Locomotion Characteristics and Match-Induced Impairments in Physical Performance in Male Elite Team Handball Players

Authors L. B. Michalsik[1], P. Aagaard[2], K. Madsen[1]

Affiliations
[1] Department of Public Health, Section of Sport Science, Aarhus University, Aarhus, Denmark
[2] Institute of Sports Science and Clinical Biomechanics, University of Southern Denmark, Odense, Denmark

Key words
- locomotion match analysis
- total distance covered
- high-intensity running
- positional differences
- temporary impaired performance

accepted after revision
October 05, 2012

Bibliography
DOI http://dx.doi.org/10.1055/s-0032-1329989
Published online: December 20, 2012
Int J Sports Med 2013; 34: 590–599 © Georg Thieme Verlag KG Stuttgart · New York
ISSN 0172-4622

Correspondence
Lars Bojsen Michalsik
Department of Public Health
Section of Sport Science
Aarhus University
Dalgas Avenue 4
8000 Aarhus C
Denmark
Tel.: +45/8716/8614
Fax: +45/8716/8378
lbmichalsik@health.sdu.dk

Abstract

The purpose of this study was to determine the physical demands and match-induced impairments in physical performance in male elite Team Handball (TH) players in relation to playing position. Male elite TH field players were closely observed during 6 competitive seasons. Each player (wing players: WP, pivots: PV, backcourt players: BP) was evaluated during match-play using video recording and subsequently performing locomotion match analysis. A total distance of 3 627 ± 568 m (group means ± SD) was covered per match with a total effective playing time (TPT) of 53:51 ± 5:52 min:s, while full-time players covered 3 945 ± 538 m. The mean speed was 6.40 ± 1.01 $km \cdot h^{-1}$. High-intensity running constituted only 1.7 ± 0.9 % of TPT per match corresponding to 7.9 ± 4.9 % of the total distance covered. An average of 1 482.4 ± 312.6 activity changes per player (n = 82) with 53.2 ± 14.1 high-intensity runs were observed per match. Total distance covered was greater in BP (3 765 ± 532 m) and WP (3 641 ± 501 m) than PV (3 295 ± 495 m) ($p < 0.05$), and WP performed more high-intensity running (10.9 ± 5.7 % of total distance covered) than PV (8.5 ± 4.3 %, $p < 0.05$) and BP (6.2 ± 3.2 %, $p < 0.01$). The amount of high-intensity running was lower ($p < 0.05$) in the second (130.4 ± 38.4 m) than in the first half (155.3 ± 47.6 m) corresponding to a decrease of 16.2 %.
In conclusion, modern male elite TH is a complex team sport that comprises several types of movement categories, which during match-play place moderate-to-high demands on intermittent endurance running capacity and where the amount of high-intensity running may be high during brief periods of the match. Signs of fatigue-related changes were observed in terms of temporary impaired physical performance, since the amount of high-intensity running was reduced in the second half. Notably, physical demands differed between playing positions, with WP demonstrating a more intensive activity pattern than BP and PV, respectively.

Introduction

The level of performance in modern Team Handball (TH) is determined by the players' technical, tactical, psychological/social and physical characteristics. All these elements are of high importance in TH and also closely interlinked making TH a particularly complex type of sport. A high level of physical conditioning e.g. is required, if elite TH players should be able to exploit their technical and tactical qualities during an entire game [24]. Despite the considerable global spread of the sport, scientific data on the physiological aspects of the game of TH are limited. Moreover, the majority of studies are of an earlier date, and thus the latest development in the TH game is not taken into account [5, 6, 8, 13, 14, 16, 36] although more recent studies also exist [9, 10, 36, 39, 40]. Since both the nature of the game of TH and the scientific methods of analysis have developed considerably in the last decades, there is a need for a thorough analysis of the physical demands of modern elite TH in order to establish the physical requirements placed on elite players of today. Analysis of the physical demands in elite TH may be used to indicate the proportion of the total training that should consist of physical training, and to identify how different physical training elements should be weighted. Knowledge of the working demands in any type of sport is a precondition for the planning and execution of optimal training [27].
Further, it is relevant to examine to which extent differences exist in the physical demands

imposed by various playing positions. In case of such differences, physical training should be organised in a more individualized manner, rather than providing a uniform type of training to all players on a team. Furthermore, it is also unclear to what extent elite TH players experience fatigue during a game. The extent to which fatigue occurs in elite TH can be assessed by analysing the change in high-intensity activity throughout a competitive game as previously suggested in elite soccer [28]. Findings regarding fatigue-related changes in TH may provide useful information for planning and implementing of physical training in elite TH players.

The aims of the present study, therefore, were (i) to determine the physical demands imposed on male elite TH players, (ii) to identify potential differences between various playing positions, and (iii) to examine if physical match performance is impaired during an elite TH match. To examine these aspects of TH, it is necessary to include a large number of players from different teams representing all playing positions, since considerable variations in activity patterns may be found from match to match, between players within each position and from team to team, respectively. Since the activity patterns of goalkeepers obviously differ markedly from those of field players, the physical demands placed on goalkeepers were not included.

Materials and Methods

Subjects

A large group of male elite TH players including in particular 2 top ranked teams were recruited for the study from teams ranked in the upper half of the Danish Premier male Team Handball League. Some of the players were competing in the European TH Champions League, and several players were also playing for their respective national teams representing multiple nations. All players were fully informed of all experimental procedures and possible discomforts associated with the study before giving their written informed consent to participate. The conditions of the study were approved by the local ethics committee. The study was conducted in accordance with recognized ethical standards as described by Harriss and Atkinson [12] and with the principles of the Declaration of Helsinki. The players were examined over a 6-year period. The physical characteristics of the players from the 2 top ranked teams (9 WP, 7 BP, 7 PV and 3 goalkeepers, n = 26) were 26.4 ± 3.1 years (group means ± SD), 188.9 ± 6.3 cm, 90.9 ± 9.0 kg and 55.2 ± 4.1 ml $O_2 \cdot min^{-1} \cdot kg^{-1}$ with 7.2 ± 3.6 years of playing experience at senior elite level (group means ± SD), respectively.

Observations during match-play video recordings

Observations during match-play took place by means of video recordings of competitive games. The match activities were taped in such a manner that one camera followed one player (field players only) close up without interruption throughout the entire course of the match. Altogether 62 tournament matches in the Danish Premier male Team Handball League were videofilmed, including semi-finals and a final of the Danish National Championship. The intensity of the matches was, therefore, representative of the level of playing intensity in male elite TH. On average 4 players were recorded per match, which provided a total of about 240 recordings. Due to substitutions, the effective playing time for each individual player varied from match to match. Defence- and offence substitutions were also carried out, which led to large differences in a player's time on court in defence and in offence, respectively. In addition, some players changed playing position on the court during match-play. In order to arrive at a realistic picture of a TH player's performance during match-play and to achieve comparability between playing positions, it was necessary to establish certain inclusion criteria with respect to playing time.

