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Physiological capacity and physical testing in male elite team handball

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Aim. **The aim of the present study was to examine the physical demands placed on male elite team handball players in relation to playing position.**
Methods. **Male elite team handball field players were evaluated during match-play over a six season time span using physiological measurements and by subsequent physical testing.**
Results. **Mean heart rate and relative workload during match-play (N.=41) were 163±5 beats·min^{-1} (group means±SD) and 70.9±6.0% of $VO_{2\text{-max}}$, respectively. Relative workload was lower (P<0.01) in the second half *vs.* the first (66.3±5.9% *vs.* 75.4±5.6% of $VO_{2\text{-max}}$). Post-match blood lactate concentration was 4.8±1.9 mM (range: 2.8-10.8 mM). Mean fluid loss was 0.81±0.41 l pr. match. Mean VO_{2max} was 5.18±0.66 l O_2·min^{-1} corresponding to 57.0±4.1 mL O_2·min^{-1}·kg^{-1}. Mean total running distance in the Yo-Yo intermittent recovery test (level 2) was 895±184 m (range: 520-1360 m), which was greater in wing players (975±123 m) than backcourt players (897±108 m) and pivots (827±264 m) (P<0.05). Fastest 30-m sprint time was 4.09±0.12 s (range: 3.87-4.28 s). The repeated sprint test (7 x 30 m) yielded a mean fatigue index of -8.1±2.7 %. Maximal jumping height in "Jump and Reach" testing was 0.71±0.08 m (range: 0.61-0.86 m). Maximal ball throwing speed was observed using the set shot with 3-step run-up (92.8±5.3 km·h^{-1}, range: 75.8-108.2 km·h^{-1}).**
Conclusion. **Modern male elite team handball imposes moderate-to-high demands on the aerobic energy system and high demands on the anaerobic energy systems during certain periods of the match. Indications of temporary fatigue and a subsequent decline in performance were observed, since the relative workload decreased both in the first and in the second half of the match. Physiological profiles and physical test results differed between playing positions, with wing players covering a greater total distance in the Yo-Yo test and showing superior jumping performance and repeated sprint running capacity than backcourt players and pivots.**

Key words: Workload - Physical exercise - Perfomance.

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Team handball (TH) is a team sport with physical contact played worldwide, which has been on the Olympic program in its indoor version since 1972 and is played professionally in a large number of mainly European countries. During the sixty minutes of match-play (30 minutes each half), the players work intensely for short, intermittent time intervals, while performing walking, running, sprinting, moving forwards and backwards and side-stepping at the same time as being tackled, grappled and pushed.[1, 2] Concurrent with the development of the game of TH through the years, more intense demands have been imposed on elite players particularly due to recent rule changes. Further, the amount of training and matches have increased substantially, which have resulted in higher physical demands on elite TH players. In addition to technical, tactical and mental skills, physical factors such as muscle strength and maximal ball throwing velocity have proved important for the performance capacity in elite TH players.[3] Previous studies have implemented various types of physical training to improve elite TH performance.[4-6] However, a complete working demand analysis of the game seems to be needed to provide a basis for identifying, planning and implementing optimal training modalities in elite TH.[7]

An analysis of the physical working demands in elite TH includes locomotion match analysis (running types, intensity and distance) and technical match analysis (technical playing actions).[8] Such analyses were conducted in the group of male elite TH players examined in the present study as reported elsewhere.[1, 2] Additionally, an optimal physical working demands analysis would also comprise physical testing of elite TH players to evaluate to which extent the physical profile has adapted to the locomotive and technical demands imposed by years of elite TH training and match-play. Physiological measurements can be performed during match-play by continuous heart rate (HR) recording and subsequent determination of the relative workload (RWL) in order to estimate cardiovascular loading intensity during match-play. Furthermore, measurements of blood lactate concentration (BLC) in connection with match-play can be used to indicate the contribution of anaerobic energy sources during high-intensity playing actions. Combined test data and physiological measurements performed during match-play can provide valuable synergistic information and additional knowledge about the physical working demands in elite TH.[8]

Only a limited number of studies have examined the physical demands and physiological characteristics of elite TH players. Moreover, the majority of previous investigations were performed more than a decade ago [4, 9-13] although more recent studies also exist.[3, 5, 14, 15] Since both the nature of the game as well as the scientific analysis methods have changed markedly in the last decades, updated knowledge is needed about the physical demands in modern elite TH in order to determine the physical requirements imposed on current elite players. In addition, it seems relevant to examine if positional differences exist in physical demands. With physical requirements differing between playing positions, physical training should be organized more individually than previously assumed. The aims of the present study, therefore, were 1) To determine the physiological and physical demands imposed on male elite TH players and 2) To examine if differences in these demands can be observed between various playing positions. As the activity patterns of goalkeepers obvious differ significantly from those of field players, the physical demands placed on goalkeepers were only included to a limited degree.

Materials and methods

Subjects

A cohort of male elite TH players were recruited from teams ranked in the upper half of the Danish Premier Team Handball League including the two top ranked teams. A majority of the participants played at the international top level (European TH Champions League, multiple national teams). 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 [16] and with the principles of the Declaration of Helsinki. The players were examined over a six-year period. No year-to-year differences were observed during the six-year study period for any of the analysed parameters. 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). The analyzed matches were performed indoor under thermoneutral conditions in terms of temperature (18-22 ºC) and humidity (50-70%). A number of teams were monitored in the present study, with new players joining individual teams during the study period, while other players conversely were leaving the teams. Physical characteristics of the players from the two top ranked teams (9 wing players [WP], 7 backcourt players [BP], 7 pivots [PV] and 3 goalkeepers, N.=26) were 26.4±3.1 years (group means±SD), 188.9±6.3 cm and 90.9±9.0 kg with 7.2±3.6 years of playing experience at the adult elite level, respectively.

Physiological measurements during match-play

Heart rate

The physiological workload during matches in the Danish Premier Male 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 analyzed in three different time domains, namely total playing time (the time span of the whole match excluding the half-time period), effective playing time (time span of actual playing time) and individual playing time (where the individual player is active on the court). Usable results were not obtained in all players, because some players refrained from using the elastic strap during match-play, while in others the chest strap heart monitor was displaced during vigorous contact-actions resulting in HR recording failure.

