal area using the whole body with bursts of explosive movements to stop shots arriving from different angles and distances at varying speeds. Goalkeepers have different anthropometry and physical performance profiles (Sporiš et al., 2010) than other positions. Given the many influencing constraints, their shot-stopping skill depends on their ability to perceive specific cues and act accordingly (Huesmann et al., 2022). The save efficiency ability of the goalkeepers can make a crucial difference in the team's final ranking (Hatzimanouil, 2020; Hatzimanouil et al., 2022).

Goalkeepers also play an offensive role in transitioning from defense to offense, with opportunities for fast breaks or shots into empty net (J. N. Prudente et al., 2022). The difference in the role of the goalkeeper compared to other players is a cause for a specific analysis of performance (Fasold, 2021).

Beach handball

Sport-specific skills like spin and in-flight shots, combined with making fewer technical faults and more defensive blocks, significantly differ between winners and defeated teams in beach handball (Gruić et al., 2011). Just like other sports, knowing the position-specific requirements in beach handball helps optimize sports performance and guide talent identification as well as help with preventing injuries (Pueo et al., 2020), especially given the positional specificity of player external load (Müller et al., 2022). The positions on the beach handball court include the pivots and defenders as back players, and wing, fixed wing and the specialist (front players) whose goals count for two points and substitutes for the goalkeeper in defense (Zapardiel & Asín-Izquierdo, 2020). Research has shown male pivots and defenders to be taller, heavier, and have a longer arm span than wings and specialists. The position of goalkeepers is unique to beach handball, given their transition to the specialist in the offense, awarding them two points per goal. Their position in attack is usually in the center, where the most goals are scored, but sometimes placed on the wing, close to the substitution area (Hatzimanouil et al., 2020). The offensive role of the goalkeeper in creating numerical supremacy and scoring a two-pointer as a specialist becomes a top priority defensively to counter (Gilio et al., 2021). The similarities observed between the sports players are somewhat expected as many elite beach handball players are indoor handball players in transitioning between sports (Eils et al., 2022).

2.1.4 Sex differences

Handball

Anthropometrics of male and female handball players show males to be heavier and taller. Physically, males are stronger, more powerful with better endurance capacity, but the gap between sexes is relatively smaller in team handball-specific tests (Wagner et al., 2019). However, the importance of female anthropometrics in elite handball has been questioned as it was not found to be a performance indicator like male handball. Common characteristics between females and males were the player's age, experience, and individual and team scoring efficiency (Noutsos et al., 2018). Female players have been found to cover greater distances per match than male players, suggesting a different playing style (García-Sánchez et al., 2023; Michalsik & Aagaard, 2014) considering full match load. This is perhaps not surprising as females have been found to train at a higher relative workload than males. However, males perform more high-intensity sprints, technical actions, and activity changes per match and receive more tackles in attack and defense than females (Michalsik & Aagaard, 2014).

Beach handball

In beach handball, the differences in playing style and workload (Gómez-Carmona et al., 2020) between the sexes must be considered regarding the male's physical superiority on physical fitness tests (Lemos et al., 2020) and body size (Gómez-Carmona et al., 2020). Elite beach handball teams have also been reported to display higher values for running distance, accelerations, and PlayerLoad when winning the segment compared to losing in both female and male play (Zapardiel et al., 2023). Male beach handball players have larger body frames than females with higher body fat percentage (Pueo et al., 2020). A recent study showed that male teams throw and score a spectacular goal worth two points more often than females. However, the sexes share frequent changes in ball possession characteristics in beach handball, with attack phases dominating defense (Modolo et al., 2022). Evidence suggests that the

decision-making in the finalization of attacks differs according to sex (Vázquez-Diz et al., 2019b). Females direct the finalization of positional attacks more into in-flight shots and the role of the specialist. The males, however, opted more for the spin shot when trailing in score against an open defense, as well as relying on the pivot (Navarro et al., 2018). Females spend longer (29.2% of the) playing time in high-intensity zone (81-90% of HRmax), longer than males (20.3%) (Pueo et al., 2017). One research tested whether there was a difference in shooting between sexes in the late stages of one tournament but found no indication (Iannaccone et al., 2020).

2.2 Performance analysis and team sports

The interest in valid and reliable key performance indicators for coaches to use persists, although their use has been rightfully questioned. The stability of available performance indicators has been questioned, given team sport's dynamic and complex nature. Limitations in the data collection process, such as human error and the reductionist nature of outcome statistics, are inbuilt (Morgulev & Lebed, 2024). Performance analysis is a relatively young discipline within sports science (O'Donoghue, 2015), and it is grounded in a systematic approach to collecting data regarding performance, technical skills, decision-making making and tactical approaches in any given sport to improve the athletes and teams (Cullinane et al., 2024).

Most modern sports coaches use performance analysis of their choosing to support their decision-making. These methods include game video analysis of their team's performance and the opponents, such as specific events, tactics or players (Cuevas et al., 2020). Data is collected at an unprecedented rate, largely thanks to advancements in automated data-capturing techniques. Data about game-related statistics, physiological load, physical load and on-court performance is available live and in abundance. The process can generally be categorized as describing, planning and monitoring external loads to support decision-making (Torres-Ronda

et al., 2022). On top of these capabilities, artificial intelligence is entering mainstream use with enormous potential to help sports performance analysts work. Still, producing meaningful information from information systems capturing isolated facets of complex dynamic events remains challenging and requires expertise (Vurgun et al., 2023). Therefore, critical thinking, skepticism, and a theoretical framework have been advocated (Torres-Ronda et al., 2022).

Parallel to great technical leaps in data collection, methods have been devised to support the coaching process in training to enhance performance in competition (Lord, 2020). It depends on the aim, context, and available resources who takes on the performance analysis. In recent research in football, the desire to have a devoted performance analyst on the team was clearly expressed while noting cost and time as the main barriers. Coaches with more experience in doing performance analysis and higher coaching degrees regarded this work as more important than lower-ranked coaches with less experience (Andersen et al., 2022). The analyst's role is to inform the coach in the most practical way possible by analysing the data regarding key performance indicators (Wright et al., 2013). Ultimately, the coach's professional philosophy influences which variables will be considered key performance indicators. The outcome of the analysis can be used to inform coaches in short and long-term planning (Wright et al., 2013).

Everything from a single coach to a team of specialists supporting the coaching staff. The performance analyst's role is to support the coach's decision-making by analysing the available data and providing meaningful information regarding individual athlete or team performance in collaboration with the coach. However, the information provided should inform the decision-making process instead of driving the coaching process, with the coach taking ultimate responsibility (Araújo et al., 2021). Performance analysis using statistics is undertaken by recording the variables of interest during an actual sport competition.

2.2.1 Theoretical perspective to team performance analysis

How can coaches find meaningful information in the big data era if they do not know what they are looking for? Information systems should be carefully designed and based on explicit models for each sport and avoid assuming that all current data collection is relevant and informative (Passos, 2016). Theoretical insights can support researchers and practitioners in searching for meaningful information from which to guide data explorations. Several models and frameworks have been suggested to build upon the understanding of data collected with notational analysis (systematic). These data collection systems should be explicitly designed to fit the needs of the sport (Torres-Ronda et al., 2022). Adopting the contemporary conceptualization of skill, expertise and talent requires coaches to shift their view of how coaches work, not as providers of solutions but as learning designers (Woods et al., 2020). This can be beneficial to coaches for broadening their perspective of technical, tactical and physical components of training and performance, supporting learning and creating appropriate strategies (Balague et al., 2013). To advance the scientific field of performance analysis, a common theoretical framework is required to direct the effort and attention of research with reference to a shared understanding of the problem.

2.2.2 Team sports are dynamic, complex, and adaptive

The most prevalent contemporary theoretical framework promoted within performance analysis is the ecological dynamics framework (Araújo et al., 2021; O'Donoghue & Sampaio, 2015; Passos, 2016). It combines dynamical systems theories with the ecological perspective, forming a holistic view of human movement behaviours' complex and dynamic process. Individual movement and the synchronization of teams in dyads with opponents are described as complex and dynamic, requiring continuous adaptation to changes. This model has helped give an overall account of the task complexity by unveiling underlying principles affecting performance (Araújo et al., 2006, 2023; Vilar et al., 2012). The applicability of incorporating

theory into performance analysis is not limited to research. It has also been suggested for coaches to hold the potential to transform their understanding and thus practice from training isolated facets of performance to synergizing the process. By synergy, the team is viewed as one unit of a complex system in a dynamic environment (Pol et al., 2020). Finally, the future of coaching requires skills in different domains to direct the training process, so a holistic approach is warranted. It includes the integration of scientific theory, using the abundance of data with valid research methods of words and numbers put into practice with proper pedagogy (Passos, 2016).

The ecological dynamics framework is comprised of several key pillars. First, it considers movement as emergent under constraints and, therefore, the athlete in the environment as the smallest relevant unit of analysis. Second is the non-linear behaviour of the dynamical system exemplified by the disproportional relationship between input and output in a system. Third is adaptability and attunement to the changing affordances of athletes and teams enabled by the movement systems variability (Seifert et al., 2018). A key element of the framework is the theory of constraints on the dynamical systems embodied in the athletes themselves and their teams (Newell, 1986). The theory provides an overall account of the constraints affecting performance at each moment through different levels and timescales. In sports, the constraints affecting human performance are derived from the individual's cognitive and physical capabilities, social and physical structures in the environment and the task's objectives, rules and equipment. Knowledge about constraints and how to manipulate them in practice to design a more task-representative training environment has produced a pedagogical approach called the Constraints-led approach (Renshaw et al., 2019).

