Sports Med (2014) 44:797–814
DOI 10.1007/s40279-014-0164-z

REVIEW ARTICLE

# On-Court Demands of Elite Handball, with Special Reference to Playing Positions

**Claude Karcher · Martin Buchheit**

Published online: 29 March 2014


**Abstract** The aim of this review is to provide the first comprehensive analysis of the various technical and physical on-court demands in elite male handball with respect to playing positions. While low-intensity activities such as standing still and walking represent the greater proportion of playing time (up to ~70 %), handball can be considered an intense activity for all players, especially because of the large number of repeated high-intensity actions occurring throughout the game (e.g., jumps, sprints, changes of direction, duels, contacts). Additionally, the substantial number of body contacts likely increases neuromuscular load, both during and following games. However, the average running pace (53 ± 7 to 90 ± 9 m·min$^{-1}$) during handball games tends to be lower than in the majority of other team sports, while blood lactate and heart rate responses tend to be similar and slightly lower, respectively. Behind these team-average data, the substantial variations in technical and physiological demands between the different positions have been overlooked in the literature. Whether physical fatigue actually occurs during games is still unclear since, in the majority of studies, games were not examined under actual competitive situations. We contend that, in practice, appropriate player rotations may allow players to maintain an optimal physical performance level or, at least, limit a possible drop in physical/playing efficiency. Future research should essentially focus on the technical and physiological responses during games in relation to specific collective systems of play and individual playing roles. The occurrence of player position-specific fatigue should also be better examined when considering individual playing time and rotation strategies.

C. Karcher · M. Buchheit
Laboratory of Exercise Physiology and Rehabilitation, EA 3300, Faculty of Sport Sciences, University of Picardie, Jules Verne, 80025 Amiens, France
e-mail: claude.karcher@gmail.com

M. Buchheit (✉)
Sport Science Department, Myorobie Association, 73700 Montvalezan, France
e-mail: mb@martin-buchheit.net

## 1 Introduction

Team handball is a professional and Olympic sport (in this actual form, since 1972) that has become increasingly popular over the past decades. In 2012, the European Handball Federation (EHF) Men's European championship (EURO) held in Serbia reached a cumulative television audience of 1.47 billion people [1]. It was broadcast into more than 200 countries [1]. In July 2009, the International Handball Federation (IHF) listed ~19 million players in ~795,000 teams [2]. In Europe, professional leagues can be found in more than 15 countries (e.g., Germany, Spain, France, Croatia, Serbia, Denmark), with more than 200 players employed per league.

Understanding the technical and physical demands of the game is essential for many reasons. First, such information is usually seen as very useful for talent-identification programs [3, 4]. Nevertheless, while scouts generally target young players presenting the expected technical, tactical, psychological, anthropological, and physical prerequisites of the elite level [5–7], it is worth noting that reaching the elite level is highly demanding of time [8] and remains likely uncertain due to the competitive nature of selections, injuries, individual time-investment possibilities [9], and the lack of long-term stability in physical performance measures throughout

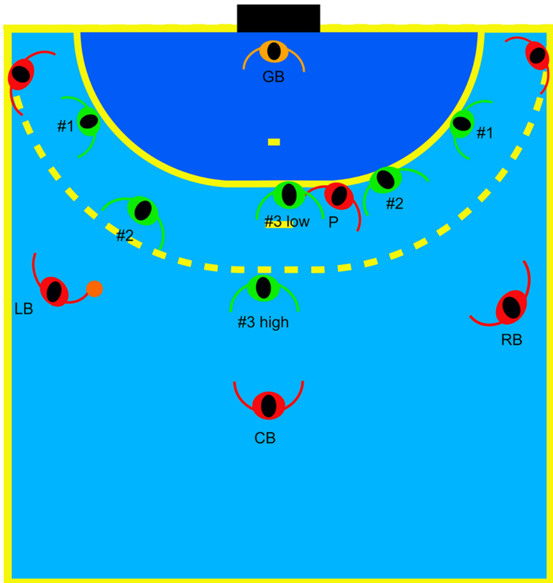



**Fig. 1** Playing positions on the court in attack build-up phases with a 5-1 defense disposition (players are counted from the goal line to the middle). Attackers are in *red* and defenders in *green*. Defenders are numbered from the side to the center. *CB* center back, *GB* goalkeeper, *LB* left back, *LW* left wing, *P* pivot, *RB* right back

adolescence [10]. Knowledge of the demands of the game is also essential for the design of handball-specific training drills in both professional and developing players. To develop their full potential, promising players need to be provided with the most appropriate learning environments, which include well designed technical, tactical, and handball-specific physical (e.g., strength, speed, and endurance) development programs. Finally, to be optimal, these training programs should also be individualized with respect to playing positions and related specific on-court demands [11].

To date, on-court physical and physiological demands during games have only been partially reviewed [12], and the impact that playing positions have on these demands has been overlooked. In the present review, we attempted to gather recent knowledge from both scientific and technical literature on the various technical, tactical, and physical aspects of elite team handball performance, with a special emphasis on positional demands. Such a comprehensive and position-specific analysis is likely beneficial for players identification and development programs. As this was a narrative, and not a systematic review, our methods included a selection of the published papers and abstracts we believed to be most relevant in the area. The reviewed articles were selected from an extensive search of the recent literature (since 2000), including major computerized databases (PubMed, SPORTDiscus, and Google scholar), with no language restriction, but limited to elite male players (i.e., competing in the strongest leagues in Europe and/or during international championships). However, the amount of published research on handball is limited in comparison with that for other team sports. For example, while the word ‘football’ retrieves 6,325 entries, ‘soccer’ 5,498, ‘rugby’ 6,832, and ‘volleyball’ 1,031, ‘handball’ retrieved only 526 entries in PubMed (October 2013). To increase the amount of data reviewed, we also examined results provided by national federations (federation online archives). Standardized differences in game demands between positions (or effect sizes [ES] [13]) have been calculated where possible, and interpreted using Hopkins’ categorization criteria, where 0.2, 0.6, 1.2, and >2 are considered small, moderate, large, and very large effects, respectively [13]. All data are expressed as mean ± standard deviation (SD) values. When the SD was not provided in the original studies, it was estimated using the sampling distribution of similar data in the companion studies. In the present document, we first provide a description of the different playing positions on the court (Fig. 1). We then review the offensive and defensive technical demands (Table 1) and describe position-specific physical demands (Tables 2, 3), with a special emphasis on high-intensity actions (Fig. 2), heart-rate (Fig. 3), and blood lactate (Fig. 4) responses. Finally, we outline overall playing position demands (Table 4) and provide some position-specific training recommendations (Table 5).

## 2 Game Dynamics

Handball rules were modified in 2000 [14], which has increased the speed of the game (e.g., quick throw-off). Seven players compete for each team (one goalkeeper and six outfield players), and the game is played on a 40 × 20-m court. Games are divided into two halves of 30 min each in adults [14]. Half-time cannot exceed 15 min. The winning team is the one that scores more goals than the other. Handball is also one of the fastest team sports, characterized by repeated jumps, sprints, changes in direction, body contact at high speed, and specific technical movement patterns occurring in response to the varying tactical situations of the game. In this review, we present data for elite adult male players playing mostly in European leagues, which are considered the ultimate playing level; playing standard, country league [15], and gender [16] are obviously likely to modify game demands and deserve more specific analyses in the future.

Attack phases can be split into two distinct phases: counter-attack and attack build-up. A counter-attack is the phase when the attacking team tries to overtake the back-up phase of the opponent team, once the ball is lost (e.g., successful defensive sequence, save from the goalkeeper, or a technical fault by the opponent attackers). Attack

**Table 1** Offensive and defensive technical demands related to playing positions in different competition and playing standards

| References | Positions | Level (country) | Players (n) | Offensive actions: Shots (n) | Passes (n) | Offensive duels (n) | Low-intensity contacts (n) | High-intensity contacts (n) | Clasping actions (n) | Defensive actions: Defensive duels (n) | Low-intensity contacts (n) | High-intensity contacts (n) | Clasping actions (n) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dott [73] | Backs | National elite (France) | 21 | $8 \pm 4^{pp}$ | $94 \pm 46.8^{ppp,ww}$ | $6 \pm 4.7$ | | | | | | | $12 \pm 7.8^{p}$ |
| | Pivots | | 7 | $3 \pm 1.9$ | $18 \pm 14.1$ | | | | | | | | $9 \pm 7.3$ |
| | Wings | | 14 | $6 \pm 1.9^{pp}$ | $43 \pm 10.1^{pp}$ | $4 \pm 5.2$ | | | | | | | $5 \pm 6.4$ |
| Michalsik [42] | All | National elite (Denmark) | 82 | $8.5 \pm 4.2$ | | | $27.0 \pm 18.4$ | $7.5 \pm 4.4$ | $2.7 \pm 1.9$ | | $24.1 \pm 12.6$ | $5.8 \pm 3.6$ | $3.9 \pm 3.0$ |
| | Backs | | 41 | $10.5 \pm 3.4^{p,ww}$ | | | $22.2 \pm 10.0^{ww,ppp}$ | $7.5 \pm 2.7^{ww,pp}$ | $2.1 \pm 1.5^{w,pp}$ | | $25.2 \pm 7.3^{ww,p}$ | $6.0 \pm 3.3$ | $3.5 \pm 2.0$ |
| | Pivots | | 18 | $7.0 \pm 2.0$ | | | $58.9 \pm 20.3^{www}$ | $11.6 \pm 3.2^{www}$ | $6.1 \pm 2.9^{www}$ | | $33.7 \pm 12.4^{www}$ | $6.6 \pm 3.2$ | $8.2 \pm 5.0$ |
| | Wings | | 23 | $6.0 \pm 2.5$ | | | $10.6 \pm 2.3$ | $4.3 \pm 2.1$ | $1.2 \pm 0.9$ | | $14.6 \pm 5.9$ | $4.9 \pm 3.3$ | $1.3 \pm 1.1$ |
| EHF [21] | Center Backs | Top elite | 47 | $7.4 \pm 4.2^{lb}$ | | | | | | | | | |
| | Left Backs | | 47 | $11.4 \pm 6^{lw,pp,rw}$ | | | | | | | | | |
| | Left Wings | | 47 | $6.5 \pm 2.7$ | | | | | | | | | |
| | Pivots | | 47 | $5.3 \pm 2.9$ | | | | | | | | | |
| | Right Backs | | 47 | $8.6 \pm 4.5^{p}$ | | | | | | | | | |
| | Right Wings | | 47 | $7.2 \pm 3.3^{p}$ | | | | | | | | | |
| Póvoas [29] | All | National elite (Portugal) | 300 | $6.7 \pm 3.5$ | | $8.2 \pm 8.8$ | | | | $12 \pm 8.8$ | | | |
| | Backs | | 100 | $10 \pm 4.4^{pp,ww}$ | | $6 \pm 3.7^{ww,pp}$ | | | | $13 \pm 6.6^{ww,p}$ | | | |
| | Pivots | | 100 | $5 \pm 2.1$ | | $17 \pm 10.3^{www}$ | | | | $19 \pm 8.9^{www}$ | | | |
| | Wings | | 100 | $4 \pm 1.8$ | | $2 \pm 1.1$ | | | | $4 \pm 2.5$ | | | |

