# Match Performance and Physiological Capacity of Female Elite Team Handball Players

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## Abstract

The present study evaluated the physical demands imposed on female elite team handball players in relation to playing position. Female elite team handball field players were examined during match-play over a 5-year period using video based computerized locomotion analysis of tournament matches. In addition, physiological measurements during match-play and in separate physical tests were carried out. A total distance of 4002±551 m (group means±SD) was covered per match with a total effective playing time of 50:42±5:50 min:s, while full-time players covered 4693±333 m. On average, each player (n=83) performed 663.8±99.7 activity changes per match, and the mean speed was $5.31\pm0.33\,km\cdot h^{-1}$. High-intensity running constituted 0.8±0.5% of total effective playing time per match corresponding to 2.5±1.8% of the total distance covered. The amount of high-intensity running was reduced ($p<0.05$) 21.9% in the second half (44.9±16.8 m) compared to the first (57.5±21.3 m). Maximal oxygen uptake ($VO_2$-max) was $3.49\pm0.37\,l\,O_2\cdot min^{-1}$ corresponding to $49.6\pm4.8\,ml\,O_2\cdot min^{-1}\cdot kg^{-1}$. Mean relative workload during match-play was 79.4±6.4% of $VO_2$-max. Mean total running distance in the Yo-Yo intermittent recovery test (level 1) was 1436±222 m, which was greater in wing players (1516±172 m, $p<0.05$) than pivots (1360±118 m) and backcourt players (1352±148 m). In conclusion, modern female elite team handball is a physically demanding intermittent team sport, where players are exposed to high relative workloads with substantial estimated aerobic energy expenditure interspersed by short periods of dominant anaerobic energy production as reflected by the limited amount of high-intensity running. Indications of fatigue and a resulting decline in physical performance were identified, since the amount of high-intensity running and the relative workload levels decreased in the second half. Positional differences were observed, with wing players covering a greater total distance than backcourt players, performing more high-intensity running and demonstrating a better intermittent recovery capacity (Yo-Yo test outcome) compared to both backcourt players and pivots.

## Introduction

The requirements for female elite team handball (TH) players have changed as the game of TH has evolved substantially over the last decades. The amount of training and the number of matches have increased considerably, and recently introduced rule changes, e.g. the quick throw-off, have led to an increased number of attacks during match-play [33]. This has contributed to elevating the intensity of game-play and increasing the physical demands imposed on the players. Consequently, modern elite TH has transformed into a fast and intense game performed by well-trained players, who must be able to perform many different movements such as running, side-cutting, jumping, shooting, changing direction and technical playing actions (e.g. tackles and screenings) with a high degree of physical contact with opponents. With this development in mind, there is a need to examine, develop and implement optimal physical training regimes in modern female TH, which should be planned and executed based on a specific working demand analysis in order to meet actual on-court playing demands [21].

Despite the fact that TH is an Olympic sport with increased professionalization and international popularity, there appears to be a profound lack of scientific studies about demands analysis in women's TH and the physiology of female elite TH players. Recently, a complete working demand analysis in male elite TH was performed [23,24]. However, due to physiological differences between the sexes [42], conclusions based on on-court match analysis data in male players cannot be transferred directly to female players. For this reason and because both the nature of the game of TH and the scientific methods of analysis have developed substantially during the recent years, it would seem to be particularly relevant to employ a comprehensive analysis of the physical demands of modern female elite TH in order to evaluate the physical requirements placed on current female elite players.

Although only rarely conducted, locomotion match analysis (time-motion analysis) appears to be useful for examining the activity pattern and physical working demands of TH [24,30]. Consequently, time-motion analysis can be used to improve playing performance in modern elite TH. In addition, various physiological measurements can be carried out during match-play. The physical demands of elite TH players can be assessed by continuous heart rate (HR) recording and subsequent determination of the relative workload to evaluate the aerobic loading during match-play. Furthermore, it would seem relevant to investigate possible differences in the physical demands between various playing positions. Different physical requirements would suggest that the physical training should be performed more individually at the expense of the more traditional collective way, where uniform training is conducted using identical intensity and frequency for all players on a team. Assuming that the players have adapted to the working demands of the game through many years of TH training, various physical performance tests (capacity analysis) can provide additional information about the working requirements [26].

Finally, it remains unknown whether the performance of female elite TH players is impaired during match-play due to accumulation of fatigue. This aspect can be examined by analysing the change in high-intensity activity throughout an entire match as was recently done in male elite TH [24]. It should be recognized, however, that players' physical performance in the latter phase of the match (i.e. the second half) may also be influenced by situational variables such as match location, quality of opposition and match status, as previously indicated in elite soccer [4,17,18,38].

The aims of the present study, therefore, were (i) to determine the physical and physiological demands placed on female elite TH players, (ii) to evaluate the physiological profile of female elite TH players, (iii) to identify positional differences in all these parameters, and (iv) to examine if physical match performance is impaired during an elite TH match. Since extensive differences in activity patterns may occur according to different matches, teams and playing positions, respectively, the present study comprised a large group of players in the Danish Premier Female Team Handball League from various teams representing all playing positions. As the activity patterns of goalkeepers obviously differ substantially from those of field players, the physical demands placed on goalkeepers were not examined.

## Materials and Methods

### Subjects

Female elite TH players were recruited for the study from teams ranked in the upper half of Danish Premier Female Team Handball League (including 2 top ranked teams), which is considered to rank among the top-leagues in international female TH. During the entire study period these 2 teams were constantly ranked among the top 4 teams in the Danish Premier Female Team Handball League that achieved entry into the season final play-off tournament for the Danish Championship. A majority of the players were competing in European TH club tournaments, 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 & Atkinson [8] and with the principles of the Declaration of Helsinki.

The players were examined over a 5-year period. The study was carried out during the entire tournament match season (September to May, with players performing 6–10 training sessions and 1–2 matches per week). A number of different teams were monitored in the present study, with new players joining individual teams, while other players were leaving the teams during the whole study period. No year-to-year differences were observed during the 5-year study period for any of the analysed parameters. The analysed matches were performed indoor under thermoneutral conditions in terms of temperature (18–22 °C) and humidity (50–70 %).

The physical characteristics of the players from the 2 top ranked teams ($n = 24$) were $25.9 \pm 3.8$ years (group means ± SD), $174.2 \pm 5.7$ cm and $70.3 \pm 7.4$ kg with $6.9 \pm 3.3$ years of playing experience at adult elite level, respectively. Wing players ($n = 10$) demonstrated lower body height ($170.6 \pm 5.0$ cm) and body mass ($65.2 \pm 2.7$ kg) compared to both pivots ($178.8 \pm 3.4$ cm, $p < 0.01$, $ES = 1.92$; $76.5 \pm 8.1$ kg, $p < 0.01$, $ES = 1.87$, $n = 7$) and backcourt players ($175.1 \pm 5.3$ cm, $p < 0.01$, $ES = 0.87$; $71.4 \pm 6.1$ kg, $p < 0.01$, $ES = 1.31$, $n = 7$).

### Observations during match-play – video recordings

Observations during match-play took place by means of video recordings of competitive games. The matches were taped in such a manner that one camera captured one player (field players only) close up continuously without interruption throughout the entire time course of the match. A total of 180 single player recordings were obtained in 46 full-length tournament matches in the Danish Premier Female Team Handball League. 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. Inclusion criteria, therefore, were determined as being 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 each half of the game of 18 min or more (i.e. ~60 % of total duration of one half). A total of 83 recordings (20 different players from several different teams, mean number of recordings per player: 4.2, range: 1–8) fulfilled these conditions and were analysed according to the established criteria [24].

