2 On-Court Physical Demands and Physiological Aspects in Elite Team Handball

Lars Bojsen Michalsik

2.1 Introduction

Modern team handball match-play imposes substantial physical demands on elite players. However, only relatively limited knowledge seems to exist about the specific on-court working requirements in elite team handball. Thus, the overall purpose of this chapter is to give a brief overview of the present knowledge about the on-court physical demands placed on adult male and female elite team handball field players in relation to playing positions. In addition, it is also the aim to characterise the physiological aspects in elite team handball and to present an outline of the potential differences in the on-court physical demands in male vs. female adult elite team handball match-play. The activity pattern of goalkeepers is very much specialised and differs substantially from those of field players, and a description of the physical demands placed on goalkeepers is not included in this chapter. Gaining increased knowledge about the physical demands in elite team handball and the physiology of elite players provides the basis for improving the design, planning and implementation of optimal physical training in elite team handball players to increase playing performance and reduce fatigue and the number of overload injuries.

2.2 The Physical Demands and Physiological Profile of Elite Team Handball Players

Team handball is an Olympic sport (in its current form since 1972 for men and 1976 for women) that has shown increasing worldwide popularity over the last decades. It is played professionally in a large number of mainly European countries, and major international championships are held regularly. Team handball is an intense physical game, and occasionally it can be a highly rough game. Despite this, great muscular strength and well-trained physique alone is not a sufficient background to perform well in elite team handball. Rather, these factors must be complemented by a variety of technical and cognitive skills including tactical understanding as well as an ability to optimally utilise the distinct physique of the individual player and the interaction of the players on the team.

Especially through the last 30 years, team handball has undergone a major development from a relatively slow ball sport into a more dynamic game with high speed and intensity including a great amount of physical confrontations between players. In addition, the rules in recent years have been changed and adapted, so team handball has

L. B. Michalsik
Department of Sport Science and Clinical Biomechanics, Muscle Physiology and Biomechanics Research Unit, University of Southern Denmark,
Odense, Denmark
e-mail: lb@michalsik.dk

L. Laver et al. (eds.), *Handball Sports Medicine*, https://doi.org/10.1007/978-3-662-55892-8_2

emerged into an exciting and very speedy ball game. Thus, modern team handball is often referred to as a rapid transition game, as players frequently switch between defensive and offensive play. Not surprisingly, the marked alterations in rules during recent years have contributed to changing the physical demands placed on the players. Consequently, present-day team handball is a faster and more physically demanding game with a substantially higher number of attacks and goals per match [1]. Furthermore, especially male players have, e.g. become bigger in size and more well-trained compared to the past [2].

Playing performance in team handball is determined by the players' technical, tactical, psychological/social and physical characteristics, which comprise a wide array of elements (see Fig. 2.1). All these elements are of high importance and also closely interlinked, making team handball a particularly complex sport. For example, a high level of physical conditioning is required, if elite team handball players should be able to exploit their technical and tactical qualities during an entire game [3]. Likewise, if a player's tactical skills are deficient, the technical quality of the player may not be fully utilised.

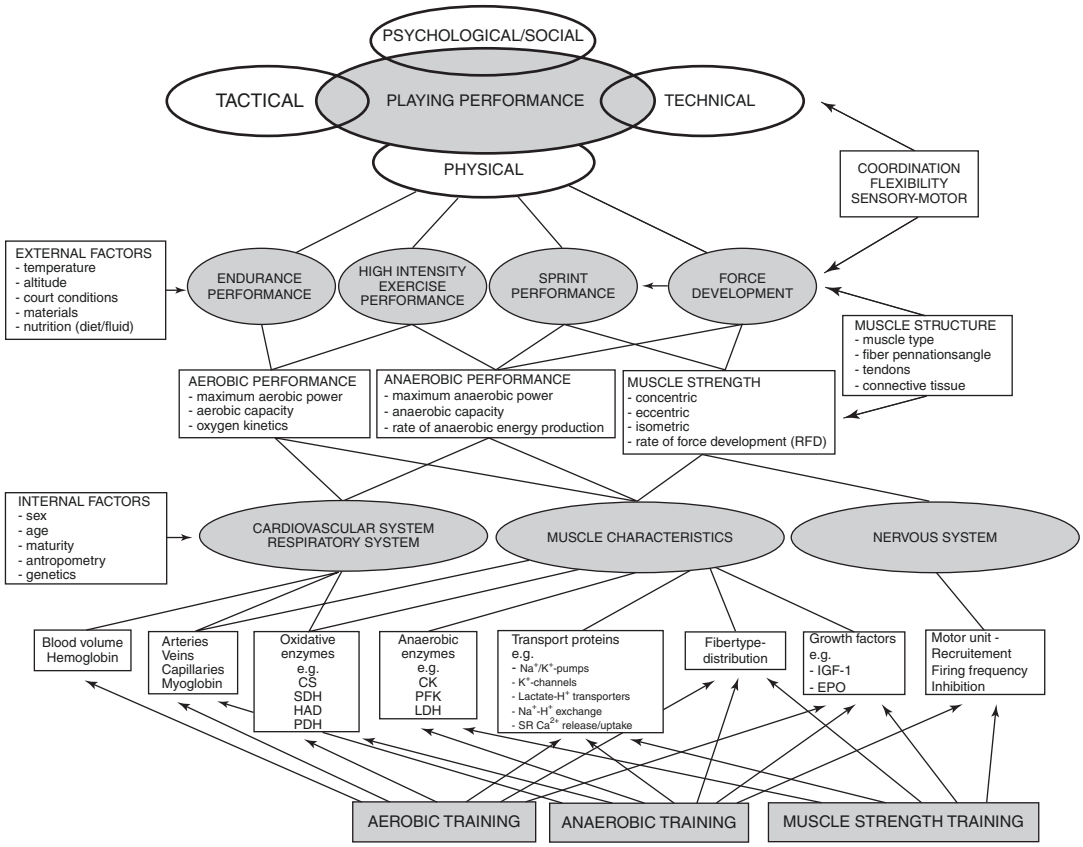

Fig. 2.1 A model of the relationship between the various factors that contribute to playing performance in team handball with special reference to the physical characteristics. Team handball playing performance is determined by the technical, tactical, psychological/social and physical capacities of each individual player. These various areas overlap and influence each other. The physiological factors can be divided into several match performance abilities (upper part). These abilities are dependent on variables, which can partly be evaluated separately (middle part). The capacity of the cardiovascular and respiratory system, muscle characteristics and neural factors constitute the basic components of the physical performance that are determined by genetic factors and training status (lower part). Performance during match-play is also influenced by various external factors, including environment and nutrition

During team handball match-play, players perform various activities ranging in intensity from standing still or walking to maximal intensity during, for example, sprint running and maximal ball throwing. The intensity can alternate at any given time, making team handball an intermittent type of sport. This distinguishes team handball from sports like rowing and marathon running, where continuous exercise is performed with either high or moderate intensity throughout the entire event. Consequently, the physical demands in team handball are more complex than in many individual sports. The physical demands, required from a team handball player, can be divided into the following categories (see Fig. 2.1):

- The ability to perform prolonged (2 × 30 min) intermittent exercise (endurance), including the ability to repeatedly recover from short-lasting, high-intensity playing actions
- The ability to exercise with high intensity
- The ability to sprint
- The ability to develop great strength and high-power output and to coordinate movements in match situations such as passing, shooting, jumping, changing direction and tackling

The basis for performance within these categories is provided by the specific characteristics of the cardiovascular and respiratory systems and the muscles, combined with the interaction with the nervous system (see Fig. 2.1). These characteristics are primarily determined by genetic factors, but they may also, to a large extent, be developed by training. Performance during match-play is dependent on gender, age and maturity and is also influenced by various external factors, including environment, materials (e.g. the ball and team handball shoes), injuries and nutrition (see Fig. 2.1).

Analysing team handball is highly complicated, not only because the game is multifactorial, but also because it is determined by both the individual performance of each player and the tactical components and interindividual interaction of the team (see Fig. 2.2). As a team ball sport, team handball is strongly influenced by tactical concepts in offence and defence as well as social/mental factors within and outside the team.