The coupling of perception and action and the premise that the two should be viewed as "*interwoven*" and thus examined in the context of each other represents another critical idea of ecological dynamics (Kelso, 1982). Each athlete is exposed to a stream of affordances to attune to, specifying information in the environment as invitations to move (Gibson, 2014). For

each individual, there exists a landscape of affordances that can be perceived according to each individual's capacities (Rietveld & Kiverstein, 2014). The process of selecting one movement solution out of many viable has been termed degeneracy (Edelman & Gally, 2001). The holistic view of athletes in the performance environment is the smallest relevant scale of analysis. The two cannot be separated as the athlete has to perceive to act and act to perceive. Here, movement is conceptualized as emergent within the informational and physical constraints imposed in the performance environment. This starkly contrasts the traditional view of movement being controlled (Davids et al., 1994). Instead, systems display a self-organizing tendency, constantly developing under everchanging constraints (Duarte et al., 2012; Riley et al., 2012). Ecological dynamics is a contemporary framework used to interpret human movements and behaviour. It can help explain why the results of teams facing the same opponents will be different each time. This perspective can help the performance analysts achieve their objective of helping how and why players organize and move during performances (Travassos et al., 2013).

Theoretically, self-organization, shared affordances, and perception-action coupling concepts are critical to understanding team behaviour (Buekers et al., 2020). As dynamic and complex units, teams exhibit self-organizing system behaviour where patterns and coordination can be detected at the attacker-defender and team levels. A critical characteristic of self-organization is continuous adaptation to small and large changes in the system without central command. Therefore, play patterns can be found under certain conditions and are lost to changes in the system (Button, 2021). A key component in the organization of coordinated movement of individuals is the concept of shared affordances, which accounts for players perceiving the invitations for action presented by the environment for other players. In team sport, this would include a player with the ball perceiving a teammate in an optimal goal-scoring position and providing an assisting pass. Game objectives are an important task constraint, directing team behaviour to score goals and defend their own. The team’s

coordinated behaviour is facilitated by the shared affordances of players who perceive each other's options for movement and action. This information perceived leads to inter-player coordination (Silva et al., 2013).

2.2.3 Theory, handball and beach handball

Team sport is a challenging topic to analyse from a holistic point of view for all the ongoing interactions between players and opponents during games. The outcome may be the same, but the way the match played out has infinite variations. Therefore, it is important to consider not only the outcome or the player with the ball but also the process and movements of the opponents without the ball (McGarry, 2009). Using a model to describe the game phases and the fast-changing tasks (Fasold, 2021) during the game according to ball possession can provide a helpful structure. In handball, the game can be split into four phases, including offense, defense and the transition in both directions (Fasold, 2021), a model that could work for similar sports like beach handball. However, a more nuanced understanding of attack and defense may allow us to see a defending team without possession on the offense, pressing and attacking the opposition's space and ball. Therefore, the phases of defense and offense may be more appropriate (Mateus, 2005).

Figure 1.
Game phase and game task model of handball by Fasold (2021).

				Primary Task	
Possession of ball		Game Phases		Player	Goalkeeper
No	Goalkeeper	Defense		Reconquering ball	Save
Yes		Offense		Scoring	Substitution for additional players
No		Transition	offensive to defensive	Reconquering ball	Save
Yes			defensive to offensive	Scoring	Game Opening

To date, a limited number of studies have been guided by the tenets of the ecological dynamics framework. Their topics of interest vary greatly, although they commonly seek to explore the play process, usually by advanced statistical methods and calculations. These researches include how teams exhibit adaptive behaviour in handball scoring (Prieto et al., 2016), self-organization in beach handball play (Modolo et al., 2022), and prediction of action positions in team handball by nonlinear hybrid neural networks (Hassan et al., 2017). Theory has also been used in studies about tactical decision-making in specific situations (Nicolosi et al., 2023), variables associated with success (Font et al., 2022), presence of goalkeepers for throwing accuracy and velocity (García et al., 2017) and the dynamic interaction of the handball center players (Flores Rodríguez & Anguera, 2018). Newell´s ideas of constraints have supported several research papers investigating the setup of training tasks. Small-sided games and manipulation of task constraints like court size and the number of players on the internal and external training load (Clemente & Rocha, 2012).

In an applied setting, the foundations of the Ecological dynamics framework have been used to form Non-linear pedagogy for practitioners to build on theory (Chow et al., 2016). One early study explored the effects of differential learning methods inspired by ecological perspectives on throwing velocity compared to traditional training (Wagner & Müller, 2008).

A second, more recent study in Spanish explored the effects of constraints manipulation of Non-linear pedagogy in handball (Flores Rodríguez & Ramírez Macías, 2021).

2.3 Performance analysis in handball and beach handball

2.3.1 Computerized notational analysis

Notational analysis is the systematic registration of match events, which was historically done manually but now using computers during the event or with a video recording post-match. The access and use of live game-related statistics have become a standard in the buisness of sports media coverage, with video telestrations allowing more depth and visualizations to enhance the viewer's experience (Cullinane et al., 2024). Efficiency percentage and frequency of discrete events are a common expression of game-related statistics for specific actions like shots and tackles (Hughes & Bartlett, 2002). Coaches have traditionally manually collected basic performance descriptors to support decisions (Hughes & Bartlett, 2002). This is a practical method, but only considering the outcome has been criticized in the past for not addressing the dynamic process behind the outcome (Prieto et al., 2015a). The sophistication of the collection and process is advancing fast with the emergence of live reporting and artificial intelligence (Marquina et al., 2023). In a review paper from 2015, only 25 papers were included, focussing on tactical and technical factors. It describes how the static perspective has been studied far more than the dynamic perspective, which requires more effort and advanced approaches. The review further recommends researching the defensive profile, national leagues and international club competitions, female studies, and including situational variables and considering critical events (Prieto et al., 2015a).

Handball has received considerable research interest in recent years. In a review article looking into performance analysis of team-invasion sports from late 1997 to 2019, 43 titles were found related to handball, only surpassed by soccer, basketball and rugby union. The published output was categorized into six subcategories: Game styles, social network analysis,

collective team behaviours, movement patterns, dynamic game actions and game actions. No research was found related to the first three categories, while most fell under dynamic game actions (n=19), game actions (n=13) and movement patterns (n=11) (Lord et al., 2020). The literature is growing in relation to beach handball, but a synthesis of the existing knowledge has not yet produced a review paper specifically on the sport to the author's knowledge. In recent years, beach handball studies have been published on several different topics, like physical performance profiles (Lemos et al., 2020; Martínez-Rodríguez et al., 2022; Müller et al., 2022), by positions (Pueo et al., 2020), throwing (Sánchez-Malia et al., 2022), game phase (Gilio et al., 2021; Navarro et al., 2018) and theoretical framework (Modolo et al., 2022). Moreover, output concerned with game-related statistics from major tournaments (Iannaccone et al., 2020; Medeiros et al., 2017; Saavedra et al., 2019) is presented regularly.

2.3.2 Game related statistics

Handball performance is subject to numerous dynamic and interactive factors requiring a multidisciplinary approach (Massuça & Fragoso, 2013). The key to informing coaches practice is to reduce the data noise with a concise report on the team's performance. Several methods exist to select the most important variables from the bulk. These methods include neural networks, multiple regression, correlations, binary logistic regression, principal component analysis, and discriminant function analysis (O'Donoghue, 2010). Discriminant analysis has been used to analyse data from several disciplines to understand and predict performance. It has been widely used for years in different sports like water polo (Escalante et al., 2012), rugby (Vaz et al., 2011), basketball (Sampaio et al., 2006), and football (Lago-Peñas et al., 2010) to discriminate between performance levels, positions and for talent identification (Fernández-Romero et al., 2016) based on performance data.

Since the millennia, there has been a rise in research output relating to performance analysis in team sport with different methods as technology has advanced. Studies using game-

related statistics have been one of the major topics in the past, contributing to about half of the published papers. Recently, intriguing new research themes have emerged, including game styles exploring the processes behind the outcome (Lord et al., 2020). This trend has been observed for some time now, with more emphasis placed on dynamic and complex analysis to gain a deeper understanding, as opposed to the retrospective analysis of the statistics (O'Donoghue, 2009). This development should come as no surprise since the incentive for sports clubs and companies to gain insights and predict winning performances is highly valuable, especially in the sports betting sector (Araújo et al., 2021).