Values are expressed as mean ± standard deviation (SD)

The magnitude of the standardized differences (effect size) between the different positions is indicated by the number of symbols: 1 symbol stands for a moderate difference, 2 symbols for a large difference, 3 for a very large difference

*EHF* European Handball Federation

[p] Substantial difference vs. pivots

[w] vs. wings

[lb] vs. left backs

[lw] vs. left wings

[rw] vs. right wings

**Table 2** Total distance and low-intensity activities (distance and playing time percentage) with respect to playing standard, playing phases, and playing positions in handball players

| References | Age (years) | Positions and players (*n*) | Experimental conditions[a] | Distance per minute ($m \cdot min^{-1}$) | Total distance (m) | Standing still Playing time[b] (%) | Walking distance (m) Playing time[b] (%) | Jogging distance (m) Playing time[b] (%) | Running distance (m) Playing time[b] (%) |
|---|---|---|---|---|---|---|---|---|---|
| Šibila et al. [30][c] | 20.3 ± 4.4 | B (36) | 6 experimental game, National team, All, 5-1 zone, NO, YES, VTS | 80 ± 7[k,www] | 3,432 ± 291 | 57[d] | | 25[e] | |
| | 20.8 ± 4.6 | GK (12) | | 44 ± 4 | 1,753 ± 166 | 86[d] | | 11[e] | |
| | 19.3 ± 3.3 | P (12) | | 80 ± 4[kkk] | 3,234 ± 166 | 62[d] | | 25[e] | |
| | 20.6 ± 4.5 | W (24) | | 96 ± 8[ppp,kkk] | 3,855 ± 333 | 58[d] | | 23[e] | |
| Luig et al. [39][f] | NA | All (~170) | NA official games, World championships, All, NA, YES, NO, VTS | 80 ± NA | 2,935 ± NA | 1,006 ± 143[d]<br>39[d] | | 1,311 ± 149<br>43[e] | |
| | | CB (25) | | 90 ± 9[kkk,pp,w] | 2,839 ± NA | NA | | NA | |
| | | B (~60) | | 88 ± 8[kkk,w,p] | 2,757 ± NA | 34[d] | | 47[e] | |
| | | GK (~20) | | 45 ± 5 | 2,058 ± 90 | NA | | NA | |
| | | P (~25) | | 80 ± 4[kkk] | 2,786 ± 238 | 35[d] | | 45[e] | |
| | | W (~40) | | 83 ± 6[kkk] | 3,710 ± 210 | 35[d] | | 39[e] | |
| Póvoas [29][g] | 24.8 ± 5.1 | B (10) | 10 official games, National Elite (Portugal), All, NA, YES, YES, hand notation | 68 ± 9[pp] | 4,964 ± 642 | 35 ± 5[ppp] | 2,408 ± 369[ppp,ww]<br>41 ± 4 | 1,221 ± 369[e,ww]<br>11 ± 4[e] | |
| | 22.4 ± 3.5 | P (10) | | 53 ± 7 | 3,910 ± 507 | 49 ± 8 | 1,677 ± 291<br>30 ± 7 | 1,052 ± 170[e,w]<br>9 ± 1 | |
| | 22.7 ± 3.5 | W (10) | | 58 ± 7[pp] | 4,234 ± 520 | 46 ± 5 | 1,956 ± 263[pp]<br>34 ± 4 | 771 ± 79[e]<br>7 ± 1[e] | |
| | 25.2 ± 3.5 | All (30) | 10 official games, National Elite (Portugal), Attack, NA, YES, YES, hand notation | 82 ± 15 | 2,297 ± 568 | 39 ± 13 | 1,227 ± 333<br>42 ± 11 | 540 ± 296[e]<br>9 ± 4[e] | |
| | | All (30) | 10 official games, National Elite (Portugal), Defense, NA, YES, YES, hand notation | 57 ± 9 | 2,073 ± 314 | 47 ± 12 | 782 ± 200<br>27 ± 0 | 481 ± 100[e]<br>8 ± 3[e] | |
| Michalsik et al. [16][h] | 24.6 ± 3.1 | All (82) | 62 official games, National Elite (Denmark), All, NA, YES, NO, hand notation | 68 ± 11 | 3,627 ± 568 | 37 | 1,424 ± 265<br>40 | 618 ± 155<br>9 | 510 ± 121<br>4 |
| | | B (41) | | 69 ± 10[p] | 3,765 ± 532[p] | 36 | 1,479 ± NA<br>40 | 672 ± NA<br>9 | 505 ± NA<br>4 |
| | | P (18) | | 62 ± 9 | 3,295 ± 495 | 42 | 1,257 ± NA<br>36 | 563 ± NA<br>8 | 458 ± NA<br>4 |
| | | W (23) | | 69 ± 10[p] | 3,641 ± 501[p] | 35 | 1,467 ± NA<br>42 | 519 ± NA<br>8 | 523 ± NA<br>5 |
| | | All (82) | 62 official games, National Elite (Denmark), Attack, NA, YES, NO, hand notation | 67 ± 12 | 1,846 ± 346 | 30 ± 10 | 830 ± 160 47 ± 9 | 284 ± 103<br>8 ± 3 | 229 ± 69<br>4 ± 1 |
| | | All (82) | 62 official games, National Elite (Denmark), Defense, NA, YES, NO, hand notation | 68 ± 13 | 1,781 ± 337 | 43 ± 10 | 594 ± 162<br>32 ± 9 | 334 ± 85<br>9 ± 2 | 281 ± 92 5 ± 2 |

**Table 2** Total distance and low-intensity activities (distance and playing time percentage) with respect to playing standard, playing phases, and playing positions in handball players

| References | Age (years) | Positions and players (*n*) | Experimental conditions[a] | Distance per minute (m·min$^{-1}$) | Total distance (m) | Standing still Playing time[b] (%) | Walking distance (m) Playing time[b] (%) | Jogging distance (m) Playing time[b] (%) | Running distance (m) Playing time[b] (%) |
|---|---|---|---|---|---|---|---|---|---|
| Póvoas et al. [40][g] | 25.2 ± 3.5 | All (30) | 10 official games, National Elite (Portugal), All, NA, YES, YES, hand notation | 60 ± 10 | 4,370 ± 702 | 43 ± 9 | 2,002 ± 427<br>35 ± 7 | 1,014 ± 335<br>9 ± 3 | |

Values are expressed as mean ± SD

*B* back player, *CB* center back, *GK* goalkeeper, *NA* not available, *P* pivot, *SD* standard deviation, *VTS* video tracking system, *W* wing

[a] Experimental conditions are described in the following order: number of games (or NA), type of game (official game or experimental game), playing standard, phase of the game (offense, defense, or both), defensive system (players' repartition from the goal line to the middle or NA, see Fig. 1), substitution allowed (YES or NO), whether the entire game has been examined (YES or NO), tracking system used (VTS or hand notation)

[b] For each variable, distance covered is given in the upper line, while time expressed as a percentage of total playing time is shown in the bottom line

[c] Šibila et al. [30]: standing still or walking up to −1.4 m·s$^{-1}$; running above 1.4 up to 3.4 m·s$^{-1}$

[d] Standing still and walking combined

[e] Jogging and running combined

[f] Luig et al. [39]: walking from 0.01 to 1.49 m·s$^{-1}$; running from 1.5 to 3.99 m·s$^{-1}$

[g] Póvoas [29]; Póvoas et al. [40]: qualitative definition of motion pattern (see Bangsbo et al. [80] for more details)

[h] Michalsik et al. [41, 42]: walking from 0.1 to 1.1 m·s$^{-1}$, jogging from 1.2 to 2.2 m·s$^{-1}$, running from 2.3 to 3.6 m·s$^{-1}$

The magnitude of the standardized differences (effect size) between the different positions is indicated by the number of symbols: one symbol stands for a moderate difference, two symbols for a large difference, three symbols for a very large difference. [p] substantial difference vs. pivots, [w] vs. wings, [k] vs. goal keepers build-up phases occur when the counter-attack is not successful, but the attacking team still possesses the ball.

The number of ball possessions has remained quite stable over the past years, with 56.0 ± 4.4 attacks per game reported in the 2008 Olympic Games [17] and 53.7 ± 4.3 (range 44–67) in the 2012 European championship. In some games (e.g., German professional league) more than 80 ball possessions are sometimes observed [18]. This means that, on average, defense and attack phases alternate every ~22 to ~36 s. In the Croatian first league, the majority of attacks (<60 %, including counter-attacks and prolonged counter-attacks) lasted <25 s [19]. Short attack build-up phases (lasting 10–25 s) were the more frequent ($n$ = 20.6 ± 5.3; range 7–39), followed by moderately-long attack build-up phases (26–50 s; $n$ = 16.2 ± 3.7; range 6–26), prolonged counter-attacks (5–10 s; $n$ = 8.91 ± 3.9; range 1–18), counter-attacks (<5 s; $n$ = 6.8 ± 3.7; range 0–19), and long attack build-up phases (>50 s; $n$ = 6.0 ± 3.0; range 0–16) [19, 20]. Additionally, 52.8 ± 15.1 % of the attacks were uninterrupted, while attacks with one or more interruptions represented 23.3 ± 7.5 and 23.8 ± 9.5 % of the attacks, respectively [1, 2]. The dynamics and the recovery/work ratio of the game must be considered by coaches and trainers to design specific training programs (with either tactical and/or conditioning contents) (Sect. 4).