Even compared to soccer, the most popular and widespread ball game in the world, team handball is more diverse. It involves considerably more physical confrontations with opponent players, and the players are more deadlocked in different playing positions, which probably lead to specific requirements of each playing position. The game is further complicated by the fact that unlike in soccer, team handball rules allow an unlimited number of player substitutions through-

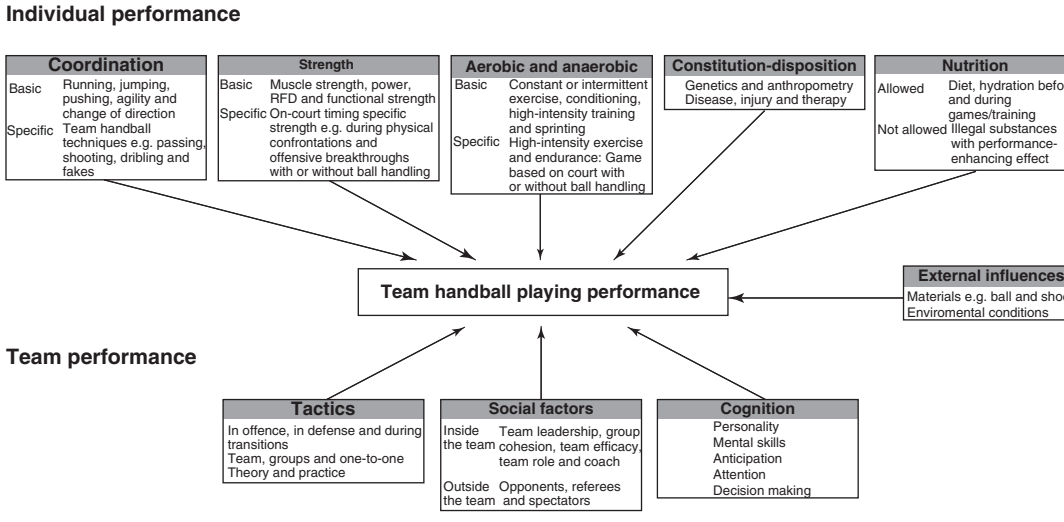

Fig. 2.2 Determinants of individual and team performance influencing team handball playing performance as a whole

out the entire course of the match. Thus, for mainly tactical reasons, some players are substituted and rotate between each transition of ball possession, i.e. some players specialise playing in offence only, while others play only in defence.

Finally, since substitutions can occur at any time during a match, these may be used as an important part of the adjustment of the physical load in various stages of team handball match-play. Apart from the tactical considerations, this may enable players to sustain a high intensity and a high level of playing performance throughout the entire match. However, such substitutions need to be considered thoroughly, especially if the performance qualities of the substitutes are lower.

The physical demands in team handball seem to reflect a complex interaction between many types of activities, including muscle strength and power, speed, anaerobic work capacity as well as aerobic power and endurance. Team handball players have to master a multitude of these categories in order to be successful. However, strengths and weaknesses probably can, to some extent, compensate for one another, both at the team level and for the individual player. In most cases, elite team handball players have a high capacity only within some of the physical categories.

From a physical point of view, the success of a team depends on selecting the right players for the various playing positions and developing a tactical approach that fits the strengths of the available players. Thus, a high level of physical capacity in some areas may not be crucial for playing at top-level. For example, a player may compensate for low endurance by having high capacities in other aspects relevant to team handball, e.g. great muscle strength or high technical standard. However, this may depend on the playing position and additionally requires that other players in the team can compensate for this deficiency by having a high endurance capacity. The applied tactical systems and individual tasks can vary both during and between consecutive games due to strategic adjustments and will influence the activity pattern of the players. Furthermore, the rotation strategies of specialised players at the elite level will likely have a significant effect on number of match activities and on the potential development of fatigue.

As the game of team handball has evolved substantially over the last few decades, the on-court requirements have increased and are especially high for elite male and female players. The increasing number of matches and national/international tournaments has led to an extension of the competition period, now covering 9–10 months per year, where elite players are required to perform constantly at a high level despite the effects of their hard training and match schedules. At the elite level, during the season, it is often common to have two matches per week compared to one at lower levels of play, and in various periods elite players often train twice a day [4].

Therefore, the physique of top-level team handball players has a governing influence on playing performance not only during each game throughout the entire regular season, but especially in various international tournaments, where multiple matches are played over a short period of time. Moreover, during the last decade, new rule changes have contributed to elevating the intensity of match-play and increasing the physical demands placed on present-day players.

2.2.1 Match Analysis of Adult Elite Team Handball

With this development in mind, there is an increasing need to develop and implement optimal physical training regimes in elite team handball that can be used to enhance players' performance, improve recovery, reduce fatigue and limit the risk of overload injuries. To establish such training regimes, it is a precondition to be thoroughly versed in the exact on-court requirements for present-day elite players. Such prior knowledge of the working demands, combined with practical experience, provides the needed basis for the identification, planning and execution of effective training paradigms [5].

Despite the considerable global spread of the sport, the amount of published studies on the physiological aspects of the game of team hand-

ball are still limited compared to other ball games like soccer, rugby, volleyball and American football. Moreover, many of the studies are of an earlier date, and thus the latest developments in the team handball are not taken into account [6–13] although significantly more studies have begun to be published in recent years [14–27]. However, these studies and most of the other new studies are dealing with training interventions, other aspects like testing and testing methods or only focusing on junior players [28–41]. Furthermore, they are mostly performed with male players.

Various technical and tactical reports concerning, e.g. the amount of attacks, shots, goals, fast breaks, ball possessions and passes are provided by national federations (federation online archives) and also described in team handball-specific journals. Moreover, the European Handball Federation (EHF) and the International Handball Federation (IHF) have published detailed statistics for every final round of the Olympic Games, World and European Championships in the last 15 years for national teams as well as the EHF Champions League for club teams. Some of these observations can be used partly as information to shed light on the physical demands of the game. However, it must be recognised that these reports are not published in peer-reviewed journals, and in almost every case the methods for providing the data are not disclosed. Additionally, such reports mostly comprise national team tournaments, where many matches are played in a short time period (8–10 matches in 10–14 days). This does not reflect the regular season scenario (1–2 matches per week), which will change the physical load and the activity pattern of the players due to less recovery time between the matches [1].

2.2.2 Methodology

The most common analysis method of the on-court physical demands is time-motion analysis based on video player observations of competitive games. The videotapes are replayed on a monitor for computerised coding of the activity pattern of each individual player. By continuously following and assessing the separate actions during the match on a video monitor, each either locomotive or technical playing action can constantly be registered by a designated software. However, this analysis method is highly time-consuming. Furthermore, it has some limitations, since it is influenced by subjective assessments by the observer and does not actually measure the precise locomotion speed.

In addition, a Portuguese study [42], e.g. aimed to determine the physical demands in male elite team handball by collecting data using video recording from the playing position and not from individual players. Thus, when a player was substituted, the substitute on the same playing position was recorded. However, the average result from the playing position (60 min playing time) will then depend highly on the substitution frequency, because substituted players most likely will show an atypically high playing intensity. Consequently, it is very difficult to compare the results within the same playing position and also to all other playing positions. Therefore, by using such time-motion procedure, the average results will not reflect the actual demands for elite players during team handball match-play. Thus, more precise analysing systems are needed in team handball.

Recently, a techno logical analysing system has been developed, which enable measurement of the actual locomotion speed of the players and in addition can account for all changing actions, i.e. accelerations and decelerations, that occur during match-play even when the speed is low. The matches are recorded using a three-camera setup in order to gain full coverage of the court [43]. As a result, the players are not required to wear a device, and the system is able to capture both playing teams. However, the system is adapted from soccer, but continues to measure the activities when the players are on the court even when the time is stopped due to brief match pauses during, e.g. suspensions, penalties, timeouts and injuries. This temporal extension compared to a normal match total effective playing time of 60 min can easily last 10–15 min. Consequently, the results from studies using this analysing method (e.g. [43]) cannot be used as scientific documentation of the physical demands in elite team handball.

In the last decade, the time-consuming challenges of video based time-motion analysis have been circumvented by the development and the application of global positioning systems (GPS) based on satellite technology into the sporting environment [44, 45]. However, at present GPS based methods are only applicable to outdoor sports and are primarily used in studies of, e.g. soccer, rugby and Australian football. In recent years, inertial measurement units (IMU) have been integrated into GPS devices, to provide additional information relating to physical loads during matches and training in ball games. Information from IMUs are independent of GPS signals. Thus, they can be used in indoor environments (as well as outdoors).