Since TH rules allow unlimited substitutions of players throughout the entire match, it was not possible to collect adequate individual data for a full match time of 60 min. Conversely, we aimed to only include players with substantial playing time, in order to ensure that their activity pattern would reflect the true physical demands of the game. The inclusion criterion, therefore, was selected as an effective playing time for the whole match of 42 min or more (i.e. ~70 % of total effective playing time (TPT)) with an effective playing time in one half of the game of 18 min or more (i.e. ~60 % of TPT). A total of 82 recordings (32 different players, mean number of recordings per player: 2.6, range: 1–7) fulfilled these conditions and were analysed according to established criteria.

The match analysis focused separately on offensive and defensive actions, respectively, and was divided into 5-min analysis periods, which permitted temporal analysis of the match. Paused game time was excluded from these periods, but was added to the total duration of the match together with time due to substitution, suspension or injury in order to illustrate opportunities for recovery during the game. Field players were divided into 3 categories in both offence and defence, namely wing players (WP), backcourt players (BP) and pivots (PV), respectively. Normally a WP in offence will also be the WP in defence (wing defence) and a BP (including the center backcourt player or playmaker) will also be the BP in defence (back defence). Furthermore, a PV will normally be the PV in defence (middle defence). However, some players changed position on the court, e.g. playing WP in offence and BP in defence.

The present analysis focused on locomotion characteristics (time-motion analysis), which has previously been used to analyse e.g. soccer [2,3,7,18,28], basketball [21,30], netball [37], rugby [15,23] and Australian football [4,22]. A total of 8 categories of locomotion were registered in accordance with previous studies in elite soccer players [2,18,28]. For each category a precise definition of the type of locomotion and a mean locomotive speed measured in $km \cdot h^{-1}$ was given. The speed was determined from detailed studies of the video recordings. Thus, the time for the player to pass known distances on the court was used to calculate the mean speed for each locomotion activity. The selected speeds were the same for all players. Using speeds given for the various locomotion categories, the distance covered for each activity within each interval was determined as the product of the total time and mean speed for that activity. Total distance covered during a match was then calculated as the sum of the distances covered during each type of locomotion.

The movement categories were low-intensity activities (standing still ($0\,km \cdot h^{-1}$), walking ($4\,km \cdot h^{-1}$)), moderate-intensity activities (jogging ($8\,km \cdot h^{-1}$), sideways movement ($10\,km \cdot h^{-1}$), backwards running ($10\,km \cdot h^{-1}$), running ($13\,km \cdot h^{-1}$)) and high-intensity running (fast running ($17\,km \cdot h^{-1}$), sprinting ($24\,km \cdot h^{-1}$)). Studies in other ball games have reported a high validity of time-motion analysis [17,22,37]. For the locomotion match analysis, a custom-made analysis program for computer based analysis of TH was produced [33].

To ensure a high reproducibility, all matches in the present study were analysed by the same experienced observer. The first and the second half of each match were analysed in a randomized order. The observer had to meet certain adaptation criteria before initiating the analysis. This was achieved by conducting an intense practise period with studies of individual players' styles of locomotion. In addition, several validation tests were performed for each player according to the predetermined categories of locomotion. Sufficient competence of the analyst was deemed to be achieved when data from successive analysis of the same match differed by less than 3% in each of the locomotive categories and in the total distance covered. Thus, no systematic differences in the final inter-observer test-retest of the match were observed.
A separate analysis of the same matches that comprised technical playing actions (e.g. fakes, side-cuttings, tackles and shots) has been reported elsewhere [25].

Statistical analysis

All statistical analyses were conducted using R2 Version 13.1 (University of Auckland, New Zealand). All results are presented as group mean values ± standard deviations (SD) unless otherwise stated. Assumption of a Gaussian distribution of data was examined and verified using QQ-plots. When 2 normally distributed parameters were compared within the same group of subjects (e.g. differences between first and second half), Student's paired t-test was used. Student's non-paired t-testing was used to compare non-matched subject groups (e.g. differences between first and second choice players). The assumption about similar variance was tested with residual plots. Statistical differences between several groups (comparing the different playing positions) were identified using one-way analysis of variance, ANOVA. Post hoc differences between each group were evaluated by Turkey's HSD test (normally distributed). The Pearson product-moment method was used to evaluate potential relationships between parameters. Effect size (ES) calculations (Cohen's d-test) were used to estimate the magnitude of the results (differences between subjects or groups) and were reported with all statistically significant results as a measure of practical significance. The level of significance was set at $p < 0.05$ using 2-tailed testing.

Results

Duration of games and effective playing time

The mean duration of an entire tournament match in the Danish Premier male Team Handball League (n=62) was 1 h 18: 54±2:01 min:s corresponding to 31.5% extension compared to a normal match TPT of 60 min. The full duration of the second half (40:42±1:49 min:s) was longer ($p < 0.05$, ES=1.49) than the first half (38:12±1:31 min:s), which corresponded to an extension compared to one half TPT of 27.3% and 35.7%, respectively. Mean TPT for all analysed players in an entire game (n=82) was 53:51±5:52 min:s. There was no difference in mean TPT between defence (27:40±3:11 min:s) and offence (26:11±3:08 min:s), nor no difference in mean TPT between the first (27:12±2:25 min:s) and the second half of the match (26:39±2:27 min:s).

