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PERFORMANCE ANALYSIS OF BEACH HANDBALL

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Coordinatrice del Corso
Chiar.ma Prof.ssa Wilma Polini

Dottoranda
Alice Iannaccone

Supervisor
Chiar.ma Prof.ssa Cristina Cortis

"Citius! Altius! Fortius"

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PREFACE- LIST OF PUBLICATIONS

This cumulative Ph.D. thesis is based on research investigations carried out at the Department of Human Sciences, Society and Health of the University of Cassino e Lazio Meridionale from 2017 to 2021. The first and second studies have been published as original research manuscripts to international peer-reviewed journals. The third study has been accepted for publication as original research manuscript to the international peer-reviewed "International Journal of Sport Physiology and Performance" on June 7th, 2021. All of them were implemented in cooperation with the Lithuanian Sports University, Kaunas, Lithuania.

1. Iannaccone A, Conte D, Fusco A, Cortis C. Notational analysis of beach handball. *Human Movement.* 2022, 23(1), Ahead of print. https://doi.org/https://doi.org/10.5114/hm.2021.101757.
2. Iannaccone A, Conte D, Cortis C, Fusco A. Usefulness of linear mixed-effects models to assess the relationship between objective and subjective internal load in team sports. *International Journal of Environmental Research and Public Health*. 2021, 18(2), 392. https://doi.org/10.3390/ijerph18020392
3. Iannaccone A, Fusco A, Skarbalius A, Kniubaite A, Cortis C, Conte D. Relationship between external and internal load measures in youth beach handball. *International Journal of Sport Physiology and Performance.* Accepted for publication on June 7th, 2021

Additional studies, which do not relate to this thesis, were published in international peer-reviewed journals.

1. Giancotti GF, Fusco A, Iannaccone A, & Cortis C. Short-term effects of suspension training on strength and power performances. Journal of Functional Morphology and Kinesiology. 2018. Vol. 3(4): 51.
2. Iannaccone A, Fusco A, Jaime SJ, Baldassano S, Cooper J, Proia P, Cortis C. Stay home, stay active with SuperJump®: a home-based activity to prevent sedentary lifestyle during COVID-19 outbreak. *Sustainability*. 2020, 12, 10135. DOI: 10.3390/su122310135

Results of research carried out during the Ph.D. studies have been also presented to international conferences as spokesman.

1. **Conference:** 66th Annual Meeting of the American College of Sport Medicine. May 28th-June 1st, 2019- Orlando (Florida, USA).

Iannaccone A, Cortis C, Edvardsen E, Capelli G. Effect of exercise therapy during treatment for gynecological cancer: a systematic review and meta-analysis. 921: Board# 155 May 29 3: 30 PM-5: 00 PM. Medicine & Science in Sports & Exercise. 2019. Vol. 51(6): 235.

2. **Conference:** 24th Annual Congress of the European College of Sport Science. July 2nd – 7th, 2019- Prague (Czech Republic).

Iannaccone A, Biffi A, Fernando F, Cortis C, Rodio A. Physiological profiles of young pilots of an elite driver academy. 24th Annual Congress of the European College of Sport Science. 2019. 1909: CP-MI02.03.07.2019.

3. **Conference:** 5th Scientific Conference "Handball for Life" of the European Handball Federation. November 21st-22nd, 2019. Köln (GER).

Iannaccone A, Conte D, Kniubaite A, Fusco A, Cortis C. Playerload of beach handball players during competitions. Conference Guide, Summary of abstracts, 28. 5th European Handball Federation Scientific Conference "Handball for Life", **2019** November 21st-22nd, Cologne

4. **Conference:** 67th Annual Meeting of the American College of Sport Medicine. Virtual congress.

Cortis C, Iannaccone A, Jaime SJ, Vozza G, Diana MG, Iodice A, Baldassano S, Cooper J, Proia P, Fusco A. A Superjump® into ACSM guidelines. 921: Board#27 May 27 9: 30 AM-11: 00 AM. *Medicine & Science in Sports & Exercise.* 2020, Vol. 52(5): S29

ABSTRACT

The aim of this project was the evaluation of performance of beach handball players.

Beach handball is considered a high-intensity mixed-metabolism sport where the performance depends on the combination of high-intensity physical patterns at player and team level. The player performances depend on specific movements involving speed and power, rapid accelerations and decelerations, and changes of directions, whereas the overall team performance depends on technical and tactical team performance indicators, such as passing, catching, throwing, and blocking during offensive and defensive situations.

The first part of this dissertation aimed to examine the differences between male and female players during shooting actions occurring during semifinal and final phases of a European Beach Handball Tournament by means of notational analysis. For the study 9 matches were analyzed. Overall, 559 (males: 353; females: 206) shots were observed; 54.7±9.4% were successful and 19.9±7.1% were saved by goalkeepers. No difference for gender emerged. Results showed that notational analysis represents a valuable tool to examine many aspects of shooting actions such as the shooting technique, the shooting area, the area of the goal to which the shots end in relation to players and goalkeepers' efficiencies.

To improve players' performances and to understand the level of adaptation to a given training program and minimizing the risk of non-functional overreaching, monitoring players' load plays a fundamental role. For this purpose, the second part of this dissertation focused on the investigation of internal (assessed using objective and subjective methods) and external loads experienced by youth male beach handball players during training sessions and competitions. Thirteen players from the Lithuanian U17 beach handball team were monitored across 2 training camps (14 training sessions) and during the Younger Age Category 17 European Beach Handball tournament where players were involved in 7 matches. For the external load inertial movement units devices units were used while the internal load was objectively recorded by means of heart rate (HR) monitors. After each session, the HR data were exported, and the individual workload was calculated according to the summated HR zones (SHRZ) method. Furthermore, the internal load was subjectively assessed by means of Rating of Perceived Exertion (RPE) scale by asking each player "How hard was your training/Match?" 30 min after the completion of the session. Successively, the session RPE (sRPE) workload was calculated by multiplying the individual RPE score for the duration of each session.

Subjective perception of internal load experienced by youth beach handball players increases with the objective internal load. However, the increase varies between players and sessions.

In addition, results showed that external load variables (PlayerLoad^{TM}, accelerations, low intensity events, medium intensity events, high intensity events, jumps, and changes of directions) showed a strong correlation with sRPE and SHRZ. The variable with the highest relationship and predictive capability, with both SHRZ and sRPE, was PlayerLoad^{TM}.
Further investigation should examine any potential difference in players of different ages and explore the influence of other contextual factors such as the match outcome or the individual players' fatigue.

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1.GENERAL INTRODUCTION

Beach handball was developed as an evolution of the classical indoor handball with the aim of promoting competitions and practices in the summer months, by using the existing beach volleyball lines (Beach Handball History, 2020). Beach handball is played on a 27x12m sand court by two teams composed by a goalkeeper and three field players. Differently from indoor handball, physical contact is not allowed (International Handball Federation, 2014).

Beach handball games are characterized by high intensity activities involving speed, power, precision, and flexibility (Pueo et al., 2017). At team level, players are involved in offensive and defensive actions (Gkagkanas, Hatzimanouil, & Skandalis, 2018) with many factors contributing to a successful performance such as goalkeeper saves, shooting techniques, blocks, or technical fouls (Saavedra et al., 2019).

To improve athletes' performances and support coaches in developing effective training strategies the most useful process is the performance analysis, consisting in the systematic observation of the performance with the objective to identify good and bad performances of a single player or the team and to facilitate comparative analysis (Hughes & Franks, 2015).

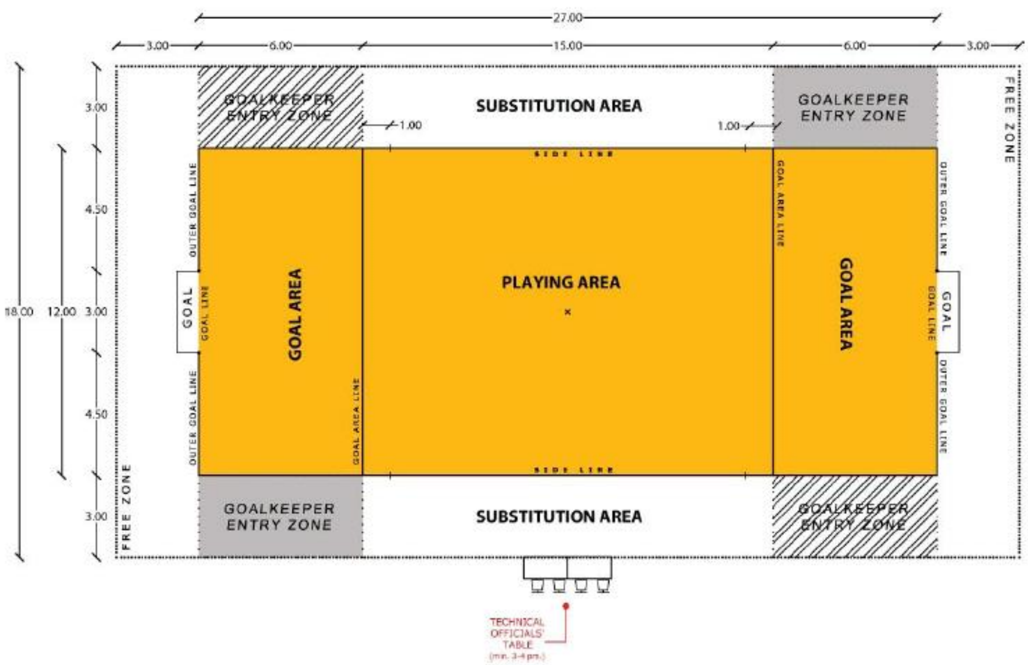
Recently, many studies dealing with individual and team performance (Gkagkanas, Hatzimanouil, & Skandalis, 2018; Gkagkanas, Hatzimanouil, Skandalis, et al., 2018; Gruic et al., 2011; Morillo-Baro et al., 2015; Saavedra et al., 2019; Skandalis & Hatzimanouil, 2017; Vázquez-Diz et al., 2019; Zapardiel, 2018; Zapardiel & Asín-Izquierdo, 2020), physiological and conditional demands (Lara Cobos, 2011; Mancha-Triguero et al., 2020; Sánchez-Sáez et al., 2021; Zapardiel & Asín-Izquierdo, 2020), or anthropometric characteristics of players (Becerra et al., 2018; Figuereido et al., 2020; Jimenez-Olmedo et al., 2019; Lemos et al., 2020; Martínez-Rodríguez et al., 2021; Padilhas et al., 2018) have been published.

In order to provide training programs as effective as possible and to minimize the risk of non-functional overreaching (Halson, 2014), this dissertation aimed to identify the internal and external workload and technical demand experienced by male and female beach handball players during training sessions and matches.

1.1 Beach handball

Beach handball is a growing team sport with a defined structure and a clear philosophy based on the principles of “fair play” (International Handball Federation, 2014). A match is played on a 27x12m sand court composed by a playing area and two goal areas (Figure 1.1-1).

Figure 1.1-1 Beach handball's playing court (International Handball Federation, 2014).

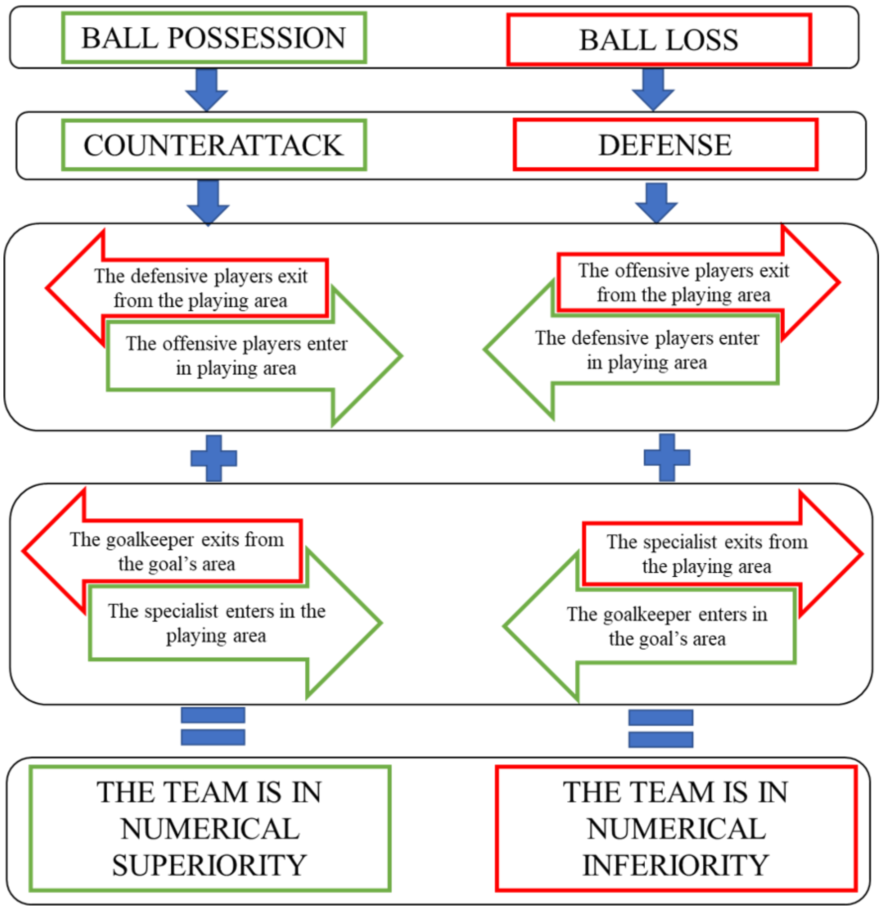


The longer boundary lines are called sidelines whereas the two shorter are the goal lines. The goal-area lines are placed at a 6m distance from and parallel to the goal line. On each side of the playing area outside the sidelines there are the substitution areas from which players must enter the court. Goalkeepers must enter the court over the sideline of their own team’s goal area from the side of their own team’s substitution area. The time scoring is suspended by the referee in case of a player’s/ team official’s suspension or disqualification of a player, 6-metre throws, team time-outs, whistle signal from the timekeeper or the technical delegate, consultations between the referees.

Each team is composed by maximum ten players with a maximum of four players per team (three field players and one goalkeeper) on the playing court at the same time. The remaining players are the substitutes placed in their own substitution area.

The peculiarity of beach handball is the rule of free substitutions: substitutes are allowed to enter the playing court, at any time and repeatedly, without notifying the timekeeper/scorekeeper, as long as the players they are replacing have already left the court. In particular, during the offensive phases the goalkeeper is allowed to exit the goal's area and be changed by a field player, the specialist player, creating a situation of numerical superiority. Therefore, beach handball matches' structure is defined "cycling eight" (Figure 1.1-2), characterized by the concurrent transition between the offensive and defensive phases (Lara Cobos et al., 2018).

Figure 1.1-2 Beach handball game structure.



During the match players can throw, catch, stop, push or hit the ball, by using hands, arms, head, torso, thighs and knees. The ball possession may last no longer than three seconds for each player; in addition, players may take only three steps while holding the ball. During ball possession, the team has to make recognizable attempts to attack or to shoot on goal otherwise actions will be considered as regarded as passive play, penalized with a free throw against the team in possession of the ball.