Several Norwegian studies have recently used IMUs to analyse the locomotive activity pattern of female elite team handball players during training and match-play [46–49]. Each player was equipped with an IMU, which was located between the shoulder blades in a custom-made vest worn under the player's match jersey. Data of accelerations, decelerations and changes of direction (in total high-intensity events) and the overall intensity per min (player load) were collected. The system proved to be reliable and very precise to direct measurement of high-intensity activities. However, IMUs cannot measure the technical playing actions and, e.g. the total distance covered. In addition, the players have to wear a device, which means that interference in the team's preparation to competitive matches will have to take place. Moreover, at present it is not allowed to wear such devices during elite team handball matches. There is currently no ideal analytical method that can accurately measure the on-court physical requirements for elite team handball players.

2.2.3 On-Court Study Results

Few studies have actually examined the on-court physical and physiological demands during competitive adult match-play for field players especially in relation to playing position. Recently, a series of studies of the on-court physical demands in both male and female adult elite team handball was conducted [2, 3, 5, 50–52]. Male and female adult elite team handball field players from the Danish Premier Male vs. Female Team Handball League were examined during match-play using video-based computerised locomotion and technical analysis of competitive matches during six and five regular match seasons for male and female elite players, respectively.

These analyses comprised assessment of locomotion characteristics (running types, intensity and distance) separated in distinct locomotive categories, while technical match activities were distributed in major types of playing actions (shots, breakthroughs, fast breaks, technical errors, defensive errors and tackles) and further divided into various subcategories (e.g. type of shot, hard or light tackles, claspings, screenings and blockings). This applied for field players who were divided into three categories, wing players, pivots and backcourt players, respectively, and analysed separately in offence and in defence.

The studies demonstrated substantial positional differences in physical demands, with wing players demonstrating a more intensive locomotive activity pattern and performing less physical confrontations with opponent players than backcourt players and pivots in both genders (for selected technical playing actions, see Table 2.1).

Players with limited on-court playing time (≤70% of full match duration) were excluded from the mentioned time-motion analysis, because the studies aimed to only include players with sufficiently long field playing time (≥70% of full match duration) to ensure that their activity pattern would adequately reflect the overall physical demands of the game. In elite team handball, there are players, who are specialised to play only in offence or only in defence, typically spending much less than 70% of full playing time on the match court. This also applies to second-choice players, who are not in the team's starting line-up and only are substituted onto the playing court for brief periods later in the match. A pilot study showed that such players (playing for, e.g. 15–20 min) had a more intense activity pattern compared to players who were involved

Table 2.1 Examples of the significant positional differences for male elite team handball players [3]. The offensive and defensive technical playing actions per match (group mean ± SD) for all players combined and for the different playing positions, respectively, are shown. The differences in the amount of tackles are highlighted

Offensive actions in total for the entire match positional differences				
	All players combined (n = 82)	Wing players (n = 23)	Pivots (n = 18)	Backcourt players (n = 41)
Playing actions	Number per match	Number per match	Number per match	Number per match
Playing time (min)	26.18 ± 3.13	26.52 ± 3.55	26.12 ± 2.68	26.02 ± 3.10
Offensive breakthroughs	1.5 ± 1.4	1.2 ± 1.2	1.0 ± 0.5	1.8 ± 1.3
Fast breaks	6.0 ± 4.2	8.9 ± 3.1*	8.3 ± 4.0	3.4 ± 3.2 $^{\pi}$
Technical errors	1.5 ± 1.3	1.2 ± 0.9	1.6 ± 1.2	1.5 ± 1.7
Hard tackles	7.5 ± 4.4	4.3 ± 2.1*	11.6 ± 3.2$^{\#}$	7.5 ± 2.7 $^{\pi}$
Light tackles	27.0 ± 18.4	10.6 ± 2.3*	58.9 ± 20.3 $^{\#\#}$	22.2 ± 10.0 $^{\pi\pi}$
Claspings	2.7 ± 1.9	1.2 ± 0.9	6.1 ± 2.9 $^{\#\#}$	2.1 ± 1.5$^{\pi\pi}$
Screenings	4.8 ± 8.3	0.4 ± 0.7*	16.7 ± 9.6 $^{\#\#}$	2.2 ± 4.3 $^{\pi\pi}$
Shots	8.5 ± 4.2	6.0 ± 2.5***	7.0 ± 2.0	10.5 ± 3.4 $^{\pi}$
Scoring percentage	44.9 ± 17.7	46.9 ± 23.9	48.8 ± 24.2	42.0 ± 14.6
Defensive actions in total for the entire match Positional differences				
	All players combined (n = 82)	Wing players (n = 23)	Pivots (n = 18)	Backcourt players (n = 41)
Playing actions	Number per match	Number per match	Number per match	Number per match
Playing time (min)	27.67 ± 4.18	26.28 ± 2.40*	27.08 ± 2.42	28.70 ± 2.80
Hard tackles	5.8 ± 3.6	4.9 ± 3.3	6.6 ± 3.2	6.0 ± 3.3
Light tackles	24.1 ± 12.6	14.6 ± 5.9*	33.7 ± 12.4 $^{\#\#}$	25.2 ± 7.3 $^{\pi}$
Claspings	3.9 ± 3.0	1.3 ± 1.1**	8.2 ± 5.0 $^{\#\#}$	3.5 ± 2.0 $^{\pi}$
Screenings	6.1 ± 3.1	0.9 ± 1.5****	12.4 ± 7.4 $^{\#\#}$	6.3 ± 3.7 $^{\pi}$
Blockings	3.7 ± 3.5	0.2 ± 0.4****	5.5 ± 3.2 $^{\#\#}$	4.9 ± 2.8
Defensive errors	3.8 ± 2.5	3.0 ± 2.2	5.4 ± 1.8 $^{\#}$	3.7 ± 2.3

Difference between wing players and backcourt players $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.005$ and $^{****}p < 0.001$, between wing players and pivots $^{\#}p < 0.05$ and $^{\#\#}p < 0.001$, between pivots and backcourt players $^{\pi}p < 0.05$ and $^{\pi\pi}p < 0.001$

for longer durations of the game. Including players with much reduced on-court playing time in the analysis may dilute the analysis of the best players. On the other hand, it definitely seems of high relevance to conduct future studies in order to examine the physical requirements of such 'specialised' team handball players with short effective playing time to provide valuable information about rotation/substitution strategies in elite team handball match-play.

In a study conducted at the 2007 Men's World Cup [53], substantial differences in the locomotive characteristics were also found to exist between various playing positions. The study showed a much higher percentage of high-intensity running compared to Michalsik et al. [3], which may be partly due to a lower mean individual effective playing time of ~30 min. These data suggest that in international male elite team handball tournaments where each team plays 8–10 matches in 12–14 days, players tend to be frequently substituted on all playing positions. However, the study was only published as an abstract, and thus the study method, including the definitions of the locomotive categories, was not fully described.

Manchado et al. [54] studied the on-court physical demands of female elite team handball players in two matches using the Sagit match analysis system (validated by Pers et al. [55]).

Total distance covered (5250 m) and the amount of high-intensity running for field players was markedly higher compared to Michalsik et al. [5]. This may be due do the very limited number of matches and especially different analysing procedures, since the locomotion activity was calculated for all field players in one position for the entire match duration. Moreover, in contrast to the studies of Michalsik et al. [5] and Luteberget and Spencer [47], no significant positional differences were detected between female field players. Field players with a higher level of VO_2-max executed locomotion activities with a higher velocity as compared to players with lower aerobic performance, independent of playing position. In addition, the acceleration profile depended on aerobic performance and field playing position. The authors concluded that a high VO_2-max appears to be important in top-level female elite team handball, which is in accordance with other studies [5, 52].