Blood lactate concentration

Blood samples were obtained in selected players (N.=38) to measure BLC 5 min prior to the game (after the warm-up), after the first half and after the end of the game. Capillary blood was obtained from the fingertip into heparinized syringes. Plasma was separated by centrifugation for determination of BLC, haemolysed in relationship 1:1 with an ice-cold Triton X 100 buffer solution and analysed on a Yellow Springs Instrument (YSI 2700 select, YSI, Inc., Yellow Springs, OH, USA). The values were analysed in duplicate with a precision of 0.5 mM.

Fluid loss

Weight loss was measured in selected players (N.=24) as an indicator of fluid loss. Players were weighed before the game (after the warm-up), after the first half and again after the end of the game, while fluid intake was closely monitored throughout the entire match including during the half-time break. Weight loss was corrected by fluid intake to yield total fluid loss.

Physical testing

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 6-min horizontal running at speeds of 10, 12, 14 and 16 $km \cdot h^{-1}$, respectively, each period separated by 2-min rest periods (submaximal test). Blood samples were obtained immediately after each exercise bout. After the completion of the submaximal test, blood samples were taken at 0, 1, 2, 4 and 14 min of resting recovery. Subsequently after a 15-min rest period, an all-out test was performed. The all-out test was initiated at a running speed at 14 $km \cdot h^{-1}$ for 2 min followed by 1 min at 16 $km \cdot h^{-1}$, and then continued with stepwise 1 $km \cdot h^{-1}$ speed increments every minute until exhaustion. Blood samples were drawn acutely after termination of the test and at 1, 2, 4 and 6 min of resting recovery. Total running time to exhaustion during the all-out test was recorded.

Respiratory measurements were conducted using online analysis (AMIS 2001, Damec Research, Odense, Denmark). 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 ($VO_{2\text{-}max}$) and HR-max were determined as the peak values recorded in a 15- 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.[17]

HR was continuously recorded in 5-s intervals throughout the test (Polar S610 HR monitor, Polar Electro OY, Kempele, Finland). The individual HR-VO_2 relationship obtained during the treadmill test (correlation equation $y=a \cdot x + b$) was used to estimate VO_2 during match-play based on the HR recording obtained during match-play according to previous procedures in soccer match analyses [18-20] and analysis of elite female TH players [21, 22]. Subsequently, RWL during match-play could be determined expressed as % of VO_{2max}.

Blood samples were taken from a catheter (antecubital vein) using heparinized syringes. Plasma was separated by centrifugation for determination of BLC and was mixed in relationship 1:1 with an ice-cold Triton X 100 buffer solution. BLC was analysed on a Yellow Springs Instrument (YSI 2700 select, YSI, Inc., Yellow Springs, Ohio, USA). The values were analysed in duplicate with a precision of 0.5 mM. For determination of the concentration of potassium in the blood, the supernatant was pipetted after centrifuging and determined using a FLM3 flame photometer (b version) Body mass was measured with the players wearing light indoor clothing (short pants, t-shirt) and no shoes, using a Tanita Body Composition Analyzer (TBF-3000, Tanita Corporation, Tokyo, Japan) (measurement error ≤0.5%).

Laboratory maximal muscle strength testing

Maximal concentric, isometric and eccentric muscle strength were assessed for the knee extensors (quadriceps femoris) and flexors (hamstring muscles) using isokinetic dynamometry (Kinetic Communicator, Chattecx Corp., Chattanooga, USA) as described in detail elsewhere.[15] Gravity corrected [15, 23] peak moment and iso-angular moment at 50º knee joint angle (0º=full extension) were determined at slow and fast angular velocities ($30^{\circ}\cdot s^{-1}$ and $240^{\circ}\cdot s^{-1}$) using a ROM of 80º (from 10º flexion to 90º of flexion).

All strength measurements were preceded by a standardized warm-up of 10-min ergometer cycling. Subsequently, the subjects were mounted in the dynamometer in a sitting position and firmly strapped at the waist and thigh. Unilateral contractions (primary take-off leg) were performed as hard and as fast as possible at each angular velocity, until subjects were unable to increase peak moment any further. On-line feedback of the exerted moment was given to the subject on a PC-screen.[15] Rest period between successive repetitions (typically 5-10) was 30-45 s.

Field testing

Maximal standing jump height without the use of the arms was measured in counter movement jumping (CMJ) with and without the addition of 50 % body mass (Eleiko Sport AB jumping matt), as described by Bosco *et al.*[24] Furthermore, a "Jump and Reach" test with run-up was carried out on an indoor TH court as well as a standing, horizontal, single-leg 5-step jump test with landing with both legs together. The ability to work intensely and to be able to recover quickly after repeated intense running work bouts were assessed on an indoor TH court using the Yo-Yo intermittent recovery test, level 2 (Yo-Yo IR2 test), as previously described by Bangsbo *et al.*[25] The Yo-Yo IR tests consist of repeated 2 x 20-m shuttle runs at increasing speeds, interspersed with a 10-s period of active recovery. A player is running until the player is not able to maintain the speed, and the distance covered at that point is the test result. All players had extensive experience with the Yo-Yo IR2-test, which was performed on a separate day.

Sprint running capacity was tested on an indoor TH court on a separate day using a repeated sprint test, in which players performed seven maximal 30-m sprints, without change of direction, separated by 25-s of low-intensity jogging between successive sprints. The fastest 30-m time, mean 30-m time and fatigue time were identified. Fatigue time was calculated as the difference between the slowest and the fastest 30-m time to provide an estimate of the player's ability to recover after maximal sprint work. Sprint times were recorded with a precision of 0.01 s by infrared light sensors mounted in pairs at the start and the finish lines, respectively (Eleiko Sport, Halmstad, Sweden).

Maximal ball throwing speed was measured in each player on an indoor TH court using Doppler radar technology (10525 GHz microwaves, Technical University of Denmark) during a variety of overarm shots (set shot, running shot (performed with right foot forward for right-handed players and left foot forward for left-handers, and jump shot, all performed with a 3-step run-up). In addition, standing set shots were performed. Players were instructed to throw a standard handball (IHF size 3) as fast as possible through a standard goal frame using their preferred throwing hand and normal shooting technique. Use of resin was voluntary. As motivation, the players were immediately informed of their performance after each shot. For each type of shot, the throw with the highest ball velocity was selected for every player for further analysis.