Tactical/technical demands differ substantially between offence and defence actions during TH match-play. The present computerized match analysis, therefore, comprised assessment of locomotion characteristics (running types, intensity and distance) separately in offensive and defensive playing actions, respectively. In this differential analysis (offence and defence) field players were further divided into 3 categories, wing players (WP), pivots (PV) and backcourt players (BP), respectively. A total of 8 locomotive categories were defined in accordance with previous studies conducted in elite soccer [1,15,28] and team handball [24]. Each movement category was classified by a precise definition of the form of locomotion and the locomotive speed measured in $km \cdot h^{-1}$. The speed was determined from detailed studies of the video recordings using known distances between the visible floor lines displayed on the playing court as calibration references. Thus, the time for the player to cover 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. Knowing the mean speed performed at each given type of locomotion, the distance covered for each form of movement was determined as the product of the total time and the mean speed for that movement. Total distance covered (TDC) during a match was then calculated as the sum of the distances covered in each type of locomotion.

The movement categories and corresponding speeds were low-intensity activities (standing still ($0\,km \cdot h^{-1}$), walking ($4\,km \cdot h^{-1}$)), moderate-intensity activities (jogging ($7\,km \cdot h^{-1}$), sideways movement ($9\,km \cdot h^{-1}$), backwards running ($9\,km \cdot h^{-1}$), running ($12\,km \cdot h^{-1}$)), and high-intensity running (fast running ($15.5\,km \cdot h^{-1}$), sprinting ($22\,km \cdot h^{-1}$)). All running speeds were specific for female elite TH players and lower than those used in male elite TH players [24] according to separate studies of the video recordings from the women's and men's games, respectively. Studies in other ballgames have reported a high validity of time-motion analysis [13,20,36]. For the locomotion match analysis, a custom-designed program was created for computer-based analysis of TH [27].

To ensure high data reliability, all matches in the present study were analysed by the same experienced observer. A similar approach has been used in previous studies [24,28,39]. Notably, the observer had to meet certain criteria before initiating the actual data analysis. To achieve this, an intense practise period with studies of individual players' styles of locomotion and several validations tests were performed in a selected subgroup of players to ensure a consistent allocation of players' activities into the predetermined categories of locomotion. The first and the second half of each match were analysed in randomized order. Sufficient competence of the analyst was deemed to be demonstrated, when individual player data from repeated analysis of the same match differed by less than 3% in each of the locomotive categories and for the total distance covered, respectively [24]. Thus, no systematic differences in the final intra-observer test-retest of the match were observed following the period of analyst training.

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].

## Physiological measurements during match-play

The physiological workload during matches in the Danish Premier Female Team Handball League was registered by continuous HR monitoring in successive 5-s intervals. Approximately 45 min before match start, the players were equipped with a chest strap heart monitor (Polar Team System, Polar Electro OY, Kempele, Finland) with the receiver part located in the transmitter strap (no need for a wristwatch receiver during match-play). By registration of the time when the match was paused and when the player was not on the court due to substitution, suspension or injury, all inactive time periods could be excluded from the HR analysis. HR was analysed in 3 different time domains, namely total playing time (the time span of the whole match), effective playing time (the time span of the actual playing time) and individual playing time (the time span when the individual player is active on the court). Blood sampling in connection with tournament matches was not allowed.

## Physiological capacity analysis – laboratory treadmill testing

On a separate day, an incremental treadmill running test was performed, which consisted of a submaximal test followed by an exhaustive incremental maximal test (all-out test). The protocol consisted of horizontal running at speeds of 8, 10, 12 and $14\,km \cdot h^{-1}$, respectively, in 6-min bouts separated by 2-min rest periods (submaximal test). Subsequently after a 15-min rest period, an all-out test was performed. The all-out test started at a running speed at $12\,km \cdot h^{-1}$ for 2 min followed by 1 min at $14\,km \cdot h^{-1}$, and then continued with stepwise $1\,km \cdot h^{-1}$ speed increments every minute until exhaustion. Total running time to exhaustion during the all-out test was recorded.

Respiratory measurements were conducted using online analysis (Oxycon Pro, Jaeger, VIASYS Healthcare, Hoechberg, Germany). During the submaximal test, $VO_2$ was measured in 30-s intervals during the final 2 min of steady-state running at each running speed. Individual maximal oxygen uptake ($VO_2$-max) and HR-max were determined as the peak values recorded in a 15-s and 5-s period, respectively, during the final phase of the all-out test. In addition, the Fitness Index (ml $O_2 \cdot min^{-1} \cdot kg^{-0.73}$) was calculated [cf. 12].

HR was continuously recorded in 5-s intervals throughout the test using a Polar S610 HR monitor (Polar Electro OY, Kempele, Finland). The individual HR-$VO_2$ relationship obtained during the treadmill test was used to estimate $VO_2$ during match-play based on the players' HR obtained during match-play according to previous soccer match analyses [1,6,13] and analysis conducted in elite male TH players [22]. The values of the individual mean match-play HR was simply placed in the correlation equation ($y = a \cdot x + b$) between HR and $VO_2$ from the treadmill test. Subsequently, the relative workload during match-play could be determined expressed as % of $VO_2$-max.

## Field testing – Yo-Yo intermittent recovery test

The ability to work intensely and to recover quickly after intense work bouts was assessed on the TH court using the Yo-Yo intermittent recovery test, level 1 (Yo-Yo IR1-test) as described by Bangsbo et al. [2]. This test has previously been documented to have high reproducibility and reliability [14,16,40]. All players had previous experience with the Yo-Yo IR1-test, which was performed on a separate day. In addition, a pre-study familiarization test round was performed in all players.

## Statistical analysis

All statistical analyses were conducted using R2 Version 13.1 (University of Auckland, New Zealand). All data are expressed as group mean values ± standard deviations (SD) unless otherwise stated. The assumption of Gaussian data distribution was visually 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. The assumption about similar variance was tested using residual plots. Statistical differences between several groups (i.e. comparing different playing positions) were evaluated using one-way analysis of variance (ANOVA). Post Hoc differences between each group were evaluated by Tukey's HSD testing (normally distributed). The Pearson product-moment correlation analysis was used to evaluate potential relationships between selected parameters. Effect size (d-values designated as ES) calculations (Cohen's d-test) were used to estimate the magnitude of the results (differences between subjects or groups) and were reported along with all statistically significant results as a measure of practical significance. The level of statistical significance was set at $p \leq 0.05$ using a 2-tailed test design.

## Results

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### Game duration and effective playing time

Mean total duration of the tournament games examined in the present study (n = 46) was 71:02 ± 2:17 min:s corresponding to 18.4 % extension compared to the nominal 60 min TPT. No difference was found between the full duration of the first (35:22 ± 1:37 min:s) and the second half (35:21 ± 1:32 min:s), which corresponded to an extension of 17.9 % and 18.9 %, respectively, relative to the nominal playing time of 30 min. Half-time duration was reduced 16.2 % compared to the nominal half-time break of 15 min, meaning that the teams refrained from using a full half-time. Mean TPT for the analysed players in an entire game (n = 83) was 50:42 ± 5:50 min:s. No difference in mean TPT was observed between defence (26:08 ± 3:50 min:s) and offence (24:34 ± 4:20 min:s), or between the first (25:24 ± 2:35 min:s) and the second half of the match (25:18 ± 2:45 min:s).

### Match performance

Mean number of activity changes per match for all players combined was 663.6 ± 100.1 per player (0.2 activity changes $\cdot$ $s^{-1}$~13 activity changes $\cdot$ $min^{-1}$) with a mean of 16.4 ± 9.7 high-intensity runs per match (▶ **Table 1**). The mean playing time per match was 37:02 ± 4:57 min:s at low intensity (~73.1 % of TPT), 13:15 ± 2:46 min:s at moderate intensity (~26.1 % of TPT) and 0:25 ± 0:15 min:s at high intensity (~0.8 % of TPT). The mean duration of fast running and sprinting for all players combined was 1.5 ± 1.0 s per action and 0.9 ± 1.1 s per action, respectively.

Mean TDC and mean speed were 4 002 ± 551 m and 5.31 ± 0.33 km $\cdot$ $h^{-1}$, respectively. The latter was calculated excluding the standing still category (which constituted 10.8 ± 3.8 % of TPT). Standing still and walking combined constituted 73.1 ± 4.8 % of TPT per match (▶ **Table 2**). In contrast, the amount of high-intensity running constituted 0.8 ± 0.5 % of the TPT per match corresponding to 2.5 ± 1.8 % of TDC per match.