Using IMUs, Luteberget and Spencer [47] demonstrated a high occurrence of high-intensity events (HIEs, intensity ≥2.5 m/s) with marked positional differences, where the backcourt players show the highest number of HIEs, followed by pivots and then wing players. This was in contrast to the results from the studies of Michalsik et al. [3, 5] who found that the wing players showed the most high-intensity locomotive activity pattern. This is probably due to the fact that the IMU measurements unlike time-motion analysis using video recording can account for all changing actions, e.g. accelerations and decelerations, also while the running speed is low. A massive physiological load is indeed imposed on players not only during the high-intensive phases of the match (intended as high-intensity running), but also every time, e.g. accelerations and decelerations are performed, even when the absolute speed is low. Thus, during organised match-play (i.e. in offence or defence), backcourt players apparently have numerous HIEs even though the absolute running speed is relatively low. Overall, the IMU studies demonstrated that elite female team handball players spend a considerable amount of energy in actions involving accelerations and decelerations, which underlines the intermittent nature of team handball also found in other studies.

There is a lack of uniformity in the few on-court analysis studies of adult elite team handball with respect to tracking systems, analysing procedures, speed zones, individual effective playing time and consideration of substitutions or rotations of the players (see [56]). In addition, sometimes the methods for providing the data are not provided. It is therefore very difficult to compare the results of the locomotion characteristics between the various studies [3, 5, 42, 47, 53–55, 57–59]. Moreover, the studies need to include a complete analysis of the technical match activities. Since team handball involves large amounts of physical contact and other technical playing actions, omission of this will lead to a systematic underestimation of the physical demands in elite team handball.

2.2.4 Physiological Aspects in Elite Team Handball

2.2.4.1 Heart Rate and Relative Workload

The optimum situation to investigate the physical demands of team handball is during official elite tournament matches. In disadvantage, some types of measurements (VO_2 sampling, blood withdrawal) cannot be performed during direct match-play. Consequently, indirect assessment of VO_2 during match-play to calculate the relative workload (RWL) expressed as % of VO_2-max based on individual HR-VO_2 relationships established in the laboratory was performed in both female and male elite players [5, 52]. This differed between male and female elite players, regarding both HR and RWL (163 vs. 171 beats min^{-1} corresponding to 71 vs. 79% of VO_2-max).

The method has previously been validated in soccer match analyses, where HR and VO_2 measured during soccer drills followed the linear HR-VO_2 relationship observed during treadmill running [60, 61]. Estimating VO_2 from heart rate (HR) measures during four-a-side team handball games was found not to be highly accurate [14].

However, by employing no resting periods, no dribbling and no physical contact with opponents, these simulated game activities differed markedly from the activity pattern typically performed during actual elite team handball match-play, which may have led to a skewed relationship between HR and VO_2. In addition, Manchado et al. [54] found mean HR during match-play to be 86% of maximum HR in female elite team handball players.

Although low-intensity activities (jogging, walking and standing still) constituted around 85% of mean effective playing time, both genders demonstrated a mean RWL of over 70% of VO_2-max during the periods of effective match-play [5, 52]. This indicates that the amount of high-intensity, strength-related technical playing actions had a marked influence on the HR response observed and hence on the RWL imposed on the players without contributing substantially to the total distance covered. Playing actions such as tackles, offensive breakthroughs, jumps and screenings may result in elevated HR for more extended periods of time (due to elevated HR in the subsequent recovery phase). Consequently, solely using the findings derived from locomotion match analyses will likely underestimate the true physical demands of elite team handball match-play. A contributing factor may arise from players running for large periods of the match with attention fixed on the ball or directly with the ball, which is known to increase VO_2 [62]. In comparison, the mentioned RWL-values are still far from the RWL in elite marathon runners that may correspond to ~90% of VO_2-max averaged over the entire race [63].

2.2.4.2 Blood Lactate Concentration

Michalsik et al. [52] found that mean post-match blood lactate concentration (BLC) was 4.8 mM for male players with large individual differences (2.8–10.8 mM), which is similar to reports on male elite soccer players [60]. The relatively high BLC values observed indicate that the rate of muscle lactate production, and hence the contribution of anaerobic energy sources, may be high during elite team handball match-play, hence indirectly supporting the notion that temporary fatigue might occur in male elite team handball. Consequently, male elite team handball appears to impose high demands on the anaerobic energy systems at least during certain periods of the match.

Lactate is produced in the muscle, and before interstitial lactate reaches a steady-state exchange with the bloodstream, a large part can be metabolised in other muscles or organs [64]. Thus, post-match BLC may be low although players during the match may have produced substantial amounts of lactate during high-intensity activities. Thus, BLC is dependent on the amount of high-intensity exercise performed in the minutes prior to blood sampling. The large interindividual variation in post-match BLC may indicate that the values obtained were influenced by the activity pattern of the players towards the end of the match. Over 30 years ago, Delamarche et al. [7] assessed the BLC in young sub-elite team handball players during practice games (30 min) and observed BLC values of 4–9 mM, which according to these authors were higher than the values derived from samples drawn only at the end of the game.

Higher BLC values might have been obtained in the study of Michalsik et al. [52], if blood sampling had been possible during the phases of active match-play (i.e. in timeouts and during substitution periods). BLC is a consequence of lactate appearance and clearance. Thus, players with low levels of blood lactate may actually work at similar, or even higher, intensities than players with high BLC due to an efficient rate of lactate clearance in the former players. Obviously, it would be more accurate to measure the lactate concentration in the muscles. However, no study has so far measured the muscle lactate production during or following team handball match-play.

2.2.4.3 Fatigue

In the studies of Michalsik et al. [2, 3, 5, 51], a reduced amount of high-intensity running, decreased HR and RWL and a reduced number of high-intensity activity changes and technical playing actions were observed during the second half, which collectively indicate that for players

with an effective playing time of more than 70% of full match duration, temporary fatigue (after the most intense periods) and perhaps more permanent locomotive fatigue (towards the end of the game) may have occurred along with impaired physical performance, at least in some players.

Luteberget and Spencer [47] also found indications of temporary fatigue with measuring of external loading. However, it should also be recognised that the players' physical performance in the later phase of the match (i.e. the second half) may also be influenced by the change of match dynamics (e.g. tactical changes) and situational variables such as match location (home vs. away), quality of opposition (top, medium and bottom) and match status (winning, drawing or losing), as previously indicated in elite soccer [65, 66]. At the same time, Thorlund et al. [25] showed with acute experiments with fatigue development that maximal and rapid muscle force characteristics (rate of force development (RFD), impulse) were negatively affected following simulated team handball match-play concurrently with supressed levels of neuromuscular activity, which are likely to be associated with an impaired team handball match-play performance. Furthermore, a weight loss (0.8 kg) during an entire match equal to 0.9% of the body mass was found in male elite team handball players who were allowed to have an unlimited fluid intake during competitive matches [52]. This is below the limit suggested to cause fatigue and impair exercise performance [67].

However, notably all these studies did not examine the specific factors responsible for onset of fatigue in elite team handball. Future studies using, e.g. muscle biopsies (to measure the muscle lactate concentration and other fatigue-related substances) and blood samples taken during match-play (and not post-match) in friendly games are needed to fully examine the extent of match-induced fatigue in male elite team handball, as previously done in soccer [68].

The development of fatigue during team handball match-play could be overrated. Substitutions/player rotations in an appropriate way may be used by coaches to avoid excessive physical loading of the players by increasing the recovery time, so the players can sustain a high intensity and a high level of playing performance or at least limit a possible decrease in physical/playing performance throughout the entire match. However, to maintain a high performance level of the team during match-play, it presupposes that the performance qualities of the substitutes are high, which is not always the case, especially at elite club level. With that in mind, it may be an advantage for a team to play most of the match with the players from the starting line-up, even if they will experience some kind of fatigue during the match.

2.2.5 Physical Testing of Elite Team Handball Players

When performing an optimal physical working demands analysis, observations and measurements during actual match-play have to be carried out. Physical test results cannot directly be considered as real on-court physical demands. However, an on-court demands analysis of elite team handball players may benefit from physical test results, which can provide additional knowledge about the players' physical performance. They can be used to evaluate to what extent the physical profile has adapted to the locomotive and technical demands imposed by years of elite team handball training and match-play. Consequently, it is highly relevant to perform separate and specific physical tests (e.g. laboratory treadmill and maximal muscle strength testing, on-court jump and Yo-Yo testing and testing of repeated sprint running capacity and maximal ball throwing speed) supplemented by anthropometric measurements in elite team handball players.