All players performed standardized warm-up before each test. On separate days, a pre-study familiarization test round was performed in all players for all test types. Players were instructed not to consume any meals 2 hours prior to all testing procedures and not to engage in any vigorous training the day on prior to testing.

Statistical analysis

All statistical analyses were conducted using R2 Version 13.1 (University of Auckland, New Zealand). Results are presented as group mean values±standard deviations (SD) unless otherwise stated. The assumption of Gaussian data distribution was visually verified using QQ-plots. Paired Student´s t-tests were used to evaluate with-in group differences (*e.g.* differences between first and second half). Student´s non-paired t-testing was used to compare non-matched subject groups. The assumption of similar variance was tested using visual inspection of residual plots. Comparisons between subject groups (*e.g.* different playing positions) were done using one-way analysis of variance (ANOVA). Post Hoc differences were evaluated by Tukey's HSD test (normally distributed). The Pearson product-moment correlation analysis was used to evaluate potential relationships between selected parameters. Cohen's d-test was used to calculate effect size (d-values stated as ES) 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≤0.05 using a two-tailed test design.

Results

Physiological measurements during match-play

Heart Rate

Mean HR during active match-play (N.=41, mean total effective playing time 52.36±5.92 min) was 163±6 beats·min^{-1}, which was higher (P<0.05) than total-time HR (158±6 beats·min^{-1}, ES=0.83) and effective HR (159±5 beats·min^{-1}, ES=0.72). No differences were observed between total-time HR and effective HR, which means that the transient pauses in match-play during penalties, timeouts, suspensions, injuries etc. (averaging 18.90 min per game, but also including activities such as re-warm-up and moving into position on the playing court) did not have any detectable influence on mean effective HR. Individual active HR was higher in the first than in the second half (mean total effective playing time 26.29±2.18 *vs.* 26.07±2.21 min) of the match for all players combined (169±6 *vs.* 158±6 beats·min^{-1}, P<0.001, ES=1.83).

TABLE I.—*Relative workload during elite team handball match-play (group means±SD) expressed in % of VO_2-max (N.=41).*

	1st half	2nd half	Entire match
All players (N.=41)	75.4±5.6 **	66.3±5.9	70.9±6.0
Wing players (N.=14)	76.0±5.6 *	70.2±6.1	73.2±4.9 #
Pivots (N.=8)	77.3±5.2 *	70.3±5.6	73.8±5.9
Backcourt players (N.=19)	74.0±5.5 ***	61.6±5.9	67.9±5.6 €

Difference between 1st half and 2nd half *P<0.05; **P<0.01 and ***P<0.001, between wing players and backcourt players #P<0.01 and between pivots and backcourt players €P<0.01.

TABLE II.—*Individual examples of the relative workload (% of $VO_{2\text{-}max}$) during match-play analysed in successive 5-min intervals among different type of field players (WP: Wing players, PV: Pivots and BP: Backcourt players).*

1st Half	1-5th Min	6-10th min	11-15th min	16-20th min	21-25th Min	26-30th min	2nd Half	1-5th min	6-10th min	11-15th min	16-20th min	21-25th min	26-30th min
WP	80%	80%	79%	76%	76%	76%	WP	66%	75%	71%	68%	70%	78%
PV	66%	67%	71%	71%	69%	65%	PV	48%	68%	66%	73%	71%	41%
WP	71%	83%	81%	77%	75%	78%	WP	73%	70%	76%	70%	74%	73%
BP	67%	70%	61%	74%	72%	74%	BP	78%	81%	72%	67%	81%	67%
WP	73%	79%	75%	69%	73%	73%	WP	65%	74%	71%	68%	74%	77%
BP	90%	81%	78%	82%	84%	85%	BP	62%	72%	69%	65%	54%	84%
BP	76%	91%	91%	83%	81%	87%	BP	48%	44%	64%	83%	92%	66%
WP	71%	68%	65%	61%	62%	58%	WP	66%	63%	69%	77%	70%	67%
PV	62%	66%	71%	68%	67%	46%	PV	56%	68%	54%	44%	66%	64%
BP	72%	75%	82%	80%	41%	74%	BP	44%	67%	66%	38%	61%	76%