The match consists of two sets, lasting ten minutes each; the between-sets rest is five minutes. In the event of a tied set, the “Golden Goal” takes place. During the “Golden Goal”, the referee restarts the match and the set’s win is awarded to the first team scoring a point. Points are awarded when players score goals, and the evaluation of goals is based on the shooting technique: attractive goals or goals made by specialist player are awarded two points whereas non-attractive goals one point. The winner of each set is awarded one point. In the event of a tied match, “Shoot-outs” are played. During “Shoot-outs”, five players for each team take throws alternating with the opposing team and the team scoring more points after 5 throws is the winner of the match.

Given its specific characteristics, beach handball is considered a high-intensity mixed-metabolism sport, characterized by the combination of high-intensity physical patterns involving speed, power, rapid accelerations and decelerations, and change of directions (Lara Cobos, 2011; Pueo et al., 2017).

1.2 Performance analysis of beach handball

Performance analysis is a process consisting in the systematic observation of behavioral data with the aim of providing a valuable estimate of technical and tactical aspects of sports (Hughes & Franks, 2015).

Findings from a systematic review (Prieto et al., 2015) showed that the information provided by performance analysis gives coaches useful feedbacks about their short, medium and long-term planning. In addition, 86% of interviewed coaches confirmed that performance analysis was “essential” or “very useful” for applying specific changes in their training and game strategies. Therefore, it is crucial to identify the performance indicators of the sport to give appropriate feedback to coaches and practitioners. To be useful, performance indicators should relate to successful performance or outcome (Hughes & Bartlett, 2002). In beach handball the performance depends on the combination of high-intensity physical patterns at player and team level (Pueo et al., 2017; Sánchez-Sáez et al., 2021; Zapardiel & Asín-Izquierdo, 2020). The player performances depend on specific movements involving speed and power, rapid accelerations and decelerations, and changes in directions (Pueo et al., 2017), whereas the overall team performance depends on technical and tactical team performance indicators, such as passing, catching, throwing, and blocking during offensive and defensive situations (Gkagkanas, Hatzimanouil, Skandalis, et al., 2018; Gruic et al., 2011). Thus, a successful performance is the result of the combination of performance indicators, such as passes, shots and field positions, representing a selection or combination of variables aimed to define some or all aspects of a performance (Saavedra et al., 2019). For beach handball, the better differentiators between winning and losing teams are the variables involving a combination of other in the calculation of their score such as the goalkeepers received and blocked shots, or shots attempts made by shooters and blocks, reflecting the importance of the goalkeeper in a team’s victory, as well as the value of goals, blocks, and technical fouls (Saavedra et al., 2019). In fact, the evaluation of goals is based on the shooting technique: attractive goals or goals made by specialist player are awarded two points whereas non-attractive goals one point (International Handball Federation, 2014).

To the best of our knowledge, only few studies have been focused on the shooting actions during beach handball matches. Skandalis & Hatzimanouil (2017) analyzed the differences between winning and defeated teams referring to the variable describing the situation effectiveness of female beach handball such as the frequency of successful and unsuccessful shots, penalties, blocks, or goalkeepers' saves. Results showed that successful shots, blocks and technical errors differentiated the winning teams from the defeated teams. Skandalis & Hatzimanouil (2017) assessed shooting performance according to the shooting positions and goalkeepers' efficiency, also in relation to gender. Results showed that for both male and female players the most frequent shooting area was the center; however, the majority of successful shots came from the right side for males and the center for females. In addition, it has been observed (Gkagkanas, Hatzimanouil, & Skandalis, 2018; Gkagkanas, Hatzimanouil, Skandalis, et al., 2018) that goalkeepers' efficiency was higher when shots came from the left shooting position for male and female players.

In addition to the shooting analysis, another relevant aspect contributing to a successful performance is represented by the tactics. For this purpose, a recent study (Gkagkanas, Hatzimanouil, & Skandalis, 2018) analyzed the defensive tactics, demonstrating that, in both male and female players, the most adopted initial defense scheme involves three players positioned by the goal area line, preferring a passive defense against the initial formation of the attackers. Similarly, for the final tactical defense scheme three players are positioned by the goal area line, probably because of the numerical inferiority situation typical of beach handball's defensive phases.

Concerning the offensive phases of the game, in the initial and final tactical options during attack, both males and females mainly use the formation with three back players and one line player (or the specialist) centrally positioned; additionally, females also frequently use the formation with three back players and one line player (or specialist) positioned at the left side of the attack (at the substitution area) (Navarro et al., 2018).

The tactical behaviors of the offensive team depend on the defense schemed adopted by the opponents (Navarro et al., 2018). For instance, in male players, when the opponents use a closed defense (3 defenders aligned by the goal area), the specialist tends to perform the assist while another player tends to end the attack by means of a spectacular shot, scoring two points. Differently, females tend to end the attack with an assist by the specialist to the right player, who then performs a spectacular shot, or with the specialist directly shooting on goal, underlying the fundamental role of the specialist player in creating and performing attacks (Vázquez-Diz et al., 2019). In fact, in males the specialist's assists are not positively related to a successful score, with the offensive actions usually ending in the central areas, in case of a closed defensive scheme. In contrast, for females the specialist player tends to end the offensive actions, also against a closed defensive system (Vázquez-Diz et al., 2019).

1.3 Monitoring workload in beach handball

Monitoring athletes' workload is an essential process to understand the level of adaptation to a given training program and it is useful in minimizing the risk of non-functional overreaching (Halson, 2014).

The load can be either external or internal. External load represents an objective measure of the work performed by the athlete (i.e. total distance covered in different speed zones and the number of sprints, accelerations, and decelerations) (Bourdon et al., 2017). External load is commonly measured by means of Global Positioning System (GPS) satellite-based navigation technology necessitating GPS satellites orbiting the Earth and sending time information to the GPS receivers. GPS devices are incorporated with Inertial Movement Units (IMUs), such as triaxial accelerometers, magnetometers, and gyroscopes, with a high frequency sample (typically 100 Hz). Another emerging tracking technology in sports settings is represented by the Local Positioning Systems (LPS). LPS determines the position of an object in the physical space continuously and in real-time and combines several technologies such as image-based technologies, the radio-frequency identification and ultrawideband (Conte, 2020).

Measures of external load may assist practitioners to optimize the training plan by varying specific measures (Cardinale & Varley, 2017). In team sports, examples of external load measures are usually represented by distance and velocity measures, accelerations, decelerations, changes of directions (CoDs), or jumps where accelerations and decelerations are defined, respectively, as positive and negative rates of change in movement velocity respectively in a horizontal or anterior-posterior direction and CoDs are rapid, whole-body movements with a sudden change of velocity and direction (right/left), in relation to sport-specific speed zones (Fox et al., 2020; Kniubaite et al., 2019; Pueo et al., 2017; Sánchez-Sáez et al., 2021; Simpson et al., 2020; Zapardiel & Asín-Izquierdo, 2020).

Internal load represents the psychophysiological response of the athlete to a given training stimulus and it can be used as primary measure when monitoring athletes (Impellizzeri et al., 2019). Internal load can be measured by means of objective methods such as HR, blood lactate concentration, or oxygen uptake and it is useful to improve performance and evaluating maladaptive responses to training programs (Bourdon et al., 2017; Foster et al., 2017). The HR is the most used objective parameter to monitor internal load in team sports (Halson, 2014) with many HR-based models developed such as the Summated Heart Rate Zone (SHRZ) model (Edwards, 1993). Internal load can be also subjectively evaluated through the use of questionnaires with session Rating of Perceived Exertion (sRPE) among the most used in team sports (Foster et al., 2021). The advantages of using sRPE relies on the fact that it is easy to use and interpret and can provide information not only regarding the physiological responses to the prescribed workload, but it takes into consideration also the psychological responses (Foster et al., 2021).

In beach handball, the analysis of external loads (Pueo et al., 2017) showed that during a match male players cover 1234.7 ± 192 m while female players cover 1118.2 ± 221.8 m. Additionally, females cover a higher total distance and distance walking than males during the first set while in the second set female cover a higher distance standing at a higher average speed. A more recent study (Sánchez-Sáez et al., 2021) also showed that for female players, 53% of the distance travelled is done at speeds between 1.5 and 5 km/h and 30% of the distance is between 9 and 13 km/h (83% of the total distance covered). Concerning internal load, different studies (Lara Cobos, 2011; Pueo et al., 2017; Sánchez-Sáez et al., 2021) involving elite beach handball players found that, during matches, the majority of the time is spent at intensity above the 80% of the maximal HR (HRmax).

2. RESEARCH DEFICIT

Research on beach handball has been carried out focusing on different aspects and there is still ongoing research contributing to its developing process (Bon & Pori, 2020). To the best of my knowledge only few studies (Gkagkanas, Hatzimanouil, & Skandalis, 2018; Gruic et al., 2011; Skandalis & Hatzimanouil, 2017) have been carried out with the aim to analyze differences between gender of shooting performance according to the technique used for shooting, the area from which the shot is performed and the goal's area in which the shot ends.

To improve players' performance, the quantification of the physical demand in warranted. From the literature review process, it emerged that there have been many studies investigating the external (Pueo et al., 2017; Sánchez-Sáez et al., 2021; Zapardiel & Asín-Izquierdo, 2020) and internal (Lara Cobos, 2011; Pueo et al., 2017; Sánchez-Sáez et al., 2021) workloads experienced by beach handball players during matches. However, none of the previous studies have monitored players' workload of youth beach handball players during training sessions and official competitions. This could have led to an under or overestimation of players' responses since during competitions many contextual factors, such as emotions or accumulated fatigue, may influence the external and internal players' workload. Moreover, none of the previous studies was focused on the quantification of internal workload subjectively assessed, via sRPE (Foster et al., 2001). Given the economical and practical use of this tool, sRPE may represent a valid alternative for the monitoring process when specific devices such as inertial movement units or HR monitors are unavailable.

3. AIMS OF THE DISSERTATION

The goal of this dissertation was to provide a comprehensive performance analysis model of beach handball by focusing on two main aspects: i) the analysis of technical-tactical performance indicators and ii) the analysis of external and internal loads.

In particular, the first research paper (Chapter 3.1) aimed to analyze the variations of shooting efficiency between male and female beach handball players by means of notational analysis.

The second research paper (Chapter 3.2) aimed to assess the correlation between objective and subjective internal load measures in beach handball players during training and competitions.

The third research paper (Chapter 3.3) aimed to examine the relationship between the internal and external load measures in youth male beach handball players during training sessions and competitions.

3.1 ARTICLE 1. Notational analysis of beach handball

MEiN	INDEX COPERNICUS	GOOGLE H5	CiteScore 2020
20	120.99	11 VIEW ARTICLES	1.6 Predicted CiteScore 2021 1.4

Iannaccone, A.; Fusco, A.; Conte, D.; Cortis, C. Notational analysis of beach handball. *Hum. Mov.* 2022, 1, Published Ahead of print on Dec 17, 2020, doi:10.5114/hm.2021.101757.

3.1.1 Abstract

Purpose. One factor affecting a successful performance in beach handball is the efficiency of shootings. As only few studies evaluated the gender-related differences in shooting performance, the aim of this study was to analyze the variations of shooting efficiency between males (M) and females (F) during beach handball matches.

Methods. Nine matches were analyzed. Overall, there were 559 (M: 353; F: 206) shots of which 54.7±9.4% were successful and 19.9±7.1% were goalkeepers' saves. Type of shot, shooting area and goal's area were recorded. Percentages of differences between gender have also been computed. Players' efficiency was calculated as (number of goals*100)/number of shots. Goalkeepers' efficiency was calculated as (number of goalkeepers' saves*100)/number of shots. Gender differences were ascertained by Pearson's Chi Square ($\chi 2$) test for independence with Bonferroni corrections. The level of significance was set at $p<0.05$.

Results. No statistically significant gender differences were found for any parameter. Goalkeepers were most efficient (M: 23.0±6.1%; F: 25.9±18.0%) when receiving inflight shots than the other types of shot. The most frequent shooting area was the front (M: 328 shots; F: 194 shots) and most shots reached lower corners of the goal (M: 139 shots; F: 77 shots).

Conclusions. No differences between gender were found during semifinal and final phases of the tournament. Notational analysis proved to be a valuable tool for better coaching through the interpretation of shots in beach handball and it may be useful to examine all the aspects related to shooting, such as the shooting area and the goal's area.

Keywords: performance, team sports, match analysis, technical indicators, shooting, competition

3.1.2 Introduction

Beach handball is a team sport played on a 27x12m sand court by two teams, each composed by one goalkeeper (GK) and three field players. Based on the rule of free substitutions, during the offensive phases the GK is allowed to exit the goal's area and be changed by a field player, the specialist, creating a situation of numerical superiority (International Handball Federation, 2014). A match includes two 10-min sets with a golden goal in case of a tied set and a series of five shoot-outs in the event of a tied match. Beach handball matches have a peculiar structure defined cyclic eight, characterized by the concurrent transition between the offensive and defensive phases (Lara Cobos et al., 2018). The numerical superiority created by specialist temporary substituting the GK generates more opportunities to create spaces and more ways to score two points where the specialist plays a crucial role in the creation of offensive situations (Gruic et al., 2011). Successful offensive situations are expressed as shootings with their relative effectiveness (Skandalis & Hatzimanouil, 2017), representing one of the main factors contributing to the success of team sport (Hughes & Franks, 2015).

Reflecting the studies on indoor handball (Michalsik et al., 2013; Wagner et al., 2014, 2018, 2019), researches on beach handball focused on physiological and kinematic aspects (Gutiérrez-Vargas et al., 2019; Lara Cobos, 2011; Pueo et al., 2017; Valtner et al., 2015; Zapardiel & Asín-Izquierdo, 2020) individual and team performance (Gruic et al., 2011; Zapardiel & Asín-Izquierdo, 2020), and shooting analysis (Gkagkanas, Hatzimanouil, & Skandalis, 2018; Navarro et al., 2018; Skandalis & Hatzimanouil, 2017). Several moderate-to-high intensity activities distributed intermittently throughout the match characterizes beach handball, with males performing more moderate and high intensity accelerations than females (Pueo et al., 2017) and kinematics variables (i.e. total distance, body load, impacts, speed average) decreasing in the second set for both males and females (Gutiérrez-Vargas et al., 2019). In a more recent study (Zapardiel & Asín-Izquierdo, 2020) differences in the conditional assessment of the specific playing positions (specialist, wing fixed wing, pivot, defender) of elite beach handball players have been studied for male and female players. Significant gender-related differences emerged in the conditional data of competition with differences depending on the playing position, both in men and women.

Compared to the indoor handball, beach handball players cover a lower distance (indoor handball (Michalsik & Aagaard, 2015): males=3627±568 m, females=4002±551 m; beach handball (Pueo et al., 2017): males=1235±192 m; females=1118±222 m) and a lower number of accelerations due to the sandy surface placing higher physiological demands on players (Pueo et al., 2017).To the best of our knowledge only one study (Gruic et al., 2011) has been focused solely on the shooting actions during beach handball matches showing that match analysis may provide specific insights useful for training plans and drills for a better preparation (Lupo et al., 2016). For instance, in other team sport, it has been reported (Lupo et al., 2010) that the frequency of occurrence of passes, shots, goals, shots originating from different zones of the court and the type of shots performed are the performance indicators better discriminating among competitions levels. The importance of match analysis in team sports has been highlighted also by Hatzimanouil (2019) who analyzed the effectiveness of shots by shooting areas and by playing positions among high-level handball players by means of video-analysis. The majority (56.9%) of throws were successful with a higher frequency of shots originating from the central attack area from a medium distance and ending to the left lower side of the goal. Nevertheless, the efficacy of shots was heterogeneous among the different attacking areas and players positions.