Physiological profiles and physical test results varied between playing positions in both male and female players, with wing players performing better in the Yo-Yo test (intermittent running test) and showing superior jumping performance and repeated sprint running capacity compared to backcourt players and pivots [5, 52]; (see Table 2.2 for selected test results). Results from several studies [18, 20, 21, 69–74], which only included physical testing in the analysis of the

Table 2.2 Examples of the significant positional differences in selected test results for male elite team handball players [52]. Jump ability (top section), repeated sprint ability (7×30-m sprint, middle section) and throwing ability (bottom section) in male elite team handball players ($n = 26$) are shown. Results are group means ± SD (range)

	All players ($n = 26$)	Wing players ($n = 9$)	Pivots ($n = 7$)	Backcourt players ($n = 7$)	Goalkeepers ($n = 3$)
CMJ height (cm)	43.9 ± 6.0	46.4± 3.5 **	41.0 ± 3.2	42.1 ± 4.3	47.5 ± 3.4 *
CMJ height with ½ body mass (cm)	24.4 ± 2.2	24.4 ± 2.1	25.0 ± 3.4	23.8± 2.6	24.3 ± 2.2
Jump and reach (m)	0.71 ± 0.78	0.75 ± 0.71	0.70 ± 0.52	0.70 ± 0.75	0.69 ± 0.67
Standing 5-step jump (m)	13.39 ± 0.70	13.21 ± 0.86	13.43 ± 0.66	13.46 ± 0.68	13.65± 0.70
Fastest time (s)	4.09 ± 0.12 (3.87–4.28)	4.05 ± 0.12 # (3.91–4.20)	4.10 ± 0.13 (4.01–4.21)	4.11 ± 0.12 (3.87–4.24)	4.15 ± 0.11 (4.06–4.28)
Mean time (s)	4.30 ± 0.13 (4.04–4.51)	4.25 ± 0.10 ## (4.09–4.49)	4.33 ± 0.13 (4.12–4.50)	4.30 ± 0.09) (4.04–4.46)	4.34 ± 0.12 (4.22–4.51)
Fatigue time (s)	0.33 ± 0.14 (0.07–0.58)	0.26 ± 0.14 ## (0.07–0.51)	0.37 ± 0.15 (0.14–0.56)	0.34 ± 0.11 (0.13–0.58)	0.39 ± 0.10 (0.31–0.51)
Jump shot (km h^{-1})	84.2±5.2	86.0±5.0	79.6±5.9 €	90.2±6.3	75.5±4.9 α
Running shot (km h^{-1})	86.1±5.5	87.5±4.4	80.8±4.5 €	90.8±6.9	83.6±9.3
Standing set shot (km h^{-1})	86.8±6.4	88.6±5.5	78.5±4.9 #	92.3±7.1	87.6±8.8
Set shot with run-up (km h^{-1})	92.8±5.3 *	95.7±5.8	84.3±5.7 €	98.6±7.3	90.4±7.6 ¤

Difference (top section) between goalkeepers and pivots and backcourt players * $p < 0.05$ and between wing players and all other field players ** $p < 0.05$; (middle section) between wing players and goalkeepers # $p < 0.05$ and between wing players and pivots and goalkeepers ## $p < 0.05$; and (bottom section) between pivots and all other field players # $p < 0.05$, between pivots and wing players and backcourt players € $p < 0.05$, between goalkeepers and backcourt players ¤ $p < 0.05$, between goalkeepers and wing players and backcourt players α $p < 0.05$ and between set shot with run-up and all other types of shots * $p < 0.05$

physical demands, have also confirmed that the physical demands in terms of the physical performing profile are related to playing positions and also to competitive level for both male and female players (see [26]).

Body anthropometry seems to have an important influence on playing performance because it is highly related to playing positions for both genders [51, 52]. Pivots are the heaviest and tallest of all playing positions, concurring with results obtained in male elite players from Croatia [75], Germany [71], Denmark [51] and Norway [70]. This likely reflects a high consistency between players' body anthropometry and the physical requirements of, e.g. pivots during match-play. Thus, large body mass (and hence muscle mass) likely has substantial importance for successful pivot playing performance due to the high frequency of in-fights and duels with opponent players. This indicates that high levels of muscle strength and RFD are essential physical performance elements in this playing position.

In contrast, wing players are lighter and smaller than all other players (including goalkeepers), which, from a physical point of view, is in accordance with the physical demands imposed on this playing position. Because of the reduced body contact both in offence and defence compared to other playing positions (see Table 2.1), high body mass and muscle strength seem of less importance for wing players. The lighter weight and smaller size of wing players enable these players to repeatedly perform rapid high-intensity movement patterns over short distances, while covering a large total distance of running per match. In general, anthropometric statistics from international team handball tournaments reveal a trend towards heavier players among the best teams, especially for male players [70].

2.2.6 Comparisons of the Physical Demands Between Male and Female Elite Team Handball Field Players

Michalsik and Aagaard [50] have published the only study so far, comparing the complete on-court physical demands between male and female adult elite team handball players, which was possible, since the aforementioned studies used the exact same analysis methods for both genders.

Marked gender differences were demonstrated for both the locomotion and technical match characteristics (see Table 2.3 for selected categories). Female players covered a longer mean total distance per match and exercised at a greater relative workload compared to male players, despite less high-intense running and fewer activity changes per match than male players. Male players received more tackles in total in offence and performed more tackles in total in defence and more high-intense technical playing actions per match compared to female players. Not surprisingly, mean body height and body mass differed between male players and female players.

2.3 Perspectives and Practical Applications

In perspective, organised attack in elite team handball typically involves relatively steady-pace playing actions, interspersed by frequent periods of standing still or walking. However, game actions comprise a high number of repetitive intense tempo changes and changes in moving direction. High-intensity running did not per se represent much of total effective playing time. Nevertheless, the ability to continuously change pace and accelerate throughout the entire match likely is of high importance for top-level playing performance. Thus, it seems relevant with an increased and differential focus in the training on improving high-intensity intermittent exercise capacity for increasing elite players' ability to repeatedly perform intense exercise and to rapidly recover after periods of high-intensity exercise. This is best done by performing especially high-intensity aerobic training on a regular basis (see Chap. 36).

High demands appear to exist for a superior acceleration and deceleration capacity, high RFD, a high ability to perform fast and hard shots, rapid side-cutting manoeuvres and a high number of strength demanding physical con-

Table 2.3 Gender differences in selected categories of the physical demands during match-play (group means ± SD) between male and female adult elite team handball players [50]

Gender differences in physical demands during match-play		
	Male players (n = 82)	Female players (n = 83)
Mean effective playing time (min)	53.85 ± 5.87	50.70 ± 5.83 *
Total distance covered (m)	3627 ± 568	4002 ± 551 *
Total distance covered, full-time players (m)	3945 ± 538	4693 ± 333 **
High-intensity running (% of total distance covered)	7.9 ± 4.9	2.5 ± 1.8 **
Standing still (% of total playing time)	36.8 ± 8.6	10.8 ± 3.8 ***
Sideways movement (% of total playing time)	7.4 ± 2.7	1.8 ± 1.3 ***
Mean speed (km h^{-1})	6.40 ± 1.01	5.31 ± 0.33 **
Activity changes (number)	1482.4 ± 312.6	663.6 ± 100.1 ***
Relative workload (% of estimated VO_2-max)	70.9 ± 6.0	79.4 ± 6.4 *
High-intense technical playing actions (number)	36.9 ± 13.1	28.3 ± 11.0 *
VO_2-max (L O_2 min^{-1})	5.18 ± 0.66	3.49 ± 0.37 ***
VO_2-max (mL O_2 min^{-1} kg^{-1})	57.0 ± 4.1	49.6 ± 4.8 ***
Fitness Index (mL O_2 min^{-1} $kg^{-0.73}$)	192.6 ± 18.2	156.4 ± 15.3 ***

Difference between male and female players *$p < 0.05$, **$p < 0.01$ and ***$p < 0.001$

frontations (i.e. tackles, screenings, claspings and blockings). Thus, an intensified focus during the competition period on anaerobic training aspects (speed training, production training and tolerance training, respectively) and on strength training on a regular basis seems highly pertinent for elite team handball players (see Chap. 36). The latter training should comprise both basic strength training and explosive-type RFD-training to make the players capable of performing the above playing actions at sustained high levels throughout the entire match. Many of the actions that are crucial for the final outcome of a match are performed at high intensity and may have a large physiological impact on the players when repeated, e.g. lead to development of neuromuscular fatigue. Excessive load in combination with insufficient recovery may affect playing performance and increase the change of injury.