2.3.3 Limitations in the use of game-related statistics

Numerous methods exist to help simplify data derived from team invasion sports' complex and dynamic nature (Lord et al., 2020). Commonly, performance analysis in handball has primarily focused on the offense, where shots, saves, and goals can be objectively assessed without expertise. In that sense, specific information about players positioning and playing style requires expertise but may enhance future analysis (Travassos et al., 2013). In a systematic review of performance analysis in handball, four themes emerged: shots from different positions, distances from the goal, and varying situations in the game. Differences between winning and losing, the significance of team time-outs and match location (W. R. Ferrari et al., 2019). Based on this review (2019), the authors identified gaps in the literature for future research. The first was to extend the comparison of winning teams to losing teams to entire seasons. There is a need to identify performance indicators in different match periods and to use advanced methods to gain insights into the evolution of the handball match. To give attention to the defense phase and analyse international club competitions. Finally, to video analyse independently the matches and standardize variables for comparison across studies and study replication. The authors point out that without overcoming the current limitations, the produced scientific work will be of limited use to the practitioners (W. R. Ferrari et al., 2019).

Furthermore, a theoretically informed approach to data analysis and interpretation may result in more depth and better understanding (Travassos et al., 2013).

2.3.4 Performance indicators

Variables of significant importance that can differentiate between winners and losing teams are termed performance indicators (Lord et al., 2020). These variables are selected from many available, considered reliable, and valid to help advance understanding of game dynamics (Hughes & Bartlett, 2002). Selecting valid performance indicators can be achieved by connecting actions to outcomes in a meaningful way. Several methods have been used to filter valid performance indicators from the rest of the data, such as expert opinions and their knowledge and contrasted with novices, comparing winners and losers and successful profiles to unsuccessful ones ("Performance Indicators in Game Sports," 2013) Collecting information about tactics and match performance during matches can provide valuable feedback for coaches for them to inform their decisions by identifying weaknesses and strong points. It can also help with detecting patterns and assist in preparation for the next matches (Wright et al., 2013). Usually, these game-related statistics are then expressed as descriptive, with mean, standard deviations, medians and range. With a more profound analysis of past performances, relationships and differences can be tested with t-tests, ANOVA and correlations. Models can be produced to predict future performances using discriminative analysis, which helps focus on fewer variables most associated with success (Lord, 2020).

In-game sports, where performances can be described as dynamic, complex and non-linear, specific profiles are constructed from performance indicators to represent typical team performances, weaknesses and strengths. The exact method depends on the sport and its statistical characteristics to accurately present the most relevant information. These profiles can then support coaches in their coaching process, knowing that individual performances may vary depending on many factors, including opposition quality (O'Donoghue, 2013).

Discussion regarding the reliability of performance indicators has been ongoing, questioning their use given that such data is unstable and complex in team sport (Lames & McGarry, 2007). Another challenge is comparing data from different sources and criteria (Hughes & Bartlett, 2002). Recently, a discussion paper criticized published research in the field for primarily using easily accessible data rather than collecting data on behaviour that matters, also for the lack of theory-guided research and for missing how knowledge about behaviour on a team or individual level can change behaviour (Morgulev & Lebed, 2024). Performance indicators in handball and beach handball have been reported in major tournaments for both males and females. However, comparison between the models is difficult due to the lack of standardization of the included variables (W. R. Ferrari et al., 2019). An example of these limitations is reported in a recent study on the performances of the Netherlands female team at the World Championships in 2019. In conclusion, each match and its performance indicators were specific regarding its dynamics and behaviour patterns observed (Flores-Rodríguez & Alvite-de-Pablo, 2022).

2.3.5 Discriminating variables for success

With discriminant analysis, analysts can produce a model that drastically reduces the number of variables to focus on in a stepwise calculation. The process separates the variables that discriminate performances the best from the rest and produces a model containing the fewest variables possible while keeping a high percentage of correct classification of cases (O'Donoghue, 2010). Statistical differences between winners and losers can be identified, testing for differences in the means. One example is from 2014, a study highlighted the positional offense efficiency, the efficiency of 7m and 9m shots were better among winning teams (W. R. Ferrari, 2014). Earlier, the efficiency from 6 and 9m had been analysed by a study on statistical trends in a series of male World championships, showing 6m to have been more constant while 9m efficiency was increasing (Meletakos et al., 2011). Another study on top

handball showed winning teams to outperform losers in all situational variables of the attack finalization, especially when the team quality differed more. The goals from pivots were shown to contribute to winning as well as the shooting efficiency from outside the 9m in situations of two teams of equal quality (Foretic et al., 2010).

For females, discriminative variables from five consecutive World championships (2007-2017) were categorized according to how balanced the score was to indicate the team quality in the match-up. When the score is balanced, defense variables contribute more (steals, blocks and goalkeeper save efficiency) than the offense (attack and shot efficiency). At the same time, surprisingly, the technical fouls seem not to make significant difference. Unbalanced and very unbalanced games share similar trends. However, stolen balls and offensive variables of throw efficiency, attack efficiency and technical fouls are key in balanced games (De Paula et al., 2020). Another study on females in the elite international tournament (Olympics 2012) identified the number of successful fastbreaks, wing shot misses, goals scored from long range (9m shot?), and number of steals and assists (Milanović et al., 2018).

Beach handball statistics have been analysed using discriminating analysis in recent years following a growing interest in the sport. The model produced based on statistics from the 2018 World Championship contained eight variables (94.5% cases correctly classified), including an index of overall performance, goalkeeper blocked spin-shots, goalkeeper conceded spins-hots, goalkeeper conceded one-pointers, spin-shot goas, specialists goals, blocks and technical fouls (Saavedra et al., 2019).

Data from five male European Championships (2002-2010) analysed and identified 15 key performance indicators from a pool of 28. The emerging variables were perhaps the most anticipated, with total scoring, shooting, and goalkeeping efficiency highly rated (Skarbalius et al., 2013). A similar approach combining consecutive World Championships (2007-2019) looked at 47 variables, classifying correctly almost 70% of cases. The results indicated that the

best teams have the tallest and more experienced players, who perform more efficiently at 9m and wing shots with a defense capable of blocking more shots (Almeida et al., 2020). Analysis of handball at the Olympics yielded a predictive model (n= 324 games) selecting only four variables (shots, goalkeeper-blocked shots, technical fouls, and attacks) that correctly classified 82% of matches (Saavedra et al., 2017).

A post-match video analysis study on situational variables on teams in the Croatian elite male league revealed the differences between winning and losing teams. The fast attacks against an unorganized defense were evident characteristics of the winning teams as opposed to long positional attacks against the organized defense of the losing teams. While in positional attack, losing teams explored many tactical options without the efficiency needed, and authors attributed the result to poorer technical-tactical skill constrained by lower physical potential (Rogulj et al., 2004).

2.4 Situational variables and performance in handball and Beach Handball

In line with the theoretical perspectives of ecological dynamics, each sport's performance is subject to various environmental constraints. How the context affects sporting performance has been the main focal point of many studies, explicitly exploring factors such as match location, scoring, opposition quality, game period, type of competition and interactive effects (Gómez et al., 2013).

2.4.1 Match location

The phenomenon of home advantage in sports is better understood now with more than 50 years of literature. However, despite evidence of its existence across sports, performance levels and sex, the reasons for home advantage remain challenging to explain theoretically, given its contextual complexity (Gómez Ruano et al., 2022). Research into handball has explicitly confirmed the advantage staged by match location on the scoring and match results, explaining

4-12% of the outcome depending on the crowd size (Debanne, 2017). Further reasons include location familiarity and positive psychological impact on confidence and motivation (Pic, 2018). Subsequently, the home advantage might be further exaggerated in favour of the higher-quality team (Aguilar et al., 2015). There are also indications that some situations of performance are more affected by the match location in handball, such as the 6m and 9m efficiency, fastbreak goals, total shots, steals, turnovers and the total 6m and 9m goalkeeper efficiency (Lago-Peñas et al., 2013). The shot efficiency from 6m might represent a specific situation where the home advantage is more pronounced (Oliveira et al., 2012). Interestingly, a recent study using a social network approach has reported closer distance and more passes between players at home when losing, indicating a social team response to the performance context (Trindade et al., 2022).

2.4.2 Opposition quality

In-game scoring results from the dynamic team contest and on a sub-level individual player dyad. The ability of teams to execute tactics and technical skills is affected by the quality of the opposition. The Interactive Performances Theory provides evidence for four essential parts. First, performances are influenced by the opponent, and second, the outcome is determined by the quality and type of the opponent. The third states how the performance process is influenced by the quality and type of the opponent, and the fourth states that each player is affected by the same opponent type in different ways (O'Donoghue, 2009). Scoring in matches is another contextual constraint shaping different performance behaviour depending on whether the team is in the lead or trailing. To the author's knowledge, the context of scoring during balanced and unbalanced games has been covered previously in handball (de Paula et al., 2020; Oliveira et al., 2012) but still not in beach handball. Analysis of balanced or unbalanced scoring can help understand the behaviours observed by teams in a close contest, performing similarly, although the team quality might differ. Research has indicated a greater influence of the home court

during balanced games than unbalanced. Toward the end of the first half, players score goals at five-minute intervals and even more in the final five minutes of the game (Oliveira et al., 2012). This is in line with research on international elite level indicating winning handball teams to score the most in minutes 40-50th and achieve the greatest aggregate in minutes 10-20th to losing teams. The research supports the trend of the winning team stepping off the throttle in the final minutes with less scoring and relatively more goals conceded (Rogulj et al., 2011), while in the last minutes of beach handball, players make more technical fouls (Vázquez-Diz et al., 2019a). Coaches have informal and formal ways of influencing the game. Taking team time-outs is usually done in relation to the overall score, recent defensive and offensive performance and game period (Gomes et al., 2014). Commonly a coach's response to a poor scoring form, the team time-outs have been found to have a positive impact on the scoring, although player substitutions might be more effective than changes in defense formation (Gutiérrez-Aguilar et al., 2016).