Findings from a systematic review on match analysis in handball (Prieto et al., 2015) showed that studies examined players' and teams' performances from two different perspectives. The most popular perspective is considering the classical static complexity approach based on the recording of the actions of players and teams (usually in terms of descriptive frequencies of events) to obtain a final dataset describing what happened at the end of the match, without considering how it happened. The other perspective takes into consideration the new dynamic complexity approach, wherein the actions are recorded considering the chronological and sequential order in which they occur. Looking at the utility of performance analysis, a study (Wright et al., 2012) examined the involvement with match, notational and technique analysis of 46 elite professional and semiprofessional coaches of different team sports (i.e., rugby league, hockey, football, basketball, rugby union). Findings showed that the information provided by performance analysis gives coaches useful feedbacks about their short-term (93%), medium-term (80%) and long-term (70%) planning. In addition, 86% of interviewed coaches confirmed that performance analysis was “essential” or “very useful” for applying specific changes in their training and game strategies. Therefore, it is crucial to identify the performance indicators of the sport to give appropriate feedback to coaches and practitioners. To be useful, performance indicators should relate to successful performance or outcome (Hughes & Bartlett, 2002).

In beach handball the performance depends on the combination of high-intensity physical patterns at player and team level. The player performances depend on specific movements involving speed and power, rapid accelerations and decelerations, and changes in directions (Lara Cobos, 2011; Pueo et al., 2017) whereas the overall team performance depends on technical and tactical team performance indicators, such as passing, catching, throwing, checking and blocking during offensive and defensive situations (Bělka et al., 2015; Wagner et al., 2014). Thus, a successful performance is the result of the combination of performance indicators, such as passes, shots and field positions, representing a selection or combination of variables aimed to define some or all aspects of a performance (Hughes & Bartlett, 2002). For beach handball the better differentiators between winning and losing teams are the variables involving a combination of other in the calculation of their score such as the GK’s received and blocked shots, or shots attempts made by shooters and blocks, reflecting the importance of the GK in a team’s victory, as well as the value of goals, blocks, and technical fouls (Saavedra et al., 2019). In fact, the evaluation of goals is based on the shooting technique: attractive goals or goals made by specialist player are awarded two points whereas non-attractive goals 1 point (Gruic et al., 2011).

Jimenez-Olmedo et al. (2019) showed that specific anthropometric characteristics (i.e., elbow perimeters and dimension of hand polygons) are positively correlated with throwing performance in beach handball players, in particular for the specialist. However, because overarm throw is a multi-joint movement with many potential degrees of freedom, basic anthropometric parameters proved to be more important than hand dimensions (Jimenez-Olmedo et al., 2019). In addition to individual's throwing capacity, the cooperation among players is crucial for a successful shooting performance (Gruic et al., 2011). Regarding the position of the shots, the right side has been reported to be the most efficient shooting position for males (Skandalis & Hatzimanouil, 2017) although the highest shooting frequency was from the center (Gkagkanas, Hatzimanouil, & Skandalis, 2018; Skandalis & Hatzimanouil, 2017) while for females, shootings from the center showed the highest frequency and efficiency (Gkagkanas, Hatzimanouil, & Skandalis, 2018; Skandalis & Hatzimanouil, 2017). Gender differences have been reported also in terms of behaviors occurring during the positional attack phases with males ending the offensive phases on the outer edges of the playing court (Navarro et al., 2018) and females on the left side (Morillo-Baro et al., 2015). Furthermore, different behaviors have been reported when the attack ends with an inflight shot with males tending to use this type of shot when they are winning and females when they are tied or losing (Navarro et al., 2018).

It is evident that research on beach handball have been carried out focusing on different points of view and there is still ongoing research contributing to its developing process (Bon & Pori, 2020). In particular, few studies have been conducted with the aim to analyze differences between gender of shooting performance. Therefore, to contribute to the further development of the sport the aim of this study was to analyze the variations of shooting efficiency between male and female beach handball players.

3.1.3 Material and methods

Experimental Approach to the Problem

According to the rules of the game of beach handball (International Handball Federation, 2014) players may use different type of shots to score a goal (Table 3.1.3-1).

Table 3.1.3-1 Classification of the type of shots used in beach handball according to the rules of the game proposed by the International Handball Federation.

Type of shot	Description	Points
Inflight	Performed while flying through the air	2
Spin shot	Taken with full turn of the body in the air	2
Specialist	Performed by the specialist player	2
Directive goal	Performed by the goalkeeper from the goal area	2
6m shot	Penalty throw performed from the 6m line	2
One pointer	Non-attractive shot	1

Since the success of a shot is the result of a combination of different performance indicators (Hughes & Franks, 2015), the analysis focused on performance indicators as described in Table 3.1.3-2.

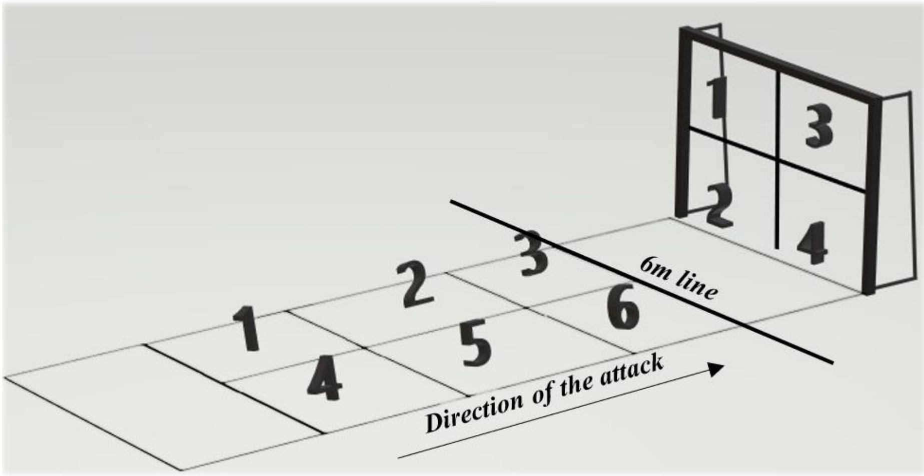
Table 3.1.3-2 Description of the performance indicators of beach handball.

Performance indicators	Description
Shooting Area	Area of the playing field from which the shot is performed
Goal's Corner	Corner of the goal to which the ball is thrown
Successful shot	Shot ended with a scored goal
GKs* save	Goal not scored because of a block from the goalkeeper

*GKs: goalkeepers

By adapting the models proposed for notational analysis (Hughes & Franks, 2015), the playing field has been divided into three horizontal areas (front, center, back) measuring 6x5m each and two vertical areas (right and left) measuring 6x15m each and the goal in four corners (upper left, lower left, upper right, lower right) measuring 1.5x2m each, as showed in Figure 3.1.3-1.

Figure 3.1.3-1 Representation of the shooting and goal's areas according to the players' point of view



Shooting areas 3-6: front; 2-5: center; 1-4: back,1-2-3: left,4-5-6: right.

Goal's areas: 1-3: high corners; 2-4: low corners; 1-2: left side; 3-4: right side.

Sample

The "Calise Cup" tournament is a beach handball competition for clubs taking place every year in Italy. The tournament lasts 3 days (temperature: 29.6±1.3°C; humidity: 58.6±11.8%): the first 2 days are dedicated to eliminatory phases (played on 2 different courts at the same time) while during the last day semifinals and finals occur (1 match at time in the main arena). Each team plays at least 5 matches all along the tournament. Before starting the video-recording for the study, the framing for all the 3 playing courts has been checked and they were all different. Only the court used for the semifinals and finals allowed a full and satisfying view of the court. Therefore, to ensure the reliability of video-recording only matches played on the main arena during the semifinal and final phases of the tournament have been considered for the present study (10 male seniors, 10 female seniors, 8 male U18 and 4 male U12). However, after preliminary analysis, differences in technical-tactical actions of U12 players have been observed with the rest of the sample. Therefore, U12 matches have been excluded from the final sample as well as matches during which technical issues happened while recording, thus leaving a final number of 9 analyzed matches involving 4 male senior

(Chemo profili Zagreb, Albena Beach Bulgaria, Beach Stars BHC, Zagreb Beach Hrvatska), 4 male U18 (Göteborg B.H. Club, Zagreb Beach Hrvatska, Pallamano Grosseto, BHC Cus Cassino) and 4 female (Beach Queens, Beach Princesses, Team Enigma Web Design The Danish Beach Handball Dream, Cannabis Energy Drink Beach Handball Club) teams.

As performance analysis could provide a valuable estimate of technical and tactical aspects of team sports (Hughes & Franks, 2015), it was hypothesized that examining efficiency of players during the final phases of the tournament (i.e., semifinals and finals) would increase the relevance and applicability of results for coaches and practitioners.

Procedures

Matches were recorded by 2 experienced researchers (C.C. and A.F.) by means of a video camera (Sony Camcorder HR-CX290/B, Sony, Minato, Tokyo, Japan) fixed at one side of the field, allowing a full view of the playing area. After each match, the recorded video was downloaded and used for further analysis. For the video analysis, carried out by 2 experienced observers (A.I. and D.C.), a keyboard created ad hoc with the software Dartfish TeamPro 5.0 (Dartfish, Fribourg, Switzerland) was used.

Preliminary Analysis

Notational analysis consists of an objective way of recording performance, so that critical events in that performance can be quantified in a consistent and reliable manner allowing to provide useful feedback, crucial in the performance improvement process (Hughes & Franks, 2015). In this context it is necessary that the feedback is accurate and precise. Therefore, before proceeding with the statistical analysis, accuracy and reliability of the data gathered through video analysis have been assessed. In line with previous notational analyses (Lupo et al., 2016; Michalsik & Aagaard, 2015), to provide a reliable analysis, either the intra- and inter-observer reliabilities were established. Before the study the observers scored twice three randomly selected matches, and each observation was separated by seven days. The intra and inter-observer reliabilities were ascertained using the weighted kappa statistic

(Robinson & O'Donoghue, 2007) for each observed variable and interpreted according to the guidelines proposed by Landis and Koch (1977). Table 3.1.3-3 shows the results for the intraobserver reliability of the two observers, as well was the inter-observers' reliability.

Table 3.1.3-3 Intraobserver and inter-observers' reliabilities for the variables observed for the analysis.

Variable	Agreement (%)			Expected Agreement (%)			Kappa		
	O1	O2	O1 vs O2	O1	O2	O1 vs O2	O1	O2	O1 vs O2
Type of shots									
Spin shot	96.0	96.8	96.3	65.2	63.3	63.5	0.88	0.91	0.90
Specialist	96.1	97.4	98.0	72.0	76.5	77.2	0.86	0.88	0.91
Inflight	95.4	98.5	97.2	71.4	76.5	76.3	0.84	0.94	0.88
One pointer	98.4	97.6	97.1	97.6	94.8	95.3	0.32	0.54	0.46
Directive goal	98.9	99.7	98.3	93.4	71.7	95.0	0.83	0.99	0.67
6m shot	99.3	99.7	99.7	93.7	75.2	90.6	0.88	0.99	0.97
Shooting area									
Front	99.1	99.1	98.7	89.2	94.1	90.7	0.91	0.85	0.86
Center	98.4	99.3	97.1	96.4	98.4	96.2	0.56	0.57	0.54
Back	96.9	98.8	98	91.0	95.2	93.6	0.65	0.76	0.69
Right/Left side	95.7	91.7	88.6	61.9	58.3	58.5	0.89	0.80	0.73
Goal's area									
Upper/Lower corner	88.7	87.0	89.8	68.0	68.4	69.7	0.64	0.59	0.66
Right/Left side	92.7	85.6	83.0	66.5	61.4	62.8	0.78	0.63	0.54
Shot's outcome									
Successful/ Unsuccessful shot	98.6	94.9	95.1	64.4	75.5	56.3	0.96	0.80	0.89

Note: O1= observer 1; O2=observer 2

For all the variables values were classified strong or moderate, except for the intraobserver reliability of observer 1 for one pointer shot (fair agreement). Since the kappa statistics is based on the proportion of frequencies of events and that only few one pointer shots were recorded, the percentages of agreement have been considered as acceptable.

Statistical analysis

Means and standard deviations were calculated for each variable. Gender differences in frequencies of shots, GKs' saves and goals in relation to the type of shot, the shooting area and the goals' area were ascertained by Pearson's Chi Square (χ^2) test for independence. Where significant results were found, Bonferroni correction for multiple post hoc comparisons were applied. Since a different number of matches was recorded for males and females, to allow comparison between gender the percentages of differences between means of male and female players have been computed and efficiencies of players and GKs have been calculated following the equations proposed by O'Donoghue P. (2014):

Players' efficiency = (frequency of goals *100)/ frequency of shots;

GKs efficiency = (frequency of GKs' saves*100)/frequency of shots.

Statistical analysis was performed using STATA statistical software version 15.1 (StataCorp, College Station, TX, USA) and the level of significance was set at $p<0.05$.

Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the Institutional Review Board of Department of Human Sciences, Society and Health of the University of Cassino and Lazio Meridionale (approval No: 3538.2019.02.19; date: February 19th, 2019).

Informed consent

The video-recording for this study took place in a public arena and no intervention or direct interaction was required. Thus, according to the rules of competitions and the guidelines and basic ethical principles described in the Belmont Report, supporting the accessibility of images of public behavior for the research's reason on human subjects there was no need of informed consent from the participants to enable the use of the analyzed video-recordings, as these are in the public domain.

3.1.4 Results

In the present study 559 shots (males: 359; females: 206) on goal made throughout 9 matches (2 semifinals female senior, 2 semifinals male senior, 2 final male U18, 1 final female senior, 2 final male senior) have been analyzed.

Among the total sample, 54.7±9.4% (males: 55.5±11.4%; females: 53.3±4.3%) of the shots were successful and 19.9±7.1% (males: 19.5±11.4%; females: 20.8±8.9%) were GKs' saves. No significant gender differences emerged for the different type of shots (Table 3.1.4-1).

Table 3.1.4-1 Absolute (n), relative (means ± standard deviations) and percentage of differences between gender of frequencies of shots, GKs' saves and goals with GKs and players efficiencies observed in relation to the type of shot in males and females.