Significant anthropometric developments appear to have occurred in elite team handball, where today's players were found to be markedly taller and heavier than 30 years ago. Elite team handball players need to maintain or even improve their functional capacity on the playing court such as acceleration capacity and ability to perform side-cutting manoeuvres and show high maximum jump height and movement agility, while attaining adequate intermittent endurance running capacity during match-play despite their larger and heavier bodies in order to push away in a breakthrough and to more effectively tackle opponent players in defence. Consequently, adequate specific physical training modalities should be employed in order to target these performance components to optimise the functional capacity in elite team handball including on-court jumping, sprinting and strength/RFD exercises performed with balls in game-like situations with the proper intensity, duration and recovery time. Over the last decades, the increase in body height and body mass has not been so pronounced among female elite players as among male elite players, which indicates that the strength-related aspect of the game has, relatively speaking, not nearly as much importance in female elite team handball.

It is important that improvements achieved by physical training can be transferred to the actual team handball game on the court. Therefore, the training needs to be as functional as possible. Physical training in team handball should, as far as possible, be performed on-court in game-like simulations (i.e. with ball handling involved), since such training has several advantages [64]. Firstly, the muscle coordination and the specific muscle groups used in team handball will be trained. In addition, the players' technical and tactical abilities will be developed under conditions relevant to the game. Finally, training with a ball will be more motivating for most players. an improved level of physical capacity enables players to train at increased intensity and in achieving a large total quantity of training. Position-specific physical training evidence-based recommendations for elite team handball players (both for male and female players) are presented in Table 2.4.

In a typical week for a male professional top-elite handball team with one match to play, the players will have seven to eight training sessions in 5 days (i.e. 2–3 days with two sessions), often with a day off after the match. If there is a second match during midweek, the team will train only 1–2 days with two training sessions to ensure proper recovery, while at the same time trying to peak playing performance for important matches. However, there are substantial variations depending on the training status of individual players and the experience of the coach [4]. Examples of programmes for an international top-class handball team during the regular competitive match season are presented in Table 2.5.

The amount of studies about team handball is still relatively limited. Thus, future studies should be conducted to obtain more knowledge regarding the physiology of team handball, e.g. examine the impact of different training regimens (aerobic, anaerobic and strength training) for enhancing neuromuscular fatigue resistance, physical fitness and playing performance during elite team handball match-play. Moreover, the physical demands imposed on national team players during international tournaments with multiple matches in a compressed period of time should be subject of further research, since the physical loads for elite team handball players under these conditions are likely to differ from

Table 2.4 Position-specific physical training recommendations for elite team handball players (both male and female players). RFD: Rate of force development; TDC: Total distance covered

Physical quality	Main training aim/area and rationale	Playing positions			
		Wing players	Pivots	Backcourt players	Goalkeepers
High-intensity exercise	Aim/area	High-intensity aerobic and anaerobic training	Anaerobic training	High-intensity aerobic training	High-intensity functional aerobic and anaerobic training
	Rationale	High TDC and large amount of high-intensity running	Relatively large number of fast breaks	Relatively high TDC	Short specific movements, for better recovery
Speed	Aim/area	Reaction speed and acceleration, 20–30 m	Reaction speed and acceleration, 15–30 m	Reaction speed and acceleration, <15 m	Very short specific movements
	Rationale	Longer mean sprinting distance	Longer mean sprinting distance	Shorter mean sprinting distance	Little need for normal running speed
Strength	Aim/area	Explosivity (RFD)	Hypertrophy, RFD	Hypertrophy, maximal strength, RFD	Maximal and reactive strength, RFD
	Rationale	For jumping and sprinting	For physical confrontations	For jumping, sprinting, shooting and duels/in-fights	Functional reactivity, speed and jumping
Injury Prevention	Main muscle groups	Hamstrings	Core muscles	Rotator cuff	Elbow and shoulder muscles
	Rationale	Due to the large amount of high-intensity running	Due to the large number of physical confrontations	Due to the large number of passes and shots	Due to elbow hyperextension during the many ball impacts

Table 2.5 An example of an in-season weekly programme for a professional male top-elite team handball (TH) when playing one or two regular season matches a week

Day	One match a week	Two matches a week
Sunday	Match	Match
Monday	Free or recovery training	*Morning* TH training with high-intensity running exercises, 60–90 min *Afternoon* Individual physical training - primarily strength training (RFD-training), 60 min
Tuesday	*Morning* Individual physical training - primarily strength training (RFD-training), 60 min *Afternoon* TH training with anaerobic tolerance training, 90–120 min	Tactical/technical TH training with jump training, 90 min Physical training for selected players
Wednesday	Tactical/technical TH training with jump training, 90 min Physical training for selected players	Match
Thursday	*Morning* Individual physical training - strength training (RFD-training), 60 min *Afternoon* TH training with anaerobic production training, 90–120 min	TH training - individual physical needs (much playing time/less playing time in yesterday's match), 60–90 min

Table 2.5 (continued)

Day	One match a week	Two matches a week
Sunday	Match	Match
Friday	*Morning* TH training with high-intensity running exercises, 90–120 min *Afternoon* Individual physical training - primarily strength training (RFD-training), 60 min	*Morning* TH training with anaerobic production/tolerance training, 90–120 min *Afternoon* Individual physical training - primarily strength training (RFD-training), 60 min
Saturday	Tactical/technical TH training, 90 min Physical training for selected players	Physical training for selected players, 60–90 min or free
Sunday	Match	Match

regular match season conditions that allow longer recovery time (typically one week) between successive matches.

Conclusions

Elite team handball is a physically demanding and complex game activity for both genders, where players work intensely for short, intermittent time intervals, while repeatedly performing different fast and dynamic types of locomotion and technical match activities. The game imposes moderate-to-high demands on the intermittent endurance running capacity interspersed by frequent brief periods of high-intensity running. Thus, there seem to be moderate-to-high demands on player's aerobic system as evidenced, e.g. by a mean relative workload during match-play ~70–80% of VO_2-max, while also imposing substantial demands on anaerobic energy systems as, e.g. reflected by moderate-to-high post-match blood lactate values for male players. In addition, elite team handball match-play is also characterised by a high number and a great variety of short-term, high-intense technical playing actions.

These activities include powerful upper body movements such as maximal ball throwing and tackles of opponents as well as forceful lower limb muscle actions during vertical jumping, sideways running, backwards running, forwards sprinting and rapid directional changes during fast breaks, which are performed intermittently throughout the entire match. Male and female elite team handball players need to master a complex interaction between many different movement categories and technical playing actions, including low- and high-intensity running, tackles and screenings and jump shots. Depending on their specific playing position, elite team handball players have to perform a multitude of these categories.

Furthermore, temporary locomotive and technical fatigue and impaired physical performance may occur during the time course of elite team handball match-play, at least in some players. Although seeming an obvious fact from the world of practice, studies have now shown that the on-court physical demands differ substantially between various playing positions. Moreover, physiological profiles and physical test results also differ considerably between the different playing positions. Finally, elite team handball is a highly strenuous body-contact team sport, where body anthropometry plays an important role for playing performance, with a varying influence at the different playing positions.

The observations of positional differences in locomotive and technical match activities, as well as in physiological capacity and physical profile, should be taken into account when planning physical training in elite team handball players. Consequently, modern elite team handball should comprise differential and specific physical training that is designed not only to more selectively target the various playing positions but also to the players' individual physical capacity within the same positions as well as their individual need to recover. Thus, the physical training should be organised in a

more individualised manner than previously assumed at the expense of the more traditional collective way. Such individualised training may be divided into separate exercises related to the specific requirements in defence and offence, respectively. The specific findings, described in this chapter, provide valuable information about match-related activity patterns and fatigue-related changes in elite team handball players. This may come useful in future development of position-specific and individual training regimens for the planning and implementing of optimal physical training in elite team handball, as well as development of test protocols and training programmes for talent identification [76].

Considerable gender-specific variations in the physical demands exist in adult elite team handball. Physical training of female elite team handball players may potentially benefit from a greater focus on aerobic training elements. Conversely, male elite team handball players would seem to benefit from an increased training focus on anaerobic exercise elements and strength training. Additionally, the physical demands differ greatly between various playing positions both in offence and in defence, reflecting almost similar trends in both male and female elite players.

