PHYSICAL DEMANDS OF ELITE HANDBALL

HOW IS THE GAME EVOLVING?

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Team handball has rapidly evolved into a prominent team sport through significant growth in financial and audience engagement. This evolution emphasizes the importance of understanding game demands to enhance player performance and reduce injuries, requiring that coaches and staff adapt their strategies accordingly.

The physical demands in team sports are shaped by various factors, (e.g., rules, field size, player numbers). This article aims to clarify the evolving demands of elite handball and highlight the factors that mitigate physical challenges for players. Constant elements remain, but significant change has been made in areas (e.g. rules modification, physical attributes). Advances in coaching strategies and technology, such as video analysis and player tracking, have significantly contributed to the sport's development.

Studies have utilized various tracking technologies to monitor external demands in handball. Table 1 outlines these technologies. These systems enhance the accuracy of tracking players' positions and movements indoors, offering precise positioning data and capturing complex movements and sport-specific actions. Despite their detailed performance data, these systems have limitations such as high setup costs, extensive infrastructure needs, and potential portability issues[1]. They also face challenges in accurately capturing certain game demands[2], like the isometric movements of pivots and the complex dynamics of play in confined spaces[3]. These shortcomings highlight the need for ongoing refinement of tracking technologies to better represent the intricate and dynamic aspects of handball, providing a more comprehensive view of player performance and game demands. Coaches should consider these limitations when using data from these systems, as they may not fully reflect the game's physical and tactical complexities.

Studies in physical demand for handball have reported conflicting results[4], highlighting the complexity and variability inherent in the sport. To address this issue, we seek to identify factors that influence physical demands in handball, to enhance our understanding of how these demands fluctuate across different settings and conditions.

Indeed, the physical demands in handball are shaped by a wide array of factors that interact in complex ways, leading to a unique set of demands for each game. This variability underscores the importance of a nuanced understanding of the sport's dynamics for coaches and training staff. By acknowledging and adapting to these multifaceted influences, coaches can tailor training regimens, game strategies, and player rotations to optimize team performance and player well-being. Let's highlight the key points that underscore this complexity.

Each playing position in handball comes with specific physical requirements. For instance, wing players need exceptional speed and agility to execute fast breaks and evade defenders, while backs require a blend of power for shooting from a distance and the endurance to participate in both offensive and defensive actions[3]. Pivots must have the strength for physical play and resilience against defensive pressure. The goalkeeper's role is highly specialized, demanding quick reflexes, agility, and the ability to read the game. Thus, the physical demands vary greatly by position, influencing training focus areas such as endurance, strength, agility, and technical skills[3].

Table 1

Technology	Operating mode	Precision	Small movements / high player density	Ball tracking	IMU effect	Flexibility setup	Home use / away	Opponent	Cost
Local Positioning Systems (LPS) with IMU	LPS uses a network of local transmitters or anchors around the tracking area that communicate with tags or sensors carried by subjects (players). The system triangulates the subject's position based on the signals between the anchors and the tags.	★★★★☆	★★★☆☆	NO	The validity and reliability of data from IMUs integrated within tracking systems depend heavily on both the quality of the IMU hardware and the sophistication of the software processing the data. High-quality sensors ensure precise motion capture, while advanced algorithms effectively merge device data, enhancing accuracy and consistency in dynamic and complex environments. This integration is key to providing comprehensive and reliable tracking solutions.	★★☆☆☆	Implementing a uniform system across all arenas in a league seems to be the optimal solution, as it ensures consistent data quality and eliminates additional costs for away teams. This approach facilitates valid comparisons between teams by standardizing the measurement environment, like practices adopted in the NBA and the Liqui Moly Handball Bundesliga in Germany. By using the same tracking systems league-wide, each team can benefit equally from the insights provided.	★★☆☆☆	★★★☆☆
Radio Frequency Identification (RFID) with IMU	RFID systems consist of readers and tags. The readers send out radio waves that are received by RFID tags, which then reflect back signals to the reader. The system calculates the position based on the timing and characteristics of this reflected signal.	★★★☆☆	★★☆☆☆	NO		★★★☆☆		★★☆☆☆	★★☆☆☆
Ultra-wideband (UWB) with IMU	UWB uses radio waves but operates at a very high frequency across a wide spectrum. This allows UWB to accurately determine the time of flight of the signal, leading to very precise positioning.	★★★★★	★★★★☆	NO[1]		★★☆☆☆		★★☆☆☆	★★★★☆
Video Tracking Systems	Video Tracking Systems also use cameras to record activities on the playing field, but they can be more flexible in terms of the type and number of cameras used. These systems may employ standard video cameras and do not necessarily require the high-end, specialized equipment used in OT systems.	★★★☆☆	★★★☆☆	YES		★★★★☆		★★★★☆	★★☆☆☆
Optical Tracking Systems (OT)	Optical Tracking Systems typically use multiple high-resolution cameras placed around the perimeter of a playing area to capture two-dimensional or three-dimensional data. These systems often rely on sophisticated algorithms to process images and detect positional data automatically.	★★★★★	★★★★★	YES		★☆☆☆☆		★★★★☆	★★★★★

Table 1: Tracking Technology Comparison in Handball . Comparison of different player tracking technologies, assessing precision, ball tracking capability, impact of IMU integration, flexibility, home and away use, opponent analysis, and cost, using a star rating system. 1: One brand has developed a connected ball equipped with an UWB embedded sensor.