### 2.1 Counter-Attacks

Counter-attacks (both their number and effectiveness), although not representing the greater proportion of ball possessions (11.7 ± 5.8 %, range 0–32 %), are highly determinant for game outcomes [2]. Counter-attacks can also be split into two subcategories: counter-attacks of <5 or 10 s, which represent 6.8 ± 3.7 (11.5 %) and 8.9 ± 3.9 (15.2 %) of ball possessions, respectively [19]. Their occurrence determines speed and repeated-sprint ability requirements, with wings generally the more involved in those actions. However, there was large between-game variability in the number of counter-attacks during EURO 2012 (coefficient of variation [CV] 52 %, range 1–19). Their success rate was highly variable (CV 32 %, range 0–100) [21]. The number and efficiency of counter-attacks decreased between the first (77.1 %, SD not available [NA]) and second half (66.9 ± NA) in the Greek Championships [22]. Whether this is evidence of physical fatigue or just a consequence of changes in playing tactics is difficult to decipher (Sect. 6). Importantly, as the counter-attacks were not recorded when the defending team managed to avoid a shoot with a good recovery phase, the actual number of counter-attack attempts is likely higher than that reported.

### 2.2 Attack Build-Up Phases and Playing Position Demands

Attack build-up phases represented the largest proportion of ball possessions (88.2 ± 5.8 %; range 68–100) in the 2012 EURO [21]. Attack build-up phases are characterized by a high player concentration in small areas, with a lot of contacts, and repetition of high-intensity actions (e.g., jumping, throwing, running during the attacking phase, and pushing and blocking actions during defensive phases). The low percentage of success of attack build-up phases during the 2012 EURO (47.3 ± 4.1 %, range 39–60 [21]) showed the importance of defensive phases and goalkeeper performance in game outcomes. Moreover, in the semi-finals and finals of the European and World championships, the total goals scored generally tends to be lower than in the first rounds, suggesting a greater emphasis on defensive phases. Since 2006, only four winning teams have managed to score more than 30–34 goals during finals; 62 % of the winning teams have conceded <25 goals in those games since 2006. Defensive phases are not detailed further in this section, but considering that a team is defending when the other is attacking, the temporal characteristics of defensive phases are likely similar to those of the offensive phases described here.

There are six different playing positions on the court (Fig. 1), based on a player's location on the field during either offensive (left wing, left back, center back, right back, right wing, and pivot) or defensive (players are counted from the side to the center of the field) phases. Goalkeepers play in a dedicated zone (Fig. 1). Each position has its own specificities. Pivots play in the smallest area (~12 $m^2$), most of the time between two defenders, wings in ~15 $m^2$, while backs and center backs play in wider spaces (~64 $m^2$). Technical demands for each position are described in Table 1.

Generally, backs shoot largely to very largely more than pivots and wings, while there is no substantial difference between wings and pivots (Table 1). However, at the elite level (Euro 2012), small to moderate differences were observed between the different back positions (ES right back vs. center back position = 0.3, left back vs. right back = 0.4, and left back vs. center back = 0.7) or between wing positions (right vs. left wing = 0.2) [21].

Passes are a fundamental skill. Due to the high number of repetitions during both training and games, they are likely to stress the shoulder joints [23]. Wings performed very largely more passes than pivots (ES for wings vs. pivots = 2.1), and backs largely more than wings (backs vs. wings = 1.4) and pivots (backs vs. pivots = 1.8) [Table 1]. Backs used their shoulders more intensively than did wings and pivots, which suggests that appropriate training must be implemented for these players (e.g., rotator cuff training [24]).

Clasping and checking are allowed in certain conditions only and are an important part of defensive phases in handball. Tactical roles of each position generate many body contacts and duels (one vs. one confrontation to gain a favorable situation, e.g., shooting, blocking an opponent). During games in the Danish first league [25], pivots received (ES vs. backs = 2.6, vs. wings = 3.6) and gave (vs. backs = 0.8; vs. wings = 1.2) moderately to very largely more contacts. Pivots also performed moderately to very largely more duels than the other players (vs. backs = 1.1, vs. pivot = 2.2). Wings received (vs. backs = −1.4) and gave (vs. back = −1.2) largely fewer contacts than backs. They were also involved in substantially fewer duels (vs. backs = −1.7) (Table 1). This also has direct implications for the design of resistance training programs for these different positions, with pivot and back defenders likely requiring more muscle hypertrophy and strength type of work than wings, for example (Table 5). While goalkeepers' performance is a key factor in the final result [26], technical demands of goalkeeping have been overlooked in the scientific literature; interested readers are referred to coaching books (e.g., Tachdjian and Omer [27]), which highlight the specific technical requirements and the strong need for flexibility and excellent hand-eye coordination capacity rather than strength and/or hypertrophy for this position.

## 3 Motion Analysis

As shown in Tables 2 and 3, there is a lack of homogeneity in the time-motion analyses with respect to tracking systems, speed zones, or the consideration of players' substitution. It is therefore difficult to make clear and definitive comparisons between studies. Additionally, whilst automated video and global positioning system (GPS) (if handball were to be played outdoors) tracking systems may be accurate enough to measure running distance at different intensities, they are likely less effective than hand notation systems to assess handball-specific actions (e.g. backward running, sidesteps, jumps) [28]. Importantly, the hand notation system may also actually underestimate the distance travelled compared with video tracking systems. For example, the average running pace was largely to very largely lower when using a hand notation system (Póvoas [29] vs. Šibila et al. [30], ES for wings = −5, backs = −1.5, pivots = −4.8). Despite these limitations, to provide a starting point on the understating of on-court demands during games, we have merged data related to several speed zones and movement patterns from different studies into unique generic descriptors. When speed zones (e.g., km/h) were not the same in the different studies, locomotion patterns were compiled in a more comprehensive way (e.g., walking, running, sprinting). The definitions of each speed or action category are detailed in the footnotes of Tables 2 and 3.

### 3.1 Team Average

The average running pace is relatively low in handball (53 ± 7 to 90 ± 9 m·min$^{-1}$, Table 2) compared with other team sports like rugby (89 ± 4 to 95 ± 7 m·min$^{-1}$ [31]), basketball (115 ± 9 m·min$^{-1}$ [32]), Australian Rules football (123 ± 19 m·min$^{-1}$ [33]), or soccer (123–135 m·min$^{-1}$ [34–36]). Different factors could explain these differences, including pitch size, player number, and specific tactical/technical organization [37]. Low-intensity activities such as standing still (34.6 ± 5.5 to 46.9 ± 12.4 %) and walking (27.5 ± 0.4 to 47.5 ± 8.8 %) represent the greatest proportion of playing time [29]. In some studies, where standing still and walking were quantified together [38, 39], low-intensity activities represented 39 ± NA to 60 ± NA % of total time. Slow running comes in at third place (range 8 ± NA to 43 ± NA %) [30, 38–41]. However, these team-averaged data are of little interest for practitioners, who need to develop position-specific training drills. The following section highlights the important position-related differences in game demands.

### 3.2 Position-Related Motion Analysis

Studies reporting between-position differences in running demands have shown very large disparities (Table 2) (e.g., 58–96 m·min$^{-1}$ for wings). In some studies, there was no consistency in the position classification between backs and wings [29, 30, 39, 41]. While in Danish and Croatian championships, wings were shown to run the most [30, 41], those 'same' players were reported to run less than back players during other international games [39]. These differences are likely related to game nature (i.e., player rotation allowed or not), playing standard, tactical systems, and tracking systems (Sect. 4). However, data are more consistent for pivots (Table 2), who generally run less than all other outfield players. Obviously, goalkeepers covered the least distance and had a different profile than all the other players (Tables 2, 3).

In addition to distance covered, the occurrence of particular movement patterns and the time spent in specific speed zones are useful to examine the different playing position demands, and eventually, to adapt training contents (Table 5). When considering those criteria, we observe that (Tables 2, 3):

- Backs walked very largely more than pivots and largely more than wings (walking distance: ES vs. pivots = 2.2, vs. wings = 1.4). They also ran moderately more than pivots and largely more than wings (vs. pivots = 0.5, vs. wings = 1.6). Backs covered largely more distance in lateral movements at moderate speed than wings (vs. wings = 1.4); however, there were no substantial difference with pivots (vs. pivots = 0).
- Pivots were very largely more involved in very low-intensity actions than the other players (standing still: ES vs. backs = 2, vs. wings = 2). They showed the lowest amount of high-intensity runs with large differences with wings and small differences with backs (fast running: vs. wings = −1.7, vs. backs = −0.3; sprinting: vs. wings = −1.2, vs. backs = −0.6). However, they performed moderately more lateral displacements than some of the other positions (lateral movements at moderate speed: ES vs. backs = 0.7, vs. wings = 1; lateral movements at high speed: vs. backs = 0.7, vs. wing 1).
- Wings performed largely more high-intensity runs than backs and pivots (fast running distance: ES vs. backs = 1.1; vs. pivots = 1.7), while their sprinting distance was moderately higher than backs and largely higher than pivots (vs. backs = 0.8, vs. pivots = 1.3). Wings also covered very largely more backward distance than the other outfield players (vs. backs = 2.7; vs. pivots = 4).

#### 3.2.1 *High-Intensity Runs*

In the present review, high-intensity running includes fast running categories and sprints. The proportion of high-intensity runs was rather small in relation to the total time/running distance, representing only, in elite Danish players, 7.9 ± 4.9 and 1.7 ± 0.9 % of total playing time and distance covered, respectively [42]. These high-intensity runs are generally crucial for game outcomes (e.g., sprinting to win a ball, sprinting during counter-attacks) and have a large physiological impact (i.e., might trigger neuromuscular fatigue [43], inflammatory responses [44], and deplete glycogen when repeated [45]). The exact number of sprints during games, and their occurrence with respect to playing positions, remains unclear, since sprint definitions vary considerably between studies (Table 3). During elite Portuguese games [29], differences between positions were small to moderate (backs vs. pivots = 0.3, pivots vs. wings = −0.7, and wings vs. backs = 0.3). During the 2007 World championships, differences were larger (backs vs. pivots = −0.2, pivots vs. wings = −1.2, wings vs. backs = 1.5) [39]. Finally, during the 2007 World Cup, average sprint distance was actually very short, i.e., from 7 to 19 m (Table 3). Pivots were shown to cover sprints over 5–7 m, backs over 8 m, and wings over 15–18 m [39]. Wings sprinted more than backs and pivots but differences were small (vs. backs = 0.3, vs. pivots = 0.3). These latter results have direct implications for the design of position-specific sprinting drills (Table 5).