References

1. Ronglan LT, Raastad T, Børgesen A. Neuromuscular fatigue and recovery in elite female handball players. Scand J Med Sci Sports. 2006;16:267–73.
2. Michalsik LB, Madsen K, Aagaard P. Technical match characteristics and influence of body anthropometry on playing performance in male elite team handball. J Strength Cond Res. 2015a;29(2):416–28.
3. Michalsik LB, Aagaard P, Madsen K. Locomotion characteristics and match induced impairments in physical performance in male elite team handball players. Int J Sports Med. 2013;34(7):590–9.
4. Michalsik LB. Preparation and Training of Elite Team Handball Players. In: European Handball Federation, editors. Medical aspects in handball—preparation and the game: scientific and practical approaches. Proceedings of the third International Conference on Science in Handball, Bucharest, Romania, 13–14 Nov 2015. p. 60–7.
5. Michalsik LB, Madsen K, Aagaard P. Match performance and physiological capacity of female elite team handball players. Int J Sports Med. 2014;35(7):595–607.
6. Cuesta G. Balonmano [Team Handball]. Madrid: Spanish Handball Federation; 1991.
7. Delamarche P, Gratas A, Beillot J, Dassonville J, Rochcongar P, Lessard Y. Extent of lactic anaerobic metabolism in handballers. Int J Sports Med. 1987;8:55–9.
8. Fleck SJ, Smith SL, Craib MW, Denahan T, Snow RE, Mitchell ML. Upper extremity isokinetic torque and throwing velocity in team handball. J Appl Sport Sci Res. 1992;6(2):120–4.
9. Hoff J, Almåsbakk B. The effects of maximum strength training on throwing velocity and muscle strength in female team-handball players. J Strength Cond Res. 1995;9(4):255–8.
10. Jensen J, Jacobsen ST, Hetland S, Tveit P. Effect of combined endurance, strength and Sprint training on maximal oxygen uptake, isometric strength and Sprint performance in female elite handball players during a season. Int J Sports Med. 1997;18:354–8.
11. Rannou F, Prioux J, Zouhal H, Gratas-Delemarche A, Delemarche P. Physiological profile of handball players. J Sports Med Phys Fitness. 2001;41:349–53.
12. Sichelschmidt P, Klein GD. Belastungssteuerung im Training. In: Handballtraining [Regulation of load in training. In: *Team Handball training*], vol. 7, 1986. p. 3–12.
13. Tanaka M, Michalsik LB, Bangsbo J. Activity profiles during an official league game of Danish elite team handball players. Jpn J Sport Meth. 2002;15(1):61–73.
14. Buchheit M, Lepretre PM, Behaegel AL, Millet GP, Cuvelier G, Ahmaidi S. Cardiorespiratory responses during running and sport-specific exercises in handball players. J Sci Med Sport. 2009;12:399–405.
15. Buchheit M, Mendez-Villanueva A, Quod M, Quesnel T, Ahmaidi S. Improving acceleration and repeated sprint ability in well-trained adolescent handball players: speed versus sprint interval training. Int J Sports Physiol Perform. 2010;5(2):152–64.
16. Dello Iacono A, Eliakim A, Padulo J, Laver L, Ben-Zaken S, Meckel Y. Neuromuscular and inflammatory responses to handball small-sided games: the effects of physical contact. Scand J Med Sci Sports. 2017b;27:1122–9.
17. Dello Iacono A, Martone D, Milic M, Padulo J. Vertical vs. horizontal-oriented drop jump training: chronic effects on explosive performances of elite handball players. J Strength Cond Res. 2017a;31(4):921–31.
18. Granados C, Izquierdo M, Ibanez J, Bonnabau H, Gorostiaga EM. Differences in physical fitness and throwing velocity among elite and amateur female handball players. Int J Sports Med. 2007;28:860–7.
19. Granados C, Izquierdo M, Ibanez J, Ruesta M, Gorostiaga EM. Effects of an entire season on physical fitness in elite female handball players. Med Sci Sports Exerc. 2008;40:351–61.

20. Granados C, Izquierdo M, Ibanez J, Ruesta M, Gorostiaga EM. Are there any differences in physical fitness and throwing velocity between national and international elite female handball players? J Strength Cond Res. 2013;27(3):723–32.
21. Gorostiaga EM, Granados C, Ibáñez J, Izquierdo M. Differences in physical fitness and throwing velocity among elite and amateur male handball players. Int J Sports Med. 2005;26(3):225–32.
22. Gorostiaga EM, Granados C, Ibanez J, González-Badillo JJ, Izquierdo M. Effects of an entire season on physical fitness in elite male handball players. Med Sci Sports Exerc. 2006;38(2):357–66.
23. Mhenni T, Michalsik LB, Mejri MA, Yousfi N, Chaouachi A, Souissi N, Chamari K. Morning-evening difference of team-handball-related short-term maximal physical performances in female team handball players. J Sports Sci. 2016;29:1–9.
24. Moss SL, McWhannell N, Michalsik LB, Twist C. Anthropometric and physical performance characteristics of elite and non-elite youth team handball players. J Sport Sci. 2015;33(17):1780–9.
25. Thorlund JB, Michalsik LB, Madsen K, Aagaard P. Acute fatigue-induced changes in muscle mechanical properties and neuromuscular activity in elite handball players following a handball match. Scand J Med Sci Sports. 2008;18:462–72.
26. Wagner H, Finkenzeller T, Würth S, Von Duvillard SP. Individual and team performance in team-handball: a review. J Sports Med. 2014;13:808–16.
27. Wagner H, Pfusterschmied J, von Wagner H, Orwat M, Hinz M, Pfusterschmied J, Bacharach DW, von Duvillard SP, Müller E. Testing game-based performance in team-handball. J Strength Cond Res. 2016;30(10):2794–801.
28. Carvalho A, Mourão P, Abade E. Effects of strength training combined with specific plyometric exercises on body composition, vertical jump height and lower limb strength development in elite male handball players: a case study. J Hum Kinet. 2014;8(41):125–32.
29. Chaouachi A, Brughelli M, Levin G, Boudhina NB, Cronin J, Chamari K. Anthropometric, physiological and performance characteristics of elite team-handball players. J Sports Med. 2009;27(2):151–7.
30. Chelly MS, Hermassi S, Aouadi R, Khalifa R, Van den Tillaar R, Chamari K, Shephard RJ. Match analysis of elite adolescent team handball players. J Strength Cond Res. 2011;25(9):2410–7.
31. Chelly MS, Hermassi S, Aouadi R, Shephard RJ. Effects of 8-week in-season plyometric training on upper and lower limb performance of elite adolescent handball players. J Strength Cond Res. 2014;28(5):1401–10.
32. Dello Iacono A, Padulo J, Seitz LD. Loaded hip thrust-based PAP protocol effects on acceleration and sprint performance of handball players. J Sports Sci. 2017c;5:1–8.
33. Hermassi S, Gabbett TJ, Spencer M, Khalifa R, Chelly MS, Chamari K. Relationship between explosive performance measurements of the lower limb and repeated shuttle-sprint ability in elite adolescent handball players. Int J Sports Sci Coaching. 2014;9(5):1191–204.
34. Hermassi S, van den Tillaar R, Khalifa R, Chelly MS, Chamari K. Comparison of in-season-specific resistance vs. a regular throwing training program on throwing velocity, anthropometry, and power performance in elite handball players. J Strength Cond Res. 2015;29(8):2105–14.
35. Ingebrigtsen J, Jeffreys I, Rodahl S. Physical characteristics and abilities of junior elite male and female handball players. J Strength Cond Res. 2013;27(2):302–9.
36. Marques MC, González-Badillo JJ. In-season resistance training and detraining in professional team handball players. J Strength Cond Res. 2006;20:563–71.
37. Massuca LM, Fragoso I, Teles J. Attributes of top elite team-handball players. J Strength Cond Res. 2014;28(1):178–86.
38. Raeder C, Fernandez-Fernandez J, Ferrauti A. Effects of six weeks of medicine ball training on throwing velocity, throwing precision, and isokinetic strength of shoulder rotators in female handball players. J Strength Cond Res. 2016;29(7):1904–14.
39. Schwesig R, Hermassi S, Wagner H, Fischer D, Fieseler G, Molitor T, Delank KS. Relationship between the range of motion and isometric strength of elbow and shoulder joints and ball velocity in women team handball players. J Strength Cond Res. 2016b;30(12):3428–35.
40. Schwesig R, Koke A, Fischer D, Fieseler G, Jungermann P, Delank KS, Hermassi S. Validity and reliability of the new handball-specific complex test. J Strength Cond Res. 2016a;30(2):476–86.
41. Van den Tillaar R, Ettema G. A comparison of kinematics between overarm throwing with 20% underweight, regular, and 20% overweight balls. J Appl Biomech. 2011;27(3):252–7.
42. Póvoas SC, Ascensão AA, Magalhães J, Seabra AF, Krustrup P, Soares JM, Rebelo AN. Physiological demands of elite team handball with special reference to playing position. J Strength Cond Res. 2014;28(2):430–42.
43. Michalsik LB, Søndergaard H, Flynn M. Team handball match analysis by computer tracking from the men's European Championships 2016. In: Baca A, Wessner B, Diketmüller R, Tschan H, Hofmann M, Kornfeind P, Tsolakidis E, editors. Crossing borders through Sport Science. Proceedings of the 21th Annual Congress of the European College of Sport Science, Vienna, Austria, 6–9 July 2016. p. 135.
44. Coutts AJ, Duffield R. Validity and reliability of GPS devices for measuring movement demands of team sports. J Sci Med Sport. 2010;13(1):133–5.
45. Dwyer DB, Gabbett TJ. Global positioning system data analysis: velocity ranges and a new definition of sprinting for field sport athletes. J Strength Cond Res. 2012;26(3):818–24.