Table 2

Performance Indicator	*Normal Range*
Goals	*25-35*
ball possession	*45-55*
average ball duration	*30''-40''*
Possession <28s (%)	*30-40%*
Positional attacks	*35-45*
Fast attack	*5-10*
fast breaks	*5-10*
2-minute suspensions	*4-6*

Table 2: Key Statistical ranges in International Handball. Common statistical ranges for various game metrics in international handball that can influence physical performance. Data retrieved from Pasual (2023), Vaz (2023), https://handballytics.de/ and https://ehfeuro.eurohandball.com/.

The offensive and defensive phases introduce varied physical demands[5]. Offensive play demands quick bursts of speed, agility to navigate through defenses, and the endurance to sustain efforts across multiple attacks. Conversely, defensive play requires players to maintain a high level of physical intensity to counteract offensive maneuvers, necessitating strength for physical confrontations[6]. Similarly, the full-court game, characterized by fast breaks and quick retreats, significantly amplifies these physical demands, increasing the number and the distance of sprints.

Strategic rotation during offensive and defensive phases not only exploits tactical advantages but also manages physical loads effectively[3]. By rotating players based on their specific strengths—such as utilizing defensive specialists or sharpshooters for offense—teams can dynamically adapt to the game's flow and the opposing strategy. This approach balances physical demands across the squad, optimally leveraging individual skills while mitigating fatigue. Frequent rotation allows teams to maintain a high level of intensity, ensuring players have adequate recovery time, which reduces the risk of overuse injuries and conserves energy for pivotal moments. Total playing time is a critical factor, as prolonged time on the court increases a player's exposure to physical stress, underscoring the need for a well-considered rotation strategy to optimize both performance and health.

Physical demands in handball are not only shaped by the immediate gameplay but also by external factors such as the opposition, location, and the game's stakes[7,8]. Facing formidable or aggressive opponents demands more from players physically and tactically, leading to increased fatigue and strategic adjustments[9]. Home advantages have also an impact while familiar settings and supportive crowds can lessen physical strain, whereas away games introduce challenges like travel fatigue and unfamiliarity, amplifying physical demands[7]. Additionally, the heightened intensity and pressure of playoffs or crucial matches may escalate physical demands for players[9].

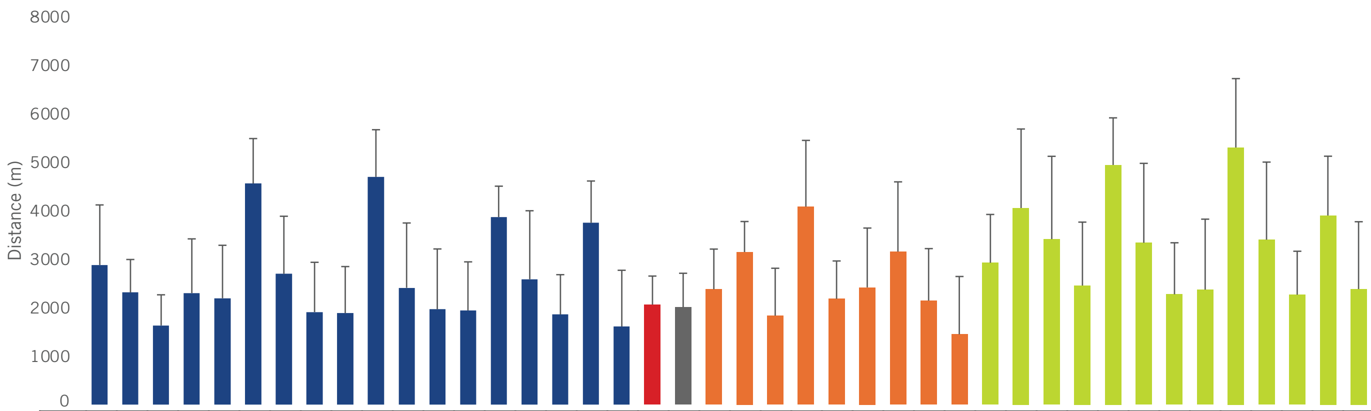
Recent modifications to handball rules, including the 2016 goalkeeper rule and the 2022 adjustments to passive play and fast throw-offs, have significantly influenced playing demands. These changes, implemented by the International Handball Federation (IHF), aim to quicken the game's pace, making handball more attractive and dynamic (IHF, IX Rules of the Game, 2022) . The main goals are to shorten the attack phase to encourage more fast breaks and quick attacks, thus increasing game density, action, and consequently, physical demands.

Although the pace of handball games has historically been relatively constant[10], it can significantly vary based on several factors such as ball possession, which is associated with higher running demands in terms of total distance and high-speed efforts, along with more high-intensity actions like jumps, shots, and duels. Scenarios such as temporary 2-minute suspensions or strategic decisions like playing 7 vs. 6 may also affect physical demands[11]. For instance, situations that require goalkeepers to exit for each ball possession could increase running demands for goalkeepers. Moreover, teams in inferiority often slow down the game pace during suspensions to reduce vulnerability to opponent attacks. Coaches can use norms provided in Table 2 for key variables (e.g. ball possession, fast breaks) to recognize potential fluctuations in physical demands and adapt training accordingly.