#### 3.2.2 *High-Intensity Actions*

In the present study, high-intensity actions refer to high-intensity activities other than high-intensity running, such as jumps, stops, changes of direction, and duels. Despite their very short duration, these actions are important to consider since they require high levels of strength and speed. Figure 2 shows their occurrence for each position in elite Portuguese players. Backs and pivots performed very largely more high-intensity actions than wings (6.6 and 4.3, respectively). Pivots performed largely more duels than backs (1.4). All those differences are likely the result of position-specific tactical demands (Sect. 2.2), and also have direct implications for position-specific training programs (Table 5).

#### 3.2.3 *Repeated High-Intensity Runs and Actions*

Despite their importance for specific training prescriptions, data on the work-recovery ratio of high-intensity runs and actions during games are scarce. In the only study to date, the mean recovery time between high- (sprinting and high-intensity lateral runs) and low-intensity activities was 55 ± 32 s [3]. The large SD of this recovery time (CV = 60 %) suggests that there are important variations in rest period duration, which are likely related to technical and position-specific demands. The average 55-s period is actually similar to that in field hockey, where more than 50 % of the recovery periods between sprints are longer than 60 s [46]. However, this mean recovery duration is shorter than that reported in football (i.e., 72 s [47]) or rugby (i.e., 192–312 s [48]). However, knowledge of the mean recovery duration alone is insufficient to examine effort distribution, since it is likely that some repeated sprint/high-speed action sequences also occur with shorter recovery periods between the efforts, as shown in soccer [47, 49, 50]. In elite Portuguese players, 63 ± 25 % of repeated maximal intensity runs (sprinting and high-intensity sideways) were separated by >90 s; 9 ± 8 % occurred with a recovery time of 61–90 s, 11 ± 12 % with a recovery time of 31–60 s, and, finally, only 18 ± 18 % with a recovery time <30 s [40]. When considering high-intensity runs (fast running, sprinting, and high-intensity sideways) recovery was >90 s for 34 ± 18 % of the sequences, 61–90 s for 11 ± 10 %, 31–60 s for 20 ± 10 %, and 0–30 s for 34 ± 16 % [40].

**Table 3** High-intensity, backwards, and sideways activities with respect to playing standard, playing phases, and playing positions

| References | Age (years) | Positions and players ($n$) | Experimental conditions[a] | Fast running distance (m) Playing time[b] (%) | Side steps medium-intensity distance (m) Playing time[b] (%) | Side steps high-intensity distance (m) Playing time[b] (%) | Backwards movements distance (m) Playing time[b] (%) | Total sprinting distance (m) Playing time[b] (%) | Sprints ($n$) | Mean sprinting distance (m) |
|---|---|---|---|---|---|---|---|---|---|---|
| Pori [70][c] | 21.9 ± 3.1 | W (12) | 6 experimental game, 1st–2nd National Elite (Slovenia), All, 0-6 zone, NO, YES, VTS | | | | | 620 ± 70 | 80 ± 14 | 8 ± 2 |
| | | B (18) | | | | | | | | |
| | | P (6) | | | | | | | | |
| Šibila et al. [30][d] | 20.3 ± 4.4 | B (36) | 6 experimental game, National team (Slovenia), All, 5-1 zone, NO, YES, VTS | 14 | | | | 3 | | |
| | 20.8 ± 4.6 | GK (12) | | 2 | | | | 0 | | |
| | 19.3 ± 3.3 | P (12) | | 10 | | | | 2 | | |
| | 20.6 ± 4.5 | W (24) | | 14 | | | | 4 | | |
| Luig et al. [39][e] | NA | All (~170) | NA official games, World championship, All, NA, YES, NO, VTS | 525 ± 102 | | | | 88 ± 64 | 33 ± 16 | |
| | | | | 16 | | | | 3 | | |
| | | CB (~25) | | | | | | | | |
| | | B (~60) | | 17 | | | | 2 | $28 \pm 13^{www}$ | |
| | | GK (~20) | | 32 ± 12 | | | | 2 ± 6 | | |
| | | P (~25) | | 17 | | | | 2 | 31 ± 12 | |
| | | W (~40) | | 20 | | | | 5 | $51 \pm 18^{ppp}$ | |
| Póvoas [29][f] | 24.8 ± 5.1 | B (10) | 10 official games, National elite (Portugal), All, NA, YES, YES, hand notation | $437 \pm 246^{w}$ | $343 \pm 123^{ww,p}$ | $154 \pm 74^{w}$ | $308 \pm 74^{ppp,w}$ | $94 \pm 62^{p,w}$ | 22 ± 11 | 16 ± 7 |
| | | | | 2 ± 1 | 6 ± 3 | 1 ± 1 | 5 ± 3 | <1 ± 1 | | |
| | 22.4 ± 3.5 | P (10) | | 364 ± 170 | 344 ± 194 | $278 \pm 208^{p}$ | 137 ± 48 | 59 ± 48 | 19 ± 7 | 18 ± 9 |
| | | | | 1 ± 1 | 6 ± 4 | 2 ± 1 | 2 ± 1 | <1 ± 0 | | |
| | 22.7 ± 3.5 | W (10) | | $694 \pm 210^{pp}$ | 165 ± 131 | 119 ± 79 | $364 \pm 63^{ppp}$ | $165 \pm 105^{pp}$ | $25 \pm 9^{p}$ | 19 ± 6 |
| | | | | 3 ± 2 | 3 ± 2 | 1 ± 1 | 6 ± 1 | 1 ± 1 | | |
| | 25.2 ± 3.5 | All (30) | 10 official games, National elite (Portugal), Attack, NA, YES, YES, hand notation | 257 ± 148 | 46 ± 37 | 14 ± 7 | 142 ± 111 | 71 ± 74 | | |
| | | | | 2 ± 1 | 2 ± 1 | <1 ± 0 | 5 ± 3 | <1 ± 0 | | |
| | | All (30) | 10 official games, National elite (Portugal), Defense, NA, YES, YES, hand notation | 247 ± 134 | 238 ± 134 | 164 ± 150 | 120 ± 67 | 39 ± 33 | | |
| | | | | 2 ± 1 | 9 ± 5 | 2 ± 1 | 4 ± 3 | <1 ± 0 | | |

**Table 3** continued

| References | Age (years) | Positions and players (*n*) | Experimental conditions[a] | Fast running distance (m) Playing time[b] (%) | Side steps medium-intensity distance (m) Playing time[b] (%) | Side steps high-intensity distance (m) Playing time[b] (%) | Backwards movements distance (m) Playing time[b] (%) | Total sprinting distance (m) Playing time[b] (%) | Sprints (*n*) | Mean sprinting distance (m) |
|---|---|---|---|---|---|---|---|---|---|---|
| Michalsik et al. [16][g] | 24.6 ± 3.1 | All (82) | 62 official games, National elite (Denmark), All, NA, YES, NO, hand notation | 207 ± 91 | 666 ± 242[h] | | 124 ± 76 | 78 ± 91 | | |
| | | | | 1 | 7 | | 1 | <1 | | |
| | | B (41) | | 175 ± NA | 711 ± NA[h] | | 163 ± NA | 60 ± NA | | |
| | | | | 1 | 8 | | 2 | <1 | | |
| | | P (18) | | 200 ± NA | 620 ± NA[h] | | 122 ± NA | 75 ± NA | | |
| | | | | 1 | 7 | | 1 | <1 | | |
| | | W (23) | | 257 ± NA | 620 ± NA[h] | | 172 ± NA | 141 ± NA | | |
| | | | | 2 | 7 | | 2 | <1 | | |
| | | All (82) | 62 official games, National elite (Denmark), Attack, NA, YES, NO, hand notation | 110 ± 52 | 265 ± 135[h] | | 77 ± 52 | 51 ± 50 | | |
| | | | | 2 ± <1 | 6 ± 3[h] | | 2 ± 1 | <1 ± <1 | | |
| | | All (82) | 62 official games, National elite (Denmark), Defense, NA, YES, NO, hand notation | 97 ± 50 | 401 ± 164[h] | | 47 ± 33 | 27 ± 31 | | |
| | | | | 1 ± <1 | 9 ± 4[h] | | 1 ± <1 | <1 ± <1 | | |
| Póvoas et al. [40][f] | 25.2 ± 3.5 | All (30) | 10 official games, elite (Portugal), All, NA, YES, YES, hand notation | 508 ± 282 | 287 ± 173 | 183 ± 165 | 268 ± 145 | 107 ± 87 | 22 ± 10 | 18 ± 7 |
| | | | | 2 ± 1 | 5 ± 3 | 1 ± 1 | 4 ± 2 | <1 | | |

Values are expressed as mean ± standard deviation (SD)

*B* backs, *CB* center backs, *GK* goalkeeper, *NA* not available, *P* pivots, *VTS* video tracking system, *W* wings

[a] Experimental conditions are described in the following order: number of games (or NA), type of game (official game or experimental game), playing standard, phase of the game (offense, defense, or both), defensive system (players' repartition from the goal line to the middle or NA, see Fig. 1), substitution allowed (YES or NO), whether the entire game has been examined (YES or NO), tracking system used (VTS or hand notation)

[b] For each variable, distance covered is given in the upper line, while time expressed as a percentage of total playing time is shown in the bottom line

[c] Pori [70]: faster than 5.2 $m \cdot s^{-1}$

[d] Šibila et al. [30]: fast running from 3.4 to 5.2 $m \cdot s^{-1}$, sprinting faster than 5.2 $m \cdot s^{-1}$

[e] Luig et al. [39]: fast running from 4 to 5.99 $m \cdot s^{-1}$, sprinting faster than 6 $m \cdot s^{-1}$

[f] Michalsik et al. [25], Michalsik et al. [16]: fast running from 4.8 to 6.7 $m \cdot s^{-1}$, sprinting faster than 6.7 $m \cdot s^{-1}$, sideways and backwards running faster than 2.7 $m \cdot s^{-1}$

[g] Póvoas [29]; Póvoas et al. [40]: qualitative definition of motion pattern (see Bangsbo et al. 1991 [80] for more details) and handball-specific movement (moderate and high speed lateral displacement)

[h] Sideways medium- and high-intensity combined

The magnitude of the standardized differences (effect size) between the different variables is indicated by the number of symbols: one symbol stands for a moderate difference, two symbols for a large difference, three symbols for a very large difference. [p] substantial difference vs. pivots, [w] vs. pivots