Activity patterns differed between various playing positions (▶ **Fig. 1**, ▶ **Table 3**). Both WP (4 086 ± 523 m, ES = 0.48) and PV (4 067 ± 485 m, ES = 0.46) covered a greater total distance per match ($p < 0.05$) than BP (3 867 ± 386 m). Players, who played full time (60 min playing time, n = 10, mostly WP), performed a greater TDC (4 693 ± 333 m, $p < 0.01$) compared to non-full-time players (3 908 ± 506 m, ES = 1.83, n = 73). No differences between full-time players and all players combined (n = 83) in percentage of TPT per match for the 8 locomotive categories was observed, indicating that full-time players covered a greater total distance per match, primarily because they played for a longer period of time (▶ **Table 3**). Assuming constancy in intensity for the remainder of the match (last 10:34 min:s), non-full-time players would have covered a mean of 4 744 m if playing full time.

WP performed more high-intensity running (3.6 ± 1.5 % of TDC) than PV (2.3 ± 1.5 %, $p < 0.01$, ES = 0.87) and particularly BP (1.3 ± 0.9 %, $p < 0.001$, ES = 1.86). High-intensity running constituted 3.3 ± 1.2 % of TDC among full-time players. Furthermore, WP (5.44 ± 0.29 km $\cdot$ $h^{-1}$, ES = 1.01) and PV (5.31 ± 0.37 km $\cdot$ $h^{-1}$, ES = 0.48) demonstrated a higher mean speed ($p < 0.05$) during match-play than BP (5.17 ± 0.19 km $\cdot$ $h^{-1}$).

### Offensive actions

Standing still and walking combined constituted 71.2 ± 6.9 % of TPT per match in offence with a mean TPT of 24:34 ± 4:20 min:s. In contrast, high-intensity running only constituted 0.7 ± 0.6 % of the TPT per match corresponding to 2.3 ± 2.1 % of TDC per match (▶ **Table 2**). Mean TDC and mean speed were 1 970 ± 323 m and 5.34 ± 0.47 km $\cdot$ $h^{-1}$, respectively (▶ **Table 3**). The latter was calculated excluding the standing still category (which accounted for 9.9 ± 6.1 % of TPT).

WP performed more high-intensity running (3.7 ± 2.0 % of TDC) than PV (2.3 ± 1.6 %, $p < 0.01$, ES = 0.77) and in particular BP (0.8 ± 0.7 %, $p < 0.001$, ES = 1.94) (▶ **Table 4**). Furthermore, WP (5.50 ± 0.48 km $\cdot$ $h^{-1}$, ES = 0.81) and PV (5.31 ± 0.37 km $\cdot$ $h^{-1}$, ES = 0.40) showed a higher mean speed ($p < 0.05$) than BP (5.18 ± 0.28 km $\cdot$ $h^{-1}$) (▶ **Table 3**). No positional differences in TDC and in TPT were demonstrated, indicating that the difference in mean speed was mainly due to differences in the standing still category.

### Defensive actions

Standing still and walking combined constituted 74.8 ± 5.5 % of TPT per match in defence with mean TPT of 26:08 ± 3:51 min:s. The actual playing time was 1:34 min:s (n.s.) longer than in offence. In contrast, high-intensity running only constituted 0.8 ± 0.6 % of TPT per match corresponding to 2.8 ± 2.1 % of TDC per match (▶ **Table 2**). Mean TDC and mean speed were 2 032 ± 362 m and 5.29 ± 0.32 km $\cdot$ $h^{-1}$, respectively (▶ **Table 3**). The latter was calculated excluding the standing still category (which accounted for 11.7 ± 4.9 % of TPT). Mean speed did not differ between offence and defence.

As in offence, positional differences were observed when players were in defence. Both WP (2 118 ± 416 m, ES = 0.56) and PV (2 103 ± 396 m, ES = 0.54) covered a greater total distance per match than BP (1 922 ± 268 m, $p < 0.05$). WP also performed more high-intensity running (3.5 ± 2.2 % of TDC, $p < 0.05$) than PV (2.4 ± 2.1 %, ES = 0.51) and BP (2.5 ± 1.8 %, ES = 0.50) (▶ **Table 4**), and both WP (5.39 ± 0.28 km $\cdot$ $h^{-1}$, ES = 0.77) and PV (5.31 ± 0.30 km $\cdot$ $h^{-1}$, ES = 0.47) showed a higher ($p < 0.05$) mean speed than BP (5.17 ± 0.29 km $\cdot$ $h^{-1}$) (▶ **Table 3**).

### Differences between first and second half of the match

Substantial differences were observed between the first and the second half. In the second half, there were in most cases either a tendency or a significant decrease in the mean distance covered and in mean speed (▶ **Fig. 2**). For all players combined, the number of low-intensity activities increased ($p < 0.05$), whereas the number of high-intensity activities were reduced ($p < 0.05$) in the second half (▶ **Fig. 3**).

Furthermore, the amount of high-intensity running was lower in the second half (44.9 ± 16.8 m) than in the first (57.5 ± 21.3 m, $p < 0.05$, ES = 0.66), corresponding to a decrease of 21.9 % with

**Table 1** Number of activity changes (group means ± SD) as a function of work intensity observed during the locomotion match analysis when movement patterns were combined in subgroups of low intensity (standing still, walking), moderate intensity (jogging, sideways movement, backwards running, running) and high intensity (fast running, sprinting).

| | Activity changes and work intensity | | | | |
|---|---|---|---|---|---|
| **All players combined (n = 83)** | **Number per match** | **% of total number** | **Playing time (min:s)** | **% of playing time** | **Duration per activity change (s)** |
| Low intensity | 330.2 ± 61.7 | 49.7 | 37:02 ± 4:57 | 73.1 | 6.7 |
| Moderate intensity | 317.0 ± 49.3 | 47.8 | 13:15 ± 2:46 | 26.1 | 2.5 |
| High intensity | 16.4 ± 9.7 | 2.5 | 0:25 ± 0:15 | 0.8 | 1.5 |
| Total | 663.6 ± 99.7 | 100.0 | 50:42 ± 5:50 | 100.0 | 4.6 |
| **Wing players (n = 35)** | | | | | |
| Low intensity | 327.6 ± 56.4 | 49.5 | 36:52 ± 5:15 | 71.8 | 6.8 |
| Moderate intensity | 312.7 ± 52.6 | 47.2 * | 13:51 ± 3:01 | 27.0 | 2.7 |
| High intensity | 22.1 ± 8.3 ** | 3.3 ** | 0:38 ± 0:15 * | 1.2 * | 1.7 * |
| Total | 662.4 ± 97.4 | 100.0 | 51:21 ± 6:53 | 100.0 | 4.6 |
| **Pivots (n = 18)** | | | | | |
| Low intensity | 376.4 ± 61.9 ## | 52.1 # | 37:22 ± 4:39 | 73.1 | 6.0 |
| Moderate intensity | 328.9 ± 58.2 | 45.5 | 13:23 ± 3:04 | 26.2 | 2.4 |
| High intensity | 17.3 ± 10.6 ## | 2.4 ## | 0:22 ± 0:14 # | 0.7 # | 1.3 # |
| Total | 722.6 ± 110.9 # | 100.0 | 51:07 ± 5:12 | 100.0 | 4.2 # |
| **Backcourt players (n = 30)** | | | | | |
| Low intensity | 305.5 ± 52.9 πππ | 48.5 ππ | 37:03 ± 4:42 | 74.5 | 7.3 |
| Moderate intensity | 314.8 ± 39.2 | 50.0 πππ | 12:27 ± 1:59 | 25.1 | 2.4 |
| High intensity | 9.3 ± 5.1 ππ | 1.5 π | 0:12 ± 0:08 π | 0.4 π | 1.3 |
| Total | 629.6 ± 79.7 ππ | 100.0 | 49:42 ± 4:53 | 100.0 | 4.7 π |

Difference between wing players and backcourt players * p < 0.01 and ** p < 0.001, between wing players and pivots # p < 0.05 and ## p < 0.01, between pivots and backcourt players π p < 0.05, ππ p < 0.01 and πππ p < 0.001.