46. Luteberget LS, Holme BR, Spencer M. Reliability of wearable inertial measurement units to measure physical activity in team handball. Int J Sports Physiol Perform. 2017a;5:1–24.
47. Luteberget LS, Spencer M. High-intensity events in international Women's team handball matches. Int J Sports Physiol Perform. 2017;12(1):56–61.
48. Luteberget LS, Trollerud HP, Spencer M. Physical demands of game-based training drills in women's team handball. J Sports Sci. 2017b;16:1–7.
49. Wik EH, Luteberget LS, Spencer M. Activity profiles in international women's team handball using PlayerLoad. Int J Sports Physiol Perform. 2017;12(7):934–42.
50. Michalsik LB, Aagaard P. Physical demands in elite team handball: comparisons between male and female players. J Sports Med Phys Fitness. 2015;55(9):878–91.
51. Michalsik LB, Aagaard P, Madsen K. Technical activity profile and influence of body anthropometry on playing performance in female elite team handball. J Strength Cond Res. 2015b;29(4):1126–38.
52. Michalsik LB, Madsen K, Aagaard P. Physiological capacity and physical testing in male elite team handball. J Sports Med Phys Fitness. 2015c;55(5):415–29.
53. Luig P, Lopez CM, Pers J, Perse M, Kristan M, Schander I, Zimmermann M, Henke T, Platen P. Motion characteristics according to playing position in international men's Team Handball. In: Cabri J, Alves F, Araujo D, Barreiros J, Diniz J, Veloso A, editors. Sport Science by the sea. Proceedings of the 13th Annual Congress of the European College of Sport Science, Estoril, Portugal, 9–12 July 2008. p. 241–2.
54. Manchado C, Pers J, Navarro F, Han A, Sung E, Platen P. Time-motion analysis in women's team handball: importance of aerobic performance. J Hum Sport Exerc. 2013;8(2):376–90.
55. Pers J, Bon M, Kovacis S, Sibila M, Dezman B. Observation and analysis of large-scale human motion. Hum Mov Sci. 2002;21(2):295–311.
56. Karcher C, Buchheit M. On-court demands of elite handball, with special reference to playing positions. Sports Med. 2014;44(6):797–814.
57. Pori P, Kovačič S, Bon M, Dolenec M, Šibila M. Various age category-related differences in the volume and intensity of large-scale cyclic movements of male players in team handball. Acta Universitatis Palckianae Olomucensis, Gymnica. 2005;45(2):199–26.
58. Pori P, Šibila M. Analysis of high-intensity large-scale movements in team handball. Kinesiologia Slovenica. 2006;12(2):51–8.
59. Sibila M, Vuleta D, Pori P. Position-related differences in volume and intensity of large-scale cyclic movements of male players in handball. Kinesiology. 2004;36(1):58–68.
60. Bangsbo J, Mohr M, Krustrup P. Physical and metabolic demands of training and match-play in the elite football player. J Sports Sci. 2006;24(7):665–74.
61. Esposito F, Impellizzeri FM, Margonato V, Vanni R, Pizzini G, Veicsteinas A. Validity of heart rate as an indicator of aerobic demand during soccer activities in amateur soccer players. Eur J Appl Physiol. 2004;93(1–2):167–72.
62. Reilly T, Ball D. The net physiological cost of dribbling a soccer ball. Res Quar Exerc Sport. 1984;55:267–71.
63. Saltin B, Larsen H, Terrados N, Bangsbo J, Bak T, Kim CK, Svedenhag J, Rolf CJ. Aerobic exercise capacity at sea level and at altitude in Kenyan boys, junior and senior runners compared with Scandinavian runners. Scand J Med Sci Sports. 1995;5(4):209–21.
64. Bangsbo J, Michalsik LB. Optimal training. A scientific and practical approach to aerobic and anaerobic training. National Olympic Committee and Sports Confederation of Denmark, Copenhagen, Denmark, editors. [Optimal træning. En videnskabelig og praktisk tilgang til aerob oganaerob træning. Danmarks Idræts-Forbund, København, Danmark, editors], 2018. p. 1–475.
65. Lago C. The influence of match location, quality of opposition, and match status on possession strategies in professional association football. J Sports Sci. 2009;27(13):1463–9.
66. Castellano J, Blanco-Villaseñor A, Álvarez D. Contextual Variables and Time-Motion Analysis in Soccer. International Journal of Sports Medicine. 2011:32(06):415–21.
67. Coyle EF. Fluid and fuel intake during exercise. J Sports Sci. 2004;22(1):39–55.
68. Krustrup P, Mohr M, Steensberg A, Bencke J, Kjaer M, Bangsbo J. Muscle and blood metabolites during a soccer game: implications for sprint performance. Med Sci Sports Exerc. 2006;38(6):1165–74.
69. Fieseler G, Hermassi S, Hoffmeyer B, Schulze S, Irlenbusch L, Bartels T, Delank KS, Laudner KG, Schwesig R. Differences in anthropometric characteristics in relation to throwing velocity and competitive level in professional male team handball: a tool for talent profiling. J Sports Med Phys Fitness. 2017;57(7–8):985–92.
70. Haugen TA, Tønnesen E, Seiler S. Physical and physiological characteristics of male handball players: influence of playing position and competitive level. J Sports Med Phys Fitness. 2016;56(1–2): 19–26.
71. Krüger K, Pilat C, Ueckert K, Frech T, Mooren FC. Physical performance profile of handball players is related to playing position and playing class. J Strength Cond Res. 2014;28(1):117–25.
71. Massuca L, Branco B, Miarka B, Fragoso I. Physical fitness attributes of team-handball players are related

to playing position and performance level. Asian J Sports Med. 2015;6(1):e24712.
73. Schwesig R, Hermassi S, Fieseler G, Irlenbusch L, Noack F, Delank KS, Shephard RJ, Chelly MS. Anthropometric and physical performance characteristics of professional handball players: influence of playing position. J Sports Med Phys Fitness. 2017;57(11):1471–8.
74. Vila H, Manchado C, Rodriguez N, Abraldes JA, Alcaraz PE, Ferragut C. Anthropometric profile, vertical jump, and throwing velocity in elite female handball players by playing positions. J Strength Cond Res. 2012;26(8):2146–55.
75. Sporis G, Vuleta D, Vuleta D Jr, Milanovic D. Fitness profiling in handball: physical and physiological characteristics of elite players. Coll Antropol. 2010;34(3):1009–14.
76. Vaeyens R, Lenoir M, Williams AM, Philippaerts RM. Talent identification and development programmes in sport: current models and future directions. Sports Med. 2008;38(9):703–14.