**Fig. 2** Number of high-intensity actions related to playing positions (group means ± SD). The magnitude of the standardized differences (effect size) between the different positions is indicated by the number of symbols: one symbol stands for a moderate difference, two for a large difference, three for a very large difference, *b* substantial difference vs. backs, *w* vs. wings. *COD* changes of direction, *SD* standard deviation

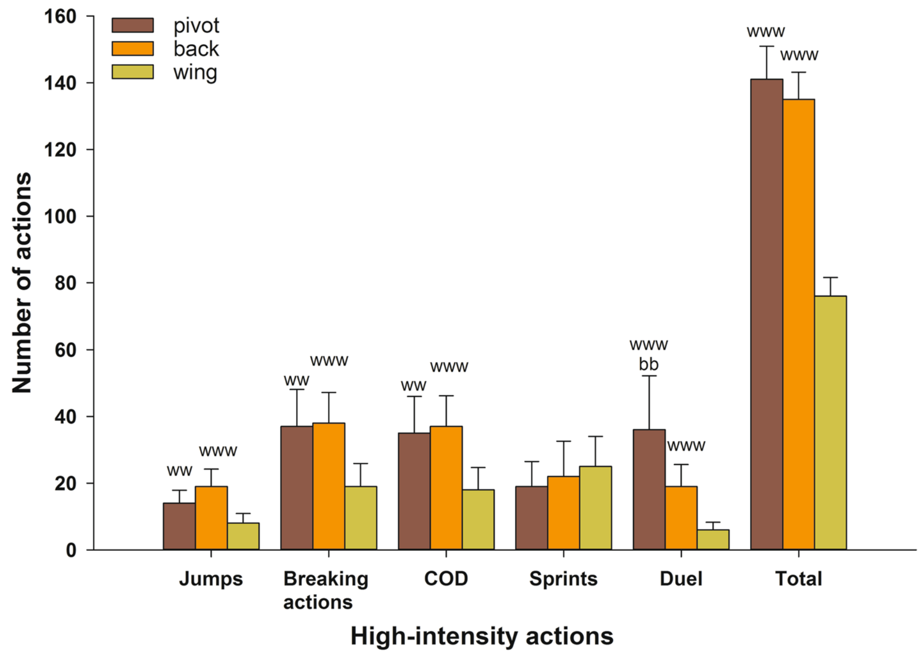
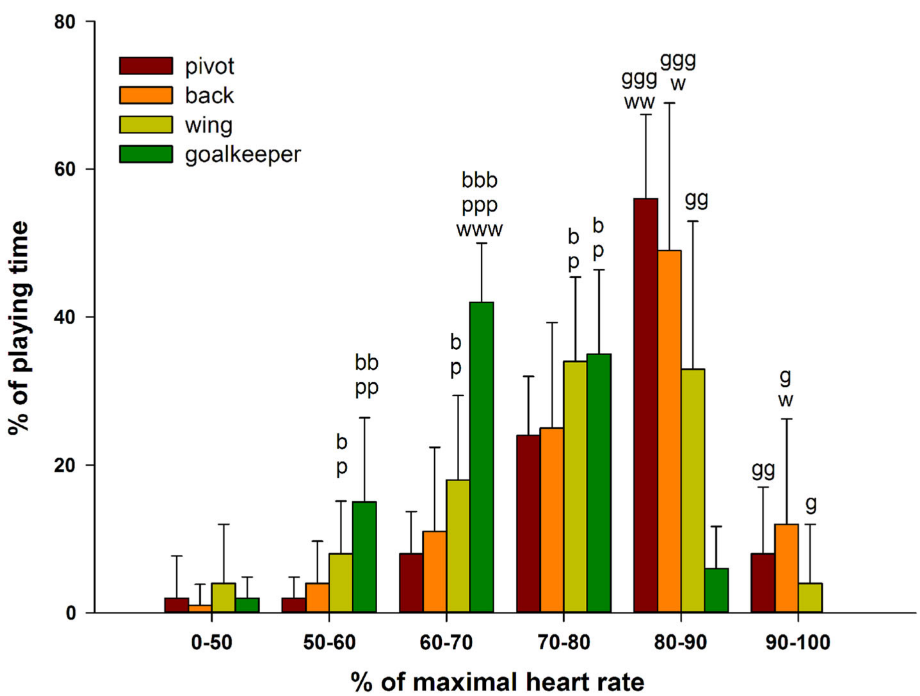



**Fig. 3** Heart rate responses during a Portuguese first league match expressed as a percentage of maximal heart rate (group means ± SD). The magnitude of the standardized differences (effect size) between the different positions is indicated by the number of symbols: one symbol stands for a moderate difference, two for a large difference, three for a very large difference; *b* substantial difference vs. backs, *g* vs. goalkeepers, *p* vs. pivots, *w* vs. wings




Recovery time might not differ greatly between playing positions. In the only study by Póvoas et al. [4], 67 ± 22 % of the recovery periods between high-intensity runs lasted more than 90 s for backs; 63 ± 18 % of the recovery periods for wings, and 57 ± 24 % for pivots. Similarly, 18 ± 16 % of recovery periods lasted 0–30 s in backs, 17 ± 13 % in wings, and 19 ± 17 % in pivots. The profile of position-specific repeated high-intensity actions is therefore still unclear and should be the matter of future research. Nevertheless, these data suggest that the time and the activity between the great majority of high-intensity actions (>60 %) is likely enough for phosphocreatine (PCr) re-synthesis, irrespective of playing positions (if we consider that PCr is recovered at 50 and 100 % within 20 and 90 s, respectively [51, 52]).

It is also important to consider that the high-intensity technical demands (e.g. jumps, shots, duels) are mostly performed within restricted space (attack build-up phases represent 88 % of ball possessions, Sect. 2.2) and are therefore, not well captured by classical time–motion analysis systems. For instance, in addition to running-based high-speed actions, 36.9 ± 13.1 intense technical actions

**Table 4** Overall playing position demands

| Position | Technical demands | | | Motion analysis | | | | High-intensity actions | | Relative intensity distribution (physiological load) | | | Need for player rotations |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Shoot | Pass | Contacts-duels | Running pace | Low-intensity movements | Moderate-intensity movements | High-intensity movements | Sprints | Total | Low | Moderate | High | |
| Back | **** | **** | *** | *** | ** | **** | *** | *** | *** | * | **** | *** | **** |
| Pivot | ** | * | **** | ** | *** | ** | ** | ** | *** | * | ** | **** | **** |
| Wing | ** | *** | ** | *** | ** | * | *** | **** | * | ** | *** | ** | ** |
| Goalkeeper | | | | * | **** | ** | * | | | *** | ** | * | ** |

The magnitude of playing position demands with respect to technical activities, distance covered, high-intensity actions, and physiological load variables is rated from low (*) to very high (****) based on the data presented in the review (Tables 1, 2; Figs. 1, 2, 3 and 4)

have been reported per game [25]. Further game analyses on repeated high-intensity actions should also examine, in addition to locomotor patterns, specific technical actions during both attacking and defensive phases. Finally, further analysis accounting for accelerations, changes of direction, and player 'loading' are also required to complete the overall profiling of game demands [53].

## 4 Physiological Demands

### 4.1 Neuromuscular Demands and Contacts

Playing handball requires the performance of a large number of high-intensity actions (Sects. 3.2.1 and 3.2.2; Fig. 2) and could lead to acute neuromuscular adjustments, and, in turn, to decreased neuromuscular performance. For example, decreases in lower limb maximal voluntary contraction capacity, rate of force development, and jumping abilities have been reported [5]. Collisions and contacts are also known to increase indicators of muscle damage [54] and may further impair neuromuscular performance [55]. While this has still to be documented, it is likely that the large number of contacts received and given during a game (37–120, Table 1) may have an important impact on the occurrence of neuromuscular fatigue during and after games. Additionally, the progressive accumulation of muscle by-products (see 4.2) can affect muscular contractility and impair neuromuscular performance throughout a game [56]. Despite the limited data available, it is reasonable to say that playing handball places large demands on the neuromuscular and musculoskeletal systems. Whether fatigue actually develops during games needs further consideration and is discussed in Sect. 6.

### 4.2 Anaerobic Glycolytic Energy Contribution

As discussed above, playing handball requires a large number of high-intensity actions (Sects. 3.2.1 and 3.2.2), which largely trigger anaerobic glycolysis [52, 57, 58]. However, to date, the only available data to examine the contribution of the anaerobic glycolytic system during games are limited to blood lactate measures, which are not without limitations. Blood measures depend on the type and amount of activity performed immediately prior to the sampling [59], the site and timing of the sampling, and the type of analyzer, and do not linearly reflect muscle lactate. Rather, they represent an accumulated response to high-intensity actions [60]. We nevertheless provide the available blood lactate values as a starting point to understand the anaerobic glycolytic requirements of the game. Blood lactate values were $3.7 \pm 1.6$ mmol·l$^{-1}$ after the first half in

**Table 5** Playing position-specific training recommendations for handball players with regard to technical, motion analysis, and physiological demands presented in the review

| Physical quality | Main training orientation/ rationale | Position | | | |
|---|---|---|---|---|---|
| | | Back | Pivot | Wing | Goalkeeper |
| Strength | Main objective | Hypertrophy–explosivity–maximal strength | Hypertrophy | Explosivity | Explosivity–reactive strength |
| | Rationale | To develop jumping, sprinting, shooting abilities and better tolerate contacts and duels (Sects. 3.2 and 4.1) | To better tolerate contacts and duels (Sects. 3.2 and 4.1) | To develop jumping and sprinting abilities (Sects. 3.2 and 4.1) | To improve reactivity and quickness (Sect. 2) |
| Speed | Main exercise format | 10–15 m | 10 m | 20–30 m | Specific movements |
| | Rationale | Shorter average sprinting distance (Table 3) | Shorter average sprinting distance (Table 3) | Longer average sprinting distance (Table 3) | No need for proper running speed (Table 3) |
| Metabolic function | Main exercise format | 30–30 s; 20–20 s | 15–15 s | 10–20 s/5–25 s/sprint repetitions | 15–15–30–30 s |
| | Rationale | Adjusted on the average activity time and attack/defense ratio (Tables 2, 3; Sects. 3.2, 4.2 and 4.3; Fig. 3) | Adjusted on the average activity time and attack/defense ratio (Tables 2, 3; Sects. 3.2, 4.2 and 4.3; Fig. 3) | Adjusted on the average activity time and attack/defense ratio (Tables 2, 3; Sects. 3.2, 4.2 and 4.3; Fig. 3) | Reproducing game activity patterns does not allow to stimulate the cardiorespiratory system at high intensity, so other generic forms of intervals have to be considered—exercise modes can be modified as well for these players not used to running, e.g., bike (Tables 2, 3; Sects. 2, 4.2 and 4.3; Fig. 3) |
| Injury prevention | Main muscle group | Rotator cuff | Core muscles | Hamstrings | Elbow–Shoulder muscles |
| | Rationale | To support the large number of passes and shots (Table 1) | To support duels and contacts (Sect. 3.2) | To prevent muscle strain due to high-speed running (longer strides) (Sect. 3.2 and Table 2) | Prevent elbow hyperextension during ball impacts |