2.4.3 Game period

Different periods represent different constraints on team behaviour, modifying their efforts and tactics to maximize chances of favourable outcomes. Tactical decision-making in handball changes during matches, with fewer patterns observed in balanced matches and no patterns in the final 10 minutes (J. Prudente et al., 2017). In that light, the first 20 minutes have been highlighted as the period where score difference is created, with the rest of the matches showing increased scoring coordination between the teams (Prieto et al., 2016). The shot efficiency also seems to be subject to the scoring, with teams trailing by five goals or more having better chances of scoring a goal than those losing by only one goal and vice versa (W. Ferrari et al., 2022). Game events such as the two-minute suspension create a situation of numerical inferiority for the sanctioned team, which the opponents are likely to take advantage of without concern for the location, scoring, opposition quality or game period. However, these effects on

the scoring are relatively small (Prieto et al., 2015b). In those situations of numerical inferiority, the winning teams are more efficient than the losing teams (Trejo Silva et al., 2020).

Differences between league and play-offs were a research topic posed by a recent study exploring game-related statistics in semi-professional handball. Results indicated practically meaningful signs of higher intensity with a faster game pace, more legal stops and more 2-minute exclusions, in part confirming the common axionym relating to more aggressive and intense handball playoffs (Laxdal, Ivarsson, Sigurgeirsson, et al., 2022).

3 Data Collection and Methods

3.1 Data Collection

HBStatz is an independent handball statistics company who have since 2018 been the official statistics software and match reporting platform. Each match in Iceland's top male and female divisions was recorded live and reported online by a trained technician. The data is then screened post-match for quality purposes. HBStatz provides access to its data via www.HBStatz.is and HSÍ, the national handball federation website in the public domain with a platform to view statistics and indexes for all teams, male and female. Beach handball data was obtained from the publicly accessible website of the IHF. Using such statistics is common in handball (Calin, 2010; Meletakos et al., 2011; Pollard & Gómez, 2012; Yamada et al., 2011). No formal consent was needed from the players or teams since the statistics are available for public access.

Table 1.
Overview of the study´s papers, including sample size, sex, performance level and season.

Study	Sport	Level	Male matches (n)	Female matches (n)	Season
1	Handball	Semi-professional domestic league	113	77	2018-19
2	Handball	Semi-professional domestic league	85	42	2018-19 and 2019-2020
3	Handball	Semi-professional domestic league		95	2018, ´19, ´20, ´21 and ´22
4	Beach handball	VIII Women's Beach Handball WC*		72	2018

Note. WC = World Championship

3.2 Data Preparation

All data was organized in Excel before being imported into SPSS for analysis. The statistics from the VIII Women's Beach Handball World Championship 2018 (n = 72) and the full season statistics of the Icelandic top male and female league were retrieved online. The statistics used were the official match statistics and specifically validated (*study 1* and *2*). The data was then

validated and tested for reliability. The selected variables in handball (20 dependent variables) can be divided into four subgroups of shots, cards and exclusions, goalkeeper blocked shots and other variables.

Table 2.
Variables and definitions included in studies 1,2 and 3 about handball

Variable	Definition
Shots	Percentage of converted shots relative to the number of shots made.
6 m shots	Percentage of converted shots at 6 m relative to the number of shots made. The area is from a zone outside the 45° angle from the left and right.
7 m shots	Percentage of penalties (7 m) converted relative to the number of penalties taken.
9 m shots	Percentage of converted shots at 9 m relative to the number of shots made. The area from a backcourt player either (a) over or through the defense and (b) after a breakthrough but with another defense player in front.
Wing shots	Percentage of converted shots in the wing area relative to the number of shots made. The area is from within an angle of 45° left and right without a defense player in front.
Fast-break shots	Percentage of shots converted in a fast-break situation – rapid switch from defense to attack without defense organized – relative to the number of shots made in this situation.
Breakthrough shots	Percentage of shots converted in a breakthrough situation – (a) from the backcourt players after breakthrough in the 9 m zone without a defense player in front, (b) of the pivot after 1:1 situation, (c) from the left or right back after breaking through 1:1 situation – relative to the number of shots made in this situation.
Yellow cards	Yellow cards received by each player and/or coaching staff.
Red cards	Red cards received by each player and/or coaching staff.
2-minutes exclusions	2-min suspension received by each player and/or coaching staff.
Assists	Number of passes from one offensive player to another leading directly to a goal score.
Technical fouls	Number of turnovers made by the offensive team where the ball is awarded to the defense due to offensive fouls.
Steals	Number of turnovers in favour of the defense due to actions of anticipation and snatching the ball.
G.B. shots	Percentage of shots stopped relative to the number of shots made by the attackers.
G.B. 6 m shots	Percentage of shots stopped at 6 m relative to the number of shots made by the attackers.
G.B. 7 m shots	Percentage of penalties (7 m) stopped relative to the number of penalties taken by the attackers.
G.B. 9 m shots	Percentage of shots stopped at 9 m relative to the number of shots made by the attackers.
G.B. wing shots	Percentage of shots stopped in the wing area relative to the number of shots made by the attackers.
G.B. fast break shots	Percentage of shots stopped in fast-break situations relative to the number of shots made by the attackers.
G.B. breakthroughs shots	Percentage of shots stopped in breakthrough situations relative to the number of shots made by the attackers.

In beach handball, there were 20 dependent variables in addition to five calculated indexes, which were then organized and calculated (efficiency) according to the scope of each paper. The independent variables were the match outcome (*1*,*2*, and *4*) or the team compared to the

opponents according to opponent quality (*study 3*). Descriptive statistics (mean and standard deviation) were provided by the match outcome in studies 1,2 and 4, by sex in *studies 1* and *2*, and by one team in *study 3*.

Table 3.
Definitions of game-related statistics variables from study 4 about beach handball

Variable	Definition
Total points	Total number of points scored
Spin shots	Converted spin shot percentage relative to the number of shots made
In-flight shots	Converted in-flight shot percentage relative to the number of shots made
Specialist shots	Converted specialist shot percentage relative to the number of shots made
Direct shots	Converted direct shot percentage relative to the number of shots made
Penalty shots	Converted penalty shot percentage relative to the number of shots made
One-pointer shots	Converted one-pointer shot percentage relative to the number of shots made
In-flight assists	Number of passes an offensive player makes to another, leading directly to a goal scored with this type of shot
Other assists	Number of other types of assists
Technical fouls	Number of turnovers made by the offensive team where the ball is awarded to the defense due to a foul in offense
Steals	Number of turnovers in favour of the defense due to actions of anticipation and intercepting and retaining the ball
Blocks	Number of shots blocked by a field player
Suspensions	Number of suspensions in defending
Players with efficiency index = 0	Number of players with a valuation of 0
Players with negative efficiency index	Number of players with a negative valuation
Players with a positive efficiency index	Number of players with a positive valuation
Overall valuation (OV)	Score obtained from the following valuation equation: OV= Points - (Spin-shot L/R/LD misses) - (Spin-shot C misses) * 1.25 - (In-flight L/R/LD misses) - (In-flight C misses) * 1.25 - (Spec 6m C misses) * 1.75 - (Spec 6m L/R misses) * 1.5 - (Spec 9m misses) * 1.75 - (Spec DG misses) * 1.5 - (Penalty 6m misses) * 2 - (One-pointer L/R/LD misses) * 1.75 - (One-pointer C misses) * 2 + (In-flight assists) * 2 (Other assists) - (Technical f.) * 2 + Steals * 2 + (Blocked shots) + (Earned susp.) + (Earned 6m) * 2 - (Suspensions) - (Committed 6m) * 2
GB shots	Shots stopped percentage relative to the number of shots made by the attackers
GB spin shots	Spin shots stopped percentage relative to the number of shots made by the attackers
GB in-flight shots	In-flight shots stopped percentage relative to the number of shots made by the attackers.
GB specialist shots	Specialist shots stopped percentage relative to the number of shots made by the attackers
GB direct shots	Direct shots stopped percentage relative to the number of shots made by the attackers
GB penalty shots	Penalty shots stopped percentage relative to the number of shots made by the attackers
GB one-pointer shot	One-pointer shots stopped percentage relative to the number of shots made by the attackers

G valuation	Sum of the goalkeeper valuations: GKV= (Spin-shot L/R/LD saves) * 3.5 + (Spin-shot saves C) * 4 + (In-flight L/R/LD saves) * 3.5 + (In-flight saves C) * 4 + (Spec 6m L/R saves) * 4.5 + (Spec 6m C saves) * 5 + (Spec 9m saves) * 2 + (Spec DG saves) * 2 + (One-pointer saves) * 2.5 + (Penalty saves) * 5 - (Received goals) * 0.5 + Player OV

3.3 Data validation procedures

In *studies 1-4*, the data collection and validation process followed a systematic approach. Trained observers entered game-related statistics into custom-designed online applications during handball matches. These data were then exported to Excel spreadsheets for further processing and error-checking. The dependent variable across the studies was the match outcome of winning or losing, apart from *study 4*, which was the performances of one successful team against high- and low-quality opponents. The independent variables were game-related statistics (see table 2 for handball and table 3 for beach handball). An observational method, supported by the LINCE software (Gabín, Camerino, Anguera & Castañer, 2012), was employed to validate the data (Anguera, 2003; Anguera, Camerino, Castañer, Sánchez-Algarra, & Onwuegbuzie, 2017). The variables were categorized into subgroups such as shots, cards and exclusions, goalkeeper-blocked shots, and other variables like assists and technical fouls. Studies used Cronbach's alpha for internal consistency, intra-class correlation coefficients (ICC) (Cohen, 1988), and Cohen's kappa for reliability assessment. Two randomly selected matches for each gender were analysed at different times to calculate intra- and inter-observer reliability (Landis & Koch, 1977), which was found to be good or very good.