**Table 2** Offensive and defensive actions per match (group means ± SD) for all players combined (n = 83) separated into the 8 locomotive categories.

| | Offensive and defensive actions in total for the entire match | | | |
|---|---|---|---|---|
| | **Playing time per match (s)** | **% of total playing time per match** | **Distance covered (m)** | **% of distance covered** |
| Standing still | 329 ± 118 | 10.8 | 0 | 0 |
| Walking | 1 893 ± 229 | 62.3 | 2 103 ± 334 | 52.6 |
| Jogging | 572 ± 112 | 18.8 | 1 114 ± 219 | 27.8 |
| Running | 149 ± 77 | 4.9 | 496 ± 252 | 12.4 |
| Fast running | 23 ± 16 | 0.7 | 93 ± 67 | 2.3 |
| Sprinting | 2 ± 2 | 0.1 | 10 ± 11 | 0.2 |
| Sideways movement | 55 ± 40 | 1.8 | 138 ± 99 | 3.5 |
| Backwards running | 19 ± 14 | 0.6 | 48 ± 32 | 1.2 |
| Total | 3 042 ± 350 | 100.0 | 4 002 ± 551 | 100.0 |
| | **Offensive actions in total for the entire match** | | | |
| | **Playing time per match (s)** | **% of total playing time per match** | **Distance covered (m)** | **% of distance covered** |
| Standing still | 146 ± 92 | 9.9 | 0 | 0 |
| Walking | 903 ± 243 | 61.2 | 1 003 ± 271 | 50.9 |
| Jogging | 312 ± 73 | 21.1 | 607 ± 141 | 30.8 |
| Running | 70 ± 40 | 4.8 | 234 ± 133 | 11.9 |
| Fast running | 10 ± 9 | 0.7 | 41 ± 39 | 2.1 |
| Sprinting | 1 ± 1 | 0.1 | 4 ± 6 | 0.2 |
| Sideways movement | 22 ± 17 | 1.5 | 56 ± 42 | 2.8 |
| Backwards running | 10 ± 8 | 0.7 | 25 ± 19 | 1.3 |
| Total | 1 474 ± 259 | 100.0 | 1 970 ± 323 | 100.0 |
| | **Defensive actions in total for the entire match** | | | |
| | **Playing time per match (s)** | **% of total playing time per match** | **Distance covered (m)** | **% of distance covered** |
| Standing still | 184 ± 79 | 11.7 | 0 | 0 |
| Walking | 989 ± 189 | 63.1 | 1 100 ± 212 | 54.1 |
| Jogging | 261 ± 65 | 16.6 | 507 ± 127 | 24.9 |
| Running | 79 ± 40 | 5.0 | 262 ± 65 | 12.9 |
| Fast running | 12 ± 8 | 0.8 | 52 ± 38 | 2.5 |
| Sprinting | 1 ± 1 | 0.1 | 6 ± 9 | 0.3 |
| Sideways movement | 33 ± 26 | 2.1 | 82 ± 64 | 4.1 |
| Backwards running | 9 ± 7 | 0.6 | 23 ± 19 | 1.2 |
| Total | 1 568 ± 230 | 100.0 | 2 032 ± 362 | 100.0 |

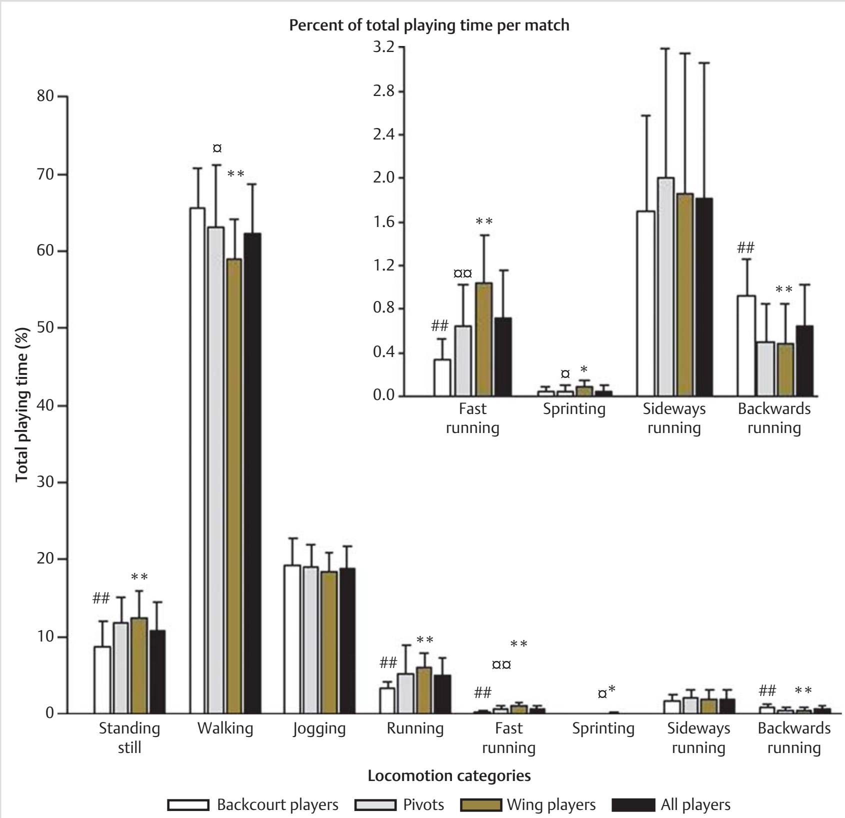


**Fig. 1** Distribution of playing actions (offensive and defensive actions combined) per match (group means ± SD) for the different playing positions and for all players combined (n = 83) expressed in % of total playing time for the 8 locomotive categories. Difference between wing players and backcourt 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 $^{##}$ $p<0.01$. Inserted: Zoomed graph display.

only 6 s less actual mean playing time in the second half. In addition, mean speed tended (p = 0.09) to decrease from the first (5.34 ± 0.36 km · h$^{-1}$) to the second half (5.29 ± 0.34 km · h$^{-1}$). No difference was observed in TDC between the first (2 010 ± 362 m) and the second half (1 993 ± 382 m).

## Physiological measurements during match-play

### Heart rate

Mean HR during active match-play (171 ± 7 beats · min$^{-1}$, n = 45) was higher (p < 0.001) than both effective HR (163 ± 11 beats · min$^{-1}$, ES = 0.87) and total-time HR (162 ± 8 beats · min$^{-1}$, ES = 1.20). No differences were demonstrated between effective HR and total-time HR (corresponding to a mean difference of 11:02 min:s per game for the transient intermissions in match-play during timeouts, suspensions, penalties, injuries etc., but also including activities such as re-warm-up and moving into position on the playing court). Individual active HR was higher in the first half than in the second half of the match for all players combined (173 ± 7 vs. 168 ± 7 beats · min$^{-1}$, p < 0.005, ES = 0.72).

### Relative workload

Mean relative workload during match-play estimated by HR recording during match-play was 79.4 ± 6.4 % of $VO_2$-max for the entire match, when all players were combined (n = 45). In this calculation all intermissions (time-outs, substitution periods etc.) were excluded from the HR analysis. However, considerable individual variations in relative workload were observed, since players typically showed transient periods with a relative workload corresponding to over 90 % of $VO_2$-max, while at other times they performed at a workload below 60 % of $VO_2$-max. Positional differences were demonstrated, where PV played with a higher mean relative workload (83.1 ± 4.9 % of $VO_2$-max, n = 17) than WP (78.4 ± 5.9 % of $VO_2$-max, p < 0.05, ES = 0.87, n = 15) and BP (75.8 ± 6.5 % of $VO_2$-max, p < 0.01, ES = 1.27, n = 13). Relative workload during match-play was higher in the first than in the second half of the match for all players combined (81.0 ± 4.7 vs. 77.5 ± 5.1 of $VO_2$-max, p < 0.001, ES = 0.71) and for WP (80.5 ± 5.1 vs. 75.9 ± 5.4 of $VO_2$-max, p < 0.001, ES = 0.88), PV (84.4 ± 5.2 vs. 81.8 ± 4.6 of $VO_2$-max, p < 0.01, ES = 0.53) and BP (77.4 ± 4.8 vs. 73.7 ± 5.6 of $VO_2$-max, p < 0.001, ES = 0.71), respectively.