For each physical quality (strength [81–83], speed [84, 85], cardiorespiratory function [86, 89], and injury prevention [87]), the first line shows the main training objectives, while the second line shows the rationale for the suggested training recommendations

Danish male elite adult players [42], 4.2 ± 2 (range 1.6–8.6) mmol·l$^{-1}$ throughout the first half in elite Portuguese adult players [29], and 9.7 ± 1.1 mmol·l$^{-1}$ after the first half in adolescent Tunisian players [61]. During the second half in the elite Portuguese game, blood lactate was 3.1 ± 1.8 (1.3–8.4) mmol·l$^{-1}$ [29]. Post-game values were actually not greater than after the first half, suggesting, at least at the team level, a stable anaerobic glycolytic energy contribution throughout the game: 4.8 ± 1.9 (2.4–10.8) [42] and 8.3 ± 1 mmol·l$^{-1}$ [61]. These values are actually similar to those found in other team sports such as basketball (4.9–5.8 mmol·l$^{-1}$) or soccer (3.9–10 mmol·l$^{-1}$) [60, 62, 63].

With the limitations of blood lactate measures to assess anaerobic glycolytic contribution, the important variations in blood lactate values reported in the literature limit our ability to draw definitive conclusions. Anecdotal data collected during games also suggest that blood lactate levels vary substantially both during the game and between players (Fig. 4). While some players show relatively stable values throughout the game, others show decreasing or increasing blood lactate throughout the game. It is likely

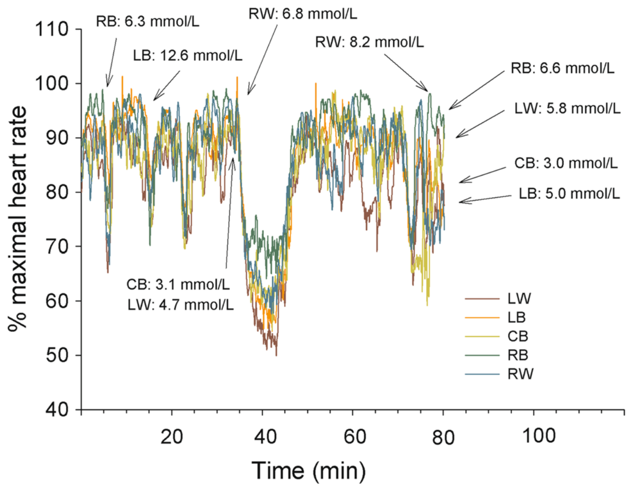



**Fig. 4** Individual heart rate and blood lactate responses during a game in well trained French national-level adult players. See Sect. 4.2 for details. *CB* center back, *LB* left back, *LW* left wing, *RB* right back, *RW* right wing

that blood lactage levels are affected by players' activities during the game, playing style, players' metabolic and locomotor profile, and activity before the sampling. In fact, in line with the large between-position differences in match activity patterns (Table 2, 3), anaerobic glycolytic contribution would also be expected to differ between positions. However, this has still to be investigated in a larger sample of players.

### 4.3 Aerobic Demands

Taken together, both game duration (individual playing time per match: 32–53 min [39, 41]) and the repetition of high-intensity runs and actions trigger the aerobic metabolism at high levels. While oxygen uptake ($\dot{V}O_2$) assessment is the most valid tool to examine aerobic demands, this requires carrying a gas analyzer during match play, which is obviously incompatible with the game demands. Therefore, there is, to date, no $\dot{V}O_2$ data collected during real games. However, interestingly, such measures were performed during non-contact small-sided handball games (2 × 3 min 45 s) [64]; mean $\dot{V}O_2$ was on average 93.9 % (88.2–99.6) of maximal $\dot{V}O_2$ ($\dot{V}O_{2max}$). In the majority of studies, the aerobic demands were rather estimated from heart rate (HR) recordings and the associated HR/$\dot{V}O_2$ relationship established previously during an incremental test [29, 40, 42, 61, 65]. The estimated $\dot{V}O_2$ reached during a game ranged between 71 ± 6 [7] and 74 ± 10 (45–92) % of $\dot{V}O_{2max}$ [29].

When considering playing positions, wings reached on average 65 ± 8 to 73 ± 6 % $\dot{V}O_{2max}$, pivots 67 ± 9 to 74 ± 6 % of $\dot{V}O_{2max}$ [29, 42], and backs 68 ± 6 to 78 ± 6 % of $\dot{V}O_{2max}$ [29, 42]. Peak estimated $\dot{V}O_2$ during a game was 92 ± 7 (74–100) % of $\dot{V}O_{2max}$ [4]. However, the validity of $\dot{V}O_2$ estimation from HR has strong limitations [64], mainly because handball-specific movement patterns/ muscle contraction types can affect HR independently of the actual $O_2$ demands. Therefore, we recommend directly examining HR data, which represent at least cardiac work and do not rely on possibly biased estimations. Mean game HR for field players are lower in handball (72 ± 16 % [66]) than in basketball (82 ± 9 % [67]), rugby (84 ± NA % [68]), or soccer (85 ± NA % [69]), and may be related to both the lower average running pace in handball (Table 2) and other factors such as pitch size, specific tactic demands, rules, and the number of players on the field [37].

Taken together with the similar blood lactate levels, the lower HR values observed in handball compared with basketball or soccer suggest that handball may put a relatively greater emphasis on anaerobic glycolytic energy. Finally, it is also worth noting that, as for motion patterns (Sect. 3.2), HR responses showed large variations between playing positions (Fig. 3). Goalkeepers showed the lowest HR demands, with ~60 % of the time spent at <70 % maximal HR ($HR_{max}$) and no time spent at >90 % $HR_{max}$. Wings spent the largest part of their time in the 70–80 and 80–90 % zones (~30 % in the two intensities), while backs and pivots spent more time in the 80–90 % zone. The greater cardiac demands observed for these two latter positions (i.e., at or close to $HR_{max}$) suggest that a greater emphasis should be placed on cardiopulmonary function during training, and/or that different rotational strategies should be implemented during games to prevent development of excessive fatigue (Sect. 6, Table 2).

## 5 Limitations of Current Game Analysis and Implications for Future Research

There are many defensive systems (i.e., man-oriented vs. ball-oriented vs. mixed defense) and many player formations on the field (e.g., 5-1, 6-0, 3-2-1). For a given playing position in the field, the defensive role, for example, can change substantially based on tactical variations. For instance, a player in position #2 (Fig. 1) in a 5-1 man-oriented defense will be involved in much more contact and fewer lateral runs than in a 5-1 ball-oriented defense. In Croatian elite players, compared with playing #1 in a 0-6 ball-oriented defense, defending #2 in a 3-2-1 defense required largely more running and fast running (total distance: ES = 1.8) and was moderately to largely more physiologically demanding (higher HR: 0.9, higher blood lactate: 1.9) [70]. Similar effects of team structure or playing systems were reported in other team sports [71, 72]. Moreover, in all time–motion and physiological analyses to date in handball [16, 29, 30, 39–41, 61], distinctions between playing positions and roles in offensive versus defensive phases has never been considered.

Jonas Källman plays (2001–2014) in the left wing position in attack but generally plays as an advanced defender in a 5-1 defense (#3 high, Fig. 1). Pivots, who play in the middle court section in attack, frequently defend in position #2 and not necessarily in #3 high or low (Fig. 1). To summarize, defensive systems practiced, defensive systems attacked, as well as playing position-specific tasks that can vary both during and between consecutive games (strategic adjustments) all have large impacts on technical, tactical, motion patterns, and physiological demands. Unfortunately, these factors have not yet been examined, and should be the subject of future research. There is no doubt that a better understanding of those specific requirements would likely improve coaching and handball-specific training drills.

In contrast to soccer, for example, players' rotations are unlimited and can occur at any time during handball games. At the elite level, mainly for strategic reasons, some players rotate at almost every ball possession (i.e., some players have only a defensive role, while others only an offensive role). The French player Didier Dinart (1993–2013), for example, was probably the best and most well known defensive-only player in the world (#3 low). In a French First League team (SC Sélestat 2002), the average game rotations during seven successive competitive games was 3 ± 2 for the wings, 13 ± 9 for the backs, and 26 ± 7 for the pivots [73]. Despite some exceptions (e.g., Icelandic left wing Guðjón Valur Sigurðsson (2000–2014) played the entire six games of his team during the 2012 EURO), playing >90 % of total time during an international competition is atypical. For instance, only nine players (~3 % of the players involved in this competition) played more than 90 % of total game time during the 2012 EURO; 14 % of the players played for >75 %, 25 % played for 75–50 %, 34 % played for 25–50 %, and 28 % played for 0–25 % of the possible total playing time [21]. Moreover, playing time could be accumulated either continuously or intermittently (i.e., via the successive defensive phases for specialist players). To our knowledge, despite the likely significant consequences of these rotation strategies on technical activities and match running performance during team sport games [74], their effect on fatigue development has not yet been investigated in handball.

During the 2007 world cup (~170 players), wings ($n$ ~ 40, 38 ± 2 min) and goalkeepers ($n$ ~ 20, 37 ± 3 min) played substantially more than backs ($n$ ~ 60, 29 ± 2 min) and pivots ($n$ ~ 25, 30 ± 3 min) (wings vs. backs = 4.2, wings vs. pivots = 3.2, goalkeepers vs. backs = 3.8, goalkeepers vs. pivots = 3.2). This playing time distribution confirms the position-specific demands that were previously highlighted (Sect. 4), where wing and goalkeeper positions seem to be less demanding than back and pivot positions.