Match performance

Mean total distance covered and mean speed were 3 627±568 m and 6.40±1.01 $km \cdot h^{-1}$, respectively. The latter was calculated without the contribution of the standing still category (which constituted 36.8±8.6% of TPT). Standing still and walking constituted 76.4±10.4% of TPT per match (▶ **Table 1**). In contrast, the amount of high-intensity running constituted 1.7±0.9% of TPT per match. Compared to the total distance covered, categories of low-intensity activities constituted 39.2±8.8%, moderate-intensity activities 52.9±9.6% and high-intensity running 7.9±4.9%. The number of high-intensity runs was 53.2±14.1 for all players combined. Each player had 1 482.4±312.6 activity changes (0.46 activity changes $\cdot s^{-1}$~28 activity changes $\cdot min^{-1}$) with some full-time players (60 min playing time) demonstrating up to 2 000 activity changes per match.
Differences were observed between various playing positions (▶ **Fig. 1**, ▶ **Table 2**). Both BP (3 765±532 m, $p < 0.05$, ES=0.91) and WP (3 641±501 m, $p < 0.05$, ES=0.69) performed a greater mean total distance covered per match than PV (3 295±495 m). Full-time players (n=13, mostly BP) performed a greater mean total distance covered (3 945±538 m, $p < 0.05$, ES=0.72) compared to non-full-time players (3 567±514 m, n=69). The percentage of TPT per match for the 8 locomotive categories was nearly similar for full-time players compared to all players combined (n=82). This means that full-time players performed a greater total distance covered per match, primarily because they play longer. Assuming constancy in intensity for the remainder of the match (last 7:19 min:s), non-full-time players would have covered a mean of 4 062 m if playing full time.
WP performed more high-intensity running (10.9±5.7% of total distance covered) than both PV (8.5±4.3%, $p < 0.05$, ES=0.48) and BP (6.2±3.2%, $p < 0.01$, ES=1.02). In terms of high-intensity running, the mean duration of fast running and sprinting for all players combined was 1.1±1.3 s and 1.0±1.4 s per action, respectively, with no difference between the first and the second half and no difference between playing positions except that WP performed more and longer ($p < 0.05$) sprints compared to BP in the second half.

Offensive actions

Standing still and walking constituted 78.0±12.5% of TPT per match in offence with a mean TPT of 26:11±3:08 min:s. In contrast, high-intensity running only constituted 2.0±1.1% of TPT per match corresponding to 8.7±5.8% of total distance covered per match (▶ **Table 1**). Mean total distance covered and mean speed were 1 845±346 m and 6.08±1.13 $km \cdot h^{-1}$, respectively. The latter was calculated without the standing still category (which accounted for 30.5±10.3% of TPT).
WP performed more high-intensity running (12.3±4.8% of total distance covered) than PV (10.7±4.1%, $p < 0.05$, ES=0.38) and in particular BP (6.3±4.0%, $p < 0.01$, ES=1.38) (▶ **Table 3**). Furthermore, both BP (1 997±312 m, $p < 0.001$, ES=1.75) and WP (1 847±271 m, $p < 0.01$, ES=1.32) performed a longer mean total distance covered than PV (1 500±254 m), while BP worked with a higher mean speed (6.21±0.97 $km \cdot h^{-1}$) compared to PV (5.83±0.99 $km \cdot h^{-1}$, $p < 0.05$, ES=0.39) and WP (6.03±0.88 $km \cdot h^{-1}$, n.s.) (▶ **Table 2**). The mean speed is probably a better measure to compare the total amount of locomotion, because it takes the difference in TPT between the various playing positions into consideration. The high values of total distance covered and mean speed in BP in spite of the low amount of high-intensity running was due to a low percentage in the standing still category and a high percentage of jogging in relation to walking compared to the other playing positions.

Defensive actions

Standing still and walking constituted 75.1±14.0% of TPT per match in defence with a mean TPT of 27:40±3:11 min:s. The

Table 1 Offensive and defensive actions per match (group means ± SD) for all players combined (n = 82) separated into in the 8 movement categories.

	Playing time per match (s)	% of total playing time per match	Distance covered (m)	% of distance covered
Offensive and defensive actions collapsed for the entire match				
Standing still	1190 ± 277	36.8	0	0
Walking	1281 ± 233	39.6	1424 ± 265	39.2
Jogging	279 ± 70	8.6	618 ± 155	17.0
Running	141 ± 34	4.4	510 ± 121	14.1
Fast running	44 ± 18	1.4	207 ± 91	5.7
Sprinting	12 ± 11	0.4	78 ± 91	2.2
Sideways movement	240 ± 87	7.4	666 ± 242	18.4
Backwards running	44 ± 27	1.4	124 ± 76	3.4
Total	3231 ± 352	100.0	3627 ± 568	100.0
Offensive actions for the entire match				
	Playing time per match (s)	**% of total playing time per match**	**Distance covered (m)**	**% of distance covered**
Standing still	480 ± 159	30.5	0	0
Walking	746 ± 139	47.5	830 ± 160	44.9
Jogging	128 ± 46	8.1	284 ± 103	15.4
Running	64 ± 19	4.0	229 ± 69	12.4
Fast running	23 ± 11	1.5	110 ± 52	6.0
Sprinting	8 ± 8	0.5	51 ± 50	2.8
Sideways movement	94 ± 51	6.1	265 ± 135	14.3
Backwards running	28 ± 18	1.8	77 ± 52	4.2
Total	1571 ± 188	100.0	1846 ± 346	100.0
Defensive actions for the entire match				
	Playing time per match (s)	**% of total playing time per match**	**Distance covered (m)**	**% of distance covered**
Standing still	710 ± 173	42.8	0	0
Walking	535 ± 140	32.2	594 ± 162	33.4
Jogging	151 ± 38	9.1	334 ± 85	18.7
Running	77 ± 25	4.7	281 ± 92	15.8
Fast running	21 ± 11	1.2	97 ± 50	5.4
Sprinting	4 ± 4	0.3	27 ± 31	1.6
Sideways movement	146 ± 59	8.7	401 ± 164	22.5
Backwards running	16 ± 12	1.0	47 ± 33	2.6
Total	1660 ± 251	100.0	1781 ± 337	100.0

actual mean playing time in defence was somewhat longer than in offence (1:29 min:s, n.s.). In contrast, high-intensity running only constituted 1.5 ± 0.8 % of TPT per match corresponding to 7.0 ± 4.1 % of total distance covered per match (▸ **Table 1**). Mean total distance covered and mean speed were 1781 ± 337 m and 6.75 ± 1.28 $km \cdot h^{-1}$, respectively. The latter was calculated without the standing still category (which constituted 42.8 ± 10.8 % of TPT). Mean speed in defence was higher ($p < 0.05$, ES = 0.56) than in offence. Like in offence, positional differences were demonstrated. WP performed more high-intensity running (9.5 ± 5.5 % of total distance covered) than both PV (6.4 ± 3.7 %, $p < 0.05$, ES = 0.66) and BP (6.2 ± 3.1 %, $p < 0.05$, ES = 0.74) (▸ **Table 3**). Furthermore, PV (7.09 ± 1.24 $km \cdot h^{-1}$, $p < 0.05$, ES = 0.50), but not WP (6.88 ± 1.52 $km \cdot h^{-1}$) demonstrated a higher mean speed than BP (6.53 ± 1.01 $km \cdot h^{-1}$). There were no differences in total distance covered between playing positions in spite of the observed differences in intensity, and the fact that BP played longer (28:42 ± 2:48 min:s) than PV (27:05 ± 2:25 min:s, n.s.) and WP (26:17 ± 2:24 min:s, $p < 0.05$, ES = 0.93) (▸ **Table 2**). In relation to total distance covered the longer playing time was neutralized by a higher percentage of standing still with BP.