The game model also plays a crucial role in shaping game demands, affected by factors like the type of defense (e.g., flat or open, such as 0/6 or 3-2-1), the game's pace (high or low), the frequency of counterattacks, and the use of defensive specialists[12]. These factors can lead to varying physical demands; for example, an open defense system might result in more player duels, while a high game pace could require more high-speed running efforts. The defensive system is determined by the coaches' choices, whereas offensive strategies are developed in response to the opponent's tactics. Consequently, coaches can only partly influence playing demands.

After examining the factors that influence game demands, we will review recent research (since 2014) to understand handball's physical performance by measuring the external load (activities and actions executing on the field).

Regardless of the analysis technique, total meters covered is a key variable for understanding the demands on handball players. Initially, studies included all players, but with advancements in technology, data have been refined by specific positions or player lines (1st or 2nd), enabling the design of tailored training tasks. This variable not only reflects the total volume of movement in a match but also informs the metabolic work needed during training. It's crucial to



POSITION	BACKS	BACKS	BACKS	BACKS	BACKS CENTER	BACKS CENTER	BACKS CENTER	BACKS CENTER	BACKS LEFT	BACKS LEFT	BACKS LEFT	BACKS LEFT	BACKS RIGHT	BACKS RIGHT	BACKS RIGHT	BACKS RIGHT	BACKS	BACKS	DEF MIDDLE	GOALKEEPERS	PIVOT	PIVOTS	PIVOTS	PIVOTS	PIVOTS	PIVOTS	PIVOTS	PIVOTS	PIVOTS	WING	WINGS	WINGS	WINGS LEFT	WINGS LEFT	WINGS LEFT	WINGS LEFT	WINGS RIGHT	WINGS RIGHT	WINGS RIGHT	WINGS RIGHT	WINGS	WINGS
GENDER	*Male*	*Male*	*Male*	*Female*	*Male*	*Male*	*Male*	*Female*	*Male*	*Male*	*Male*	*Female*	*Male*	*Male*	*Male*	*Female*	*Male*	*Male*	*Male*	*Male*	*Male*	*Male*	*Male*	*Male*	*Male*	*Male*	*Male*	*Female*	*Female*	*Male*	*Male*	*Female*	*Male*	*Male*	*Male*	*Female*	*Male*	*Male*	*Male*	*Female*	*Male*	*Male*
PHASE	*Both*	*Both*	*Off*	*Both*	*Both*	*Both*	*Both*	*Both*	*Both*	*Both*	*Both*	*Both*	*Both*	*Both*	*Both*	*Both*	*Both*	*Both*	*Def*	*Both*	*Both*	*Both*	*Both*	*Both*	*Both*	*Both*	*Both*	*Both*	*Both*	*Off*	*Both*	*Both*	*Both*	*Both*	*Both*	*Both*	*Both*	*Both*	*Both*	*Both*	*Both*	*Both*
TECHNOLOGY	*Video Tracking*	*IMUs*	*IMUs*	*IMUs*	*IMUs*	*IMUs*	*Video Tracking*	*IMUs*	*IMUs*	*IMUs*	*Video Tracking*	*IMUs*	*IMUs*	*IMUs*	*Video Tracking*	*IMUs*	*IMUs*	*IMUs*	*IMUs*	*IMUs*	*IMUs*	*IMUs*	*IMUs*	*IMUs*	*IMUs*	*Video Tracking*	*Video Tracking*	*IMUs*	*IMUs*	*IMUs*	*Video Tracking*	*IMUs*	*IMUs*	*IMUs*	*Video Tracking*	*IMUs*	*IMUs*	*IMUs*	*Video Tracking*	*IMUs*	*IMUs*	*IMUs*
LEVEL	*Elite Players*	*Elite Players*	*Elite Players*	*Sub-Elite*	*Elite Players*	*Sub Elite Players*	*Elite Players*	*Elite Players*	*Elite Players*	*Sub Elite Players*	*Elite Players*	*Elite Players*	*Elite Players*	*Sub Elite Players*	*Elite Players*	*Elite Players*	*Elite Players*	*Elite Players*	*Elite Players*	*Elite Players*	*Elite Players*	*Elite Players*	*Elite Players*	*Sub Elite Players*	*Elite Players*	*Elite Players*	*Elite Players*	*Elite Players*	*Sub-Elite*	*Elite Players*	*Elite Players*	*Sub-Elite*	*Elite Players*	*Sub Elite Players*	*Elite Players*	*Elite Players*	*Elite Players*	*Sub Elite Players*	*Elite Players*	*Elite Players*	*Elite Players*	*Elite Players*
STUDIES	*Buchel et al. (2019)*	*Lefevre et al. (2023)*	*Lefevre et al. (2023)*	*Garcia-Sanchez et al. (2023)*	*Manchado et al. (2021)*	*Font et al. (2023)*	*Cardinale et al. (2017)*	*Zapardiel et al. (2024)*	*Manchado et al. (2021)*	*Font et al. (2023)*	*Cardinale et al. (2017)*	*Zapardiel et al. (2024)*	*Manchado et al. (2021)*	*Font et al. (2023)*	*Cardinale et al. (2017)*	*Zapardiel et al. (2024)*	*Font et al. (2021)*	*Saal et al. (2023)*	*Lefevre et al. (2023)*	*Lefevre et al. (2023)*	*Lefevre et al. (2023)*	*Font et al. (2021)*	*Manchado et al. (2021)*	*Font et al. (2023)*	*Saal et al. (2023)*	*Cardinale et al. (2017)*	*Buchel et al. (2019)*	*Zapardiel et al. (2024)*	*Garcia-Sanchez et al. (2023)*	*Lefevre et al. (2023)*	*Buchel et al. (2019)*	*Garcia-Sanchez et al. (2023)*	*Manchado et al. (2021)*	*Font et al. (2023)*	*Cardinale et al. (2017)*	*Zapardiel et al. (2024)*	*Manchado et al. (2021)*	*Font et al. (2023)*	*Cardinale et al. (2017)*	*Zapardiel et al. (2024)*	*Font et al. (2021)*	*Saal et al. (2023)*