## Physiological capacity

### Maximal aerobic power

Mean body mass and absolute $VO_2$-max of the players from the 2 top ranked teams was 70.3 ± 7.4 kg and 3.49 ± 0.37 l $O_2$ · min$^{-1}$, respectively, and in both cases clear identical differences emerged between playing positions (▶ **Table 5**). Expressed relative to body mass (ml $O_2$ · min$^{-1}$ · kg$^{-1}$) or as Fitness Index (ml $O_2$ · min$^{-1}$ · kg$^{-0.73}$), $VO_2$-max did not differ between playing positions (▶ **Table 5**). WP ran for a longer time during the all-out treadmill test (377 ± 43 s, p < 0.05) than both PV (335 ± 57 s, ES = 0.83) and BP (331 ± 40 s, ES = 1.11).

### Yo-Yo testing

Total running distance for all field players combined (n = 18) in the Yo-Yo IR1-test averaged 1 436 ± 222 m corresponding to level 16:8. Positional differences were demonstrated with WP (1 516 ± 172 m) performing better (p < 0.05) than both PV (1 360 ± 118 m, ES = 1.06) and BP (1 352 ± 148 m, ES = 1.02). The best individual performance was recorded in a WP, who ran 2 000 m (level 18:7).

**Table 3** Total distance covered and mean speed (group means ± SD) for the different playing positions, displayed for full-time players and for all players combined for the entire match and in offence and in defence, respectively. Mean speed was calculated excluding the time spent in the standing still category.

| **Offensive and defensive actions in total for the entire match** | | | | | |
|---|---|---|---|---|---|
| **Total distance covered and mean speed** | | | | | |
| | **All players combined (n = 83)** | **Full-time players (n = 10)** | **Wing players (n = 35)** | **Pivots (n = 18)** | **Backcourt players (n = 30)** |
| Playing time (min:s) | 50:42 ± 5:50 | 60:00 ± 0:00 ## | 51:21 ± 6:53 | 51:07 ± 5:12 | 49:42 ± 4:53 |
| Total distance covered (m) | 4002 ± 551 | 4693 ± 333 # | 4086 ± 523 * | 4067 ± 485 | 3867 ± 386 π |
| Mean speed (km·h$^{-1}$) | 5.31 ± 0.33 | 5.28 ± 0.21 | 5.44 ± 0.29 ** | 5.31 ± 0.37 *** | 5.17 ± 0.19 π |

| **Offensive actions in total for the entire match** | | | | |
|---|---|---|---|---|
| **Total distance covered and mean speed** | | | | |
| | **All players combined (n = 83)** | **Wings players (n = 35)** | **Pivots (n = 18)** | **Backcourt players (n = 30)** |
| Playing time (min:s) | 24:34 ± 4:20 | 24:44 ± 4:53 | 24:28 ± 4:12 | 24:28 ± 3:49 |
| Total distance covered (m) | 1970 ± 323 | 1966 ± 386 | 1964 ± 265 | 1979 ± 271 |
| Mean speed (km·h$^{-1}$) | 5.34 ± 0.47 | 5.50 ± 0.48 ** | 5.31 ± 0.37 *** | 5.18 ± 0.28 π |

| **Defensive actions in total for the entire match** | | | | |
|---|---|---|---|---|
| **Total distance covered and mean speed** | | | | |
| | **All players combined (n = 83)** | **Wing players (n = 30)** | **Pivots (n = 18)** | **Backcourt players (n = 35)** |
| Playing time (min:s) | 26:08 ± 3:51 | 26:37 ± 4:04 | 26:39 ± 4:22 | 25:14 ± 3:17 |
| Total distance covered (m) | 2032 ± 362 | 2118 ± 416 * | 2103 ± 396 | 1922 ± 268 π |
| Mean speed (km·h$^{-1}$) | 5.29 ± 0.32 | 5.39 ± 0.28 * | 5.31 ± 0.30 | 5.17 ± 0.29 π |

Difference between wing players and backcourt players * $p < 0.05$ and ** $p < 0.01$, between wing players and pivots *** $p < 0.05$, between full-time players and not-full time players # $p < 0.01$ and ## $p < 0.001$ and between pivots and backcourt players π $p < 0.05$.

**Table 4** Offensive and defensive actions per match (group means ± SD) for the different playing positions separated into the 8 locomotive categories.

| **Offensive actions in total for the entire match** | | | | | | |
|---|---|---|---|---|---|---|
| **Playing positions** | | | | | | |
| | **Wing players (n = 35)** | | **Pivots (n = 18)** | | **Backcourt players (n = 30)** | |
| | **% 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 | 14.9 ** | 0 | 9.4 €€ | 0 | 7.7 ## | 0 |
| Walking | 56.2 ** | 47.9 ** | 62.3 €€ | 51.8 € | 64.4 # | 54.0 |
| Jogging | 20.0 ** | 29.9 | 20.5 | 29.8 | 21.5 # | 31.6 |
| Running | 6.0 ** | 15.2 ** | 4.9 | 12.1 € | 3.4 # | 8.5 # |
| Fast running | 1.1 ** | 3.5 ** | 0.6 €€ | 2.1 €€ | 0.2 ## | 0.6 ## |
| Sprinting | 0.1 | 0.2 | 0.1 | 0.2 | 0.1 | 0.2 |
| Sideways movement | 1.2 * | 2.3 * | 1.7 | 3.1 | 1.8 | 3.3 |
| Backwards running | 0.5 ** | 1.0 ** | 0.5 | 0.9 | 0.9 ## | 1.8 ## |
| Total | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |

| **Defensive actions in total for the entire match** | | | | | | |
|---|---|---|---|---|---|---|
| **Playing positions** | | | | | | |
| | **Wing players (n = 30)** | | **Pivots (n = 18)** | | **Backcourt players (n = 35)** | |
| | **% 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 | 10.4 * | 0 | 10.8 € | 0 | 12.1 | 0 |
| Walking | 62.5 | 52.4 ** | 62.9 | 53.1 | 64.1 | 56.1 |
| Jogging | 17.2 * | 25.0 | 17.4 | 25.7 | 15.9 | 24.4 |
| Running | 5.7 * | 13.6 | 5.4 | 13.7 | 4.5 # | 11.9 |
| Fast running | 1.1 * | 3.1 * | 0.7 € | 2.2 € | 0.7 | 2.3 |
| Sprinting | 0.1 * | 0.4 * | 0.1 € | 0.2 € | 0.1 | 0.2 |
| Sideways movement | 2.6 * | 4.7 * | 2.2 € | 4.2 | 1.8 | 3.5 |
| Backwards running | 0.4 ** | 0.8 ** | 0.5 | 0.9 | 0.8 ## | 1.6 ## |
| Total | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |

Difference between wing players and backcourt players * $p < 0.05$ and ** $p < 0.001$, between wing players and pivots € $p < 0.05$ and €€ $p < 0.001$ and between pivots and backcourt players # $p < 0.05$ and ## $p < 0.001$.