Differences between first and second half of the match

Differences emerged from the first to the second half of the match. There was in several cases either a tendency or significant decrease in mean distance covered and in mean speed in the second half (▸ **Fig. 2**). Basically, the same pattern was observed, when separate analysis was performed for offensive and defensive actions, respectively. However, for all players combined no difference was observed in mean total distance covered between the first (1838 ± 235 m) and the second half (1789 ± 232 m). The amount of high-intensity running for all players combined was lower ($p < 0.05$, ES = 0.58) in the second (130.4 ± 38.4 m) than in the first half (155.3 ± 47.6 m) corresponding to a decrease of 16.2 % with 33 s less mean actual playing time in the second half. Only a few differences between mean distance covered in successive 5-min intervals between the 2 halves were identified (▸ **Fig. 3**). Thus, mean distance covered was higher ($p < 0.05$, ES = 0.84) in the first 5 min of the first half compared to the corresponding first 5 min of the second half and lower ($p < 0.05$, ES = 1.19) in the last 5 min of the first half compared to the last 5 min of the second half. The mean distance covered was also higher ($p < 0.01$, ES = 1.82) in the first 10 min of the first half compared to the last 10 min of the first half.

Discussion

To our best knowledge, this is the first study that has examined the physical demands in male elite TH using a complete locomotion match analysis. As a main finding in the present study, distinct positional differences in physical demands were demonstrated, while decreases in mean speed and amount of high-intensity running in the second half were observed.

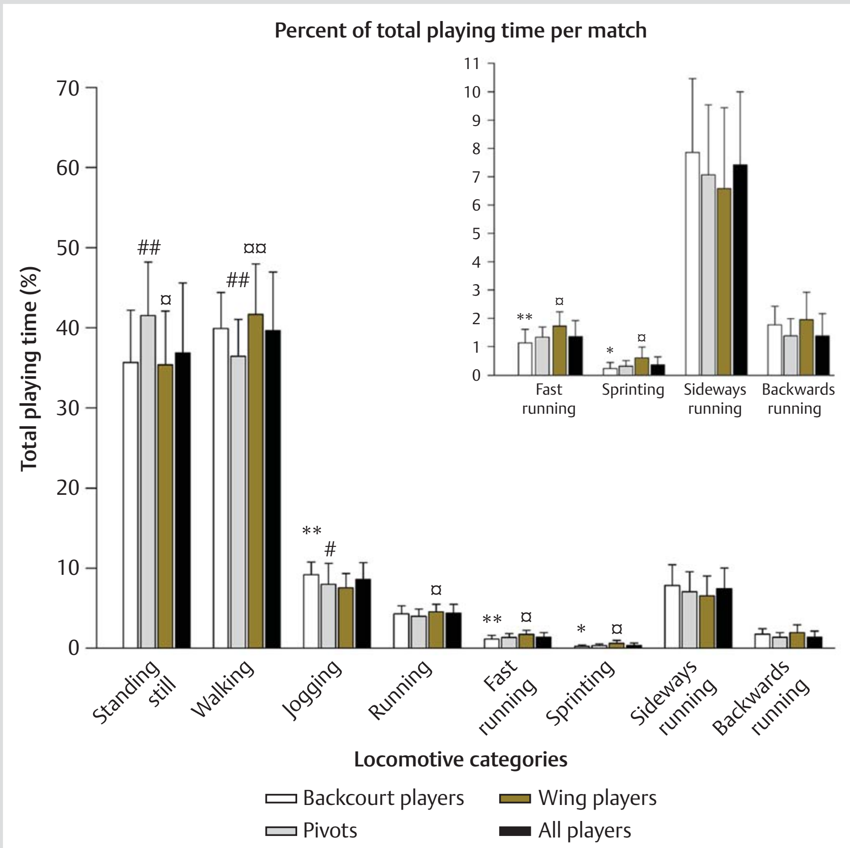

Fig. 1 Distribution of offensive and defensive actions per match (group means ± SD) for the different playing positions and for all players combined (n = 82) expressed in % of total playing time for the 8 locomotive categories. Difference between wing players and backcourt players * p < 0.05 and ** p < 0.01, between wing players and pivots ¤ p < 0.05 and ¤¤ p < 0.01 and between pivots and backcourt players # p < 0.05 and ## p < 0.01. Inserted: Zoomed graph display.

Table 2 Total distance covered and mean speed (group means ± SD) for the different playing positions, for full-time players and for all players combined for the entire match and in offence and in defence, respectively. Mean speed was calculated without of the use of the time spent in the standing still category.

Offensive and defensive actions collapsed for the entire match – Total distance covered and mean speed	All players combined (n = 82)	Full-time players (n = 13)	Wing players (n = 23)	Pivots (n = 18)	Backcourt players (n = 41)
Playing time (min:s)	53:51 ± 5:52	60:00 ± 0.00 ##	52:48 ± 5:24	53:12 ± 6:11	54:43 ± 5:31
Total distance covered (m)	3 627 ± 568	3 945 ± 538 #	3 641 ± 501 *	3 295 ± 495 π	3 765 ± 532
Mean speed (km · h⁻¹)	6.40 ± 1.01	6.34 ± 0.88	6.45 ± 0.95	6.47 ± 0.93	6.37 ± 0.91

Offensive actions for the entire match – Total distance covered and mean speed	All players combined (n = 82)	Wing players (n = 23)	Pivots (n = 18)	Backcourt players (n = 41)
Playing time (min:s)	26:11 ± 3:08	26:31 ± 3:33	26:07 ± 2:41	26:01 ± 3:01
Total distance covered (m)	1 846 ± 346	1 847 ± 271 **	1 500 ± 254 ππ	1 997 ± 312
Mean speed (km · h⁻¹)	6.08 ± 1.13	6.03 ± 0.88	5.83 ± 0.99 π	6.21 ± 0.97

Defensive actions for the entire match – Total distance covered and mean speed	All players combined (n = 82)	Wing players (n = 23)	Pivots (n = 18)	Backcourt players (n = 41)
Playing time (min:s)	27:40 ± 3:11	26:17 ± 2:24	27:05 ± 2:25	28:42 ± 2:48 €
Total distance covered (m)	1 781 ± 337	1 794 ± 400	1 795 ± 311	1 768 ± 320
Mean speed (km · h⁻¹)	6.75 ± 1.28	6.88 ± 1.52	7.09 ± 1.24 π	6.53 ± 1.11

Difference between wing players and pivots * p < 0.05 and ** p < 0.01, between wing players and backcourt players € p < 0.05, between full-time players and non-full-time players # p < 0.05 and ## p < 0.001 and between backcourt players and pivots π p < 0.05 and ππ p < 0.001

Total distance covered and mean speed

In the present study, mean total distance covered was 3 627 m with a mean TPT of 53:51 min:s, which is a little higher than previously reported in elite TH players [1,5]. However, even higher values than ours were found in other studies of elite players [16,20,35]. In the latter study, goalkeepers had the lowest total distance covered of all playing positions, which complicates comparison with results of field players' total distance covered from other studies like the present study.