Type of shot	Players	Shots (abs)	Shots (rel)	GKs' saves (abs)	GKs' efficiency	Goals (abs)	Players' efficiency
Spin shot	Males	157	43.9±11.2	32	20.9±12.8	92	57.9±13.9
	Females	117	56.4±10.4	23	20.4±6.7	60	50.2±6.8
	diff (%)		28.5		-2.4		-13.3
Specialist	Males	82	23.4±4.6	15	17.7±11.7	40	47.9±21.4
	Females	37	18.1±5.7	8	22.2±12.7	17	46.1±3.4
	diff (%)		-22.6		25.4		-3.8
Inflight	Males	71	19.7±8.3	15	23.0±6.1	42	52.8±19.7
	Females	34	16.8±6.5	10	25.9±18.0	21	62.4±18.9
	diff (%)		-14.7		12.6		18.2
One pointer	Males	12	4.3±8.3	3	12.0±20.6	6	32.4±40.4
	Females	2	1.0±1.8	-	-	-	-
	diff (%)		-76.7		-100.0		-100.0
Directive goal	Males	14	4.0±2.5	2	12.5±20.9	6	33.3±25.8
	Females	4	1.8±2.1	2	-	-	-
	diff (%)		-55.0		-100.0		-100.0
6m shot	Males	17	4.7±2.4	1	16.7±40.8	12	63.3±39.7
	Females	12	5.8±1.0	-	-	12	100.0±0.0
	diff (%)		23.4		-100.0		58.0
Pearson's Chi Square (χ2)		*11.600*		*25.445*		*20.541*	
p-value		*0.041*		*0.005*		*0.38*	
Level of significance with Bonferroni correction		*0.0042*		*0.0042*		-	

Note: Abs = absolute frequency; rel = relative frequency; GKs = goalkeepers, diff % = percentage of difference.

No significant gender differences emerged for the different shooting areas (Table 3.1.4-2).

Table 3.1.4-2 Absolute (n), relative (means ± standard deviations) and percentage of differences between gender of frequencies of shots, GKs' saves and goals with GKs and players' efficiencies observed in relation to the shooting area in males and females.

Shooting area	Players	Shots (abs)	Shots (rel)	GKs' saves (abs)	GKs' efficiency	Goals (abs)	Players' efficiency
Front all (including 6m shots)	Males	328	92.0±6.1	66	21.6±9.3	185	54.1±13.4
	Females	194	93.7±1.8	43	20.6±9.1	108	55.9±4.8
	diff (%)		1.8		-4.6		3.3
Front right	Males	156	44.1±3.2	35	22.9±10.0	82	51.3±18.6
	Females	95	46.1±0.9	24	23.3±10.1	53	55.8±5.0
	diff (%)		4.5		1.7		8.8
Front left	Males	154	43.3±5.9	30	20.6±12.1	90	57.1±14.9
	Females	86	41.9±2.4	18		43	50.0±5.2
	diff (%)		-3.2		1.0		-12.4
Center all	Males	6	1.9±1.9	-	-	3	25.0±41.8
	Females	7	3.4±0.6	-	-	1	11.1±19.2
	diff (%)		78.9				-55.6
Center right	Males	4	1.1±1.4	-	-	2	16.7±40.8
	Females	1	0.5±0.8	-	-	1	33.3±57.7
	diff (%)		-54.5				99.4
Center left	Males	2	0.8±1.9	-	-	1	8.3±20.4
	Females	6	2.9±0.2	-	-	-	-
	diff (%)		262.5				-100.0
Back all (including directive goals)	Males	19	6.4±5.2	2	11.1±20.2	10	40.6±32.0
	Females	5	2.3±2.8	2	41.7±52.0	-	-
	diff (%)		-64.1		275.7		-100.0
Back right	Males	3	1.0±1.6	-	-	3	33.3±51.6
	Females	1	0.5±0.8	-	-	-	-
	diff (%)		-50.0		-		-100.0
Back left	Males	4	1.4±2.8	-	-	3	27.8±44.3
	Females	-	-	-	-	-	-
	diff (%)		-100.0		-		-100.0
Pearson's Chi Square (χ2)		*8.7026*		*0.8466*		*8.2215*	
p-value		*0.275*		*0.838*		*0.313*	

Note: Abs = absolute frequency; rel = relative frequency; GKs = goalkeepers; diff % = percentage of difference.

No significant gender differences emerged for the different goal's areas (Table 3.1.4-3).

Table 3.1.4-3 Absolute (n), relative (means ± standard deviations) and percentage of differences between gender of frequencies of shots, GKs' saves and goals with GKs and players efficiencies observed in relation to the goal's area in males and females.

Goal's area	Players	Shots (abs)	Shots (rel)	GKs' saves (abs)	GKs' efficiency	Goals (abs)	Players' efficiency
Upper corner (all)	Males	110	44.6±5.6	27	25.1±17.4	83	74.9±17.4
	Females	63	45.3±15.6	12	17.3±13.2	51	82.7±8.8
	diff (%)		1.6		-31.1		10.4
Upper right corner	Males	53	16.2±4.0	11	25.9±23.1	42	74.1±23.1
	Females	27	17.3±9.3	8	10.1±13.2	19	89.9±13.2
	diff (%)		6.8		-61.0		21.3
Upper left corner	Males	57	15.1±2.4	16	22.6±16.6	41	77.4±16.6
	Females	36	13.3±4.8	4	31.5±23.0	32	68.5±23.0
	diff (%)		-11.9		39.4		-11.5
Lower corner (all)	Males	139	55.4±5.6	21	16.0±5.4	115	82.0±6.5
	Females	77	54.7±15.6	19	21.8±10.8	58	78.2±14.5
	diff (%)		-1.3		36.3		-4.6
Lower right corner	Males	66	20.8±6.0	12	14.3±8.5	51	85.7±8.5
	Females	38	19.0±7.8	8	24.5±16.6	30	75.5±16.6
	diff (%)		-8.7		71.3		-11.9
Lower left corner	Males	73	18.5±3.0	9	18.0±2.1	64	77.7±6.3
	Females	39	18.3±4.0	11	18.3±16.9	28	81.7±16.9
	diff (%)		-1.1		1.7		5.1
Pearson's Chi Square (χ^2)		*8.3120*		*12.2086*		*3.8340*	
p-value		*0.140*		*0.032*		*0.280*	
Level of significance with Bonferroni correction		-		*0.0042*		-	

Note: Abs = absolute frequency; rel = relative frequency; GKs = goalkeepers; diff % = percentage of difference.

3.1.5 Discussion

The aim of this study was to analyze the variations of shooting efficiency between gender in beach handball. Findings from this study showed that i) no statistically significant difference between male and female players were found; ii) GKs were most efficient when receiving inflight shots than the other types of shot; iii) shots originated most frequently from the front shooting area; iv) the majority of shots reached the lower corners of the goal.

In line with the shots' frequency observed in female tournaments (Lara Cobos & Sánchez Sáez, 2018), the most frequent shot observed in the present study was the spin shot while the less frequent was the one pointer shot with respect to the other types of shot. In fact, it has been reported (Lara Cobos & Sánchez Sáez, 2018) that there is a decrease over the years of the frequency of one pointer shots, suggesting a change in the attacking models adopted by the teams.

In the present study female players showed highest efficiency values when using inflight shots over the types of shot, not considering the 6m shot which will be discussed separately. GKs also showed highest efficiency values when blocking inflight shots, with respect to the other types of shot. For male players highest values of efficiency have been found for the spin shots with respect to the other types of shot. Male GKs showed highest efficiency values when blocking inflight shots, with respect to the other types of shot. When comparing the percentage of differences of relative frequencies for males and females the results, even though not statistically significant, indicate that females used more spin shots and 6m shots than males. However, female GKs showed higher values of efficiency than males when defending shots made by the specialist or using the inflight shots over the other types of shot. Moreover, female players were more efficient than males only when shooting with inflight shots, excluding the 6m shots.

These results observed for female players differ from what was previously reported (Zapardiel, 2018) where field players were more efficient using spin shots probably due to the defensive system adopted. In fact, the defensive systems may influence the style of play of offensive teams. In particular, if the defensive team focuses on the specialist player of the opponent leaving the outer zones of the playing field unprotected, the offensive team will probably try to shoot from those zones using spin shots (Zapardiel, 2018). Therefore, it can be assumed that defensive systems adopted in the observed matches did not allow players to have higher efficiency's values than those observed in the present study and allowed to be more efficient when shooting with the inflight shots, with respect to the other types of shot.

A relevant technical aspect of beach handball shooting is the 6m shot, the penalty throw awarded by the referee. Therefore, it is not a technical-tactical choice of the players and, as for the indoor handball (Hatzimanouil et al., 2017), only the GK and the shooter are involved. The shooter can benefit from the short distance from the goal and the central shooting position and the GK has few chances to block the ball. Thus, it is not surprising that players had higher efficiency and GKs lower efficiency when compared to the other types of shot, with females showing higher values than males.

To the best of our knowledge none of the studies investigating beach handball shots focused on the different shooting areas. In the present study, the most frequent shooting area was the front (area 3 and 6), for both males and females. Although no gender differences emerged, male players shot more frequently from the back area while female GKs were more efficient when receiving shots from the back. It is possible that shooting from the back area requires more strength than shooting from the front due to the distance from the goal, thus favoring male players which are usually stronger than female ones (Wagner et al., 2019). The difficulty in shooting from the back could also depend on the velocity of the defensive system often leading to a directive goal. In fact, a slow defensive system gives the offensive team more time in numerical superiority where the GK has the chance to shoot quickly with a directive goal before the teams reach the numerical balance. Conversely, if the ball is slower, the GK of the team in numerical inferiority could have more time to re-enter in the goal's area, having higher possibility to save the goal. Furthermore, for team handball, probably true also for beach handball, it has been demonstrated (Vila et al., 2020) that high throwing velocity and efficiency are inversely related, suggesting that there is a need of identifying the right combination between efficiency and velocity.

With respect to the goal's area, in the present study most of the shots reached the lower corners, coherent with findings reported in a previous study (Skandalis & Hatzimanouil, 2017). Male players showed higher efficiency values when shooting to the upper right corner while female players showed highest efficiency values when shooting to the lower right corner. Male GKs were most efficient when defending the upper right corner of the goal and female GKs when defending the upper left corner of the goal. One of the main factors influencing the success of a shot could be the anticipatory strategy of GK as for team handball (Gutierrez-Davila et al., 2011), in which it has been demonstrated that GKs are able to identify the clues suggesting the goal's side in advance although it is more difficult to predict the height of the shot.

When analyzing shooting efficiencies several variables, including anthropometric characteristics, should be taken into consideration. In fact, female GKs are typically lower than males, thus they might have more difficulties in reaching the highest corner of the goal to save the ball (Skandalis & Hatzimanouil, 2017). Moreover, the shooting efficiency could also be influenced by the defensive systems, especially used at national level. In particular, the defensive systems try to reduce the shooting efficiency by stealing the ball from the opponents or by inducing the offensive teams to make mistakes while attacking (Gkagkanas, Hatzimanouil, Skandalis, et al., 2018).

Although meaningful data have been shown from the present study, some limitations should be considered when interpreting findings. Firstly, the sample included senior club players and results might not be generalized to different level of competitions and ages. Secondly, in the present study it was not possible to collect players' anthropometrical data. As anthropometrics could affect the throwing performance (Jimenez-Olmedo et al., 2019; Michalsik & Aagaard, 2015; Wagner et al., 2019), further research should investigate also the possible impact of players' anthropometrical characteristics on their shooting efficiencies. Moreover, only semifinal and final phases of the tournament were recorded giving the possibility to analyze a limited number of shots. Therefore, future studies should investigate whether qualification and eliminatory phases might influence players' and GKs efficiencies. Finally, as technical and tactical indicators are regularly affected by the margin of victory (i.e., difference between teams according to score) (Lupo & Tessitore, 2016), further research should also control for the score between opposite teams.

3.1.6 Conclusions

Findings from the present study could provide valuable information for coaches and practitioners helping them to develop training strategies to make the dynamic system of a beach handball match more unpredictable for the opponent. From the present study no statistically significant differences between gender emerged for the shots on goal made during the semifinal and final phases of the “Calise Cup” tournament. However, it is important to examine not only the outcome of the shots but also the other related aspects such as the shooting area and the goal’s area. For this, notational analysis proved to be a valuable tool for better coaching through the interpretation of technical and tactical aspects of shots in beach handball.

Some observations can be made for planning training strategies. In particular, female players tended to prefer the spin shots than the other types of shot but the highest efficiency was observed for inflight shots meaning that the technique of spin shot should be improved. Also, coaches should pay their attention to the specialist player. In fact, this player has the chance to score 2 points without doing a spectacular action. In the present study, only in males the second most frequent type of shot was the specialist, but it was not the most efficient when compared to the other types. For GKs, trainings should be focused on improving the anticipatory strategy during the situation of the 6m shots thus increasing the possibility to save the ball. Moreover, the ability to use the directive goal should be specifically trained as the offensive team has the advantage of the numerical superiority.

The majority of shots was made from the front shooting area and players showed highest values of efficiency when compared to the other shooting areas. GKs also showed highest values of efficiency for shots originating in the front shooting area. However, both male and female GKs were not able to save the ball when the shot came from the center suggesting that specific training strategies should be adopted to improve this aspect.

Most of the shots ended to the lower corners of the goal and players were most efficient when shooting to that area while GKs were most efficient when defending the upper corners of the goal. Since shots usually reach that area, coaches should focus more on the ability to defend the lower corners of the goal when training GKs.

Nevertheless, further research should be conducted to investigate the other contextual factors related to shooting in beach handball such as the match outcome, the scoring differences or the ball possession.

3.2 ARTICLE 2. Usefulness of linear mixed-effects models to assess the relationship between objective and subjective internal load in team sports.

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3.2.1 Abstract

Background: Internal load can be objectively measured by heart rate-based models, such as Edwards' summated heart rate zones, or subjectively by session rating of perceived exertion. The relationship between internal loads assessed via heart rate-based models and session rating of perceived exertion is usually studied through simple correlations, although the Linear Mixed Model could represent a more appropriate statistical procedure to deal with intrasubject variability. This study aimed to compare conventional correlations and the Linear Mixed Model to assess the relationships between objective and subjective measures of internal load in team sports.

Methods: Thirteen male youth beach handball players (15.9 ± 0.3 years) were monitored (14 training sessions; 7 official matches). Correlation coefficients were used to correlate the objective and subjective in-ternal load. The Linear Mixed Model was used to model the relationship between objective and subjective measures of internal load data by considering each player individual response as random effect. Random intercepts were used, and then random slopes were added. The likelihood-ratio test was used to compare statistical models.

Results: The correlation coefficient for the overall relationship between the objective and subjective internal data was very large ($r = 0.74$; $\rho = 0.78$). The Linear Mixed Model using both random slopes and random intercepts better explained ($p < 0.001$) the relationship between internal load measures.

Conclusion: Researchers are encouraged to apply Linear Mixed Models rather than correlation to analyze internal load relationships in team sports since it allows to consider the individuality of players.

Keywords: team sports; statistical analysis; correlation; monitoring; RPE; heart rate; beach handball; training load; youth athletes

3.2.2 Introduction

Monitoring athletes' workload is an essential process to understand the level of adaptation to a given training program and it is useful in minimizing the risk of nonfunctional overreaching (Fusco, Sustercich, et al., 2020; Halson, 2014). The workload can be either external and internal, where the external load represents an objective measure of the work performed by the athlete (i.e., total distance covered in different speed zones and the number of sprints, accelerations, and decelerations), while the internal load represents the psychophysiological response of the athlete to a given training stimulus (Bourdon et al., 2017).