Figure 1: Total Distance Traveled by Position in Handball Games. Total distance traveled by players in different positions (backs, defenders, goalkeepers, pivots, wings) during offensive, defensive, and both phases of handball games, differentiated by gender and tracked using different technologies, across various studies since 2014. Blue, red, orange, and green stand respectively for back middle defender, goalkeepers, pivots and wings.

consider both player positions and the game model—despite its frequent neglect—to develop tasks that meet specific needs[3,13]. Figure 1 provides an overview of the total distance covered, incorporating various factors from publications since 2014.

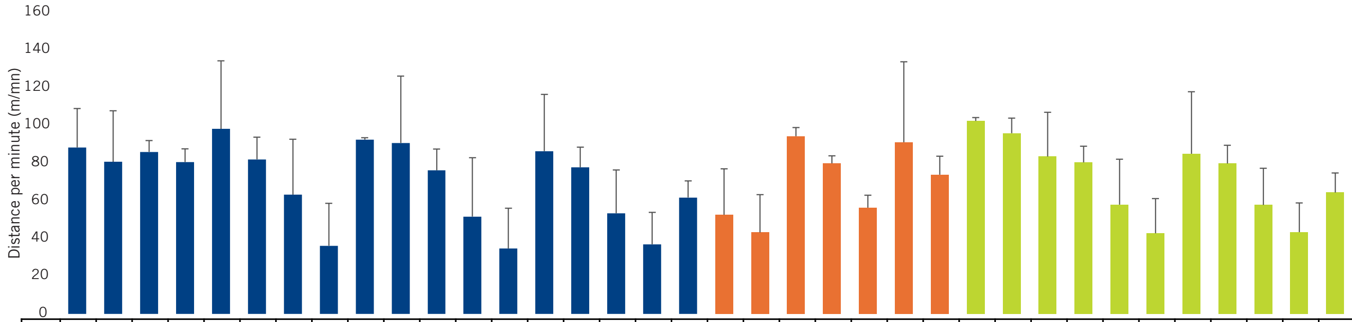
Linked to the meters covered in a match, the 'distance per minute' metric provides insights into match intensity by analyzing the distance players cover per minute of play. This measure not only reflects game intensity but also facilitates comparisons with training intensities[3]. Moreover, normalizing distance by time minimizes the impact of playing time on the total distance covered by the players. Figure 2 presents an overview of meters per minute traveled by players under various conditions, such as playing position and game phase. The variability of these results can be attributed to the factors discussed earlier in this article.

Running at high speeds (HSR, >18 km/h) is a key performance determinant in handball but also increases the risk of muscle injuries, especially in the posterior chain[3,13]. Consequently, coaches and trainers must carefully design and adjust training programs to prepare players for these intense demands, now more prevalent in contemporary handball. Although reaching maximum speed during matches is rare due to the limited dimensions of a handball field and team dynamics, HSR remains a crucial measure of game intensity. Scientific consensus (Figure 3) shows that wings, often involved in fast counterattacks, cover the most HSR meters[5,13–15].

It is important to note that within the locomotion demands of handball, field players may execute up to 50% of their movements in non-forward directions, including lateral and backward displacements. This significant amount of multi-directional movement underlines the complexity of physical demands in handball and highlights the need for specialized training that encompasses these diverse movement patterns[12,16].