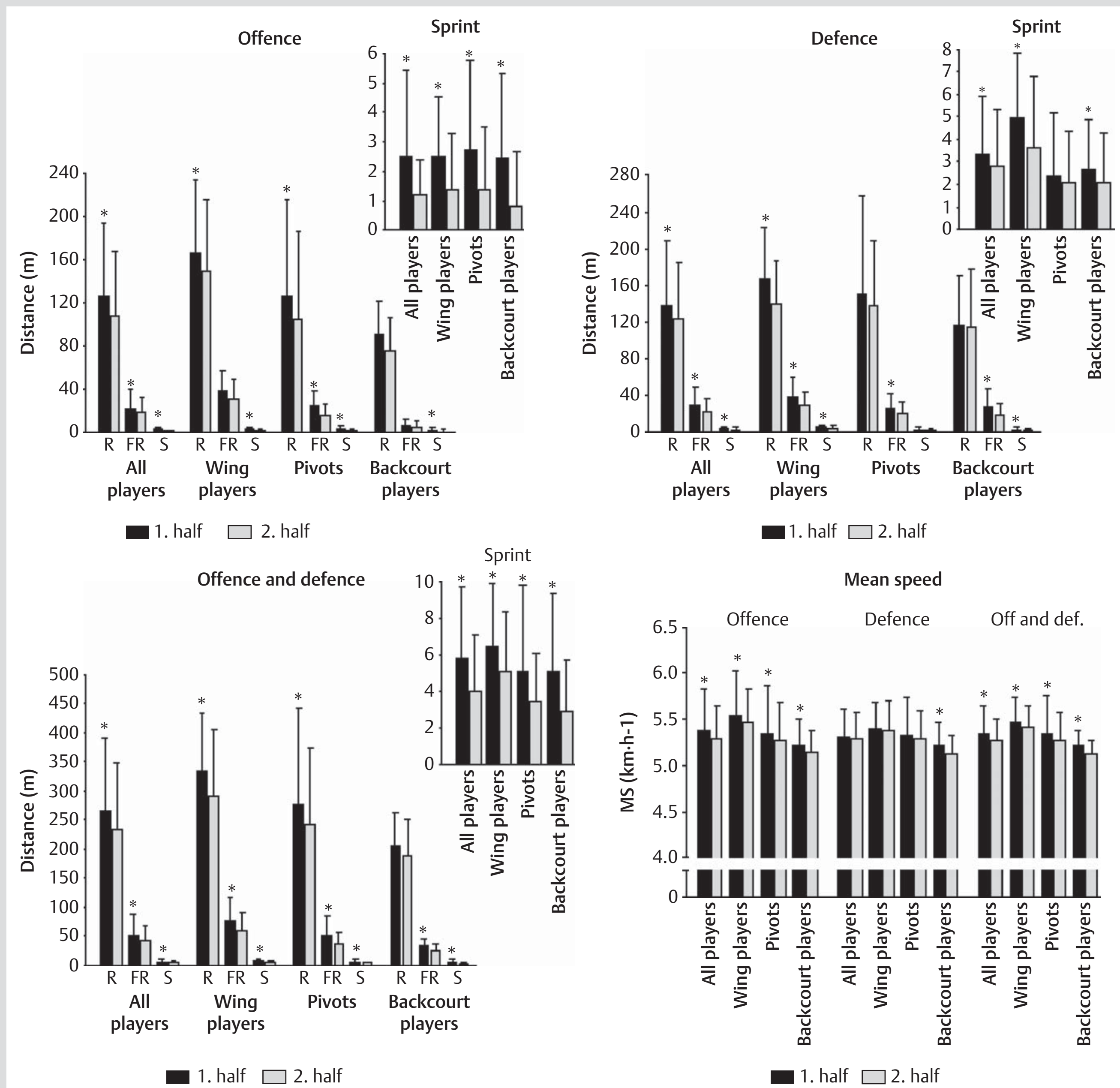


**Fig. 2** Distance covered in the 3 locomotive categories running (R), fast running (FR) and sprinting (S) as well as the mean speed (MS) (lower right panel) in 1st half and 2nd half of the match when in offence (top left panel), in defence (top right panel) and for offence and defence combined (bottom left panel). Data (group means ± SD) are shown for all players combined (n = 83) and for different playing positions. Difference between 1st half and 2nd half * $p<0.05$. Inserted: Zoomed graph display.

## Discussion

To the best of our knowledge, this is the first study to examine the physical demands in female elite TH using a complete locomotion match analysis. As a primary finding in the present study, physical demands differed substantially between playing positions, while decreases in relative workload and amount of high-intensity running in the second half also were observed.

### Total distance covered

In the present study, mean TDC was 4002 m with a mean TPT of 50:42 min:s. Players active in the entire match covered a total distance of 4693 m, which is lower than the 5251 m reported by Manchado et al. [19] in female elite TH players. Variations in the classification of movements as well as different methods of observation (video recording, multiple-camera setup, GPS systems) may account for differences between studies, as recently reported in analysis of soccer [31]. However, in the latter TH study, mean TPT and the number of analysed matches were not provided. Studies in male elite TH [5,24,35,39] have documented that differences exist between playing positions. Consequently, mean TDC for all players combined will depend on the specific number of players analysed in the various playing positions. In addition to the factors mentioned above, the teams' tactical approach may also influence TDC. A large degree of inter- and intra-player variability in movement pattern was evident between different games and even within specific playing positions, possibly in part due to variable contextual factors such as

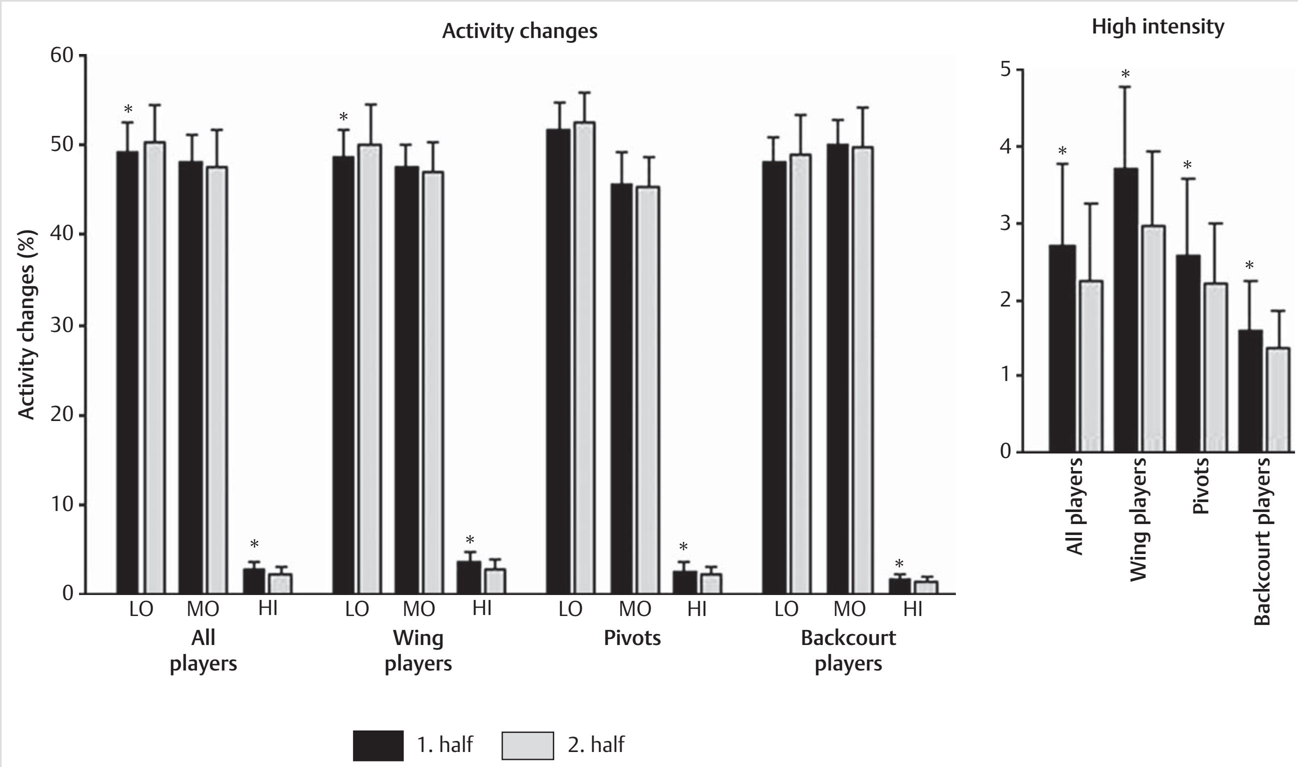


**Fig. 3** Percentage of the total number of activity changes (group means ± SD) as a function of work intensity observed during the 1st half and 2nd half of the match, respectively, for all players combined (n = 83) and for the different playing positions. LO: Low intensity (standing still, walking); MO: Moderate intensity (jogging, sideways movement, backwards running, running) and HI: High intensity (fast running, sprinting). Difference between the first and the second half *p < 0.05. Inserted: Zoomed graph display.