External load can be assessed by means of Global Positioning Systems (GPS), Inertial Movement Units (IMU) (Bourdon et al., 2017), accelerometers (Bourdon et al., 2017), and Local Positioning Systems (LPS) (Conte, 2020). Although these systems are widely used in team sports such as basketball (Conte et al., 2018; Fox, Stanton, & Scanlan, 2018; Sansone et al., 2019), handball (Kniubaite et al., 2019), and beach handball (Zapardiel & Asín-Izquierdo, 2020), they present several limitations, such as high cost, the need of high technical expertise, and the risk of technical errors leading to a loss of data (Haddad et al., 2017).

Internal load indicates the functional outcome of a given external load and can be used as an inexpensive way of monitoring athletes (Impellizzeri et al., 2019). Internal load can be measured by means of objective methods such as heart rate (HR), blood lactate concentration, and oxygen uptake, and it is useful for improving performance and evaluating maladaptive responses to training programs (Fox, Stanton, Sargent, et al., 2018; Fusco, Knutson, et al., 2020; Fusco, Sustercich, et al., 2020). HR is the most commonly adopted objective parameter used for monitoring internal load in team sports (Halson, 2014), with many HR-based models such as the Summated Heart Rate Zone (SHRZ) model (Edwards, 1993). Internal load can be also evaluated subjectively using questionnaires, such as the session Rating of Perceived Exertion (sRPE), which is among the most commonly used in team sports (Bourdon et al., 2017; Foster et al., 2021). The advantages of using the sRPE include its ease of use and interpretation and its ability to provide information not only on the physiological responses to the prescribed load but also the psychological responses (Foster et al., 2017). Moreover, the sRPE represents a valid tool for monitoring internal load when HR monitoring is not possible (Foster et al., 2001). To use the sRPE as an alternative to HR-based methods, it is warranted to assess its validity, which represents the extent to which method results are associated with those of other accepted methods that measure the same parameter (Martin Bland & Altman, 1986). For this purpose, simple correlations have been previously adopted as main statistical tests to assess the concurrent validity of objective and subjective methods for monitoring the internal load, proving that the sRPE method is a valid, alternative tool to HR-based methods. However, when using simple correlation analyses, the within-subject variability it is not considered (Albert, 1999; Schober & Vetter, 2018).

One way to overcome this limitation and improve the statistical analysis is the use of Linear Mixed Model (LMM) (Atkinson et al., 2011), which involves a generalization of linear regression but with both fixed and random effects. Fixed effects are analogous to the linear predictor from a standard linear regression, while the random effects are not directly estimated but are summarized according to their estimated variances and covariances. This structure gives additional flexibility to the statistical model, making it possible to model the random intercept and random slope as independent, correlated, or independent with equal variances (Laird & Ware, 1982). In addition, LMMs make it possible to handle missing data instead of withdrawing subjects from the analysis. However, to the best of our knowledge, no previous study applied LMMs to analyze the relationship between the subjective and objective methods used for monitoring the process of internal load in team sports. Therefore, the present study aims to (1) assess the correlation between objective and subjective internal load measures in team sports and (2) investigate these relationships by taking into account the individuality of players by means of LMMs.

3.2.3 Materials and methods

Participants

Thirteen youth male players were recruited from the Lithuanian Under 17 beach handball team and volunteered to participate to this study. All players were novice to beach handball, but they had regularly trained for at least 5 years in indoor handball. Prior to the beginning of the study, all players, their parents, and the coaching staff were informed about the study aim, procedures, potential risks, and benefits associated with participation, and informed consent was obtained from participants' parents. The study was approved by the Institutional Review Board of the Department of Human Sciences, Society and Health of the University of Cassino and Lazio Meridionale (approval number: 3R1B.2019.05.06) according to principles outlined in the Declaration of Helsinki.

Experimental Design

Players' internal loads were monitored across 2 training camps (14 training sessions) and during the Young Age Category 17 European Beach Handball tournament held in Stare Jablønki (Poland) from the 27 to 30 June 2019 where players were involved in 7 matches. Data were excluded from the analysis if players did not complete the entire session due to possible injuries. In total, data were collected across 21 sessions, resulting in 192 (136 trainings and 57 matches) individual values. The average temperature of the training sessions and matches was 20.5 ± 3.5 °C and the relative humidity was 65 ± 17.7%. To provide ecological conditions during the training sessions, the team's coaching staff freely planned their workouts without any intervention from the research staff. Since beach handball tournaments usually encompass 2 daily matches, the training regimen during the training camps encompassed 1 daily morning session mainly focused on sand-based physical conditioning and individual technical skills and 1 daily afternoon session mainly focused on team tactical trainings and small-sided games. All training sessions lasted ~1.5 h and they were composed by ~15 min of warm-up without and with balls, ~1 h of specific work, and ~15 min of cool-down and stretching exercises.

Procedures

During each experimental session, the workload was objectively recorded by means of HR monitors (H7, Polar Team System, Kempele, Finland). The duration of each training session was recorded to successively recognize the HR corresponding to the training activities. For matches, the entire playing time was considered. The 30 min of standardized warm-up preceding each match and the between-halves rest times were excluded from the analysis. After each session, the HR data were exported in 1 s epochs via proprietary software and the individual workload was calculated according to the SHRZ (Edwards, 1993). This methodology allowed us to identify the individual workload score by calculating the product of the accumulated session duration (min) of 5 HR zones by a coefficient relative to each zone (50–59.9% of HRmax = 1, 60–69.9% of HRmax = 2, 70–79.9% of HRmax = 3, 80–89.9% of HRmax = 4, 90–100% of HRmax = 5). Then, the SHRZ workload (in AU) was calculated by summating the results. According to previous methodology used in sand-based sports (Pueo et al., 2017; Tessitore et al., 2012) and other team sports (Berkelmans et al., 2018), the peak HR registered across training sessions and matches was considered for the calculation of the SHRZ workload (Berkelmans et al., 2018). Data were subsequently expressed as percentages of the HRpeak.

Furthermore, the workload was subjectively assessed by means of the sRPE method (Foster et al., 1995, 2001). Since recent evidence has suggested that RPE scales are interchangeable (Arney et al., 2019a, 2019b), in the present study, the category-ratio 10 (CR10) scale modified by Foster et al. (Foster et al., 1995) was administered by asking each player: “How hard was your training/match?” within 30 min after the completion of each training session and each match. The sRPE workload was then calculated by multiplying the individual score of the CR10 scale for the duration (min) of the training/match (Foster et al., 2001).

Preliminary Analysis

Means and standard deviations were calculated for each analyzed variable. Normal distribution was verified by the Shapiro–Wilk test. The Shapiro–Wilk test showed that the sRPE and SHRZ were not normally distributed when all of the sessions were combined. However, the sRPE and SHRZ showed different distribution patterns when training and matches were split. These results highlight that, in team sports, data could vary between subjects and sessions. Thus, the intersubject variability should be considered when analyzing data in order to avoid inaccurate results emerging from an over- or under-estimation of statistical significance in repeated measures of the study design (van Dongen et al., 2004).

Statistical Analysis

The overall relationship between the SHRZ and sRPE methods was assessed by means of the Pearson product moment and Spearman correlations, and then with linear regression. The sample was analyzed by combining all of the sessions and subsequently dividing trainings and matches. The magnitude of correlations was defined by the following criteria: trivial (<0.1), small (from 0.1 to 0.29), moderate (from 0.3 to 0.49), large (from 0.5 to 0.69), very large (from 0.7 to 0.89), and almost perfect (from ≥0.9 to 1) (Cohen, 1988; Hopkins, 2002). Additionally, the relationships between the SHRZ and sRPE methods were analyzed via LMM using the sRPE and SHRZ values as fixed effects while the random effects were represented by the individual response of each player. First, the models were fitted with only random intercepts for each player. However, by merely fitting the random intercept at the subject level, the variability of each player between sessions was not taken into consideration. Therefore, subsequently random slopes of the relationship between the SHRZ and sRPE were fitted into the models. Bryk/Raudenbush R-squared (R^2) values were calculated for each random intercepts LMM. Finally, the likelihood-ratio test was used to compare the each LMM developed with the linear regression analysis and to compare the 2 LMMs with only random intercepts, and with random intercepts and random slopes. Statistical analysis was performed using STATA statistical software version 15.1 (StataCorp, College Station, TX, USA) and the level of significance was set at $p < 0.05$.

3.2.4 Results

Descriptive characteristics of players are presented in Table 3.2.4-1.

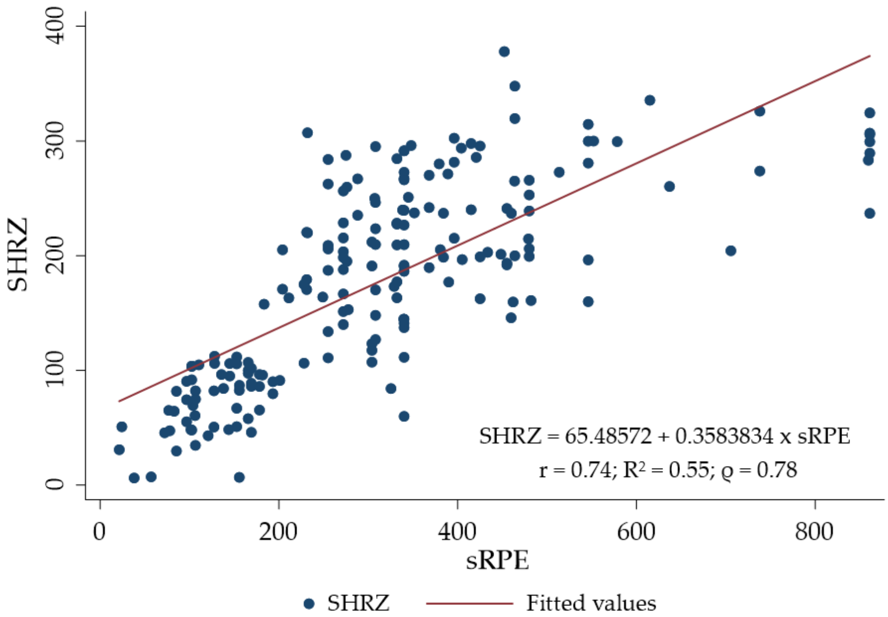
Table 3.2.4-1. Players' descriptive characteristics. Values represent mean ± standard deviation (SD).

Characteristics	**Mean ± SD**	**[95% CI]**
Age (years)	15.9 ± 0.3	15.8-16.1
Weight (kg)	67.4 ± 6.8	62.2-72.7
Height (m)	1.8 ± 0.1	1.8-1.9
BMI ($kg \cdot m^{-2}$)	20.4 ± 1.5	19.2-21.6
Heart Rate Peak ($beat \cdot min^{-1}$)	195.9 ± 8	191-200.7

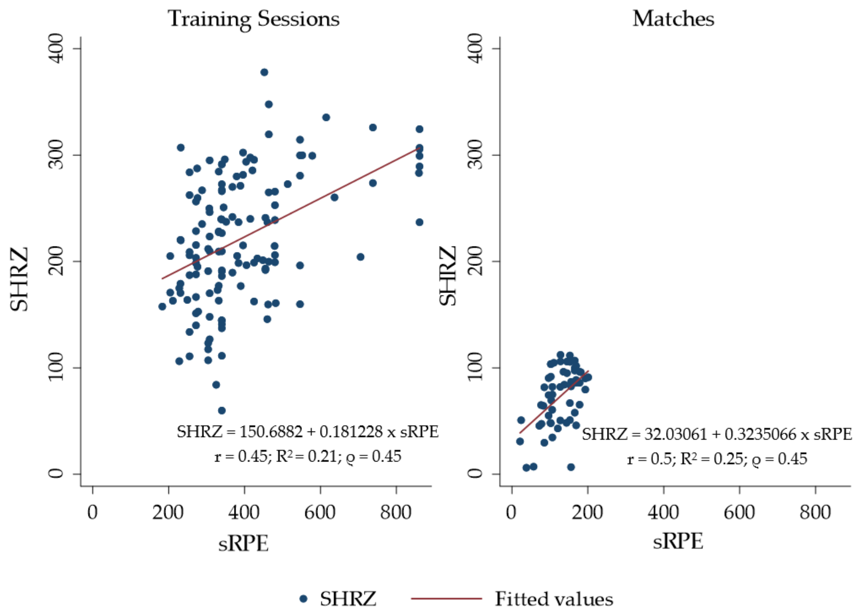
Note: CI: Confidence Interval; BMI: Body Mass Index; Heart Rate peak: peak heart rate registered across training sessions and matches.

When combining training sessions and matches, results revealed a %HRpeak of 71.3 ± 8 (training sessions: 70.1 ± 6.5 %HRpeak; matches: 74.2 ± 10.5 %HRpeak), a SHRZ workload of 178.8 ± 13.2 AU (training sessions: 222 ± 61.0 AU; matches: 73.2 ± 27.9 AU), and a sRPE workload of 315.4 ± 178.2 AU (training sessions: 392.9 ± 153.1 AU; matches: 127.1 ± 42.8 AU). The correlation coefficients for the overall relationship between the SHRZ and sRPE methods were very large ($r = 0.74$; $R^2 = 0.55$; $\rho = 0.78$) when combined training sessions and matches were assessed. When training sessions were studied singularly, moderate ($r = 0.45$; $R^2 = 0.21$; $\rho = 0.45$) correlation coefficients were shown. When only matches were considered, moderate-to-large ($r = 0.5$; $R^2 = 0.25$; $\rho = 0.45$) correlation coefficients were shown. Relationships investigated via linear regression are graphically shown in Figure 3.2.4-1.

Figure 3.2.4-1 Relationship between the Summated Heart Rate Zone (SHRZ) and session Rating of Perceived Exertion (sRPE) for all sessions (a) and for training sessions and matches separately (b).



a)



b)

The first fitted LMM included random intercepts for each player by adding a random-effects part on the linear regression model for the whole sessions. The estimated standard deviation (SD) of the random intercepts was 28.2 AU (95% confidence interval: 16.8–47.3), with a standard error of 7.4 and $R^2 = 0.61$. The likelihood-ratio test showed that this model offered significant (Chi^2: 25.2; $p < 0.001$) improvement over a linear regression model with only fixed effects, meaning that the intercepts were significantly different between players. When applying the same procedure exclusively to training sessions, the SD of the estimated random intercepts was 34.3 AU (95% confidence interval: 21.8–53.9), with a standard error of 7.4 ($R^2 = 0.33$). Similarly, the likelihood-ratio test proved that this model was significantly (Chi^2: 41.8; $p < 0.001$) better than the linear regression model with only fixed effects. Considering only the matches sessions, the SD of the estimated random intercepts was 15.6 AU (95% confidence interval: 8.8–27.4), with a standard error of 4.5 and $R^2 = 0.39$. Likewise, the likelihood-ratio test proved that this model was significantly (Chi^2: 12.8; $p < 0.001$) better than the linear model with only fixed effects.

Overall, including random slopes into the developed models did not bring significant improvements with respect to the random-only intercepts LMMs when training sessions and matches were separated ($p > 0.05$). However, when considering all of the sessions together, the developed model showed significant ($p < 0.001$) player-to-player variation in the slope coefficients, with a significant improvement ($p < 0.05$) with respect to the only random intercepts model (Table 3.2.4-2).