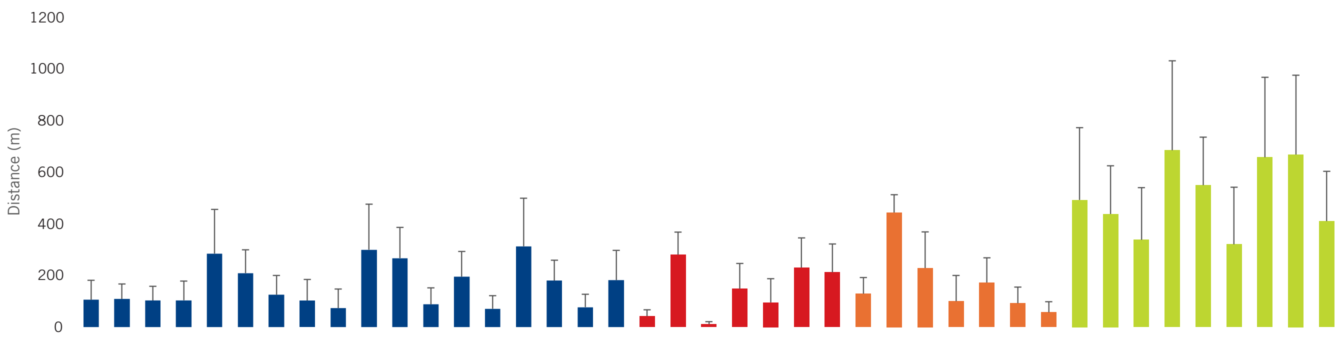
Handball is characterized by frequent, high intensity actions (e.g. accelerations, decelerations, COD) which significantly influence game demands[17]. Accelerations and decelerations, particularly, are crucial for understanding these demands. In the confined spaces of a handball field, players often reach high values in these metrics during 1v1 situations or changes of direction, involving significant braking and speed actions[18,19]. Data on these actions are limited, and while there is no consensus on thresholds for analyzing high-intensity actions, studies have shown that players typically perform over 1000 such movements per game, averaging 3.9 ± 1.5 high-intensity events per minute, underscoring their importance for performance[14,18].

Different playing positions exhibit varying levels of high-intensity accelerations (HIA) and decelerations



STUDIES	POSITION	PHASE	GENDER	TECHNOLOGY
Manchado et al. (2020)	ALL	OFFENSIVE	Male	IMUs
Manchado et al. (2020)	ALL	DEFENSIVE	Male	IMUs
Barbero et al. (2014)	BACKS	Both	Male	IMUs
Sibila et al. (2004)	BACKS	Both	Male	Video Tracking
Manchado et al. (2021)	BACKS CENTER	Both	Male	IMUs
Cardinale et al. (2017)	BACKS CENTER	Both	Male	Video Tracking
Zapardiel et al. (2024)	BACKS CENTER	OFFENSIVE	Female	IMUs
Zapardiel et al. (2024)	BACKS CENTER	DEFENSIVE	Female	IMUs
Barbero et al. (2014)	BACKS CENTER	Both	Male	IMUs
Manchado et al. (2021)	BACKS LEFT	Both	Male	IMUs
Cardinale et al. (2017)	BACKS LEFT	Both	Male	Video Tracking
Zapardiel et al. (2024)	BACKS LEFT	OFFENSIVE	Female	IMUs
Zapardiel et al. (2024)	BACKS LEFT	DEFENSIVE	Female	IMUs
Manchado et al. (2021)	BACKS RIGHT	Both	Male	IMUs
Cardinale et al. (2017)	BACKS RIGHT	Both	Male	Video Tracking
Zapardiel et al. (2024)	BACKS RIGHT	OFFENSIVE	Female	IMUs
Zapardiel et al. (2024)	BACKS RIGHT	DEFENSIVE	Female	IMUs
Font et al. (2021)	BACKS	Both	Male	IMUs
Zapardiel et al. (2024)	PIVOTS	OFFENSIVE	Female	IMUs
Zapardiel et al. (2024)	PIVOTS	DEFENSIVE	Female	IMUs
Barbero et al. (2014)	PIVOTS	Both	Male	IMUs
Sibila et al. (2004)	PIVOTS	Both	Male	Video Tracking
Font et al. (2021)	PIVOTS	Both	Male	IMUs
Manchado et al. (2021)	PIVOTS	Both	Male	IMUs
Cardinale et al. (2017)	PIVOTS	Both	Male	Video Tracking
Barbero et al. (2014)	WINGS	Both	Male	IMUs
Sibila et al. (2004)	WINGS	Both	Male	Video Tracking
Manchado et al. (2021)	WINGS LEFT	Both	Male	IMUs
Cardinale et al. (2017)	WINGS LEFT	Both	Male	Video Tracking
Zapardiel et al. (2024)	WINGS LEFT	OFFENSIVE	Female	IMUs
Zapardiel et al. (2024)	WINGS LEFT	DEFENSIVE	Female	IMUs
Manchado et al. (2021)	WINGS RIGHT	Both	Male	IMUs
Cardinale et al. (2017)	WINGS RIGHT	Both	Male	Video Tracking
Zapardiel et al. (2024)	WINGS RIGHT	OFFENSIVE	Female	IMUs
Zapardiel et al. (2024)	WINGS RIGHT	DEFENSIVE	Female	IMUs
Font et al. (2021)	WINGS	Both	Male	IMUs

Figure 2: Mean Distance Traveled per Minute in Handball Games. Mean distance traveled per minute by players in various positions and phases of play, across genders, and using different tracking technologies, as reported in selected studies since 2014. Blue, orange, and green stand respectively for back, pivots and wings.