The reliability thresholds were defined using established scales. For internal consistency (α), values below .50 were deemed unacceptable, while values above .91 were considered excellent. For ICC, values up to .50 were poor, and values above .91 were excellent. Cohen's kappa values were categorized from no agreement to very good agreement. The internal consistency and reliability results were reported as good or very good across male and female

data. The methodology for data validation was consistent with standard procedures in observational studies.

3.4 Statistical methods

In the statistical analyses, basic descriptive statistics (mean and standard deviation) were calculated for game-related statistics by match outcome across studies 1-3 (winning and losing teams) and by sex (*studies 1 and 2*) and one team opponent quality in *study 4*. The normality of each variable was assessed using the Kolmogorov-Smirnov test. Depending on whether the variables met normality, parametric (unpaired t-test) or non-parametric (Mann-Whitney U test) tests were applied to determine differences between winning and losing teams. Effect sizes were interpreted as small, moderate, or large, following Cohen's guidelines (Cohen, 1988).

Discriminant analysis was a key component in these studies, using the sample-splitting method to identify variables that discriminated between match outcomes (or team performances, *study 4*). This method initially included variables that minimized Wilks's lambda (λ), with further pairwise combinations of variables to refine the selection. The analysis measured deviations within each group relative to total deviations and included variables based on a critical value for F-statistics. Canonical correlation indices and the percentage of correctly classified matches were also calculated to validate the predictive power of the discriminant variables. *Studies 1, 2,* and *4* applied this method to both men's and women's data, whereas *study 3* focused on comparing a selected female team's performance against top-ranked and lower-ranked teams.

Across all studies, statistical significance was set at p-value < .05. The software packages used for statistical analyses included IBM SPSS Statistics versions 24, 25 and 27 (IBM, Armonk, NY, USA).

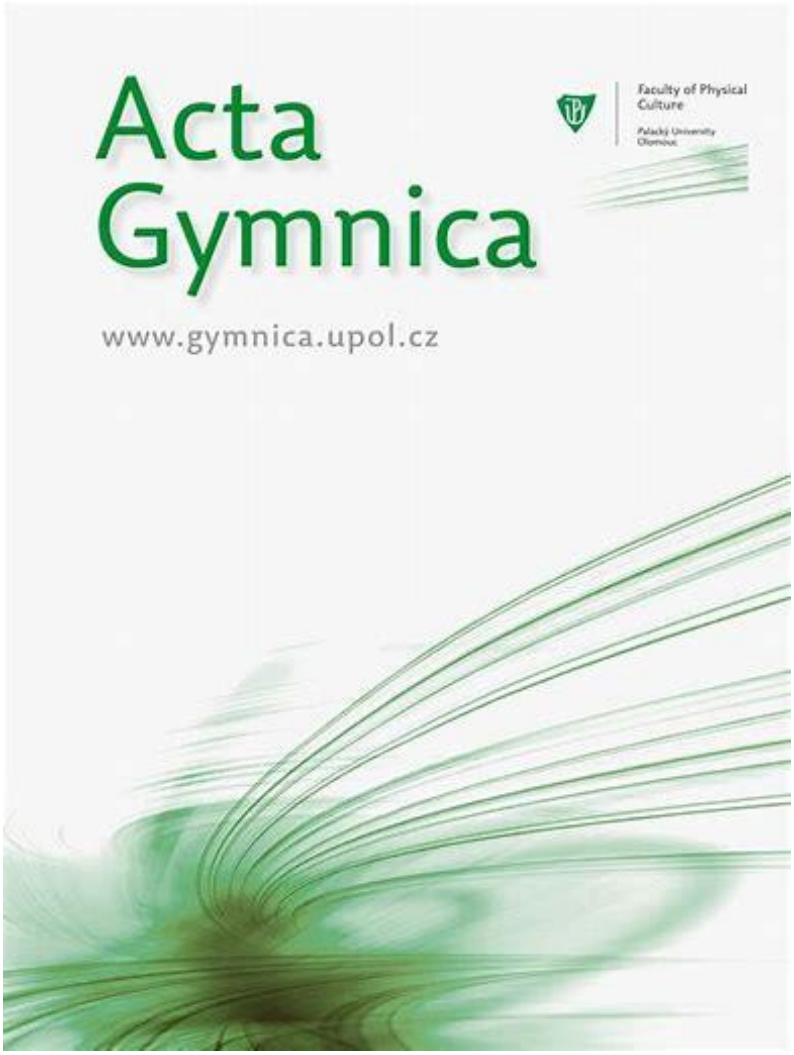
3.5 Ethical considerations

The data used in studies of this PhD project are all available publicly online from the official websites of the respective federations. The players willingly participate in matches, which are public events followed by media and spectators. Researchers have no direct involvement or interaction with the subjects (Flores-Rodríguez & Alvite-de-Pablo, 2022). Therefore, no informed consent or an ethics committee review was required. It should also be noted that all authors declared no conflict of interest in all the studies performed.

4 Original scientific studies

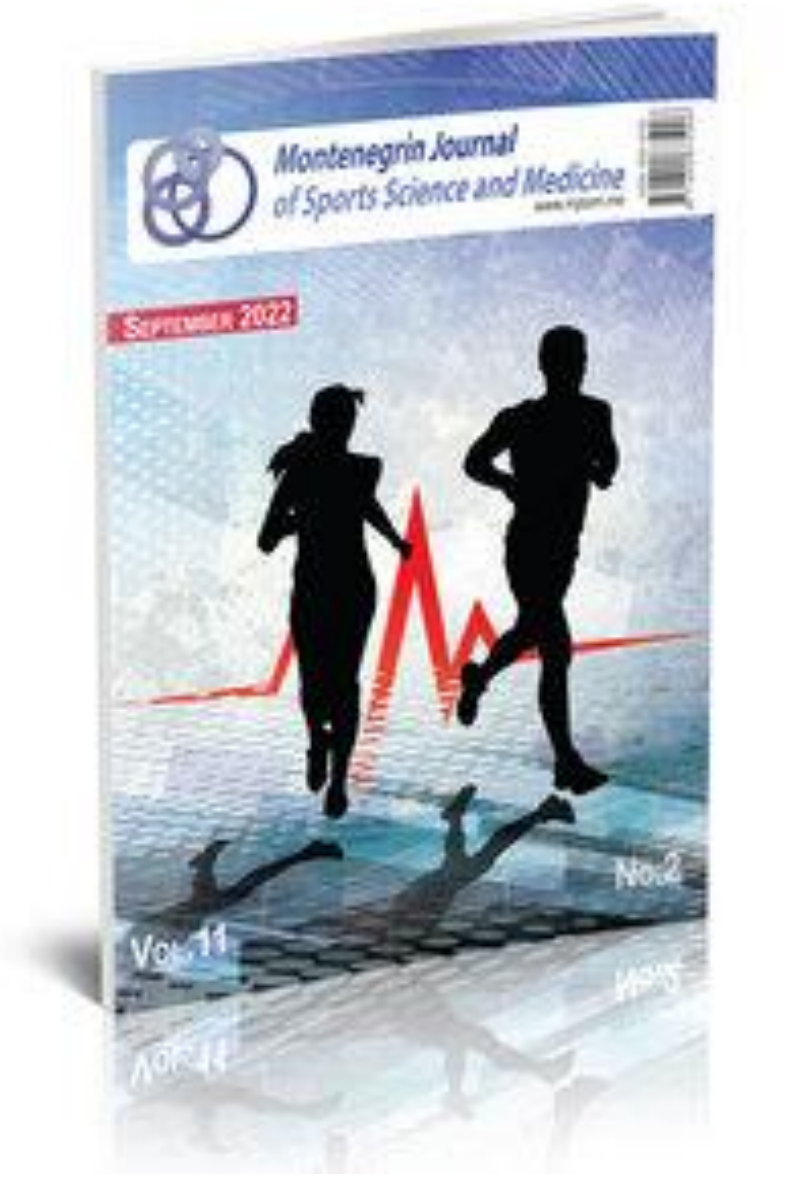
4.1 *Study 1*: Gender-Based differences in game-related statistics between winning and losing teams in an amateur handball league

Þorgeirsson, S., Pic, M., Lozano, D., Sigurgeirsson, O., Sekulic, D., & Saavedra, J.M. (2022). Gender-based differences in game-related statistics between winning and losing teams in an amateur handball league. Acta Gymnica, 52, Article e2022.001. https://doi.org/10.5507/ag.2022.001