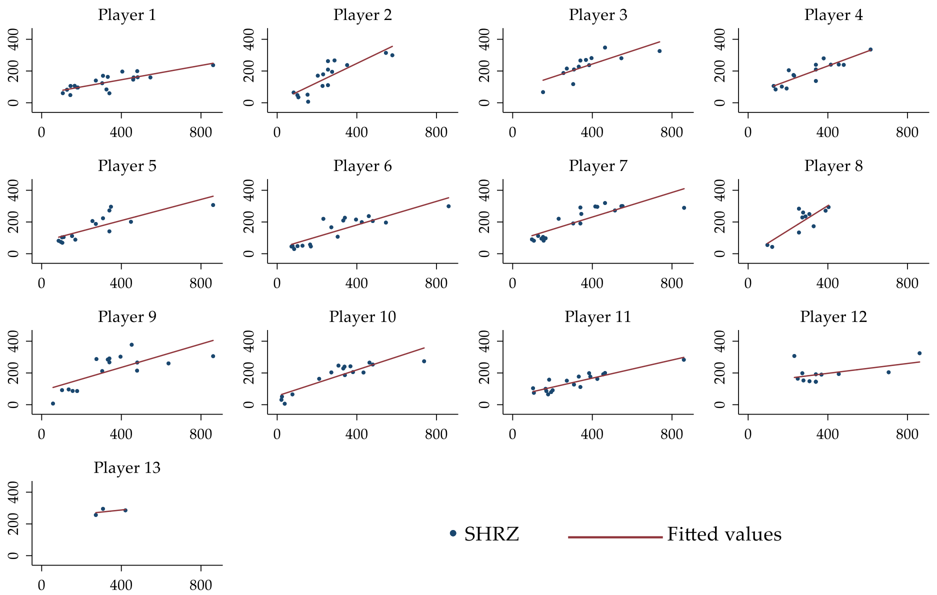
Table 3.2.4-2 Comparison of Linear Mixed Models developed for the whole sessions.

	Coef.	SE	z	p > |z|	[95% CI]	
(A) Random Intercept Model						
sRPE-SHRZ Relationship	0.36	0.02	16.82	0	0.32	0.40
Intercept	70.92	11.05	6.42	0	49.26	92.58
					p < 0.001	
(B) Random Intercept plus Random Slope Model						
sRPE-SHRZ Relationship	0.39	0.03	11.98	0	0.33	0.45
Intercept	61.19	7.65	7.99	0	46.18	76.19
					p < 0.001	
Likelihood-Ratio test (Model A vs. Model B): p < 0.05						

Note: sRPE = session Rating of Perceived Exertion; SHRZ = Summated Heart Rate Zone; coef. = Coefficient; SE = Standard errors; CI = Confidence Interval.

Visual representation of the relationships between SHRZ and sRPE with different intercepts and slopes across each player for the whole sessions are displayed in Figure 3.2.4-2.

Figure 3.2.4-2 Graphical representation of the different individual players' responses for all the sessions. sRPE = session Rating of Perceived Exertion; SHRZ = Summated Heart Rate Zone.



Random intercepts and slope coefficients for each player based on the whole session LMM are reported in Table 3.2.4-3.

Table 3.2.4-3 Random intercepts and random slope coefficients for each player based on the whole session Linear Mixed Model.

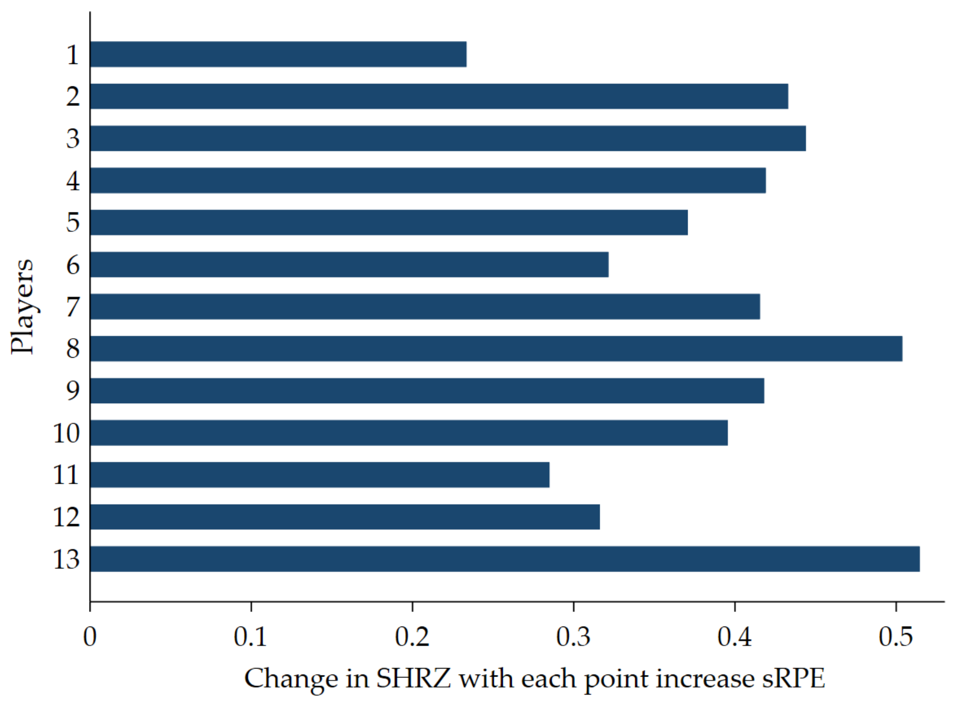
Player	Random Slope (mean)	Random Intercept (mean)
1	-0.16	-2.02
2	0.04	-2.23
3	0.05	1.02
4	0.03	-0.17
5	-0.02	0.88
6	-0.07	-2.91
7	0.03	1.30
8	0.11	0.61
9	0.03	1.81
10	0.01	-0.30
11	-0.11	-1.64
12	-0.07	1.63
13	0.12	2.01

To clarify the relationship between SHRZ and sRPE an equation (1), combining the fixed and random slopes sRPE was developed:

$$SHRZ = 61.19 + (u1j+0.39)\ sRPEij + U0j + \epsilon i \qquad (1)$$

In other words, the slope for player equals the fixed-effect slope for the whole sample, plus the random-effect slope for that player. Figure 3.2.4-3 displays the calculated 13 combined slopes for each player. For player number 8, for instance, the combined slope is *u1j* (+0.11 for player 8) + 0.39 = 0.5.

Figure 3.2.4-3 Inter-individual variability of the relationship between session Rating of Perceived Exertion (sRPE) and Summated Heart Rate Zone (SHRZ) workloads. In some players (for example, 13 and 8), the SHRZ increased most steeply as sRPE increases.



3.2.5 Discussion

The present study aimed to assess the correlation between objective and subjective measures of internal load in team sports, such as beach handball, and to investigate this relationship by considering the individuality of players by means of LMM. Results showed that LMM can give more powerful and appropriate information regarding the relationship between SHRZ and sRPE workloads rather than the usual procedure using correlations and linear regression with only fixed effects.

In line with studies investigating the indoor handball characteristics (Kniubaite et al., 2019; Michalsik et al., 2013; Wagner et al., 2014, 2018, 2019), many aspects of beach handball, such as physiological parameters (Lara Cobos, 2011), individual and team performance (Gruic et al., 2011; Jimenez-Olmedo et al., 2019), and shooting actions (Gkagkanas, Hatzimanouil, Skandalis, et al., 2018; Iannaccone et al., 2022; Navarro et al., 2018; Skandalis & Hatzimanouil, 2017), have been investigated.

However, no previous study has investigated the relationship between the objective (SHRZ) and subjective (sRPE) methods used for assessing the players' internal load.

Our results showed a very large relationship between the SHRZ and sRPE methods, independently from the type of session. When looking at training sessions and matches separately, this relationship was moderate and moderate-to-large, respectively. The trend was confirmed by the results of the linear regression analysis, showing a large relationship when the sessions were analyzed as a whole and small relationships when the training sessions and matches were analyzed separately. For other team sports, correlation coefficients have shown a strong (Lupo et al., 2017b), high (Lupo et al., 2014), or very high relationship (Impellizzeri et al., 2004), promoting the sRPE as a useful method for monitoring internal load in youth trainings. However, in the case of team sports, not only the team as a whole has to be considered, but also the interindividual variability when analyzing workload data. The response to exercise training may not only differ between athlete, but also within the same athlete on different sessions. Previous studies have indicated that correlation coefficients for the relationship between internal load assessed using HR-based methods and via sRPE ranged between $r = 0.71$ for soccer (Impellizzeri et al., 2004) and $r = 0.85$ for basketball (Lupo et al., 2017b) when the team was analyzed as a whole. When within-athlete correlation coefficients were calculated, values ranged between $r = 0.8$ and $r = 0.96$ for basketball (Lupo et al., 2017b), $r = 0.5$ and $r = 0.77$ for soccer (Impellizzeri et al., 2004), and $r = 0.62$ and $r = 0.93$ for beach volleyball (Lupo et al., 2020). However, when multiple players are monitored across multiple sessions, the tendency to summarize the data with a single number may lead to the exclusion of intra- and intersubject variability from the analysis (Koerner & Zhang, 2017). In fact, for team sports, models based on physiological parameters might underestimate the internal load during anaerobic and high-intensity activities, underlying the higher sensitivity of the sRPE method to workload changes, especially during the transition from base to higher intensities of conditioning programs (Scanlan et al., 2014). Thus, simply measuring the strength of a relationship using correlations, without taking into account changes in an individual predictor variable, may lead to a misinterpretation of the relationship between two variables (Koerner & Zhang, 2017). Furthermore, one of the most common issues occurring during data collection is represented by missing data (Little et al., 2014). For this reason, LMMs should be used, since they have the advantage to handle missing data without removing participants from the analysis (Lininger et al., 2015).

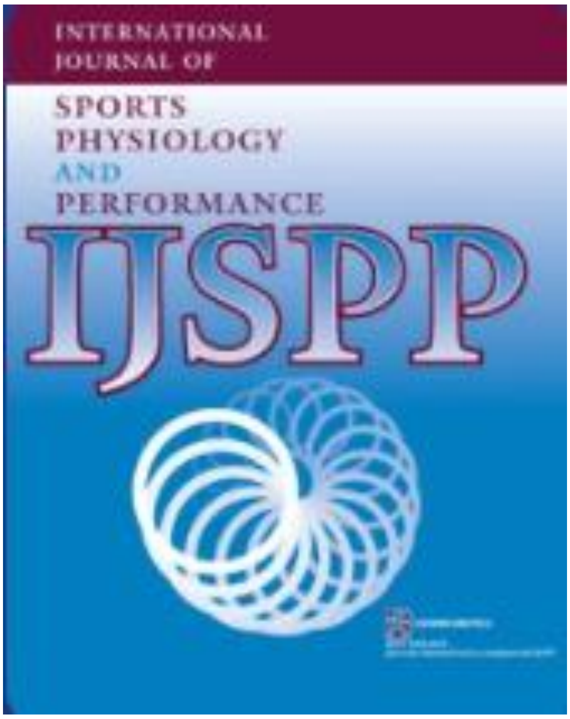
This study aimed to analyze the relationship between SHRZ and sRPE by means of LMM. For the analysis, only random intercepts were initially used. However, the SHRZ workload increased as the sRPE workload increased (Figure 3.2.4-1), with different individual responses (Figure 3.2.4-2). To overcome the issue of interindividual variability, it was hypothesized that adding random slopes to the model would help to deeply investigate the relationship. Currently, the use of mixed models is becoming popular among sport science researches. Govus et al. (2018) used the LMM to analyze the relationship between subjective wellness score and external load, between external load and sRPE, and between subjective wellness score and sRPE in American college football players. For the LMM, the authors used the random intercept for athletes (to calculate the intraindividual variability) and the random slope for training sessions (to model a separate slope for the different types of training sessions). LMMs have also been used to evaluate the effects of individual characteristics (i.e., playing position, playing time, or playing experience) and contextual factors (i.e., season phases, previous game outcome, or opponent level) on three dependent variables (weekly training load, pre-game recovery, and performance index rating) in basketball (Sansone et al., 2021) and to investigate (Conte et al., 2020) workload and well-being across games played on consecutive days during the in-season phase in basketball players, with the game day as the fixed effect and players, opposition rank, location, and score difference as random effects. It is therefore evident that LMMs are more commonly applied when analyzing data of relative workload in team sports.

Although this study provides interesting insights for coaches and sport scientists, some limitations should be acknowledged. First, the sample encompasses only youth beach handball male players. Therefore, future research should be carried out to investigate any potential difference in the internal load in players of different ages and/or gender. Moreover, the use of LMMs is becoming more common when analyzing team sports data, for example, to assess the relationships between external and internal load or between workload and well-being data. However, no previous study has used LMMs to correlate subjective and objective measures of internal load. Thus, no comparisons were allowed, and it should be verified whether the proposed statistical model could also be meaningful in other team sports.

3.2.6 Conclusions

The main findings suggest that subjective perception of internal load experienced by youth beach handball players increases with the objective internal load. However, the increase varies between players and sessions. To correlate those two measures to monitor the internal load, simple correlation is usually performed. However, correlation does not allow for the consideration of the intra- and interindividual variability which occurs when working with team sports, and it is not possible to handle missing data, resulting in a loss of information. To overcome with these issues, LMMs represent a more appropriate and powerful statistical approach for providing a more comprehensive view of the players' responses to a given training stimulus. Therefore, researchers are encouraged to apply LMMs rather than simple correlations to analyze internal load.

3.3 ARTICLE 3. Relationship between external and internal load measures in youth beach handball



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Impact Factor

Iannaccone A., Fusco A., Skarbalius A., Kniubaite A., Cortis C, Conte D. Relationship between external and internal load measures in youth beach handball. *International Journal of Sport Physiology and Performance*. Accepted for publication on June 7th, 2021.

3.3.1 Abstract

Purpose: assessing the relationship between external and internal load in youth male beach handball players.

Methods: eleven field players from the Lithuanian U17 beach handball team were monitored across 14 training sessions and 7 matches. The following external load variables were assessed by means of inertial movement units: PlayerLoad™, accelerations, decelerations, changes of direction, and jumps and total of inertial movements. Internal load was assessed objectively and subjectively using the summated heart-rate zones and training load calculated via session rating of perceived exertion, respectively. Spearman correlations (ρ) were used to assess the relationship between external and internal load. The inter-individual variability was investigated using linear mixed models with random intercepts with Internal load as dependent variable, PlayerLoad™ as the independent variable and players as random effect.

Results: The lowest significant ($p<0.05$) relationship was for high jumps with objective ($\rho=0.56$) and subjective ($\rho=0.49$) internal load. The strongest relationship was for PlayerLoad™ with objective ($\rho=0.9$) and subjective ($\rho=0.84$) internal load. From the linear mixed model, the estimated standard deviation of the random intercepts was 19.78 AU (95% confidence interval: 11.75– 33.31), standard error = 5.26 and R^2 = 0.47 for the objective internal load and 6.03 AU (95% confidence interval: 0.00–7330.6), standard error = 21.87, and R^2 = 0.71 for the subjective internal load.