## 6 Does Fatigue Occur During Games?

As previously mentioned (Sects. 3 and 4), the work–recovery ratio between the majority of high-intensity actions may allow sufficient recovery to maintain the performance level of the majority of actions. Whether the decreased occurrence of high-intensity activities and HR [40, 42] observed during the second versus the first half results effectively from fatigue or more from changes in game dynamics is actually unclear (e.g. the importance of the latter issue may force players to reduce game pace; disciplinary sanctions and team time out are generally more frequent in the second half). At first glance, the few studies reporting decreased physical performance following games suggest that substantial physical fatigue can occur after a game. For instance, decreases in counter movement jump height (ES = −1), maximal quadriceps isometric strength (ES = −0.7), quadriceps rate of force development (0–50 m·s$^{-1}$ ES = −5, 0–100 m·s$^{-1}$ ES = −4.5), and impulse during maximal quadriceps isometric contraction (0–100 m·s$^{-1}$ ES = −4.3, 0–200 m·s$^{-1}$ ES = −7.8) were observed after a simulated game in elite Danish players [5]. Similarly, after a friendly game in elite Portuguese players [29, 41], counter movement jump height decreased moderately (ES = −0.8). However, these latter results should be considered with care, since, in the study by Thorlund et al. [43], the game simulation was probably too intense to reflect what actually happens during real games: substitutions were not allowed, and game pace (i.e., 131 m·min$^{-1}$) was more than twice as great as during usual games (Table 2). In the studies by Póvoas et al. [29, 40], data were collected for all playing positions together, and players' rotations, which likely directly affect performance changes during games (Sect. 5), were not accounted for in the analysis. Taken together, these methodological aspects prevent a proper examination of the data. In other studies [41, 42], inclusion criteria (42 min of total playing time and at least 18 min in each half) were probably too excessive to reflect real practice (Sect. 3.1) and did not allow the analysis of playing position-related fatigue.

There is therefore a feeling that the occurrence of fatigue during handball games may have been overestimated. We can also suggest that the nature and the occurrence of fatigue in a game are likely playing position-dependent, as suggested by the differences in technical and physiological demands (see Sect. 3 and 4), as well as total playing time [39]. Finally, our field experience suggests that coaches who manage players' rotations in an appropriate way can actually avoid excessive physiological loading of the players, which can prevent fatigue and likely improves player efficiency throughout the game.

## 7 Fatigue Throughout the Competitive Season

In elite male players, physical fitness improves generally during the first part of the season, and tends to plateau or even decrease slightly by the end of the season [75, 76]. However, the effect of accumulated playing time and match numbers on training status during an entire season has not yet been investigated. International players can participate in up to 80 official games per season (Olympic Games, international competitions, international club competitions, and national competitions), while others may play considerably fewer (~30 games in national competitions, personal data). The number of games per week can also vary greatly, from one during the regular season (national championship) to five during international competitions, and is also likely to affect fitness level. To our knowledge, the number of matches played and total playing time over a full season have not yet been reported. However, we can speculate that these variables have significant consequences (e.g., on-court performance, fitness level, or injury rate) as shown in Australian Rules football [77] or rugby [78]. This should also be the subject of further research.

## 8 Conclusion

This review is the first to provide a comprehensive analysis of the various technical and physical on-court demands in elite male handball with respect to playing positions. Defense and attack phases alternate on average every ~22 to ~36 s, and attack build-up phases represent the larger part of ball possession (88 ± 6 %); counter-attacks represent 12 ± 6 % of game possession. Handball is clearly an intense activity for all players, with a large number of high-intensity actions (i.e., jumps, duels, sprints, changes of direction, contacts). While low-intensity activities such as standing still (43–37 %) and walking (35–43 %) represent the greater proportion of playing time, the large amount of body contact likely increases neuromuscular load both during and following games. The mean recovery time between high-intensity activities (sprinting and high-intensity sideways) is around 55 s, with the largest proportion (63 %) of repeated high-intensity actions separated by more than 90 s. The average running pace (53 ± 7 to 90 ± 9 $m \cdot min^{-1}$) during handball games is actually lower than in the majority of other team sports, while blood lactate (post-game values: 4.8 ± 1.9 to 8.3 ± 1.0 $mmol \cdot l^{-1}$) and HR responses (82 ± 9 to 87 ± 9 % $HR_{max}$) tend to be similar and slightly lower, respectively. Behind these team-average data, the substantial variations in technical and physiological demands between the different positions have been overlooked in the literature. Data on goalkeepers are scarce and, due to their particular activity profile, more detailed and specific analyses (e.g., biomechanics) are still needed. Pivots cover generally the smallest distance on the field, but still exercise at a relative high intensity due to the high number of body contacts they give and receive. Wings perform the greatest amount of high-intensity runs, receive and give the least number of contacts, and show the lowest physiological demands. Finally, the playing activity of the backs is in between those described for the two other on-field positions but they shoot and pass substantially more than all other players and therefore deserve specific physical preparation in accordance with these demands (Tables 4, 5). Whether physical fatigue actually occurs during games is still unclear, since in the majority of studies, games were not examined under real competitive situations. We contend that, in practice, appropriate player rotations may allow players to maintain their physical performance level, or, at least, limit a possible drop in physical/playing efficiency. As highlighted in the different sections of the present review, future research should essentially focus on the technical and physiological responses during games in relation to specific collective systems of play and individual playing roles. Playing position-specific fatigue should also be better examined when considering individual playing time and rotation strategies. The match activities of goalkeepers should receive more attention in the future. Finally, exploring the relationship between training drills and game demands [79, 88, 89] might improve the design of individualized handball-specific training contents in the future.

**Acknowledgments** The authors thank Philippe Schlatter, Frederic & Thierry Demangeon, and Jean-Luc Legall for their advice and help during the manuscript preparation. We also thank the Ligue d'Alsace de Handball and Sélestat Alsace Handball for their financial support. Claude Karcher also dedicates this work to Lonis, his son, for the time they missed together while preparing this review. No sources of funding were used to assist in the preparation of this review. The authors have no potential conflicts of interest that are directly relevant to the content of this review.

## References

1. InfrontSport. Handball hits new heights. 2012. http://www.infrontsports.com/mediarights/handball/.
2. Wikipedia contributors. Team handball. 2013.
3. Vaeyens R, Gullich A, Warr CR, et al. Talent identification and promotion programmes of Olympic athletes. J Sports Sci. 2009;27(13):1367–80.
4. Vaeyens R, Lenoir M, Williams AM, et al. Talent identification and development programmes in sport: current models and future directions. Sports Med. 2008;38(9):703–14.
5. Chaouachi A, Brughelli M, Levin G, et al. Anthropometric, physiological and performance characteristics of elite team-handball players. J Sports Sci. 2009;27(2):151–7.

6. Sporiš G, Vuleta D, Vuleta D Jr, Milanović D. Fitness profiling in handball: physical and physiological characteristics of elite players. Coll Antropol. 2010;34(3):1009–14.
7. Srhoj V, Marinović M, Rogulj N. Position specific morphological characteristics of top-level male handball players. Coll Antropol. 2002;26(1):219–27.
8. Ericsson KA, Krampe RT, Tesch-Römer C. The role of deliberate practice in the acquisition of expert performance. Psychol Rev. 1993;100(3):363.
9. Tucker R, Collins M. What makes champions? A review of the relative contribution of genes and training to sporting success. Br J Sports Med. 2012;46(8):555–61.
10. Buchheit M, Mendez-Villanueva A. Reliability and stability of anthropometric and performance measures in highly-trained young soccer players: effect of age and maturation. J Sports Sci. 2013;31(12):1332–43.
11. Di Salvo V, Baron R, Tschan H, et al. Performance characteristics according to playing position in elite soccer. Int J Sports Med. 2007;28(3):222–7.
12. Ziv G, Lidor R. Physical characteristics, physiological attributes, and on-court performances of handball players: a review. Eur J Sport Sci. 2009;9(6):375–86.
13. Hopkins WG, Marshall SW, Batterham AM, et al. Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc. 2009;41(1):3–13.
14. International Handball Federation. The official handball rules. 2010. http://ihf.info/files/Uploads/NewsAttachments/0_RuleGame_GB.pdf.
15. Meletakos P, Bayios I. General trends in European men's handball: a longitudinal study. Int J Perform Anal Sport. 2010;10(3):221–8.
16. Michalsik LB, Aagaard P, Madsen K. Physical demands in elite team handball: comparisons between male and female players. In: 17th Annual ECSS-Congress; Bruges; 2012.
17. Skarbalius A. Monitoring sport performance in handball. In: Federation EH, editor. European Handball Federation. Scientific Conference. 2011. http://ebook.eurohandball.com/EHF%20Scientific%20Conference%202011/.
18. Seco JdDR. La evolución del juego de ataque en balonmano. Revisión histórica: Los inicios del Siglo XXI. E-balonmano com: Revista de Ciencias del Deporte. 2007;3(4):79–99.
19. Rogulj N, Vuleta D, Milanović D, et al. The efficiency of elements of collective attack tactics in handball. Kineziol Slov. 2011;17(1):5–14.
20. Rogulj N, Srhoj V, Srhoj L. The contribution of collective attack tactics in differentiating handball score efficiency. Coll Antropol. 2004;28(2):739–46.
21. European Handball Federation. Official Statistics men's European Championship. 2012. http://www.ehf-euro.com/Men-s-EHF-EURO-2012.2281.0.html.
22. Yiannakos A, Sileloglou P, Gerodimos V, et al. Analysis and comparison of fast break in top level handball matches. Int J Perform Anal Sport. 2005;5(3):62–72.
23. Jancosko JJ, Kazanjian JE. Shoulder injuries in the throwing athlete. Phys Sportsmed. 2012;40(1):84–90.
24. Borsa PA, Laudner KG, Sauers EL. Mobility and stability adaptations in the shoulder of the overhead athlete: a theoretical and evidence-based perspective. Sports Med. 2008;38(1):17–36.
25. Michalsik LB, Aagaard P, Madsen K. Technical activity profile and influence of body anthropometry in male elite Team Handball players. In: European Handball Scientific Conference. 2011. http://ebook.eurohandball.com/EHF%20Scientific%20Conference%202011/.
26. Gutiérrez O. Discriminant analysis between winners and losers in the Asobal league 2008–2009. EHF Web Periodicals; 2011.
27. Tachdjian C, Omer J. Gardien de but de Handball: L'analyse et le travail; 2006.
28. Carling C, Bloomfield J, Nelsen L, et al. The role of motion analysis in elite soccer: contemporary performance measurement techniques and work rate data. Sports Med. 2008;38(10):839–62.
29. Póvoas S. Estudo do Jogo e do Jogador de Andebol de Elite: Universidade do Porto; 2009.
30. Šibila 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.
31. Waldron M, Twist C, Highton J, et al. Movement and physiological match demands of elite rugby league using portable global positioning systems. J Sports Sci. 2011;29(11):1223–30.
32. Ben Abdelkrim N, Chaouachi A, Chamari K, et al. Positional role and competitive-level differences in elite-level men's basketball players. J Strength Cond Res. 2010;24(5):1346–55.
33. Wisbey B, Pyne D, Rattray B. Quantifying changes in AFF player games demands using GPS tracking, 2011 AFL SEASON2011.
34. Stolen T, Chamari K, Castagna C, Wisloff U. Physiology of soccer: an update. Sports Med. 2005;35(6):501–36.
35. Rampinini E, Coutts AJ, Castagna C, et al. Variation in top level soccer match performance. Int J Sports Med. 2007;28(12):1018–24.
36. Rampinini E, Impellizzeri FM, Castagna C, et al. Technical performance during soccer matches of the Italian Serie A league: effect of fatigue and competitive level. J Sci Med Sport. 2009;12(1):227–33.
37. Hill-Haas S, Dawson B, Impellizzeri F, et al. Physiology of small-sided games training in football. Sports Med. 2011;41(3):199–220. doi:10.2165/11539740-000000000-00000.
38. Pori P, Kovačič S, Bon M, et al. Various age category-related differences in the volume and intensity of the large-scale cyclic movements of male players in team handball. Acta Univ Palacki Olomuc Gymnica. 2009;35(2):119–26.
39. Luig P, Manchado C, Pers J. Motion characteristics according to playing positions in international men's team handball. In: 13th Annual ECSS-Congress; Estoril; 2008.
40. Póvoas SC, Seabra AF, Ascensao AA, et al. Physical and physiological demands of elite team handball. J Strength Cond Res. 2012;26(12):3365–75. doi:10.1519/JSC.0b013e318248aeee.
41. Michalsik L, 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. doi:10.1055/s-0032-1329989.
42. Michalsik L. Match performance and physiological capacity of male elite team handball players. In: European Handball Federation Scientific Conference. 2011. http://ebook.eurohandball.com/EHF%20Scientific%20Conference%202011/.
43. Thorlund JB, Michalsik LB, Madsen K, et al. 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(4):462–72.
44. Marin DP, dos Santos M, de Cassia R, Bolin AP, et al. Cytokines and oxidative stress status following a handball game in elite male players. Oxid Med Cell Longev. 2011;2011:804873.
45. Balsom PD, Gaitanos GC, Soderlund K, et al. High-intensity exercise and muscle glycogen availability in humans. Acta Physiol Scand. 1999;165(4):337–45.
46. Spencer M, Lawrence S, Rechichi C, Bishop D, et al. Time-motion analysis of elite field hockey, with special reference to repeated-sprint activity. J Sports Sci. 2004;22(9):843–50.
47. Bradley PS, Sheldon W, Wooster B, et al. High-intensity running in English FA Premier League soccer matches. J Sports Sci. 2009;27(2):159–68.
48. McLellan CP, Lovell DI. Performance analysis of professional, semi-professional and junior elite rugby league match-play using