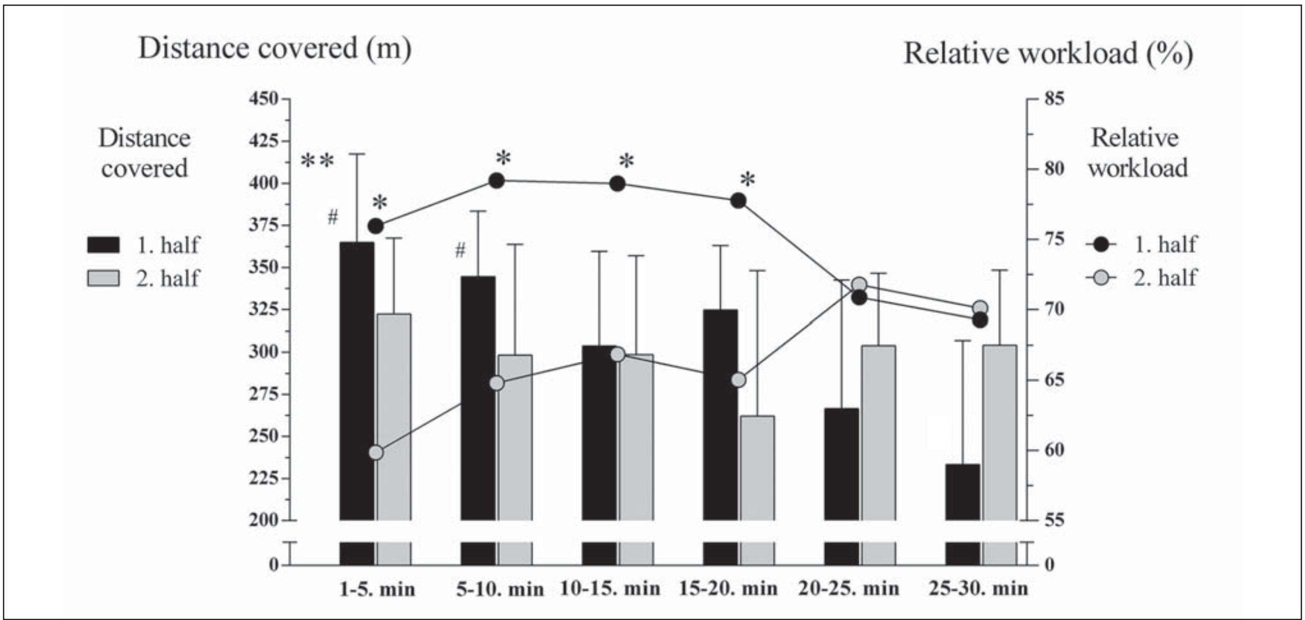

Figure 1.—Distance covered (black bars: 1st half, grey bars: 2nd half) and relative workload during match-play expressed as % of VO_{2max} (dark line: 1st half, grey line: 2nd half) in successive 5-min intervals during 1st and 2nd half-time periods, respectively. Results are group means±SD (N.=41). Higher relative workload in 1st half than in the corresponding time period in the 2nd half * (P<0.005). Longer distance covered in 1st half compared to the corresponding time period in 2nd half ** (P<0.05). Longer distance covered in initial two 5-min intervals in 1st half than in the final two 5-min intervals in 1st half # (P<0.01). Longer distance covered in the final 5 min of 2nd half compared to the corresponding time interval in 1st half § (P<0.05).

Relative workload

Relative workload (RWL) during match-play estimated by HR recording during match-play was 70.9±6.0 % of $VO_{2\text{-}max}$ (individual range: 62.7-79.2 % of $VO_{2\text{-}max}$) for the entire match for all playing positions combined (Table I). In this calculation all intermissions (time-outs, substitution periods etc.) were excluded from the HR analysis. However, large individual variations in RWL were observed, since players typically showed transient periods with a RWL corresponding to over 90 % of VO_{2max}, while at other times performing with a load below 50% of VO_{2max} (Table II). A higher (P<0.05) RWL was observed in PV (73.8±5.9 % of VO_{2max}, ES=1.02) and WP (73.2±4.9 % of $VO_{2\text{-}max}$, ES=1.01) than in BP (67.9±5.6 % of $VO_{2\text{-}max}$). No differences in mean on-court playing time between the first and the second half of the match were observed both for all players combined and for the different playing positions.

RWL during match-play was higher in the first than in the second half of the match for all players combined as well as at each specific playing position (Table I). RWL during match-play was also analysed in successive 5-min intervals (Figure 1). RWL was higher (P<0.005, ES=1.44) for all players combined in the first 20 min of the first half compared to the first 20 min of the second half. In addition, RWL was higher (P<0.001, ES=2.65) in the first 20 min of the first half compared to the very initial phase (0-5 min) of the second half (Figure 1). RWL decreased after 20 min of the first half until 5 min of the second half (P<0.05), after which there was a statistical tendency (P=0.07) for RWL to rise again during the second half.

A longer distance (P<0.05, ES=0.81) was covered in the initial 5 min of the first half compared to the corresponding phase in the second half. Further, a reduced distance (P<0.05, ES=0.88) was observed in the final 5 min of the first half compared to the final 5 min of the second half (Figure 1). In the first half, a longer distance (P<0.01, ES=1.85) was covered in the initial 10 min compared to the final 10 min. Mean speed decreased, while the total distance covered remained unchanged in the second half.[2] No relationship was found between mean RWL and the distance covered throughout the entire match. The amount of high-intensity running was lower ($P<0.05$, ES=0.58) in the second than in the first half.[2] When analysing the match in successive 5-min intervals, no relationship between mean RWL and the amount of high-intensity running could be demonstrated.

Blood Lactate Concentration

Mean blood lactate concentration (BLC) in capillary blood for selected players (N.=38, mean total effective playing time 52.20±5.80 min) was 1.5±0.5 mM prior to the match (after the warm up) and 3.7±1.6 mM and 4.8±1.9 mM after the first half and after the end of the match, respectively, with individual post-match values ranging from 2.8 to 10.8 mM. It was only possible to take blood samples in certain matches and only in selected players, because some players refused to have blood sampled in connection with tournament matches.

Fluid loss

Mean intake of fluid and loss of weight for selected players (N.=24, mean total effective playing time 51.28±4.72 min) were 0.61±0.20 l and 0.45±0.23 kg, 0.59±0.31 l and 0.36±0.21 kg and 1.20±0.43 l and 0.81±0.41 kg after the first half, after the second half and averaged for the entire match, respectively. Consequently, the mean total fluid loss was at corresponding times 1.06±0.33 l, 0.95±0.38 l and 2.01±0.47 l, respectively. The players' intake of fluid and their weight loss did not differ, respectively, between the first and the second half resulting in a similar magnitude of fluid loss in the two halves. The amount of mean weight loss (0.8 kg) in an entire match was equal to 0.9 % of mean body mass in the selected players.

Physical testing

Maximal aerobic power

Mean body mass of the players from two top ranked teams was 90.9±9.0 kg with marked dif-

Table III.—*Body mass, VO_{2max} (absolute, normalized) and Fitness Index in male elite team handball players (N.=26). Mean lactate and potassium-concentration at rest and after maximal exhaustion during treadmill testing are shown. Results are group means±SD.*