STUDIES	POSITION	PHASE	GENDER	TECHNOLOGY
Garcia-Sanchez et al. (2023)	BACKS	Both	Female	IMUs
Lefevre et al. (2023)	BACKS	Both	Male	IMUs
Lefevre et al. (2023)	BACKS	Off	Male	IMUs
Manchado et al. (2021)	BACKS CENTER	Both	Male	IMUs
Zapardiel et al. (2024)	BACKS CENTER	Both	Female	IMUs
Font et al. (2023)	BACKS CENTER	Both	Male	IMUs
Manchado et al. (2020)	BACKS CENTER	Off	Male	IMUs
Manchado et al. (2020)	BACKS CENTER	Def	Male	IMUs
Manchado et al. (2021)	BACKS LEFT	Both	Male	IMUs
Zapardiel et al. (2024)	BACKS LEFT	Both	Female	IMUs
Font et al. (2023)	BACKS LEFT	Both	Male	IMUs
Manchado et al. (2020)	BACKS LEFT	Off	Male	IMUs
Manchado et al. (2020)	BACKS LEFT	Off	Male	IMUs
Manchado et al. (2021)	BACKS RIGHT	Both	Male	IMUs
Zapardiel et al. (2024)	BACKS RIGHT	Both	Female	IMUs
Font et al. (2023)	BACKS RIGHT	Both	Male	IMUs
Manchado et al. (2020)	BACKS RIGHT	Off	Male	IMUs
Font et al. (2021)	BACKS	Both	Male	IMUs
Lefevre et al. (2023)	DEE MID	Def	Male	IMUs
Manchado et al. (2020)	FRONT CENT	Def	Male	IMUs
Lefevre et al. (2023)	GOALKEEPERS	Both	Male	IMUs
Manchado et al. (2020)	MIDDLE LEFT	Def	Male	IMUs
Manchado et al. (2020)	MIDDLE RIGHT	Def	Male	IMUs
Manchado et al. (2020)	OUTSIDE LEFT	Def	Male	IMUs
Manchado et al. (2020)	OUTSIDE RIGHT	Def	Male	IMUs
Lefevre et al. (2023)	PIVOT	Both	Male	IMUs
Zapardiel et al. (2024)	PIVOTS	Both	Female	IMUs
Font et al. (2023)	PIVOTS	Both	Male	IMUs
Manchado et al. (2020)	PIVOTS	Both	Male	IMUs
Font et al. (2021)	PIVOTS	Both	Male	IMUs
Manchado et al. (2021)	PIVOTS	Both	Male	IMUs
Garcia-Sanchez et al. (2023)	PIVOTS	Both	Female	IMUs
Garcia-Sanchez et al. (2023)	WINGS	Both	Female	IMUs
Lefevre et al. (2023)	WINGS	Off	Male	IMUs
Manchado et al. (2021)	WINGS LEFT	Both	Male	IMUs
Zapardiel et al. (2024)	WINGS LEFT	Both	Female	IMUs
Font et al. (2023)	WINGS LEFT	Both	Male	IMUs
Manchado et al. (2021)	WINGS RIGHT	Both	Male	IMUs
Zapardiel et al. (2024)	WINGS RIGHT	Both	Female	IMUs
Font et al. (2023)	WINGS RIGHT	Both	Male	IMUs
Font et al. (2021)	WINGS	Both	Male	IMUs

Figure 3: Mean High-Speed Distance in Handball Games. Mean high-speed distance covered by players during handball games, categorized by position, gender, phase of play, and tracked with different technologies, as reported in various studies since 2014. Blue, red, orange, and green stand respectively for back, defensive specialist, pivots and wings.

(HID). Wings perform slightly more HIA, with averages of 134.8 ± 60.7, compared to backs and pivots (128.1±55.2 and 112.0±33.6 respectively)[14]. Backs and wings display comparable high-intensity deceleration (HID) actions (114.6±51.77 vs. 112.9±56), which are higher when compared to pivots (99.6±28.9)[14]. These results are due to wings' critical roles in counter attacks, demanding rapid movements and agility, while backs, responsible for organizing positional attacks, experience "fixation movement" leading to intense eccentric contractions and neuromuscular fatigue[14]. Pivots, mainly engaged in static blocking, exhibit fewer dynamic movements, leading to lower HIA and HID.

This play pattern requires specialized training to manage the eccentric loads, particularly for backs, to prevent tissue damage[20]. The high intensity of game actions emphasizes the need for tailored training to accurately replicate these movements and mitigate injury risks. Strength and conditioning coaches must develop training regimens that enhance muscle and tendon capacity to handle these loads, considering the significant physiological impacts of these contractions[21].

Technical actions and his derivative are also important to characterize physical demands. In handball, players must withstand high impacts, provoked by opposing players having to properly prepare their body structures to withstand these uncontrolled perturbations[22]. Pivots, for example, who register lower levels in many of the external load variables due to the demands of their position, register higher values in this variable (10.6+3:4 vs 8.2±6.3 for backs and 1.8±1.5 for wings) due to the fact that they are constantly in the middle of opposing defenses performing a great deal of strength work, in many cases, isometric[17].

Handball players frequently perform jumping and landing actions, whether for throwing or defensive blocking. Saal et al.[17] reported that backs execute approximately 8.6±6.5 jumps per game, followed by pivots with 6.5±3.6, and wings with 4.6±3.5. Given the frequency of these actions and their association with lower limb injuries—such as injuries to ankles, knees, hamstrings, and hips[22]—it is crucial to incorporate varied and high-intensity training for these movements. Training should aim not only to enhance power and height but also to prevent injuries by simulating game-like conditions. Exercises should be designed to train these jumps at maximum intensity, incorporating real disturbances to prepare for the decisive and potentially harmful nature of these actions in matches[23].