**Table 5** Body mass, absolute and relative maximal oxygen uptake, Fitness Index and total running time to exhaustion during treadmill testing (group means ± SD) in female elite team handball players.

| Playing positions | All players combined (n = 24) | Wing players (n = 10) | Pivots (n = 7) | Backcourt players (n = 7) |
|---|---|---|---|---|
| Body mass (kg) | 70.3 ± 7.4 | 65.2 ± 2.7 * | 76.5 ± 8.1 *** | 71.4 ± 6.1 |
| $VO_2$-max ($l\ O_2 \cdot min^{-1}$) | 3.49 ± 0.37 | 3.29 ± 0.37 * | 3.77 ± 0.33 *** | 3.49 ± 0.33 |
| $VO_2$-max ($ml\ O_2 \cdot min^{-1} \cdot kg^{-1}$) | 49.6 ± 4.8 | 50.5 ± 5.0 | 49.3 ± 5.8 | 48.8 ± 4.5 |
| Fitness Index ($ml\ O_2 \cdot min^{-1} \cdot kg^{-0.73}$) | 156.4 ± 15.3 | 155.9 ± 16.8 | 158.9 ± 18.6 | 154.7 ± 13.8 |
| Total running time (s) | 351 ± 53 | 377 ± 43 # | 335 ± 57 | 331 ± 40 |

Difference between wing players and pivots * p < 0.01, between wing players and backcourt players ** p < 0.01, between pivots and backcourt players *** p < 0.01 and between wing players and pivots & backcourt players # p < 0.05.

match location (home vs. away), opponent level (top, medium or bottom) and match status (win, lose or draw). Yet, due to the large number of matches and players analysed in present study (46 matches of different tactical/strategic importance, involving 83 analysed players from several different teams), the present data still represent a valid overall estimate of mean TDC in female elite TH players during actual match-play.

### High-intensity running

The limited total amount of high-intensity running observed in the present study does not mean that the ability to work at high intensity is of little importance in modern female elite TH. Potentially, a large high-intensity running capacity is crucial for playing actions such as fast breaks, explosive fakes, side cuttings and fast retreats, and thus probably also plays a decisive role in the outcome of a match. The number of changing actions, e.g. accelerations and decelerations, were high even though the amount of high-intensity running was limited. A physiological strain is imposed on players not only during the high-intensity phases of the match (defined and registered as high-intensity running), but also every time accelerations and decelerations are performed, even when speeds remain low. Thus, the anaerobic energy yield in female elite TH would most likely have been substantially higher in the present study, if we had measured and expressed "high-intensity locomotion activities" as high power output instead of as high-intensity running based solely on the running speed. Consequently, physical training in female TH should comprise exercises for improving elite players' ability to repeatedly perform high-intensity activities and to rapidly recover during less intense periods of physical activity.

### Sprint actions

The mean sprint time also covered sprinting in situations other than fast break and in addition, the duration of the majority of these numerous small accelerations was shorter than the mean sprint duration. Despite this, the mean duration of the separate sprint actions (0.9 s ~6 m sprint) was markedly lower compared to the time it takes to perform a fast break at maximum speed (about 4–5 s). This indicates that in female elite TH, a fast break is only rarely a maximal sprint all the way up the court (~30 m sprint). In TH it is essential to react quickly and perform powerful changes in direction, while moving quickly over short distances ( < 15 m). Physical training exercises, therefore, should primarily target reaction speed and acceleration capacity (i.e. rate of force development, RFD) rather than focusing on maximum running speed.

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

Unexpectedly, mean TDC and mean speed in offence (1 970 m and 5.34 $km \cdot h^{-1}$, respectively) were similar compared to defence (2 032 m and 5.29 $km \cdot h^{-1}$, respectively) with less actual playing time in offence of 1:34 min:s. The time covered in the standing still category in offence (9.9 % of TPT) and in defence (11.7 % of TPT) revealed that female elite TH players are hardly standing still during match-play, but tend to constantly move both in offence and in defence. The amount of high-intensity running per match was similar in defence (2.7 % of TDC) and offence (2.3 % of TDC), which is somewhat surprising, since players in the organized play typically are more free to shift positions during offence than in defence due to tactical variations. Thus, these data indicate that retreats are often performed at high intensity, because defenders need to run fast or sprint in situations of lost ball possession to prevent possible fast break goals from opponent attackers. Notably, the number of players in offence and in defence differed among WP and BP as a result of some players playing WP in offence and BP in defence (mainly tall WPs), while others playing BP in offence and WP in defence (typically small BPs).

For all players combined, there was no difference in TDC (0.8 %, n.s.) between the first and the second half, concurring with previous findings in male elite TH players [24]. In contrast, the amount of high-intensity running decreased 21.9 % in the second half. Likewise, the distance covered during fast running and sprinting as well as the mean speed were all reduced in the second half, also when analysed separately for offence and defence. The reduced amount of high-intensity running, decreased HR and relative workload and the reduced number of high-intensity activity changes observed during the second half indicate that temporary fatigue (decrease after the most intense periods) and perhaps a more permanent form of locomotive fatigue (decrease towards the end of the game) may have occurred along with impaired physical performance, at least in some players. However, the present study did not look at the specific factors responsible for onset of fatigue in elite TH. The declines in the analysed parameters in the second half were influenced by situational variables such as match location, quality of opposition and match status. However, due to the large number of matches and players analysed in the present study (46 matches of different tactical/strategic importance, involving 83 analysed players from several different teams) our findings likely provide a realistic picture of the locomotion match profile of female elite TH players and thus of the match-induced impairments in physical performance in the second half.

### Differences between playing positions

Both WP and PV covered a greater total distance per match than BP. WP also performed more high-intensity running than PV and BP, and in together with PV showed a higher mean speed during match-play than BP. Very surprisingly, BP demonstrated markedly lower percentage of high-intensity running in offence than in defence. Given that BP performed considerably less fast breaks than other playing positions [25], this indicates that BP ran numerous intense retreats due to their slightly withdrawn position on the court at transition from offence to defence. Owing to their central position on the court, BP tended to be constantly in motion during offence reflected by a similar TDC concurrently with a lower mean speed compared to all other playing positions. In defence, BP covered a very low total distance and also worked with a low mean speed despite a high percentage in the standing still category. Thus, in terms of horizontal body movements BP were surprisingly more stationary (less active) than all other field playing positions during match-play.

Conversely, PV did not perform large amounts of running during organised attack due to their relatively fixed position at the 6-m line, but instead were engaged in a lot of physical contact with opponent players. Nevertheless, PV covered a similar total distance and demonstrated a relative high percentage of high-intensity running compared to the other playing positions in offence, which at least in part may be explained by a high number of fast breaks and attempts to perform fast breaks [25]. Furthermore, PV covered a higher total distance in defence than in offence, which indicates that PV were highly active in the middle defence, but also performed many intense retreats. WP showed the highest percentage of high-intensity running in offence, probably as a result of demonstrating the highest number of fast breaks [25]. At the same time, however, WP were more stationary than PV, which resulted in a similar amount of the TDC and a higher mean speed when compared to the other playing positions. Both WP and PV performed identical amounts of high-intensity running in offence compared to defence, which was somewhat unexpected given the greater range of free locomotion opportunities during organised offence. As seen for PV, WP covered a higher total distance in defence than in offence, while also displaying the highest amount of high-intensity running. This indicates that WP were involved a high number of intense retreats. Consequently, higher anaerobic demands in terms of high-intensity running appear to be placed on players who play WP in offence and cover BP in defence as compared to players who play BP in offence and cover WP in defence (**Table 4**).