Positions	Total (N.=26)	Wing players (N.=9)	Pivots (N.=7)	Backcourt players (N.=7)	Goalkeepers (N.=3)
Body mass (kg)	90.9±9.0	80.9 ±5.5 *	101.4±8.3 #	91.7±6.7	94.3±6.8
HR-max (beats·min^{-1})	5.18±0.66	4.72±0.14 *	5.70±0.79 #	5.23±0.71	5.20±0.54
VO_2-max (l O_2·min^{-1})	191±8	197±6	186±9	191±7	187±7
VO_2-max (ml O_2·min^{-1}·kg^{-1})	57.0±4.1	58.3±3.5	56.2±5.8	57.0±4.5	55.1±2.7
Fitness Index (ml O_2·min^{-1}·kg$^{-0.73}$)	192.6±18.2	191.0±19.0	195.7±21.2	193.2±15.3	188.2±19.7
Maximal running time (s)	281±30	290±14	278±16	283±20	253±26 €
K^+- concentration, at rest (mM)	3.86±0.48 $^{\pi}$	3.67±0.55 $^{\pi}$	4.12±0.66 $^{\pi}$	3.90±0.38 $^{\pi}$	3.77±0.40 $^{\pi}$
K^+- concentration, at max (mM)	5.53±0.57	5.44±0.52	5.51±0.61	5.58±0.52	5.72±0.87
La^+- concentration, at rest (mmol/l)	1.09±0.31 $^{\pi}$	1.18±0.51 $^{\pi}$	1.21±0.34 $^{\pi}$	0.95±0.23 $^{\pi}$	0.87±0.21 $^{\pi}$
La^+ -concentration, at max (mM)	10.49±2.94	10.20±0.87	10.42±3.12	10.74±2.80	10.94±5.52
Running speed at 4 mM (km·h^{-1})	12.9±1.8	13.6±1.5	12.8±2.1	12.4±1.5	12.3±0.9
VO_2-max at 4 mM (ml O_2·min^{-1}·kg^{-1})	45.4±5.7	48.5±6.1	44.1±5.1	43.8±4.5	43.2±6.2

Difference between wing players and other playing positions *$P<0.001$, between pivots and other playing positions #$P<0.05$, between goalkeepers and other playing positions $P<0.05$, and between values obtained at rest and at maximal exhaustion $^{\pi}P<0.001$.

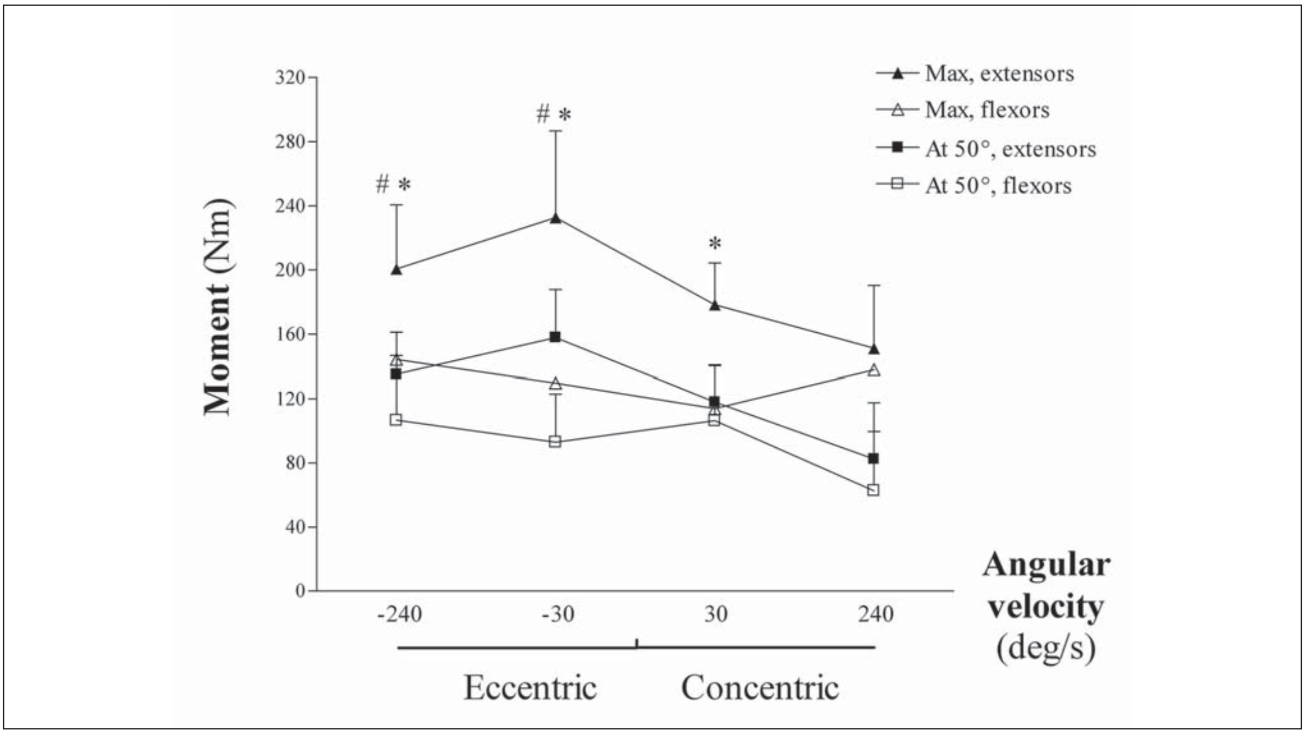

Figure 2.—Maximal concentric and eccentric muscle strength obtained for the knee extensors (closed symbols) and flexors (open symbols) in the primary take-off leg of male elite team handball players (N.=22). Peak moment and moment (triangles) and iso-angular moment at 50° knee joint angle (0°=full knee extension) are indicated. Negative and positive joint angular velocities denote eccentric and concentric muscle actions, respectively. Results are group means ± SD. Difference between maximal eccentric and concentric work for the extensors #P<0.05 and for the flexors **P<0.05 and between knee extensor strength and knee flexor strength *P<0.001.

ferences observed between playing positions (Table III). Absolute VO_{2-max} averaged 5.18±0.66 l $O_2 \cdot min^{-1}$, and positional differences were observed that closely mimicked differences in body mass. The highest value of 6.43 l $O_2 \cdot min^{-1}$ was obtained in a PV with a body mass of 115 kg. Highest HR measured (HR-max) averaged 191±9 beats·min^{-1} for all players combined with no differences between playing positions.

VO_{2-max} normalized relative to body mass (ml $O_2 \cdot min^{-1} \cdot kg^{-1}$) or expressed as Fitness Index (ml $O_2 \cdot min^{-1} \cdot kg^{-0.73}$) did not differ between playing positions. Normalized VO_{2max} and Fitness Index for all players combined were 57.0±4.1 ml $O_2 \cdot min^{-1} \cdot kg^{-1}$ and 192.6±18.2 ml $O_2 \cdot min^{-1} \cdot kg^{-0.73}$, respectively. Mean running speed at 4 mM BLC was 12.9±1.8 $km \cdot h^{-1}$ for all players combined with no differences observed between playing positions, although WP tended to run at a faster speed (13.6±1.5 $km \cdot h^{-1}$) than all other playing positions (P=0.07). Mean BLC and concentration of potassium at rest was 1.1±0.3 mM and 3.9±0.3 mM, respectively, which was substantial lower (P<0.001) than observed at maximal exhaustion in the treadmill test (10.5±2.9 mM, ES=4.56 and 5.5±0.6 mM, ES=3.37, respectively). No differences were observed between playing positions (Table III).