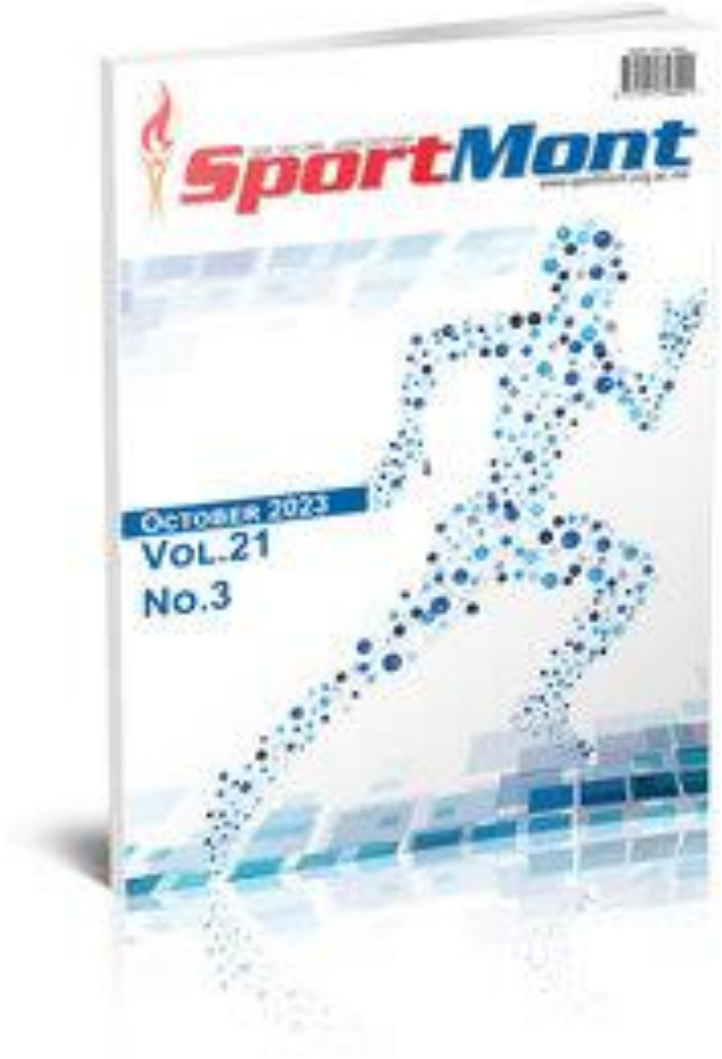
4.2 *Study 2:* The difference between winners and losers in balanced handball games in the final 10 minutes

Þorgeirsson, S., Pic, M., Lozano, D., Sigurgeirsson, O., Sekulic, D., & Saavedra, J. M. (2022). The difference between winners and losers in balanced handball games in the final 10 minutes. *Montenegrin Journal of Sports Science and Medicine*, *11*(2), 37-43. doi: https://doi.org/10.26773/mjssm.220905



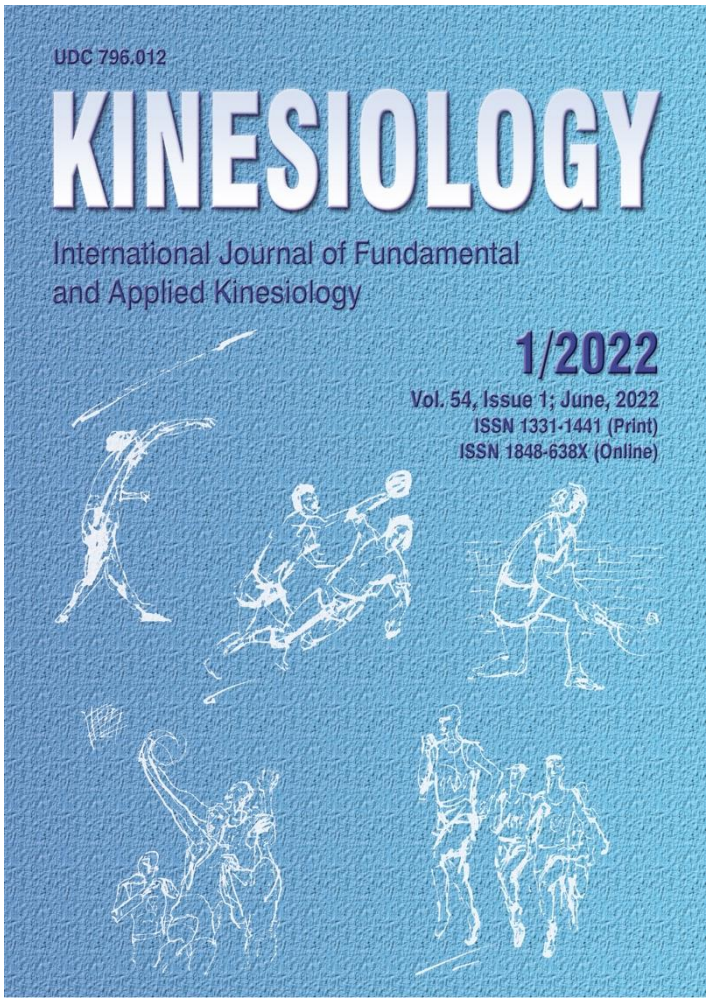
4.3 *Study 3:* Performance profiling in handball using discriminative variables and its practical applications

Þorgeirsson, S., Laxdal, A., Sigurgeirsson, O., Sekulic, D., & Saavedra, J. M. (2023). Performance profiling in handball using discriminative variables and its practical applications. *Sport Mont, 21*(3), 3-8. doi: 10.26773/smj.231001



***Study 4*: Women's beach handball game statistics: Differences and predictive power for winning and losing teams**

Þorgeirsson, S., Lozano, D., Zapardiel, J. C., Jimenez, F., Sekulic, D., & Saavedra, J. M. (2022). Women's beach handball game statistics: Differences and predictive power for winning and losing teams. *Kinesiology*, *54*(1), 126–132. Retrieved from https://hrcak.srce.hr/ojs/index.php/kinesiology/article/view/20834



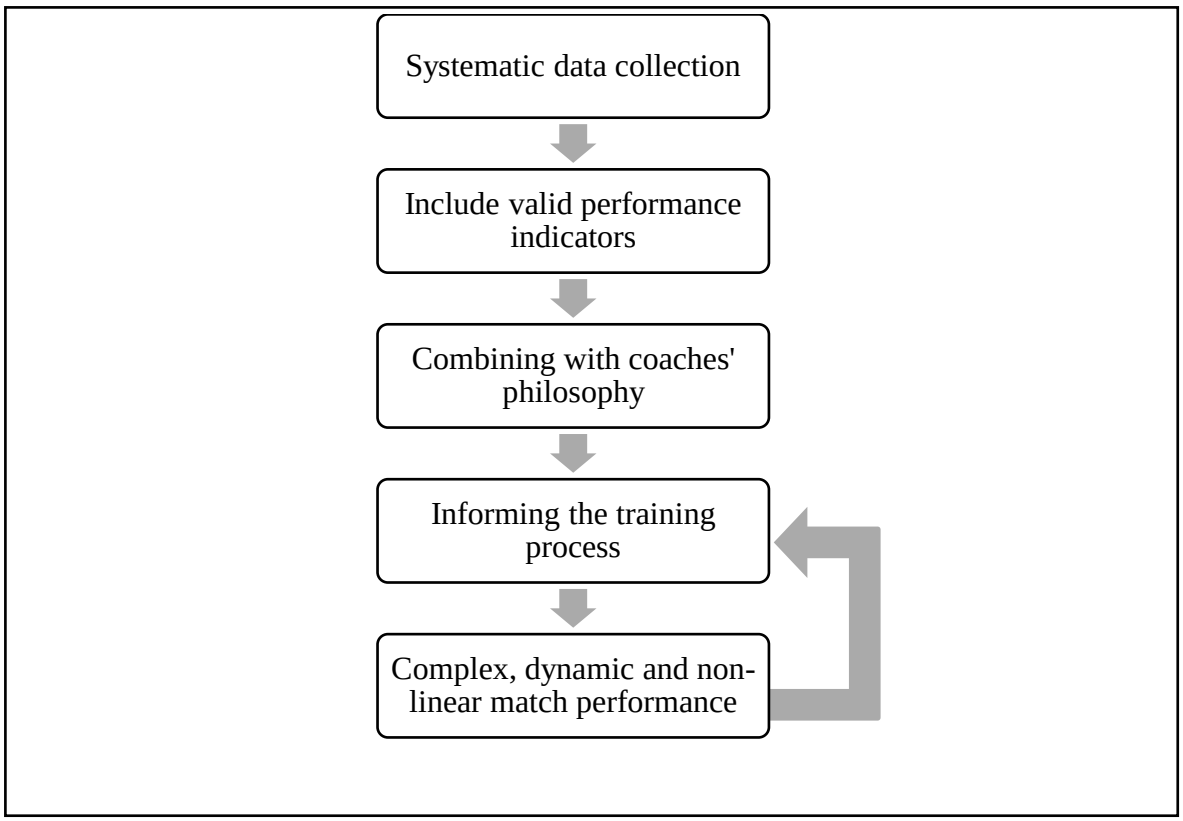
5 Cross-paper synthesis of the findings of studies 1-4

5.1 Discussion

The main objectives of the PhD projects were to i) analyse differences, and discriminative factors behind winning teams compared to losers for males and females in semi-professional handball and beach handball. The second objective was to ii) analyse differences between the match play of males and females in game-related statistics.