Conclusions: Objective and subjective internal load measures can be used as a monitoring tool when external load monitoring is not possible. Coaches can predict internal based on a given external load, by using the equations proposed in this study.

Keywords: team sports; monitoring; sRPE; heart rate; PlayerLoad

3.3.2 Introduction

Beach handball is a rapidly growing team sport played on a 27x12m sand court by two teams, each composed by one goalkeeper and three field players. As for indoor handball (Kniubaite et al., 2019; Wagner et al., 2019), there is a growing body of literature assessing the performance profile of beach handball players (Iannaccone et al., 2021, 2022; Sánchez-Sáez et al., 2021). Specifically, previous research assessed the individual and team performance profile (Iannaccone et al., 2021, 2022; Zapardiel & Asín-Izquierdo, 2020) showing that beach handball is a high-intensity mixed-metabolism sport, characterized by the combination of high-intensity physical patterns including specific movements involving speed and power, rapid accelerations and decelerations, and change of directions (CoDs) (Pueo et al., 2017).

Monitoring training and match loads is fundamental to provide useful information for practitioners to design sound training sessions and recovery strategies (Halson, 2014). Training and match loads can be classified as either external or internal. External load (EL) indicates the objective measure of the work performed by the athlete (i.e. total distance covered in different speed zones and the number of sprints, accelerations, and decelerations), and can be assessed using global positioning system (GPS), local positioning system (LPS), or via inertial movement units (IMU), which include inertial sensors gyroscopes, accelerometers and magnetometers (Luteberget et al., 2018). Differently, the internal load (IL) represents the psychophysiological response of the athlete to a given training stimulus (Bourdon et al., 2017; Impellizzeri et al., 2019). Specifically, IL indicates the functional outcome of a given EL, and it can be used as primary measure when monitoring athletes (Impellizzeri et al., 2019). IL can be assessed using objective methods such as heart rate (HR), blood lactate concentration or oxygen uptake useful to improve performance and evaluating maladaptive responses to training programs (Fusco, Knutson, et al., 2020; Fusco, Sustercich, et al., 2020; Halson, 2014). The HR is the most used objective parameter for monitoring IL in team sports (Halson, 2014) with many HR-based models developed such as the Summated Heart Rate Zone (SHRZ) model (Edwards, 1993). Additionally, IL can be evaluated subjectively through the use of scales with the session Rating of Perceived Exertion (sRPE) among the most used in team sports (Bourdon et al., 2017; Foster et al., 2017). The advantages of using sRPE relies on the fact that it is easy to use and interpret and can provide information on the physiological and psychological responses to the prescribed load (Foster et al., 2017). Overall, to ensure a correct balance between the perception of the athletes and the objective load responses, a combination of objective and subjective measurements is recommended (Bourdon et al., 2017).

The assessment of the dose-response relationship between EL and IL seems fundamental to understand the level of adaptation to a given training program and it is useful in minimizing the risk of non-functional overreaching (Fusco, Sustercich, et al., 2020; Impellizzeri et al., 2019). A previous meta-analysis demonstrated that EL and IL measures are positively correlated during training and competitions in team sports, with the highest correlation coefficients found for total distance (sRPE: $r = 0.79$; HR-based models: $r = 0.74$) and accelerometer load (sRPE: $r = 0.74$; HR-based models: $r = 0.54$) (McLaren et al., 2018). This information is essential in team sports to anticipate the IL based on the prescribed EL. However, the dose-response relationship between EL and IL should be considered as sport-specific since EL depends on the nature of the discipline and could elicit different IL across different sports (Impellizzeri et al., 2019). To the best of our knowledge, no previous study investigated the relationship between EL and IL in beach handball. Since beach handball is played on sand, which could theoretically provide a different IL response to a determined EL stimulus compared to other non-sand-based team sports, the assessment of the relationship between EL and IL in beach handball is warranted. Therefore, the aim of this study was to assess the relationship between EL and IL objectively (SHRZ) and subjectively (sRPE) measured in beach handball during training and matches.

3.3.3 Methods

Subjects

Eleven youth male field players (age: 15.9 ± 0.4y; height: 180.9 ± 5.5cm; body mass: 64.6 ± 4.3kg) were recruited from the National Lithuanian Under 17 beach handball team and volunteered to participate to this study. All players have been regularly training for at least five years in indoor handball and were novice to beach handball. Before the beginning of the study, all players, their parents and the coaching staff were informed about the study aim, procedures, potential risks and benefits associated with participation and the informed consent was obtained from participants' parental guardian. The study was approved by the Institutional Review Board of the Department of Human Sciences, Society and Health of the University of Cassino and Lazio Meridionale (approval number: 3R1B.2019.05.06) according to principles outlined in the Declaration of Helsinki.

Design

Players were monitored across 2 training camps organized in preparation of the Younger Age Categories 17 European Beach Handball tournament held in Stare Jabłønki (Poland) from the 27th to 30th June 2019, in which players were monitored during matches. Data were excluded from the analysis if players did not complete the entire training session or match due to possible injuries. Since 2 players did not take part to the tournament, data from 9 players were collected across 14 training sessions and 7 matches, resulting in 183 (125 training sessions and 58 matches) individual values. The average temperature of training and matches was 20.5 ± 3.5°C and the relative humidity was 65 ± 17.7%. During training sessions, the research staff did not interfere with coaching staff strategies. The training schedule included one daily morning session focused on sand-based physical conditioning and individual technical skills and one daily afternoon session focused on team tactical training and small-sided games. All training sessions lasted ~1.5 hour and included ~15 min of warm-up, ~1 hour of sport-specific work and ~15 min of cool-down and stretching exercises.

Matches consist of two 10-min sets separated by 5-min rest (International Handball Federation, 2014).

Methodology

External load monitoring

For the EL monitoring during all experimental sessions, players were equipped with IMUs (ClearSky T6, Catapult Innovations, Melbourne, Australia) placed in manufacturer-supplied neoprene vests for secure the attachment between the scapulae and worn under their jersey. Each player used the same IMU device each session to limit possible inter-devices differences (Coutts & Duffield, 2008). IMUs recorded triaxial accelerometer data at 100 Hz to calculate PlayerLoad^{TM} (PL) in arbitrary units (AU), which is expressed as the square root of the sum of the squared instantaneous rate of change in acceleration in each of the three vectors (X, Y and Z axis) and divided by 100 (Boyd et al., 2011). According to previous research (Fox et al., 2020; Simpson et al., 2020), the included EL variables were the absolute number of inertial accelerations, decelerations and CoDs. All the events were then classified as low (LIE) (<2.5 m•s^{-2}), medium (MIE) (2.5-3.5 m•s^{-2}) or high intensity (HIE) (>3.5 m•s^{-2}). The absolute number of jumps was also assessed and classified as low (<0.2 m), medium (0.2-0.4 m) or high (>0.4 m).

Objective internal load monitoring

HR monitors (H10 Polar Electro, Kempele, Finland) were used for assessing IL. The duration of each training session was recorded to successively recognize the HR corresponding to the training activities (Fox et al., 2020). For matches, the entire playing time was considered including live and stoppage times, while the 30-min of standardized warm-up preceding each match, the between-halves rest, and the shoot-outs time were excluded from the analysis (Iannaccone et al., 2021). During training sessions and matches, HR was continuously recorded concomitantly with IMUs and subsequently IL and EL data were downloaded and stored using the same proprietary software (Catapult Sprint Version 5.1.7, Catapults Innovations, Melbourne, Australia) (Zapardiel & Asín-Izquierdo, 2020). The individual SHRZ score was determined by multiplying the accumulated time (min) in five HR zones for a coefficient relative to each zone (50–59.9% of HRmax = 1, 60–69.9% of HRmax = 2, 70–79.9% of HRmax = 3, 80–89.9% of HRmax = 4, 90–100% of HRmax = 5) and summing the results (Edwards, 1993). According to previous methodology used in sand-based sports (Pueo et al., 2017) and other team sports (Berkelmans et al., 2018), the peak HR registered across training sessions and matches was considered for the calculation of the SHRZ load. Data were subsequently expressed as percentages of the HRpeak.

Subjective internal load monitoring

Furthermore, the IL was subjectively assessed via sRPE method (Foster et al., 2001). Since recent evidence suggests that RPE scales are interchangeable (Arney et al., 2019a, 2019b), for the present study the category-ratio 10 (CR10) scale was administered by asking each player: “How hard was your training/match?” within 30 min after the completion of each training and match. The sRPE load was then calculated by multiplying the individual score of the CR10 scale for the duration (min) of the training/match (Foster et al., 2001).

Statistical analysis

Means and standard deviations (SD) were calculated for each variable as descriptive statistics. The sample was analyzed by combining all sessions and subsequently dividing training sessions and matches. Data distribution was verified by the Shapiro-Wilk test. Given the different distribution of data patterns, the relationships between IL and EL variables were investigated using Spearman Rank correlation coefficients (ρ). The magnitude of correlations was defined as trivial (<0.1), small (0.1- 0.29), moderate (0.3- 0.49), large (0.5- 0.69), very large (0.7- 0.89), and almost perfect (≥0.9) (Hopkins, 2002). The relationships between IL and PL were also analyzed via Linear Mixed Models (LMM) since simple correlation does not consider the intra- and inter-individual variability typical for team sports (Iannaccone et al., 2021). Specifically, IL measures were used as dependent variables while PL was used as independent variable. PL was chosen as EL variable since it showed the strongest correlation with IL. All models were fitted with random intercepts at players’ level. Bryk/Raudenbush

R-squared (R^2) values were calculated for each LMM. Statistical analysis was performed using STATA statistical software version 15.1 (StataCorp, College Station, TX, USA) and the level of significance was set at $p<0.05$.

3.3.4 Results

Mean and SD values for each variable during training and matches are reported in Table 3.3.4-1.

Table 3.3.4-1 Means and standard deviations (SD) for each variable of internal and external load relative to all sessions and training sessions and matches, separately.

Variables	All sessions		Training sessions		Matches	
	Mean	SD	Mean	SD	Mean	SD
Internal Load						
SHRZ	175.3	86.1	222.7	61.2	77.4	26.5
sRPE	318.4	179.2	406.1	147.6	129.5	44.5
External Load						
PlayerLoad™	294.4	150.8	382.9	92.1	109.6	42.0
Accelerations	74.2	45.3	97.1	36.3	26.4	14.1
Decelerations	55.3	29.0	69.3	23.3	26.0	14.3
CoD	208.1	107.5	253.1	96.0	114.2	58.2
LIE	250.6	123.9	311.0	98.2	124.8	61.6
MIE	59.6	32.3	74.1	27.9	29.2	15.1
HIE	27.5	15.8	34.5	13.8	12.8	7.2
Jumps	86.9	84.6	121.8	82.4	14.2	10.9
Low Jumps	20.1	18.2	27.2	17.9	5.2	5.3
Medium Jumps	59.0	68.3	84.5	69.9	5.8	4.3
High jumps	7.8	9.6	10.0	10.7	3.2	4.0

Note: CoD= Changes of Direction; LIE= Low Intensity Events; MIE= Medium Intensity Events; HIE=High Intensity Events; SHRZ=Summated Heart Rate Zone workload; sRPE=session Rating of Perceived Exertion workload.

Spearman Rank correlation coefficients for the relationships between EL and IL variables are reported in Table 3.3.4-2.

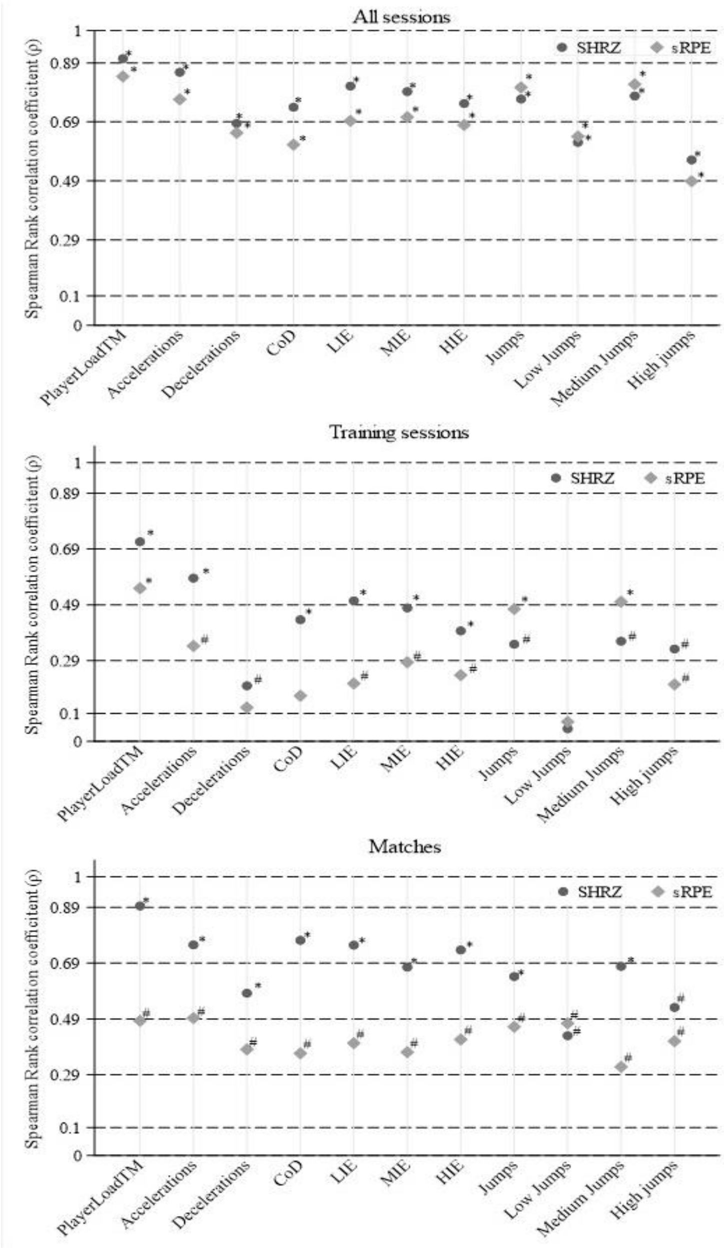
Table 3.3.4-2 Spearman Rank correlation coefficients (ρ) for the relationships between external and internal load variables for all sessions, and training sessions and matches, separately.