Maximal muscle strength

The knee extensors (m. quadriceps) were stronger (p<0.05) during eccentric than at concentric contractions both at 240°·s^{-1} and 30°·s^{-1} (Figure 2). In contrast, maximal strength of knee flexors (the hamstrings) did not differ between eccentric and concentric contraction conditions except for iso-angular moment obtained at high speed (240°·s^{-1}). No relationship was found between the isolated muscle strength capacity and others parameters investigat-

TABLE IV.—*Jump ability (top section), sprint ability (middle section) and throwing ability (bottom section) in male elite team handball players (N.=26). Results are group means±SD (range).*

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

Difference (top section) between goalkeepers and pivots & backcourt players; * P<0.05 and between wing players and all other field players; ** P<0.05; (middle section) between wing players and goalkeepers; # P<0.05 and between wing players and pivots & goalkeepers; ## P<0.05 and (bottom section) between pivots and all other field players # P<0.05, between pivots and wing players & backcourt players; § P<0.05, between goalkeepers and backcourt players π P<0.05, between goalkeepers and wing players & backcourt players α P<0.05 and between set shot with run up and all other types of shots *P<0.05.

ed such as maximal CMJ height (with or without ½ body mass), maximal "Jump and Reach" height, standing 5-step jumping distance, 30-m sprint times, body mass and body height.

Jumping ability

While WP demonstrated greater unloaded CMJ jumping height than all other players (P<0.05), loaded CMJ performance did not differ between playing positions (Table IV). Maximal jumping height in the "Jump and Reach" test was 0.71±0.08 m (range: 0.61-0.86 m). Maximal horizontal jump distance in the standing 5-step jump test was 13.39±0.70 m with a best performance of 14.32 m achieved by a WP. No positional differences were observed for these two tests (Table IV).

Yo-Yo testing

Mean total running distance in the Yo-Yo IR2-test for all players combined (N.=26) was 895±184 m corresponding to level 21:3. Positional differences were demonstrated with WP (975±123 m) performing better (p<0.05) than all other playing positions (BP (897±108 m, ES=0.67), PV (827±264 m, ES=0.72), goalkeepers (807±205 m, ES=0.99). The best individual performance was recorded in a PV, who ran 1360 m (level 22:7).

Repeated sprint ability

WP showed superior repeated sprint running ability (7 x 30 m) compared to the other players (Table IV). Fastest lap time and mean time for 7 x 30 m sprint averaged for all players were 4.09±0.12 s and 4.30±0.13 s, respectively. The corresponding fastest individual times were 3.87 s and 4.04 s, respectively, achieved by a BP. Fatigue time averaged 0.33±0.14 s, which provided a mean fatigue index (FI) of -8.1±2.7 %. FI=100 x $(S_{best}-S_{worst})/S_{best}$, where S refers to sprint performance.[26] The smallest drop in performance (0.07 s~FI of -1.7 %, indicating low repeated sprint fatigue) was observed in a WP. A negative correlation was observed between VO_{2-max} ($ml\ O_2\cdot min^{-1}\cdot kg^{-1}$) and fatigue time, *i.e.* a higher VO_{2-max} was associated with a reduced fatigue time (r =-0.87, P<0.05).

Ball throwing velocity

The fastest shots (all players combined) was observed using the set shot with 3-step run-up ($92.8\pm5.3\ km\cdot h^{-1}$), which on average was 10.2 % faster than the jump shot that had the lowest mean speed ($84.2\pm5.2\ km\cdot h^{-1}$) (Table IV). The fastest individual shot was recorded in a BP releasing the ball with 108.2 $km\cdot h^{-1}$. Differences were observed between playing positions, where WP and BP performed faster shots than PV and goalkeepers (Table IV).

Discussion

Combined with recent match-play observations in the present group of players,[1, 2] this is the first study to examine the physical demands in male elite TH by means of a complete working demand analysis. The major findings of the present study were that modern male elite TH match-play places moderate-to-high demands on the players' aerobic (cardio-vascular) system as evidenced by a mean RWL of ~70% of $VO_{2\text{-max}}$, while the observation of moderate-to-high post-match BLC-values suggest a concurrent, substantial involvement of anaerobic muscle energy production. In addition, positional differences in physiological demands and in physical test results were demonstrated, along with indications of temporary fatigue during the time-course of match-play.

Physiological measurements during match-play

Heart rate

The present matches were performed in relatively constant temperature and humidity conditions (18-22 ºC, 50-70%). In addition, the players were allowed an unlimited fluid intake during the matches. Consequently, mean weight loss (0.8 kg) during an entire match was equal to 0.9 % of mean body mass, which was below the limit suggested to impair exercise performance.[27] Thus, the influence from dehydration, body weight loss and hyperthermia on the recorded HR values was deemed to be minimal. However, future studies are needed to further examine the physiological strain related to the development of match-induced fatigue in elite TH.

The analyzed players were active about 90% (~54 min) of the total effective playing time (60 min) with a mean HR of 163 beats·min^{-1}, whereas when calculated for total match time (~79 min), players showed mean HR values of 158 beats·min^{-1}. The difference between HR during active match-play and total-time HR (~3%) was surprisingly small given the difference between individual playing time and total match duration (~25 min). The time difference 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, which likely prevented HR to drop substantially during the phases of paused play.

Relative workload

The optimum situation to investigate the physical demands of TH is during official elite tournament matches. In disadvantage some types of measurements (VO_2 sampling, blood withdrawal) cannot be performed during direct match-play. Consequently, the present study used indirect assessment of VO_2 during match-play to calculate RWL expressed as % of $VO_{2\text{-max}}$ based on individual HR-VO_2 relationships established in the laboratory. Similar procedures have been used to assess the physiological demands during match-play in elite female TH players.[21, 22] The method has previously been validated in soccer match analyses, where HR and VO_2 measured during soccer drills followed the linear HR-VO_2 relationship observed during treadmill running.[19, 20] Estimating VO_2 from HR measures during four-a-side TH games was found not to be highly accurate.[28] However, by employing no resting periods, no dribling and no physical contact with opponents these simulated game activities differed markedly from the activity pattern typically performed during actual elite TH match-play, which may have led to a skewed relationship between HR and VO_2.