Deviations in the amount of locomotion due to differences in TPT can be minimized by comparing players' mean speed rather than total distance covered. When mean speed in the present study was

Table 3 Offensive and defensive actions per match (group means ± SD) for the different playing positions separated into the 8 movement categories.

	Offensive actions for the entire match					
	Playing positions					
	Wing players (n = 23)		**Pivots (n = 18)**		**Backcourt players (n = 41)**	
	% of total playing time per match	**% of total distance covered**	**% of total playing time per match**	**% of total distance covered**	**% of total playing time per match**	**% of total distance covered**
Standing still	31.1**	0	41.2 ###	0	25.8 ππππ	0
Walking	48.8	46.7 ***	41.6 ###	46.0	48.5 ππππ	42.7 ππππ
Jogging	6.0***	11.5 ***	6.2	14.3	9.9 ππππ	17.2 ππππ
Running	3.7*	11.6 *	3.0	11.3	4.5 ππππ	12.8 ππππ
Fast running	1.8***	7.3 *	1.4 #	7.0	1.3	4.7
Sprinting	0.8***	5.0 ***	0.5 #	3.7 #	0.3	1.6
Sideways movement	5.0***	11.2 *	4.4	12.7	7.2 ππππ	15.5 π
Backwards running	2.8	6.7	1.7 # #	5.0 # #	2.5 π	5.5
Total	100.0	100.0	100.0	100.0	100.0	100.0
	Defensive actions for the entire match					
	Playing positions					
	Wing players (n = 23)		**Pivots (n = 18)**		**Backcourt players (n = 41)**	
	% of total playing time per match	**% of total distance covered**	**% of total playing time per match**	**% of total distance covered**	**% of total playing time per match**	**% of total distance covered**
Standing still	39.7*	0	41.8 ##	0	44.4	0
Walking	34.5	33.7	31.4	31.6	32.3	35.4
Jogging	9.1	17.1	9.7	19.4	8.6	18.6
Running	5.4*	17.2	4.9	16.1	4.0	14.1
Fast running	1.6***	6.8*	1.3	5.3	1.0	4.6
Sprinting	0.4*	2.7*	0.2 #	1.1 #	0.2	1.6
Sideways movement	8.2	19.8	9.7	23.9	8.4	22.7
Backwards running	1.1	2.7	1.0	2.6	1.1	3.0
Total	100.0	100.0	100.0	100.0	100.0	100.0

Difference between wing players and backcourt players * $p<0.05$, ** $p<0.01$ and *** $p<0.001$, between wing players and pivots # $p<0.05$, ## $p<0.01$ and ### $p<0.001$ and between pivots and backcourt players π $p<0.05$ and ππππ $p<0.001$

calculated by including the time spent in the standing still category (this being included in TPT to enable comparisons with previous studies), a mean speed value of ~70 $m \cdot min^{-1}$ was observed, which is considerably lower than that reported by Konzag and Schäcke in 1968 [16] despite the fact that the game of TH obviously is more intense today than 40 years ago. Further, Sichelschmidt and Klein [36] assessed mean speed to range between 85–112 $m \cdot min^{-1}$, suggesting that the deviation in total distance covered between studies may not be attributable to differences in TPT alone. In a study conducted at the 2007 Men's World Cup [20], mean speed was calculated to be ~92 $m \cdot min^{-1}$, however the mean TPT of 32:07 min:s was markedly lower than seen in the present study. These data suggest that in international male elite TH tournaments where each team play about 10 matches in 12–14 days, players tend to be frequently substituted on all playing positions, especially for BP and PV. The short TPT per match during important tournaments may enable players to sustain a very high intensity and mean speed during match-play, while yet being able to consistently perform at a high level through the entire duration of the tournament due to the multiple rest periods.

The above differences between various studies may be due to the analysed playing positions. Several studies did not describe the specific positions of the analyzed players [1,16,36]. The present study and several others [5,19,35,38] have demonstrated, however, that substantial differences exist between various playing positions (cf. **Table 3**). This means that the total distance covered for all players combined depends heavily on the relative proportion of specific playing positions analysed.

In a number of the aforementioned studies, the method used for the time-motion analysis was not described, which makes comparisons difficult. Factors such as TPT, level of competition, playing positions, tactical systems employed, match development, home advantage, etc. may influence total distance covered, but deviations from our results as high as 2 000 m cannot be explained against that background. However, it should be noted that different methods of observation and variations in the classification of movements may account for differences between studies. Also it is problematic that the previous studies were based on results obtained in 11 matches or less. As a large inter- and intra-player variability in movement pattern are evident between different games and even within each playing position, it is possible that the present study (62 matches, 82 analysed players from several different teams) may provide a more valid estimate of male elite TH players' total distance covered during match-play.

High-intensity running

The fact that the amount of high-intensity running was low in the present study does not mean that high-intensity running is not important in modern male elite TH. Potentially, a large high-intensity work capacity may be of substantial importance on the outcome of a match. The ability to work at high intensity (together with high muscular strength) is possibly the most important factor that separates superior TH teams from the less superior teams. In support of this notion, analysis of male soccer has demonstrated that elite players performed more high-intensity running during a game than sub-elite professional players [28]. This could