Shooting and passing, particularly when performed with maximal intensity, are critical technical actions in handball. Shooting speed is not only a critical factor for success but also a potential source of injuries, with overhead throwing ranking among the most explosive sporting actions (maximal internal rotation velocities up to 7430±1270 deg/sec[24]. Backs typically exhibit faster shooting speeds compared to other players, often ranging from 24 to over 26 m/s, whereas wings and pivots generally have slower shooting speeds[5,25]. Players could also perform different type of throw like overarm shot, underarm shot[26], diving shot, wing[27], jumping with both feet[6] that has also specificities. Passing in elite handball, while generally less intense than shooting, still requires substantial effort that can significantly stress the shoulder, potentially leading to acute or chronic injuries. Backs are the most active, averaging 55.9±51.4 passes per game, significantly more than wings (14.8±10.8) and pivots (23.3±15.1)[17]. The stress placed on players' shoulders during shooting and passing significantly depends on the time spent in the offensive phase, their playing position, and skill level with more proficient players typically shooting more frequently.

This underscores the necessity for specialized training designed to address these high demands and mitigate injury risks, especially for backs who are regularly involved in intense shooting actions[28]. Coaches should train players for diverse throws and passes at high intensity and speed, under defensive pressure, with a focus on the braking mechanics of throwing to lower injury risk[29]. New technologies such as iBall and shoulder IMUs provide valuable data on shoulder load, shot dynamics, and ball handling, enhancing training and reducing injury risks[25,26,30].

The chaotic game structure significantly impacts play intensity, necessitating player preparedness for the most demanding scenarios to succeed and minimize injuries. Although these worst-case scenarios (WCS) occur infrequently during games, Players must be prepared to withstand the most

Shooting and passing, particularly when performed with maximal intensity, are critical technical actions in handball. Shooting speed is not only a critical factor for success but also a potential source of injuries, with overhead throwing ranking among the most explosive sporting actions.