Although low-intensity activities (jogging, walking and standing still) constituted 85% of mean effective playing time,[2] players demonstrated a mean relative workload of ~70% of $VO_{2\text{-max}}$ during the periods of effective match-play. This indicates that the amount of high-intensity, strength related technical playing actions [1] had a marked influence on the HR response observed and hence on the relative workload imposed on the players without contributing substantially to the total distance covered.[2] 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, solely using the findings derived from locomotion match analyses will likely underestimate the true physical demands of elite TH match-play.

Male elite TH appears to impose moderate-to-high demands on players´ aerobic energy production as evidenced by a moderate-to-high mean RWL during match-play (~70% of VO_{2-max}, individual range: 62.7-79.2% of 57.0 mL $O_2 \cdot min^{-1} \cdot kg^{-1}$). At transient time periods individual RWL were found to exceed 90% of VO_{2-max} (Table II). A contributing factor may arise from players running for large periods of the match with attention fixed on the ball or directly with the ball, which is known to increase VO_2.[29] In comparison, this is still far from the RWL in elite marathon runners that may correspond to ~90% of VO_{2-max} averaged over the entire race.[30]

PV and WP demonstrated substantially higher RWL than BP. A high RWL was expected for WP, since they performed the largest amounts of high-intensity running and covered the greatest total distance, while PV covered the lowest total distance of all players and did less high-intensity running than WP.[2] These combined observations strongly suggest that RWL is influenced by the technical actions of the game. PV performed considerably more physical confrontations with opponent players during match-play than all other playing positions [1]. Consequently, the PV is a highly physical demanding playing position. On the other hand, BP were found to perform low amounts of high-intensity running and play with a low mean speed [2], which explain the present observation of a low RWL during match-play in this playing position.

For all players combined and at all separate playing positions, the RWL during match-play was lower in the second than in first half of the match (Table I), which was also observed for the amount of high-intensity running [2] in accordance with previous studies in elite soccer.[31] The differences in RWL between the two halves could not be fully explained by differences in the distance covered. Unexpectedly, no relationship emerged between RWL and the total distance covered or the amount of high-intensity running, further suggesting that technical actions have also a vital influence on the RWL. Several indications of temporary fatigue and performance impairment were observed in players with a mean total effective playing time of more than 50 min. Thus, the RWL was higher during the first 20 min of the first half than in the corresponding 20 min period in the second half (all players). Further, RWL tended to be reduced ($P=0.07$) in the final 10 min of the first half, until 5 min after onset of the second half after which the RWL slowly rose again (Figure 1). These data suggest that elite TH players may experience temporary fatigue already after 20 min of play. Nevertheless, the coach still keeps these players on the playing court probably for technical and tactical reasons. Likewise, soccer players have been observed to perform fewer sprints during the middle phase of the first half compared to the initial phase of the match, although recovering towards the end of the first half.[31]

Blood Lactate Concentration

Mean postmatch blood lactate concentration (BLC) was 4.8 mM with large individual differences (2.8 to 10.8 mM), which is similar to reports in male elite soccer players,[20] but a higher than reported in German male elite TH players 25 years ago.[10] Lactate is produced in the muscle and before interstitial lactate reaches a steady state exchange with the blood stream, a large part can be metabolized in other muscles or organs.[8] No previous study has measured muscle lactate production during or following TH match-play. Observed in a friendly soccer match, muscle lactate was not correlated with BLC.[32] Thus, postmatch blood lactate may be low although players during the match may have produced substantial amounts of lactate during high-intensity activities.

Furthermore, in a study on elite soccer players during test match-play, high BLC were measured during both half's, whereas relative low values were observed in the break and following the match.[33] Thus, BLC is dependent on the amount of high-intensity exercise performed in the minutes prior to blood sampling.[33] The large interindividual variation in post-match BLC may indicate that the values obtained in the present study were influenced by the activity pattern of the players towards the end of the match. Delamarche *et al.*[11] assessed the BLC in young sub-elite TH players during practice games (30 min) and observed BLC values of 4-9 mM, which according to these authors were higher than the values derived from samples drawn only at the end of the game. These reports suggest that higher BLC values might have been obtained in the present group of players, if blood sampling had been possible during the phases of active match-play (i.e. in time-outs and during substitution periods). BLC is a consequence of lactate appearance and clearance. Thus, players with low levels of blood lactate may actually work at similar, or even higher, intensities than players with high BLC due to an efficient rate of lactate clearance in the former players.

The relatively high BLC values observed in the present study indicate that the rate of muscle lactate production may be high during elite TH match-play, hence indirectly supporting the notion that temporary fatigue might occur in male elite TH. Consequently, male elite TH appears to impose high demands on the anaerobic energy systems at least during certain periods of the match.

Physical tests

Maximal aerobic power

Normalized to body mass, no differences in VO_{2-max} (mL $O_2 \cdot min^{-1} \cdot kg^{-1}$) were observed between playing positions. For all players combined, VO_{2max} was 57 mL $O_2 \cdot min^{-1} \cdot kg^{-1}$ (individual range: 50-63 mL $O_2 \cdot min^{-1} \cdot kg^{-1}$), higher than previous data from Ramadan *et al.* [34] in Kuwait national players (51 mL $O_2 \cdot min^{-1} \cdot kg^{-1}$), but roughly corresponding to previous reports by Delamarche *et al.*[11] in French sub-elite players (58 ml $O_2 \cdot min^{-1} \cdot kg^{-1}$). Using portable VO_2 equipment, VO_{2-max} in elite TH players during a graded aerobic test performed on an indoor track was 57 ml $O_2 \cdot min^{-1} \cdot kg^{-1}$, while four-a-side handball game-play (2 x 225 s) produced values of 60 ml $O_2 \cdot min^{-1} \cdot kg^{-1}$.[28] In comparison, Jensen [35] reported mean VO_{2max} obtained by graded treadmill testing in 47 male players from the Danish National Team squad to be 59 mL $O_2 \cdot min^{-1} \cdot kg^{-1}$. The apparent VO_{2max} level of male elite TH players (~50-60 ml $O_2 \cdot min^{-1} \cdot kg^{-1}$) resembles that reported for other ball games like basketball [36] and soccer [37, 38]. Direct comparison of VO_{2-max} between subjects of different body mass become possible, when VO_{2-max} is expressed as Fitness Index (ml $O_2 \cdot min^{-1} \cdot kg^{-0.73}$).[17] Notably, in the present study no differences were demonstrated between various playing positions for this parameter.