	Training and match combined				Training sessions				Matches			
External Load variables	SHRZ		sRPE		SHRZ		sRPE		SHRZ		sRPE	
	ρ	p-value	ρ	p-value	ρ	p-value	ρ	p-value	ρ	p-value	ρ	p-value
PlayerLoad™	0.90	<0.001	0.84	<0.001	0.72	<0.001	0.55	<0.001	0.90	<0.001	0.48	0.0004
Accelerations	0.86	<0.001	0.77	<0.001	0.59	<0.001	0.34	0.0005	0.76	<0.001	0.49	0.0003
Decelerations	0.68	<0.001	0.65	<0.001	0.20	0.0467	0.12	0.2297	0.58	<0.001	0.38	0.007
CoD	0.74	<0.001	0.61	<0.001	0.44	<0.001	0.16	0.1044	0.77	<0.001	0.37	0.0096
LIE	0.81	<0.001	0.69	<0.001	0.50	<0.001	0.21	0.0382	0.75	<0.001	0.40	0.0041
MIE	0.79	<0.001	0.71	<0.001	0.48	<0.001	0.28	0.0042	0.68	<0.001	0.37	0.0087
HIE	0.75	<0.001	0.68	<0.001	0.40	<0.001	0.24	0.0173	0.74	<0.001	0.42	0.0029
Jumps	0.77	<0.001	0.81	<0.001	0.35	0.0004	0.47	<0.001	0.64	<0.001	0.46	0.0008
Low Jumps	0.62	<0.001	0.64	<0.001	0.05	0.6543	0.07	0.4869	0.43	0.002	0.47	0.0006
Medium Jumps	0.78	<0.001	0.82	<0.001	0.36	0.0002	0.50	<0.001	0.68	<0.001	0.32	0.0258
High jumps	0.56	<0.001	0.49	<0.001	0.33	0.0008	0.20	0.0415	0.53	0.0001	0.41	0.0034

Note: CoD= Changes of Direction; LIE= Low Intensity Events; MIE= Medium Intensity Events; HIE=High Intensity Events; SHRZ=Summated Heart Rate Zone workload; sRPE=session Rating of Perceived Exertion workload.

Spearman Rank correlation coefficients for the relationships between EL and IL variables are graphically represented in Figure 3.3.4-1.

Figure 3.3.4-1 Graphical representation of Spearman Rank correlation coefficients (ρ) for the relationships between external and internal load variables for all sessions (a) and training (b) and matches (c), separately.



Note: CoD= Changes of Direction; LIE= Low Intensity Events; MIE= Medium Intensity Events; HIE=High Intensity Events; SHRZ=Summated Heart Rate Zone workload; sRPE=session Rating of Perceived Exertion workload.

When pooling sessions, SHRZ showed an almost perfect (ρ = 0.9) correlation with PL, and very large correlations with accelerations (ρ = 0.86), LIE (ρ = 0.81), MIE (ρ = 0.79), medium jumps (ρ = 0.78), total jumps (ρ = 0.77), HIE (ρ = 0.75) and CoDs (ρ = 0.74). When considering only training sessions, SHRZ showed a very large (ρ = 0.72) correlation with PL, and a large correlation with accelerations (ρ = 0.59) and LIE (ρ = 0.5). For matches, SHRZ showed an almost perfect (ρ = 0.9) correlation with PL, and very large correlations with CoDs (ρ = 0.77), accelerations (ρ = 0.76), LIE (ρ = 0.75), and HIE (ρ = 0.74).

When pooling training and matches, sRPE showed very large correlations with PL (ρ = 0.84), medium jumps (ρ = 0.82), total jumps (ρ = 0.81), accelerations (ρ =0.77), and MIE (ρ = 0.71). When considering only training, sRPE showed large correlations with PL (ρ = 0.55) and medium jumps (ρ = 0.5) whereas for matches, sRPE showed moderate correlations (ρ ranging between 0.31 for medium jumps and 0.49 for accelerations) with all the EL variables.

Results of LMMs for the SHRZ are reported in Table 3.3.4-3.

Table 3.3.4-3 Linear Mixed Models for the relationship between PlayerLoad™ and internal load objectively (Summated Heart-Rate Zones- SHRZ) assessed.

	Coefficient	Standard Error	z	P>z	[95% CI]	
Relationship between PlayerLoad™ and SHRZ						
All sessions						
Slope	0.5	0.02	30.81	<0.001	0.47	0.53
Intercept	27.63	8.56	3.23	<0.05	10.85	44.4
Trainings						
Slope	0.41	0.03	12.19	<0.001	0.34	0.48
Intercept	64.39	16.73	3.85	<0.001	31.59	97.19
Matches						
Slope	0.56	0.04	12.88	<0.001	0.48	0.65
Intercept	15.56	5.58	2.79	<0.05	4.62	26.5

When all sessions were pooled, the estimated SD of the random intercepts was 19.78 AU (95% confidence interval: 11.75– 33.31), standard error (SE) = 5.26 and R^2 = 0.47. For training sessions, the estimated SD of the random intercepts was 29.78 AU (95% confidence interval:18– 49.26), SE = 7.65, and R^2 = 0.31. For matches, the estimated SD of the random intercepts was 7.9 AU (95% confidence interval: 4.32– 14.42), SE = 2.43, and R^2 = 0.81. To illustrate the relationship between the PL and SHRZ, equations combining the fixed and random effects for all the sessions combined (1), and training (2) and matches (3) separately were developed:

$$SHRZ = 27.63 + (0.5 \cdot PL) \quad (1)$$

$$SHRZ = 64.39 + (0.41 \cdot PL) \quad (2)$$

$$SHRZ = 15.56 + (0.56 \cdot PL) \quad (3)$$

Results of LMMs for the sRPE are reported in Table 3.3.4-4.

Table 3.3.4-4 Linear Mixed Models for the relationship between PlayerLoad™ and internal load subjectively (session Rating of Perceived Exertion- sRPE).

	Coefficient	Standard Error	z	P>z	[95% CI]	
Relationship between PlayerLoad™ and sRPE						
All sessions						
Slope	1.01	0.05	20.83	<0.001	0.92	1.11
Intercept	21.15	16.17	1.31	0.19	-10.54	52.83
Trainings						
Slope	1.01	0.11	8.84	<0.001	0.79	1.23
Intercept	23.16	44.95	0.52	0.61	-64.94	111.25
Matches						
Slope	0.51	0.13	3.87	<0.001	0.25	0.77
Intercept	72.18	16.58	4.35	<0.001	39.69	104.67

When all sessions were pooled, the estimated SD of the random intercepts was 6.03 AU (95% confidence interval: 0.00– 7330.6), SE = 21.87, and R^2 = 0.71. For training sessions, the estimated SD of the random intercepts was 0.0001 AU (95% confidence interval: 0.00– 1570.08). SE = 0.0008, and R^2 = 0.39. For matches, the estimated SD of the random intercepts was 20.66 AU (95% confidence interval: 10.42– 40.94), SE = 7.21, and R^2 = 0.51 (Table 2). To explain the relationship between the PL and sRPE, equations combining the fixed and random effects for all the sessions combined (4), training (5) and matches (6) separately were developed:

$$sRPE = 21.15 + (1.01 \cdot PL) \quad (4)$$

$$sRPE = 23.16 + (1.01 \cdot PL) \quad (5)$$

$$sRPE = 72.18 + (0.51 \cdot PL) \quad (6)$$

3.3.5 Discussion

The present study aimed to investigate the relationship between EL and IL, objectively (SHRZ) and subjectively (sRPE) measured, in beach handball players. Findings showed that i) there is a high correlation between EL (PL, accelerations, LIE, MIE, HIE, jumps. CoDs) and IL measures; ii) PL presents the highest relationship and predictive capability, with both SHRZ and sRPE.

Results showed that the relationships between EL measures and sRPE were weaker than with SHRZ. Surprisingly, results of the present study differ from those observed in other team sports (McLaren et al., 2018). In fact, McLaren et al. (2018) showed that the relationships with external measures of volume are stronger with sRPE when compared with IL objectively measured. This difference may be due to the playing surface or the players' age. McLaren et al. (2018) involved many team sports such as football, soccer, or rugby which are usually played on grass surfaces. Beach handball is played on a sandy surface and it may induce a higher perception of the effort than that experienced while playing on natural or artificial turf. Nevertheless, in semi-professional basketball players EL variables showed a higher commonality with SHRZ than sRPE, with the strongest correlation observed between PL and SHRZ (training: $r = 0.88$; matches: $r = 0.69$) and sRPE (training: $r = 0.74$; matches: $r = 0.53$) (Fox et al., 2020). A possible explanation for those differences may be that as sRPE represents an index of the global intensity perceived by the athlete, it can be influenced by many factors such as accumulated fatigue (Fusco, Knutson, et al., 2020; Fusco, Sustercich, et al., 2020), personality (extraversion, neuroticism, depression, anxiety), subjects' characteristics (age, fitness level, experience), environmental temperature (Haddad et al., 2017), or game-related aspects (match score, or location for instance) (Fox et al., 2020). Moreover, McLaren et al. (2018) did not include adolescent players which may be exposed to high stress periods, due to family or educational responsibilites (Bourdon et al., 2017), or different relationships between individual capabilities and training requests (Lupo et al., 2017a).

Despite this, SHRZ showed large correlation with other EL variables such as accelerations and LIE during training and very large correlations with CoDs, accelerations, LIE, and HIE during matches. The sRPE was very largely correlated with medium jumps during training and moderately correlated with all the EL variables during matches. Thus, EL measures showing a high commonality with IL can be used to anticipate IL response. However, PL showed the highest correlation probably because it is a cumulative measure of EL (Boyd et al., 2011). Therefore, practitioners should mainly consider this EL measure to predict IL during training and matches.

Usually, correlation coefficients are used to assess the relationship between EL and IL in team sports (Fox et al., 2020; Simpson et al., 2020). However, a more appropriate statistical analysis approach (Iannaccone et al., 2021) (LMMs) allowed to develop equations for predicting the IL based on a given PL. This integrated monitoring approach seems fundamental in team sports since by examining EL and IL independently, would only provide insights concerning the prescribed stimulus or the players' psychophysiological responses (Fox et al., 2017). In fact, although it is possible to assess the extent to which players are internally responding to the training, the internal response cannot be directly controlled. Therefore, the IL can be altered only by modifying the prescribed EL (Fox et al., 2017). Nevertheless, estimating the individual's IL basing on the EL presents some limitations since IL may be influenced by many modifiable and nonmodifiable factors such as training status, health, psychological status, and genetics (Impellizzeri et al., 2019), making difficult to accurately predict the IL (Bourdon et al., 2017). However, a rigorous approach in a training program, even with a method presenting some limitations, may provide meaningful insights, especially if integrated with other objective and subjective measures (Bourdon et al., 2017).

Although the present study provides meaningful information, some limitations should be acknowledged. Data were collected on a single youth male beach handball team. Therefore, results might not be generalized for players with different ages and gender. Moreover, the objective IL of SHRZ was used given its application in other team sports such as netball (Simpson et al., 2020) or basketball (Fox et al., 2020). Consequently, results may not be representative of IL assessed with different approaches such as the Lucia's or Banister's methods.

Future research should be conducted to investigate any potential difference derived by the competitive level of tournaments and/or in relation to different seasonal periods. Additionally, given that the sample of the present study was composed by merely field players, future studies should investigate the external and internal load experienced by beach handball goalkeeper in order to provide specific training strategies useful for coaches and practitioners.

3.3.6 Practical applications

The current study suggests that internal load measures can be used as a monitoring tool when external load monitoring is not possible.
Furthermore, a strong correlation between dose (EL) and response (IL) was found. Therefore, coaches can predict sRPE and SHRZ based on a given PlayerLoad^{TM}, by using the proposed equations. When the concurrent monitoring of EL and IL is possible, coaches can manipulate the psychophysiological response by modifying the PlayerLoad^{TM}.

3.3.7 Conclusion

The present study showed that EL is correlated with IL in youth male beach handball players. PL showed the strongest relationship with IL measures. IL can be predicted by means of the proposed predictive models for monitoring training and match loads in youth beach handball players.

4. SUMMARY AND PERSPECTIVES

Beach handball is a rapidly developing team sport; therefore, this dissertation aimed to investigate two main aspects of performance analysis: the analysis of performance indicators, and the analysis of the external and internal loads experienced by beach handball players.

The first study “Notational analysis of beach handball” investigated the shooting actions of male and female players during matches by means of notational analysis. Notational analysis proved to be a valuable tool for coaches to analyze technical and tactical aspects of shots in beach handball such as the shooting technique, the shooting area, or the goal’s area in relation to the outcome of the action. Even though no difference for gender emerged, results provided valuable insights for coaches for developing specific training strategies. However, for the study only senior club players were analyzed; therefore, results might not be generalized to different level of competitions and ages. Moreover, only semifinal and final phases of the tournament were analyzed resulting in a limited number of shooting actions. Future studies should investigate whether qualification and eliminatory phases might influence shooting actions. Finally, as technical and tactical indicators are regularly affected by the margin of victory, further research should also control for the score between opposite teams. Nevertheless, future research should be carried out to investigate the other contextual factors related to shooting in beach handball such as the match outcome, the scoring differences or the ball possession.

The second study “Usefulness of linear mixed models to assess the relationship between objective and subjective internal load in team sports” aimed to analyze the relationship between objective and subjective methods for assessing internal load in team sports. From a statistical perspective, results showed that the linear mixed model using both random slopes and random intercepts better explained the relationship between internal load measures, compared to the model with only random intercepts, and to simple correlations. From a practical standpoint, it emerged that the subjective perception of internal load experienced by youth beach handball players increases with the objective internal workload, with different responses between players and sessions.

Nevertheless, the study presented some limitations. In particular, the analyzed sample encompassed only youth beach handball male players. Therefore, future research should investigate any potential difference in the internal load in players of different ages and/or gender. Moreover, no previous study has used linear mixed models to correlate subjective and objective measures of internal load. Thus, it should be verified whether the proposed statistical model could also be meaningful in other team sports.

The third study of this dissertation “Assessing the relationship between external and internal load measures in youth beach handball during training and matches” has been focused on the relationship between the external load measures and internal load objectively and subjectively measured in beach handball players. Findings showed that external load measures are highly correlated with both measures of internal load, suggesting that internal load measures can be used as a monitoring tool when external load monitoring is not possible. Moreover, given that the highest relationship with both objective and subjective internal load measures was found for the PlayerLoad^{TM}, coaches can predict the internal load based on a given PlayerLoad^{TM}, by using the equations proposed in the study. Nevertheless, the study presented some limitations; in fact, data were collected on a single youth male beach handball team. Therefore, results might not be generalized for players with different ages and gender. Additionally, the objective internal load was assessed by means of SHRZ; consequently, results may not be representative of internal load assessed with different approaches such as the Lucia (Lucía et al., 2000) or Banister (Banister, 1991) methods. Future research should be carried out for investigating any potential difference in workload in relation to players of different ages and/or gender and t the influence of specific contextual factors, such as sleep, muscle soreness, fatigue on players’ performances.

Overall, the present dissertation aimed to provide a comprehensive approach concerning the performance analysis of beach handball with the goal of providing practical and useful insight for coaches and practitioners and contributing to a further development of the sport.

Technical-tactical aspects related to shooting actions observed during the semifinal and final phases of the “Calise Cup” beach handball tournament held in

Gaeta (Italy) in 2017, with a focus on gender differences, have been investigated. Nevertheless, future research should investigate the other performance indicators influencing a successful performance such as ball possession, passes, or match score.

Physical and physiological demands have also been investigated. In particular, the internal and external loads experienced by youth male beach handball players have been studied in relation to congested periods of training sessions and during the European beach handball tournament “Younger Age Category-17” held in Stare Jabłønki (Poland) in 2019. Further investigation is needed in order to assess the influence of other factors (such as mood, fatigue, or muscle soreness) on internal and external loads.

More detailed recommendations can be found in the research papers’ conclusions sections.

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