global positioning systems. J Strength Cond Res. 2013;27(12):3266-74.
49. Buchheit M, Mendez-villanueva A, Simpson BM, et al. Repeated-sprint sequences during youth soccer matches. Int J Sports Med. 2010;31(10):709–16.
50. Carling C, Le Gall F, Dupont G. Analysis of repeated high-intensity running performance in professional soccer. J Sports Sci. 2012;30(4):325–36.
51. Balsom PD, Seger JY, Sjodin B, et al. Maximal-intensity intermittent exercise: effect of recovery duration. Int J Sports Med. 1992;13(7):528–33.
52. Glaister M. Multiple sprint work: physiological responses, mechanisms of fatigue and the influence of aerobic fitness. Sports Med. 2005;35(9):757–77.
53. Aughey RJ. Applications of GPS technologies to field sports. Int J Sports Physiol Perform. 2011;6(3):295–310.
54. McLellan CP, Lovell DI, Gass GC. Biochemical and endocrine responses to impact and collision during elite Rugby League match play. J Strength Cond Res. 2011;25(6):1553–62.
55. McLellan CP, Lovell DI. Neuromuscular responses to impact and collision during elite rugby league match play. J Strength Cond Res. 2012;26(5):1431–40. doi:10.1519/JSC.0b013e318231a627.
56. Girard O, Mendez-Villanueva A, Bishop D. Repeated-sprint ability—part I: factors contributing to fatigue. Sports Med. 2011;41(8):673–94.
57. Gastin PB. Energy system interaction and relative contribution during maximal exercise. Sports Med. 2001;31(10):725–41.
58. Spencer M, Bishop D, Dawson B, et al. Physiological and metabolic responses of repeated-sprint activities: specific to field-based team sports. Sports Med. 2005;35(12):1025–44.
59. Krustrup P, Mohr M, Steensberg A, et al. Muscle and blood metabolites during a soccer game: implications for sprint performance. Med Sci Sports Exerc. 2006;38(6):1165–74. doi:10.1249/01.mss.0000222845.89262.cd.
60. Bangsbo J, Iaia FM, Krustrup P. Metabolic response and fatigue in soccer. Int J Sports Physiol Perform. 2007;2(2):111–27.
61. Chelly MS, Hermassi S, Aouadi R, et al. Match analysis of elite adolescent team handball players. J Strength Cond Res. 2011;25(9):2410–7.
62. Ben Abdelkrim N, Castagna C, Jabri I, et al. Activity profile and physiological requirements of junior elite basketball players in relation to aerobic–anaerobic fitness. J Strength Cond Res. 2010;24(9):2330–42.
63. Ben Abdelkrim N, El Fazaa S, El Ati J. Time-motion analysis and physiological data of elite under-19-year-old basketball players during competition. Br J Sports Med. 2007;41(2):69–75.
64. Buchheit M, Lepretre PM, Behaegel AL, et al. Cardiorespiratory responses during running and sport-specific exercises in handball players. J Sci Med Sport. 2009;12(3):399–405.
65. Souhail H, Castagna C, Mohamed HY, et al. Direct validity of the yo-yo intermittent recovery test in young team handball players. J Strength Cond Res. 2010;24(2):465–70.
66. Povoas SC. Activity motor pattern and heart rate during elite team handball matches. In: European Handball Federation, Scientific Conference. 2011. http://ebook.eurohandball.com/EHF%20Scientific%20Conference%202011/.
67. McInnes SE, Carlson JS, Jones CJ, et al. The physiological load imposed on basketball players during competition. J Sports Sci. 1995;13(5):387–97.
68. Gabbett T, Kelly J, Pezet T. Relationship between physical fitness and playing ability in rugby league players. J Strength Cond Res. 2007;21(4):1126–33.
69. 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(07):665–74.
70. Pori P. Analysis of loading and effort of wing players in team handball. Ljubljana: University of Ljubljana; 2003.
71. Bradley PS, Carling C, Archer D, et al. The effect of playing formation on high-intensity running and technical profiles in English FA Premier League soccer matches. J Sports Sci. 2011;29(8):821–30.
72. Ben Abdelkrim N, Castagna C, El Fazaa S, et al. The effect of players' standard and tactical strategy on game demands in men's basketball. J Strength Cond Res. 2010;24(10):2652–62.
73. Dott E. Analyse qualitative et quantitative des actions motrices en handball. France: Master Thesis, Strasbourg Sports Science University; 2002.
74. Mooney M, Cormack S, O'Brien B, et al. Do physical capacity and interchange rest periods influence match exercise-intensity profile in Australian football? Int J Sports Physiol Perform. 2013;8(2):165–72.
75. Gorostiaga EM, Granados C, Ibanez J, et al. Effects of an entire season on physical fitness changes in elite male handball players. Med Sci Sports Exerc. 2006;38(2):357–66.
76. Buchheit M. Quels tests de terrain pour le suivi de la performance athlétique en sport collectif? Sci Sports. 2008;23(1):29–31.
77. Cormack SJ, Newton RU, McGuigan MR, et al. Neuromuscular and endocrine responses of elite players during an Australian rules football season. Int J Sports Physiol Perform. 2008;3(4):439–53.
78. Johnston RD, Gibson NV, Twist C, et al. Physiological responses to an intensified period of rugby league competition. J Strength Cond Res. 2013;27(3):643–54.
79. Casamichana D, Castellano J, Castagna C. Comparing the physical demands of friendly matches and small-sided games in semiprofessional soccer players. J Strength Cond Res. 2012;26(3):837–43.
80. Bangsbo J, Nørregaard L, Thorsoe F. Activity profile of competition soccer. Can J Sport Sci. 1991;16(2):110–6.
81. Cormie P, McGuigan MR, Newton RU. Developing maximal neuromuscular power: Part 1—biological basis of maximal power production. Sports Med. 2011;41(1):17–38.
82. Kraemer WJ, Ratamess NA. Fundamentals of resistance training: progression and exercise prescription. Med Sci Sports Exerc. 2004;36(4):674–88.
83. Cormie P, McGuigan MR, Newton RU. Developing maximal neuromuscular power: part 2—training considerations for improving maximal power production. Sports Med. 2011;41(2):125–46.
84. Haff GG. Current research: training for strength, power, and speed. Strength Cond J. 2012;34(2):76–8.
85. Sheppard J, Young W. Agility literature review: classifications, training and testing. J Sports Sci. 2006;24(9):919–32.
86. Buchheit M, Laursen PB. High-intensity interval training, solutions to the programming puzzle: Part I: cardiopulmonary emphasis. Sports Med. 2013;43(5):313–38.
87. Bahr R, Engebretsen L (editors). Handbook of sports medicine and science: sports injury prevention. Hoboken (NJ): Wiley-Blackwell, 2011.
88. Corvino M, Tessitore A, Minganti C, et al. Effect of court dimensions on players' external and internal load during small-sided handball games. J Sports Sci Med. 2014 (in press).
89. Buchheit M. Programming high-intensity training in handball. Aspetar Sports Med J. 2014(3) (in press).