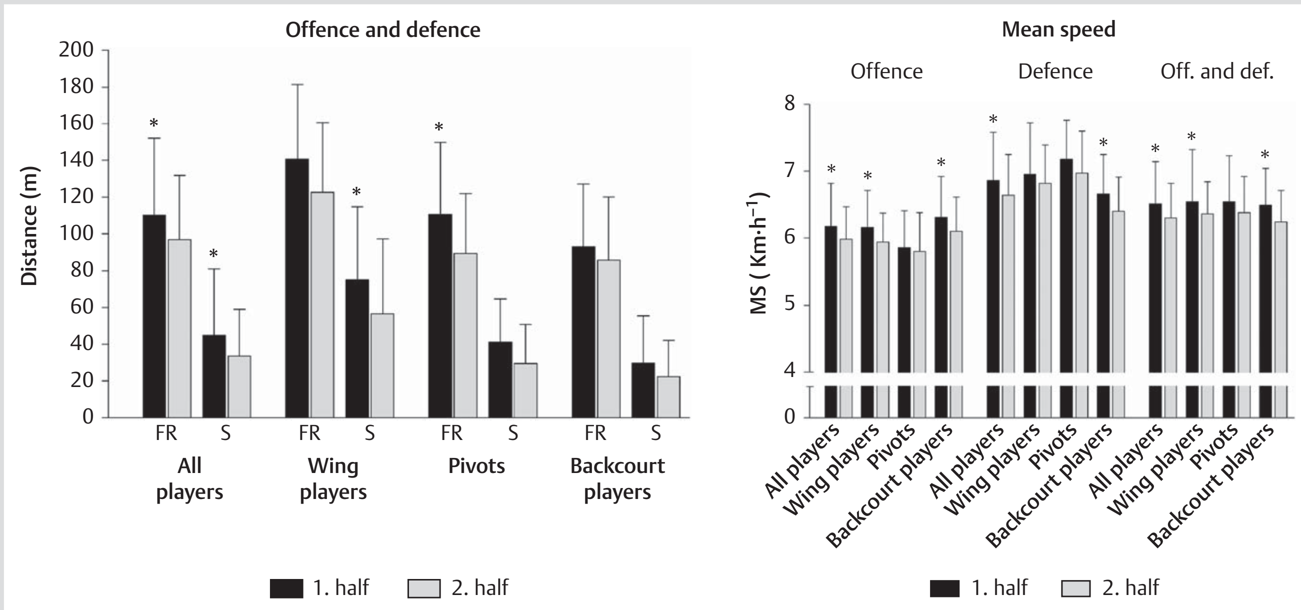

Fig. 2 Distance covered in the 2 locomotive categories fast running (FR) and sprinting (S) for offence and defence collapsed (left panel) as well as the mean speed (MS) (right panel) in 1. half and 2. half of the match. Data (group means ± SD) are shown for all players combined (n = 82) and for different playing positions. Difference between 1. half and 2. half * $p < 0.05$.

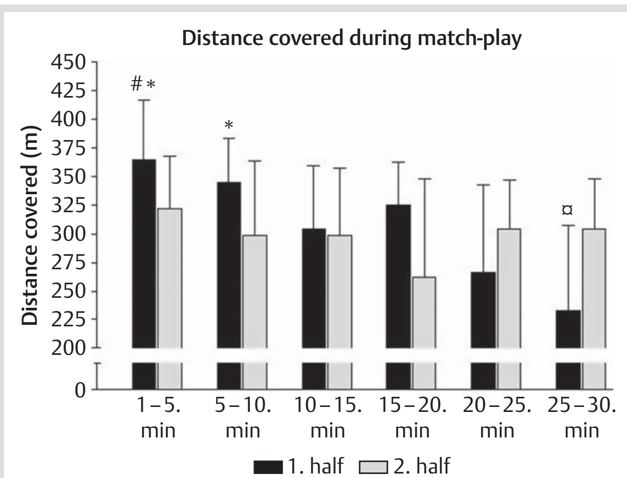

Fig. 3 Distance covered in successive 5 min-intervals (group means ± SD, n = 41) during the 1. half and 2. half time periods, respectively (black bars: 1. half, grey bars: 2. half). Longer distance covered in 1. half compared to the corresponding time period in 2. half # $p < 0.05$. Longer distance covered in first two 5-min intervals in 1. half than in the last two 5-min intervals in 1. half * $p < 0.01$. Longer distance covered in the last 5 min of 2. half compared to the corresponding time interval in 1. half ¤ $p < 0.05$.

hold true for TH players as well, in which case high-intensity running exercises should be in focus for improving elite players' ability to repeatedly perform intense exercise and to rapidly recover after such actions. The latter conception was supported by the findings from Rannou et al. [32], indicating that anaerobic metabolism is an important element in male elite Team Handball.

Compared to the present data, a higher relative amount of high-intensity running has previously been reported for male elite TH players [1,16]. However, in both studies the definitions of the locomotive categories were not described explicitly. Tanaka et al. [38] also found a higher percentage of high-intensity running (4.3 % of mean TPT) compared to the present data, which may primarily be due to a smaller TPT per match (mean TPT 36 min). This probably allowed for more high-intensity locomotion, due to the frequent rest periods of individual players enabled by the unlimited number of running substitutions. A much higher percentage of high-intensity running in field TH players (20.9 % of total distance covered per match vs. 7.9 % in our study) was reported by Luig et al. [20], partly due to a different definition of fast running and sprinting compared to our categorization. Caution has to be taken when interpreting the reason for the different findings between studies. However, this difference may be due to an optimized exploitation at the 2007 World Cup of the rule on fast throw-off, which has made the game more intense [34] and also a substantially lower mean TPT (32:07 min:s) compared to the present study. Nevertheless, these data emphasize that modern male TH is played at a fast pace during certain periods of the match, and that the ability to work repeatedly at a high intensity is very important for the elite TH player.

Although mean running speed was low, and the amount of high-intensity running was limited, the number of changing actions, e.g. accelerations and decelerations, were high. Consequently, a massive physiological load is imposed on players not only during the high intensive phases of the match (intended as high-intensity running), but also every time accelerations are performed, even when speed is low. No previous time-motion studies in TH have taken this component into account, which will allow a better definition of the concept "high intensity" on the basis of actual metabolic power rather than based on running speed alone. This type of analysis approach was recently performed in soccer [31], which revealed that "high intensity" expressed as high power output is 2–3 times greater than when analysed only from running speed. Thus, the anaerobic energy yield in TH is most likely significantly higher than presented in previous investigations, including the present study, that have merely focused on the amount of high-intensity running.

Sprinting actions

The mean duration of a sprint action (1.0 s ~7 m sprint) was quite short compared to the time it takes to perform a complete fast break at maximum speed (about 3–4 s). Although the mean sprint time also covered sprinting in other situations than fast break (e.g. multidirectional accelerations of very short duration), this indicates that in male elite TH, a fast break typically is not a maximum sprint all the way up the court. In TH it is important to react quickly and perform powerful changes in direction, while moving quickly over short distances (< 15 m). Physical training exercises, therefore, primarily should target reaction speed and acceleration (i.e. rate of force development, RFD) rather than focus on maximum running speed.