The present locomotion match analysis demonstrates that significant differences exist in the movement pattern of the various field playing positions. Running training in female elite TH should therefore be organised in a way that it takes into account the specific playing positions, while also recognizing the players' individual level of physical capacity and recovery profile.

### Physiological measurements during match-play

The present matches were performed under relatively constant temperature and humidity conditions (18–22 °C, 50–70 %). In addition, the players were allowed an unlimited fluid intake during the matches, suggesting that the influence from dehydration and body weight loss on the HR values was likely minimal. However, future studies are needed to examine the physiological strain related to the possible development of fatigue in elite TH. A subdivision in HR percentages classes was not provided, since for logistic reasons it was not possible to obtain HR max values in all analysed players (maximal lab tests were performed only in a subgroup of players). However, future studies could benefit from using HR distribution analysis in elite TH to analyse the phases of high-intensity and low-intensity match activity in greater detail.

The analysed players were active about 85% (~51 min) of the total effective playing time (60 min) with a mean HR of 171 $beats \cdot min^{-1}$, whereas the calculation of total match time (~71 min) showed mean HR values of 162 $beats \cdot min^{-1}$. The difference between HR during active match-play and total-time HR (5.3%) was surprisingly small in relation to the difference between individual and total match time (~20 min). The latter was due to paused game time and time due to substitution, suspension or injury (excluding the half-time break, but including activities such as re-warm-up and moving into position on the playing court) and likely reflects the opportunity for active recovery during total match-play.

Determination of $VO_2$ using portable analysis systems is not allowed in TH tournament matches. Consequently, the present study used indirect determination of $VO_2$ to calculate relative workload expressed as % of $VO_2$-max according to previous analysis of male elite TH players [22]. Buchheit et al. [3] found that the accuracy of HR measures for estimating $VO_2$ during small TH-like games is poor for the individual player, although it may be valid at the overall group level. However, in their study the players were performing 4-a-side handball games with no resting periods and were not allowed to have any physical contact with opponents. Consequently, these simulated game activities did not mimic the locomotive and technical activity pattern typically performed during true elite TH match-play. It cannot be ruled out that the exclusion of physical confrontations and refraining from occasional "rest periods" may have influenced the observed HR response and potentially influenced the observed relationships between HR and $VO_2$.

Although low-intensity activities (standing still, walking) constituted about 73% of mean effective playing time, players demonstrated a mean relative workload of 79.4% of $VO_2$-max during the periods of effective match-play. This indicates that the amount of high-intensity, strength-related technical playing actions [25] had a marked influence on the high HR values and hence on the relative workload without contributing substantially to TDC. Playing actions such as tackles, offensive breakthroughs, claspings and screenings may result in elevated HR for more extended periods of time (due to elevated HR in the subsequent recovery phase). Consequently, using only the findings from locomotion match analyses will likely underestimate the physical demands of elite TH match-play.

The present data show that female elite TH imposes high aerobic demands on the players during match-play as reflected by a high mean relative workload (~80% of $VO_2$-max), which may partly be due to the players running for a large proportion of the match with attention fixed on the ball or directly with the ball, which increases $VO_2$ [32]. However, this is still far from the relative workload in elite marathon runners (~90% of $VO_2$-max) during competition [34]. A high level of aerobic power and capacity allows the individual player to play at a high tempo. Although a high aerobic performance may not per se be the decisive physical factor during the actual game, it also improves the ability to tolerate a high intensity and quality of the daily training along with a high overall total training volume and to recover in long tournaments, where numerous matches are played over a short period of time [26]. The importance of this was emphasized by Ronglan et al. [33], who reported a slow recovery from fatigue in female elite TH players. This was indicated by incomplete restoration of performance between tournament matches and training sessions.

WP and PV played at a considerably higher relative workload than BP. A high relative workload was expected in accordance with the high running demands in WP, but PV also covered a high total distance and performed a high amount of high-intensity running. Furthermore, PV had the highest amount of physical confrontations compared to the other playing positions [25]. Consequently, PV is a highly physical demanding playing position. BP were surprisingly less active, which resulted in a low relative workload during match-play. Signs of locomotive fatigue-related changes were observed, since the relative workload during match-play was substantially lower in the second half for all player categories.

### Physiological capacity

For all players combined, $VO_2$-max was 50 ml $O_2 \cdot min^{-1} \cdot kg^{-1}$ (range: 42–58 ml $O_2 \cdot min^{-1} \cdot kg^{-1}$) with no differences between playing positions. In comparison, the Danish Female National Team showed $VO_2$-max mean values of 53, 53 and 49 ml $O_2 \cdot min^{-1} \cdot kg^{-1}$ in 1989, 1992 and 1994 (European Champions), respectively [11]. Other studies have reported values exceeding 50 ml $O_2 \cdot min^{-1} \cdot kg^{-1}$ in both sub-elite [9] and elite female TH players [10]. $VO_2$-max of female elite TH players (48–54 ml $O_2 \cdot min^{-1} \cdot kg^{-1}$) is comparable to that seen in other ballgames such as basketball (44–54 ml $O_2 \cdot min^{-1} \cdot kg^{-1}$) [38] and soccer (44–57 ml $O_2 \cdot min^{-1} \cdot kg^{-1}$) [15]. Since the physical dimension of the game and the players' physical training volume have increased considerably over the past 20 years, this indicates that maximal aerobic power may be of some importance in modern female elite TH, although it may not play a crucial role in elite playing performance. Supporting this notion, endurance performance differed between Spanish elite and amateur female TH players [7], suggesting that achieving a minimum level of endurance performance is necessary for succeeding in female TH. Direct comparison of $VO_2$-max between subjects with different body mass was done with $VO_2$-max expressed as Fitness Index (ml $O_2 \cdot min^{-1} \cdot kg^{-0.73}$) [12]. Notably, this parameter (156 ml $O_2 \cdot min^{-1} \cdot kg^{-0.73}$) did not differ between playing positions in the present study.

### Yo-Yo testing

Mean total running distance covered for all field players combined in the Yo-Yo IR1-test (1436 m) was somewhat lower (~5–7%) than that measured in the Danish Female National Team, which won Olympic Gold medals in 2000 (1505 m, n = 16) and the European Championship in 2002 (1538 m, n = 18) (Michalsik, unpublished data), and in female top elite soccer players (1600 m) [2]. A recent study from Souhail et al. [37] demonstrated a positive association between locomotion match activities in young male TH players and distance covered in the Yo-Yo IR1-test, which may, therefore, be considered as a relevant test for the assessment of intermittent high-intensity endurance in TH players. In the present study, Yo-Yo test performance was found to differ between playing positions as WP ran longer than all other field players in accordance with the elevated demands for high-intensity running in WP.

## Conclusions

In conclusion, modern female elite team handball is a physically demanding intermittent team sport, which during match-play imposes high aerobic demands on the players as evidenced by a high relative workload (~80 % of $VO_2$-max) interspersed by very brief time periods of substantial anaerobic energy production as reflected by a limited amount of high-intensity running (~1 % of total effective playing time per match). The decrease in the total number of high-intensity activity changes, the amount of high-intensity running, mean speed, HR and relative workload in the second half of the match collectively indicates that at least temporary fatigue and impaired physical performance appear to occur in players with more than 50 min playing time per match. In addition, extensive positional differences were observed in the physical demands during match-play. The present findings may be useful in the planning and implementation of training regimens to optimize the position-specific physical training in female elite team handball. In addition, an increased and differential focus for improving high-intensity intermittent exercise capacity would seem relevant to ensuring optimal individual development in the physical capacity of elite team handball players.

In perspective, future studies should be conducted to implement more precise analytical means for qualifying high-intensity locomotion activities in female team handball in order to account for movement accelerations and decelerations during the various phases of the match as has recently been done in soccer [29]. In addition, future studies should examine the impact of contextual variables such as match location, opposition level and match status on the locomotive and technical activities during elite team handball match-play.

## Acknowledgements

We would like to thank the recruited players and their respective clubs particularly the 2 top ranked teams for their valuable participation, effort and engagement. Primary study data have been presented at the European Handball Federation Scientific Conference 2011.

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