The main contribution of this thesis is knowledge produced from the semi-professional handball in Iceland. This project expands on handball statistics literature by including a relevant but under-researched performance level in handball and the emerging sport of beach handball. Predictive models are then extended to show how performance indicators are specific to sport, team, quality, sex and game period. The produced model could inform coaches preparing for semi-professional handball and elite beach handball competitions. In this synthesis, the findings are organized in the sequential order of the steps using game-related statistics. Each step will be discussed in more depth in the following paragraphs, including data reliability and validity, performance indicators, coaches' role, performance profiling, and, finally, training and performance in the context of ecological dynamics theory. The model is featured in Figure 1, which shows the steps and cyclical process.

Figure 2.
The steps in adopting game-related statistics into handball and beach handball team performance analysis for training preparation, in-match support and post-match evaluation.



5.1.1 Using reliable and valid data is fundamental

The data used for performance analysis must be of high quality to lay a solid foundation. The exploration of the statistics of Icelandic handball, a semi-professional male and female league, was enabled by the systematic computerized registration of game-related statistics using the HBStatz online platform. Such statistics platforms are commonly used in sports to register actions and outcomes (Gemma 2024). The inclusion of more than twenty variables in HBStatz statistics (see Table 2), the platform was originally based on variables IHF had already selected, with a few additions inspired by football and basketball. These variables are commonly used in handball statistics, but exact definitions may vary slightly. The consistency and reliability of the registration tested in *study 1* (and used in *studies 2* and *3*) were found to be good or very good (Cronbach's alpha, intra-class correlation coefficient and Cohen's kappa). By the same methods, the data from beach handball World championships in *study 4* was found to have very

good consistency, reliability and intra-class correlation. These positive results allowed the use of the data for further analysis.

5.1.2 Selecting performance indicators

Methods by which performance indicators are selected are usually determined by the outcome, contrasting winning performances with losing. Previously, elite and international performance levels had been explored for performance indicators in handball and beach handball (De Paula et al., 2020; Saavedra et al., 2019; Skarbalius et al., 2013). Given the dynamic, complex and adaptive behaviour observed in a team sport, this PhD project's main objective was to determine the performance indicators of winning/successful teams in semi-professional (handball) and elite (beach handball) contexts. The study's findings based on game-related statistics from discriminative analysis are listed in table 4. Although each model is unique, the variables had emerged individually in other sets of variables in other studies with similar methods but in another context (referenced in each paper discussion). These findings can potentially inform coaches at this performance level in their selection of team performance indicators.

Sex differences in anthropometry and physical performance constitute different physical constraints to performance, causing females to perceive affordances in gameplay differently than males. In *study 1*, four variables with a moderate effect size differed significantly between the sexes: technical fouls, 2-minute exclusion red cards and 9 m shots. Despite playing by the same rules, objectives and court size, the handball play differs according to sex, as studies in handball literature have found (Gómez-Carmona et al., 2020; Michalsik & Aagaard, 2014), and in line with *studies 1* and *2* findings. Furthermore, different performance models describe different contextual challenges for players and teams to solve. The importance of context specificity is underscored in *study 2*, which examines the semi-professional level but within the constraints of balanced game scoring in the final 10 minutes. A second model, with a lower predictive percentage for males (40.4%, but n.a. for females), was created,

identifying technical fouls and goalkeeper-saved shots from 9m, not found in earlier models. Considering the specific task constraints during this decisive period with balanced scoring, these findings were expected to differ. However, it remains challenging to explain for the many interacting and situational factors involved conclusively.

Reliable performance indicators are hard to find in complex open systems like beach and team handball. It is worth noting that this PhD. Study results selected total shot efficiency (from all players and positions combined) in both *studies: 1* (both male and female) and *3* (against lower-ranked teams). Similarly, the total goalkeeper saved shot efficiency, combining shots from all positions, was included in *study 1* for both males and females, nr *3* (against low-ranking teams) and study 4 in beach handball. Finally, in *study 4*, "overall valuation", an index including offensive and defensive variables were included as one of two variables. This hints that the most generic variables are also the most useful when comparing whole tournaments and seasons without regard to situational factors. Technical fouls emerged in *studies 1* and *2*, signaling a more specific match event for coaches to pay attention to, although their occurrence in each match is way less frequent than shots and saves.

5.1.3 Coaches' philosophy and engagement in performance analysis

Suppose coaches overcome cost and time barriers to engage in performance analysis. In that case, game-related statistics are readily available on platforms such as HBStatz or the official IHF website, which can be helpful. Combined with other commonly used methods like video analysis (qualitative), game-related statistics represent an objective (quantitative) method to inform coaches in their process systematically. The coaches should design (in collaboration with a performance analyst if applicable) a bespoke information system for their team according to the coach's philosophy of play. The information system then supports the coaching process in preparation for, during and post competition. A team-specific performance profile with key performance indicators can be constructed by merging the specific variables

of interest to the coach (expert) with established performance indicators from the literature. This would serve the coaching staff by focusing on a reduced set of variables, which is practical in a time-stressed environment with a team of players.

Recently, performance indexes containing several weighted variables have been developed and warrant a further look by coaches. In *study 4* on beach handball, the Overall valuation index comprised of all offensive and defensive variables in one formula (see table 3) was highlighted in addition to the total goalkeeper shot efficiency. One example of a newly developed index that has proven reliable is the PlayerScore, created for the IHF World Championship 2019 and 2021 and EHF 2020 (Wagner et al., 2023). Another example is the Handball Performance Index, which is based on a baseline score of 100 with weighted points deducted or added depending on the result of match actions. It has recently been developed and used in the German Bundesliga since 2020-21 season (LIQUI MOLY HBL, 2024).

5.1.4 The use of performance profiles

The two models created for a successful female team in *study 3* exemplify how performance indicators can be selected based on the team's performances against opponents of different qualities. Given the current capabilities, the coach should modify that model to best-fit plans for team development. The model in *study 3* further provides the medians with 95% confidence intervals, showing the range of frequencies and efficiency for coaches to refer to. The means and standard deviation of the winner's and loser's performances are also reported in *studies 1* and *4* for the coaches to refer to in their information model and, for example, when setting goals with the team.

In preparation for each match, coaches have the challenge of synthesizing the available information about the opponent, with knowledge about the team´s past performances and devising a game plan. In this highly dynamic and complex environment, coaches must make tactical decisions to allow their team the best chances of success. Success in individual matches

can depend highly on the opposition, thus requiring the team to adapt to the specific context successfully. Therefore, the handball and beach handball play can vary substantially between matches and change dynamically within the games for reasons detailed in the Interactive performances theory (O'Donoghue, 2009), and further supported in the underpinning theories of Ecological dynamics (Araújo et al., 2023). Hence, the "*typical successful performance profile*" has definite limitations, as matches can be won in infinite unique ways. Using game-related statistics in a post-match analysis, coaches will be objectively informed about the outcome and spared from relying on memory alone. However, they must depend on expert observation, video analysis, or other advanced statistics to infer the processes that lead to a particular outcome.

5.1.5 Training for match performance

Regarding training at the semi-professional level and above, the coach must develop the team's tactical and technical efficiency through specifically designed representative training tasks, as suggested in *study 3*. This can be accomplished by carefully manipulating the task constraints such as the main objective, court size, rules and equipment to afford players with specifying information. Small-sided games with specific task constraints are an example of a training method used to develop coordination of players at individual and cooperative levels (e.g., 2 vs 2, 3 vs 3). In *study 2*, the performance context was the final 10 minutes of balanced games. The predictive model for males included technical fouls and goalkeeper saves efficiency from 9m. Without process information about how the technical fouls occurred, it is impossible to train for the decrease in frequency in match setting. 9m shot efficiency and 9m goalkeeper save efficiency emerged as significantly different between winning teams and losing with large effect sizes (in addition to total shot efficiency and goalkeeper saved shot efficiency). This indicates a specific situation where the defense opts for a more passive style of play, closing spaces and reducing risky behaviour in response to the scoring. More passive defense invites

uninterrupted shots from outside 9m (lower situational efficiency compared to 6m and 7m shots), defensive blocks (included in the female model from *study 3* against Top4 and low-ranking teams) and the helpful goalkeeper-defense cooperation (Krawczyk et al., 2020).

An example of a suggestion for a lower quality team faced with a higher quality team based on the ecological dynamics framework would include the following. To train these balanced scoring situations towards the end of friendly matches against high-quality teams. This can be done in the preparatory phase by resetting the score, which is likely uneven by then. The lower-quality team is given a 1-3 goal advantage with 5-10 minutes remaining on the clock. This could represent a renewed challenge for the high-quality team and, importantly, prepare the lower-quality team for these specific situations to grasp an unexpected win. Important constraints affecting performance include high competitive stress and fatigue, which can be challenging to replicate in regular training. This recommendation is supported by evidence suggesting that situational variables like balanced scoring, opposition quality, and game period play a role in match outcome (Gómez et al., 2013).