Offensive and defensive actions and differences between first and second half of the match

Mean total distance covered in offence was surprisingly similar (1 846 m) compared to defence (1 781 m), but the actual mean playing time was also a little shorter (1:29 min:s, n.s.) than in defence. However, mean speed in offence (6.08 km·h^{-1}) was lower than in defence (6.75 km·h^{-1}), because the standing still category in defence (42.8 % of TPT) was much higher compared to offence (30.5 % of TPT). Consequently, the players were standing still much more during defence, but while moving they demonstrated a relatively higher mean speed. The amount of high-intensity running per match constituted on average more in offence (2.0 % of TPT~8.7 % of total distance covered) than in defence (1.5 % of TPT~7.0 % of total distance covered), which is not surprising, since players in organized play are more locked in a tactical sense to their positions in defence compared to offence. In general, the amount of locomotion in defence was higher than probably expected.

For all players combined, no difference in mean total distance covered (2.7 %, n.s) between the first and the second half was demonstrated. In contrast, the amount of high-intensity running decreased 16.2 % in the second half. The reduction in mean distance covered for fast running and sprinting and in mean speed also applied separately in several cases for both offence and defence. These findings indicate that at least some players may experience locomotive fatigue and impaired physical performance in the second half. In line with this, studies have shown that elite soccer players performed more high-intensity running in the first compared to the second half and further that the players performed less high-intensity running at the end (last 15 min) of the second half [28]. However, we could not verify that the latter also occurs in elite male TH. It can be argued that the reduced amount of high-intensity running in the second half was related to the fact that the outcome of the match was already decided early in the second half. However, such a relationship was not found.

When successive 5-min intervals in the 2 halves were analysed, a longer running distance and higher amount of high-intensity running were observed in the first 5 min of the first half compared to the first 5 min of the second half (▶ **Fig. 3**). A possible reason for this may arise from a lack of warm-up prior to the second half. In support of this notion, parallel reductions in muscle temperature and sprint capacity were observed in elite soccer players following the half-time break, which could be fully prevented by a re-warm-up procedure [29]. Possibly, elite TH players might benefit in a similar manner if employing re-warm-up activities prior to the onset of the second half of the match.

Likewise, mean distance covered was higher in the first 10 min of the first half compared to the last 10 min of the first half (▶ **Fig. 3**), indicating that locomotive fatigue might occur temporarily already in the first half in (nearly) full-time TH players. In support of this notion, mean distance covered was found to be lower in the last 5 min of the first half compared to the last 5 min of the second half. Thus, TH players might recover through periods of less amount of locomotion in the second half, enabling them tactically and physically to demonstrate an enhanced all-out performance in the final phase of the match. Significant fatigue induced reductions in muscle strength and maximum jump height have previously been observed in both male and female elite TH players, respectively, following simulated TH match exercises [39,40]. Although the results in the present study were supported by results from the technical match analysis [25] and from the physiological measurements during match-play [26], muscle biopsies and blood samples taken in connection with the matches obviously would be needed to fully examine the extent of match-induced fatigue in male elite TH.

Differences between playing positions

All playing positions consistently showed not surprisingly a higher percentage of high-intensity running in offence than in defence. In addition, marked positional differences in the physical demands were observed. Both in offence and in defence WP on average performed more high-intensity running than PV and in particular BP. In spite of the low amount of high-intensity running in offence, BP together with WP performed a higher mean total distance covered, and BP also worked with a higher mean speed compared to PV. Due to their central position in the offence, BP rarely stood still showing a lot of motion with many sideway movements. PV on the other hand did not run very much in the organised attack due to their relatively fixed position at the 6 meter line, but instead had a lot of physical contact with opponent players. A different picture was seen in defence, where PV worked with a higher mean speed than BP. The proportion of high-intensity running and thus the anaerobic demands in terms of running was similar in players, who played WP in offence and who covered BP in defence compared to players, who played BP in offence and covered WP in defence (cf. ▶ **Table 3**). On the other hand, the latter players performed more moderate-intensity activities, potentially imposing greater aerobic demands on these players (cf. ▶ **Table 3**).

In international elite top-level players, WP performed a longer mean total distance covered than PV and BP [5,20]. Identical positional differences in movement pattern were observed in experimental matches (TPT 40 min) in male TH players [35], although all teams were restricted by having to play a particular defence system, which affects the results compared to a normal game with varying defence systems as reported by Gomes and Volossovitch [11]. Overall, the present results combined with previous study data thus suggest that running training with and without ball possession in male elite TH should be more individually planned instead of the traditional collective way. In addition, the physical training should not only be adjusted to the specific playing position, but also to the players' individual physical capacity as well as their individual need to recover.

Conclusions

In conclusion, indications of temporary locomotive fatigue and impaired physical performance were observed during male elite TH match-play, reflected by reduced amounts of high-intensity running in the second half. Further, match-play appeared to place moderate-to-high demands on intermittent endurance running capacity as evidenced by a total distance covered of ~3 600 m, interspersed by brief periods with high amounts of high-intensity running (~8% of TDC) making modern male elite TH a physically demanding intermittent team sport. Major individual differences in physical demands were observed between playing positions, with WP demonstrating a more intensive activity pattern than BP and PV, reflected by WP performing more high-intensity running (~11% of TDC) than BP (~6%) and PV (~9%). The current findings provide valuable information about match related activity patterns in male elite TH players, which may be useful in the development of position-specific training regimens.

In perspective, organized attack in male elite TH 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. Although based on the present data high-intensity running did not per se represent much of TPT, the ability continuously to change pace and accelerate throughout the entire match is likely of high importance for top-level playing performance. Future studies should be conducted to implement more precise analytical means to quantify high-intensity locomotion activities in TH e.g. on the basis of actual metabolic power rather than on the running speed alone, hence including all types of accelerations and decelerations performed. In addition, an increased and differential focus in the training on improving high-intensity intermittent exercise capacity would seem relevant to ensure optimal individual development of the physical capacity in elite TH players. Finally, it would be of major interest in future studies to investigate the extent of fatigue in TH using e.g. muscle biopsies and blood samples taken during match-play in friendly games as previously done in soccer [19] and to examine the impact of different training regimens (aerobic vs. anaerobic exercise) to provide improved fatigue resistance during elite TH match-play.

Acknowledgements

The study was partly supported by the Danish Elite Sports Association (Team Danmark). We like to thank the elite TH players particularly the 2 top ranked teams that volunteered to participate in the study. Primary study data have been presented at the European Handball Federation Scientific Conference 2011.