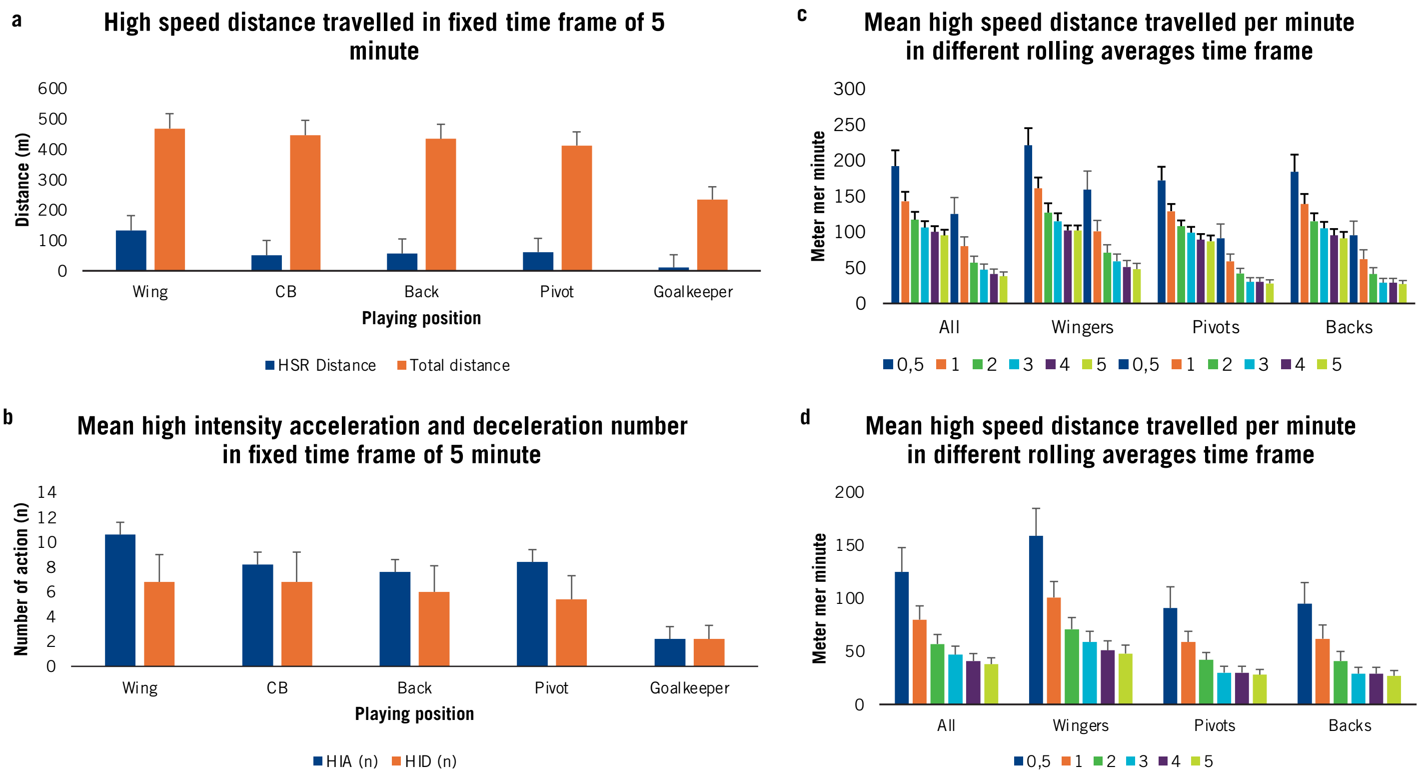


Figure 4: Analysis of peak locomor demands Playing Position. A) High-Speed Distance: Distance covered at high speed within a fixed 5-minute frame by position (Carton-Llorente et al., 2023). B) Acceleration/Deceleration Events: Average number of high-intensity acceleration and deceleration actions within 5 minutes by position (Carton-Llorente et al., 2023). C) Distance Per Minute: Average distance traveled per minute over varying rolling average time frames (Fleureau et al., 2023). D) High-Speed Distance Per Minute: Average high-speed distance traveled per minute across varying rolling average time frames (Fleureau et al., 2023).

demanding scenarios to both win games and reduce injury risk[31]. Therefore, it is essential to characterize this effort across different time frames. To date, only few studies has been conducted, with the results detailed in Figure 4. Understanding these results is crucial for designing tasks that effectively replicate these demands.

Apart from the external load, it is crucial to consider its impact on players' bodies by simultaneously assessing the internal load. This comprehensive approach allows for more effective control of player load[32]. Reflecting this, Póvoas et al.[33] described handball as an intermittent sport that predominantly utilizes aerobic metabolism, punctuated by high-intensity actions that significantly challenge anaerobic metabolism. This duality underscores the need for tailored training and recovery strategies to address the diverse metabolic demands placed on players[34].

Since our last review in 2014, there has been limited new data on internal load measures such as oxygen consumption, heart rate or blood lactate in handball. We recommend that readers consult our previous work for detailed insights. Therefore, there is a clear need for further research in this area, particularly considering the playing position and various game variables[35].

Monitoring the physical load in team handball can effectively be done by evaluating hormonal responses during and after exercise, using blood or saliva samples. These responses, particularly the increase in cortisol and decrease in immunoglobulin A observed in studies, indicate significant physiological stress and are valuable indicators of physical loads[36]. Mariscal et al.[37] found that competitive matches in female athletes activate stress pathways, such as the hypothalamic-pituitary-adrenal axis and adrenergic system, leading to decreased immunocompetence. This highlights the need for careful monitoring and management of recovery, as returning to baseline values can take several hours to days.

The miniaturization and the development of diverse sports wearables (e.g. EMG, ECG, NIRS), have the potential to enhance our understanding of the physiological demands of handball[38]. However, the contact nature of the sport may slightly impede the widespread deployment of these technologies.

As team handball advances, with marked improvements in engagement and technology, grasping its physical demands is critical. This article has examined these demands, shaped by evolving rules, positions, and strategies.

Yet, current technologies fall short of fully capturing the game's physicality, particularly for goalkeepers whose unique role warrants further investigation. As we delve into high-intensity dynamics, the need for ongoing research and training innovation becomes evident to protect player health.

Staff members should apply these findings to devise training programs aligned with competitive demands and player safety. With handball's increasing complexity, coaching and performance analysis must advance accordingly.

Looking ahead, enhanced data collection and insight into the physiological effects

The variability in game demands necessitates a nuanced understanding of handball dynamics to effectively adapt training and game strategies.

of play are essential. This will improve our strategies to elevate performance and reduce injuries, creating a safer, more competitive handball landscape for all players, particularly addressing the underrepresented area of goalkeeper physical demands.

CONCLUSION

Team handball has undergone significant evolution, marked by enhancements in player engagement and technological advancements. This development underscores the need to comprehend the complex physical demands of the sport to optimize player performance and minimize injury risks. The physical requirements in handball are influenced by an array of factors including game rules, player positions, and strategic dynamics, which have been elaborated through the examination of recent rule modifications and the application of advanced tracking technologies.

Despite these advancements, challenges persist in fully capturing the game's physicality, particularly in the detailed aspects of play and player movements. This gap highlights the need for ongoing refinement of tracking technologies and methodologies to ensure a comprehensive representation of the sport's demands. Such insights are crucial for coaches and training staff as they develop tailored training programs that address both the high demands of competitive play and prioritize player health and safety.

Moreover, the variability in game demands necessitates a nuanced understanding of handball dynamics to effectively adapt training and game strategies. This includes considering the specific physical requirements of different playing positions and the strategic use of player rotations to manage physical loads and prevent injuries. The role of external factors such as opposition strength, game location, and match significance also play a critical part in shaping game dynamics and physical demands.

Furthermore, recent research highlights the need for an enhanced understanding of how physical demands fluctuate, which is crucial for developing interventions that optimize performance and reduce injury risks. However, there remains a notable gap in data, particularly concerning the physical demands on goalkeepers, who often face unique challenges that are not as thoroughly documented as those of outfield players.

In conclusion, as handball continues to evolve in complexity and intensity, so must the approaches to coaching, player development, and performance analysis. This evolution will benefit from more refined data collection methods and deeper insights into the physiological impacts of play, which will collectively enhance our ability to design effective training and recovery protocols. This approach not only promises to foster a safer and more competitive environment but also ensures that all aspects of physical demands, including those less represented like goalkeeper demands, are adequately addressed.

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