Viewing profiles of successful team performances can show coaches how to direct future training efforts by comparing them to their team. In *study 3*, the absence of steals in defense from the performance profile of the semi-professional handball team was pointed out as a potential room for improvement since the variable had been associated with winning on higher performance levels. Another method would be to compare the team´s statistics to the descriptive statistics from *study 1*, further informed by the variables significantly different for winners and their effect sizes.

Table 4.
Performance indicators included in discriminating analysis between winning and losing in studies 1,2 and 4, and success in relation to opposition quality in study 3.

	Condition	Male				Female			
		Offense	Defense	Goalkeeping	%	Offense	Defense	Goalkeeping	%
Study 1	Semi-professional league (whole season)	Shots	Steals, Tech. fouls	Shots save, 7m shot save	84.1	Shots		Shots save	87.0
Study 2	Last 10 minutes of play in balanced semi-professional matches from two seasons		Tech. fouls	9m shot save	40.4	The model did not select any variables			
Study 3	Model of successful female team in semi-pro league from five seasons against TOP4 teams	9m shots	Legal stops Blocked shots		70.2	Assists Shots	Blocked shots Legal stops 2min	Shots save	94.4
Study 4	Elite beach handball championship matches	Study only in females				Overall evaluation		Shots save	80.6

Note. *Tech.fouls = Technical fouls, **2min = 2-minute suspension

5.2 Limitations

These four studies share limitations for most parts as they are grounded in similar approaches to the data. First is the static outcome-based nature of the data, which cannot provide insights into the dynamic processes leading to the outcome. This limits the practical applicability for coaches since there are so many ways a player can score a goal or make a save that, in the end, are all counted the same. In this line, the selection of events to be counted or omitted is limited to practicality and expertise. In these studies, all analyses were performed on outcome statistics, which are publicly available and commonly used in notational analysis by coaches and media. Some variables, like suspensions and steals, are counted, while others were calculated for efficiency without regard to the relative contribution to the outcome. No direct markers of the game style (e.g., type of defense, court positions, tactics applied) were analysed in this research as they were not collected in the initial set of variables.

The general representativeness of the data is limited to a specific sample of elite beach handball (in *study 4*) and semi-professional handball (in *studies 1-3*), and conclusions must be reviewed in that context. Teams of different qualities and profiles were split according to winning or losing performances for the predictive model analysis in studies *1* and *2*. *Studies 2* and *3* introduced a more specific scope by analysing a limited match period (*2*) and taking a one-team perspective (*3*). The statistics collected by HBStatz technicians are extensive but limited to its domestic semi-professional level (*study 1, 2* and *3*), while the beach handball data reflects elite play in a single tournament.

Depending on the variable definition detailed in Tables 2 and 3, some variables require interpreting game actions into match events. Following such definitions, it can be challenging to log the events live in real-game situations, especially those not directly indicated by the match officials (like assists, steals, blocks, saves, and technical faults). To overcome such

limitations, a standardized list of variable definitions is called for, along with post-match quality control of the data, which is already part of the process.

5.3 Future research directions

In line with recent criticism of the current practice in performance analysis, the future steps in the field should be to do theory-guided research with sound practical applications for coaches (Morgulev & Lebed, 2024). It requires a rich understanding of the contemporary theorization of team sport with a dedicated effort to collect and analyse the data with the relevant and most likely advanced statistical methods.

As live reporting of statistics in handball becomes publicly available, the opportunities for instant data analysis become possible and wanted. An immense volume of statistics is fed directly into models capable of producing filtered information about the process of the game. Statistical products like xG (expected goals) and the new Attack Momentum™ are efforts in that direction (Sofascore, 2024). Previously, the statistics may have been descriptive, crude frequency and efficiency, but it has the potential to become more sophisticated. A review paper on the state of performance analysis in handball made a few further suggestions, such as exploring entire seasons of game-related statistics and describing the effect of key events on match development. The use of standard variables was also recommended, enabling comparisons and replication (W. R. Ferrari et al., 2019). Researching defense was suggested as it has received far less attention than offense, just as female sport has in comparison to male sport (Prieto et al., 2015a).

On the other side, there is a lack of qualitative literature describing the challenges and perspectives of the coaches in handball, giving weight and direction to the current gap between theory and practice. Sports development will remain with the coaches, who should be supported with reliable information.

5.4 Conclusions

This study's findings on game-related statistics suggest unique predictive performance models apply for winners compared to losers for a whole season (*study 1*) and the last 10 minutes of balanced games (*study 2*) for both sexes (*study 1*). The same was true when opposition quality was accounted for (*study 3*) in a performance profile for one successful team at semi-professional level handball. Generally, keeping records of shot efficiency (from all positions) and goalkeeper save efficiency is recommended in addition to more context-specific variables according to sex, game period, opposition quality, scoring and the coach's philosophy. The use of indexes is also further justified by findings at international elite beach handball (*study 4*) and the literature. Defining a performance profile for each team based on game-related statistics is a practical method to inform the coach's decisions cost-free and reliably with known limitations. The statistics can support the tactical preparation in training for matches, which is suggested to be theoretically guided to achieve the desired effect.

5.5 Practical applications

Following this PhD study results, recommendations to coaches in handball and beach handball include some important suggestions for using game-related statistics in handball and beach handball. The first is to use reliable data sources such as official statistics from HBStatz or IHF. Coaches could consider using performance indicators with scientifically demonstrated validity according to their specific performance context and indicators relevant to their coaching philosophy. Generally, indexes comprising several sub-variables may represent a more stable performance indicator when comparing multiple performances.

To target the desired tactical performance element, coaches could use training methods that align with (e.g., team or opponent weaknesses) ideas of the Ecological Dynamics framework. This includes representative training design and task constraint manipulations. Individual player movement solutions, tactical decision-making, and team coordination/synergy will emerge because of the interacting constraints and perceived affordances. Therefore, performance analysis should consider how information derived from game-related statistics reflects only the context-specific outcome, not the complex, dynamic and non-linear processes behind it. Finally, it is suggested that acknowledging the non-linear principles of complex systems and the interactive, adaptive and dynamic behaviour of teams will benefit the coaches understanding and use of game-related statistics.

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7 Biography

Sveinn Þorgeirsson; was born on the 25th of January 1987 in Reyjavík, Iceland. Sveinn is a father of three children, Lísa Björk, Erik Logi and Emil Orri and married to Anna Margrét Guðmundsdóttir. Sveinn graduated from Reykjavik University with a bachelor's degree in Sport Science in 2010 and with an MSc. in Exercise Science and Coaching in 2012. Sveinn trained in handball and football from an early age to later specialize in handball and compete for Fjölnir and the youth national team in handball. Sveinn played semi-professionally for 13 years in Iceland's top and first league for his boyhood club Fjölnir, Víkingur, Haukar and Fram. Parallel to his playing career, Sveinn has coached and organized handball training at Fjölnir youth and senior level to this day. From 2014 to 2022, Sveinn was the project manager of Borgarholtsskóli Sport Academy, overseeing the athletic program for more than 100 student-athletes at the secondary level.

In 2014, Sveinn became a staff member of the Department of Sport Science, primarily teaching at the undergraduate level and supervising the Sports science laboratory. Since then, Sveinn has had other responsibilities, including master's thesis supervision and course development. Sveinn has been the university coordinator with HSÍ regarding systematically testing youth national teams for the past seven years. He has taken part in the development and implementation of the theoretical part of HSÍ´s Master coach program, making coaches eligible for a Pro Licence certificate. Within the university, Sveinn is a member of the curriculum council and Sport Science Research Council member. Sveinn has also been active in the PAPESH (Physical Activity, Physical Education, Health and Sport Research Centre) research center activities since its establishment.

8 Curriculum vitae

Personal information

Icelandic, born on 25 January 1987, in Reykavík, Iceland

E-Mail: sveinn.thorgeirsson@gmail.com

Mother language: Icelandic. Other languages: English (advanced)

Education

2022 – today, PhD student (Faculty of Kinesiology, University of Split, Croatia)

2010 – 2012 MSc. of Sport and Exercise Science (Sport Science, Reykjavík University, Iceland)

2007 – 2010 BSc. Sport Science (Sport Science, Reykjavík University, Iceland)

Grants and awards

Landsbanki 1st year student grant (Nýnemastyrkur) on basis of academic achievement from secondary school and experience

Dean´s List of Honor for Outstanding Academic Achievement in Sport Science

- for autumn 2007
- for spring 2008
- for autumn 2008
- for autumn 2009
- for spring 2010

Work experience

2014 – today – Reykjavik University, a teacher at the department of Sport Science

2014 – 2022 – Borgarholtsskóli, Sport academy, project manager

2011 – 2013 – Borgarholtsskóli, Physical Education teacher

2009 – 2018 – Fjölnir Handball, head of coaches

2004 – 2014 – Fjölnir handball, youth coach

Selected publications

Donoghue, P. O., Kristjánsdóttir, H., Halldórsson, K., & **Þorgeirsson, S.** (2023). A comparison of tournament systems for the men's World Handball Championship. International Journal of Computer Science in Sport, 22(2), 62–76. https://doi.org/10.2478/ijcss-2023-0011

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