References

1 *Al-Lail A.* A Motion Analysis of Work-Rate & Heart Rate of Elite Kuwayti Handball Players. Asian Handball Federation, Kuwait, Commission for Promotion & Public Relations IHF 2000
2 *Bangsbo J.* The physiology of soccer – with special references to intense intermittent exercise. Acta Physiol Scand Suppl 1994; 619: 1–155
3 *Bradley PS, Sheldon W, Wooster B, Olsen P, Boanas P, Krustrup P.* High-intensity running in English FA Premier League soccer matches. J Sports Sci 2009; 27: 159–168
4 *Coutts AJ, Reaburn PRJ.* Time and motion analysis of the AFL field umpire. J Sci Med Sport 2000; 3: 132–139
5 *Cuesta G.* Balonmano [Team Handball]. Spanish Handball Federation, Madrid: 1991
6 *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: 55–59
7 *Di Salvo V, Baron R, Tschan H, Calderon Montero FJ, Pigozzi F.* Performance characteristics according to playing position in elite soccer. Int J Sports Med 2007; 28: 222–227
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 Science Res 1992; 6: 120–124
9 *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: 357–366
10 *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: 225–232
11 *Gomes F, Volossovitch A.* The defensive performance in handball analysis of the first three first placed teams in men's European Championship 2006. In: Cabri J, Alves F, Araujo D, Barreiros J, Diniz J, Veloso A (eds.). Proceedings of the Annual Congress of the European College of Sport Science. Estoril, Portugal: 2008; 565
12 *Harriss DJ, Atkinson G.* Update – ethical standards in sport and exercise science research. Int J Sports Med 2011; 32: 819–821
13 *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: 255–258
14 *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: 354–358
15 *King T, Jenkins D, Gabbett T.* A time-motion analysis of professional rugby league match-play. J Sports Sci 2009; 27: 213–219
16 *Konzag I, Schäcke C.* Zur physischen Belastung im Hallenhandballspiel. Theorie und Praxis der Körperkultur [To the physical load in the game of Team Handball. Theory and practice of the Body culture] 1968; 17: 875–882
17 *Krustrup P, Bangsbo J.* Physiological demands of top class soccer refereeing in relation to physical capacity and training. J Sports Sci 2001; 19: 881–891
18 *Krustrup P, Mohr M, Ellingsgaard H, Bangsbo J.* Physical demands during an elite female soccer game: importance of training status. Med Sci Sports Exerc 2005; 37: 1242–1248
19 *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: 1165–1174
20 *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 (eds.). Proceedings of the Annual Congress of the European College of Sport Science. Estoril, Portugal: 2008; 241–242
21 *McInnes SE, Carlson JD, Jones CJ, McKenna MJ.* The physiological load imposed on basketball players during competition. J Sports Sci 1995; 13: 387–397
22 *McKenna MJ, Patrick JD, Sandstrom ER, Chennells MHD.* Computer-video analysis of activity patterns in Australian Rules Football. In: Reilly T, Lees A, Davids K, Murphy W (eds.). Science and Football. London: E & FN Spon, 1988; 274–281
23 *McLean DA.* Analysis of the physical demands of international rugby union. J Sports Sci 1992; 10: 285–296
24 *Michalsik LB.* Analysis of working demands of Danish handball players. In: Jørgensen P, Vogensen N (eds.). What going on in the gym? Learning, Teaching and Research in Physical Education. Proceedings of International Conference on PE-teaching, Learning and Research, University of Southern Denmark, Denmark: 2004; 321–330
25 *Michalsik LB, Aagaard P, Madsen K.* Technical activity profile and influence of body anthropometry in male elite Team Handball players. In: European Handball Federation (eds.). European Handball Federation Scientific Conference 2011 – Science and Analytical Expertise in Handball. Proceedings of the first International Conference on Science in Handball. Vienna, Austria: 2011; 174–179
26 *Michalsik LB, Aagaard P, Madsen K.* Match performance and physiological capacity of male elite Team Handball players. In: European Handball Federation. (eds.). European Handball Federation Scientific Conference 2011 – Science and Analytical Expertise in Handball. Proceedings of the first International Conference on Science in Handball. Vienna, Austria: 2011; 168–173

27 *Michalsik L*, *Bangsbo J*. Fysisk træning. In: Danmarks Idræts-Forbund (eds.). Aerob og anaerob træning. [Physical training. In: National Olympic Committee and Sports Confederation of Denmark (eds.). Aerobic and anaerobic training.], 2002; 130–152
28 *Mohr M*, *Krustrup P*, *Bangsbo J*. Match performance of high-standard soccer players with special reference to development of fatigue. J Sports Sci 2003; 21: 519–528
29 *Mohr M*, *Krustrup P*, *Nybo L*, *Nielsen JJ*, *Bangsbo J*. Muscle temperature and sprint performance during soccer matches – beneficial effect of re-warm-up at half-time. Scand J Med Sci Sports 2004; 14: 156–162
30 *Narazaki K*, *Berg K*, *Stergiou N*, *Chen B*. Physiological demands of competitive basketball. Scand J Med Sci Sports 2009; 19: 425–432
31 *Osgnach C*, *Poser S*, *Bernardini R*, *Rinaldo R*, *Prampero PE*. Energy cost and metabolic power in elite soccer: A new match analysis approach. Med Sci Sports Exerc 2010; 42: 170–178
32 *Rannou F*, *Prioux J*, *Zouhal H*, *Gratas-Delemarche A*, *Delemarche P*. Physiological profile of handball players. J Sports Med Phys Fitness 2001; 41: 349–353
33 *Riise C*, *Michalsik LB*, *Wittendorff M*. Computer analysis in Team Handball. Institute of Exercise and Sport Sciences, University of Copenhagen, Denmark: 2006
34 *Ronglan LT*, *Raastad T*, *Børgesen A*. Neuromuscular fatigue and recovery in elite female handball players. Scand J Med Sci Sports 2006; 16: 267–273
35 *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: 58–68
36 *Sichelschmidt P*, *Klein GD*. Belastungssteuerung im Training. Handball-training [Regulation of load in training. In: Team Handball training] 1986; 7: 3–12
37 *Steele JR*, *Chad KE*. Relationship between movement patterns performed in match-play and in training by skilled netball players during competition. J Hum Mov Stud 1991; 20: 249–278
38 *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
39 *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: 462–472
40 *Zebis MK*, *Bencke J*, *Andersen LL*, *Alkjaer T*, *Suetta C*, *Mortensen P*, *Kjaer M*, *Aagaard P*. Acute fatigue impairs neuromuscular activity of anterior cruciate ligament-agonist muscles in female team handball players. Scand J Med Sci Sports 2011; 21: 833–840