Danish national team players have become taller and heavier with increased muscle mass over the last decades, while concurrently demonstrating a higher aerobic power per kg body mass.[34] Thus, in the mid-seventies mean Fitness Index in Danish national team players was 180 mL $O_2 \cdot min^{-1} \cdot kg^{-0.73}$, while reaching 195 mL $O_2 \cdot min^{-1} \cdot kg^{-0.73}$ in the early nineties [35]. Collectively, these previous data combined with the present findings suggest that maximal aerobic power is an important element in modern elite TH, but it does not seem to represent a limitation for elite performance. This notion is supported by Gorostiaga *et al.*,[3] who failed to find any differences between Spanish elite and amateur TH players during all-out endurance run testing on an indoor TH court, suggesting that endurance capacity (and hence aerobic power) does not *per se* differentiate elite players from non-elite players. However, aerobic power is an important basis for the players that make them able 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 with numerous matches in a short period of time.[8]

The Fitness Index values of ~190 mL $O_2 \cdot min^{-1} \cdot kg^{-0.73}$ observed in the present group of elite TH players is far from that seen in endurance athletes such as elite cross-country skiers (274 ml $O_2 \cdot min^{-1} \cdot kg^{-0.73}$).[17] Although the Fitness Index (and VO_{2-max}) in elite male TH seems to have stabilized at a level of ~200 mL $O_2 \cdot min^{-1} \cdot kg^{-0.73}$ (60 mL $O_2 \cdot min^{-1} \cdot kg^{-1}$), players' absolute VO_{2-max} (L $O_2 \cdot min^{-1}$) appears to have been continuously improved in line with the increase in muscle mass and body mass, respectively. It is crucial for the players to be able to preserve their functional characteristics on the TH court with the larger and heavier body.

Maximal muscle strength

Maximal eccentric and concentric thigh muscle strength obtained in the present elite TH players were somewhat lower (5-15% reduced) than previously observed in Danish male elite (National Team) athletes using identical test setup (yachtsmen, volleyball players).[39] Surprisingly, no relationship were observed between maximal isolated muscle strength and jumping ability.

Jumping ability

WP demonstrated higher unloaded CMJ jumping height and a tendency (P=0.08) for greater maximal jumping height in the "Jump and Reach" test compared to the other field playing positions. The mean jumping height of the "Jump and Reach" test (0.71 m) was similar to previous results obtained in the Danish National Team (EC Gold 2008, 0.69 m), but less than reported for elite Austrian volleyball players.[40] Maximal jumping height during CMJ testing (without the use of the arms) was somewhat higher (43.9 cm) than previously observed in Danish elite TH players (39.2 cm),[15] when the latter players were tested at the beginning of the season. The aspect of test timing may have influenced the results, since CMJ jumping height was higher after intensive in-season training compared to season start in Spanish elite TH players [6]. In the present study, testing was performed during the middle of the regular tournament match period, where physical training efforts were peaking.

Yo-Yo testing and repeated sprint ability

The Yo-Yo test provides a simple and valid way to obtain important information of an individual´s capacity to perform repeated intense running exercise and to examine training-induced changes in intermittent exercise performance.[25] Mean total running distance covered in the Yo-Yo IR2 test was markedly lower (895 m) than reported in elite soccer players (1240 m) and also lower than observed in young top-level male badminton players (1020 m).[25] In team ball sports, a large variability in the Yo-Yo test outcome within a team is often seen. Nevertheless, a certain minimum standard may be set in given sport disciplines. For example, in elite soccer very few players at the international level demonstrate values below 760 m.[41] With more testing, similar cut-off values may be established in TH as well.

Positional differences were observed as WP ran longer than all other players in accordance with the elevated demands for high-intensity running in WP.[2] In contrast, no positional differences were observed between elite male outfield soccer players, except that the performance of attackers tended to be lower.[41, 42] In the repeated sprint test, the best average performance in all three result categories was obtained by WP. Consequently, WP appears to have a higher capacity for high-intensity running compared to other field players.

Ball throwing velocity

A central element of elite TH is throwing ability. The present data on maximal throwing velocity in the various types of shots confirm previous reports in Danish national team players.[35] Mean maximal ball velocity in the standing set shot and the 3-steps run-up set shot was of similar magnitude as previously reported in international elite TH players,[5] which, however, used a different methodology. Notably, for all types of shots examined the present ball speeds were higher than reported for Danish national team players tested 35 years ago [9] using an identical methodology. This indicates the development of greater muscle strength and power (and/or better technique) in present-day elite TH players. Maximal throwing velocity was highest in BP. This was not surprising, since BP are tall with great body mass that perform most shots behind the 9-m line 1. Previous studies have reported higher maximal ball throwing velocities in elite compared to non-elite players,[3, 43, 44] indicating that maximal throwing velocity is an important element in modern elite TH.

Notably, throwing velocity can be improved with resistance and power training [3, 6] and also with functional strength training with overweight balls,[45] which underlines that it is very necessary to transfer newfound strength to the specific shot movement in TH. In elite TH with an often tough and cash defence, it is rare that a player is given time and opportunity to shoot with full run-up or force. It is often the surprise, the variation and accuracy, which determine whether a shot will result in a goal. However, a Norwegian Study [44] demonstrated that when accuracy in an experimental shot for elite players was prioritized, the velocity of the shot decreased, but the accuracy did not improve.[43]

Overall, training in male elite TH should be individualized to reflect position specific differences in physiological and physical profiles observed in the present study. However, the present physical test data were contradicting findings in Tunisian elite TH players, who showed no positional difference in physical test performance.[46]

Conclusions

In conclusion, modern elite male team handball is a physically demanding game activity that appears to place moderate-to-high demands on player's aerobic system, while also imposing substantial demands on anaerobic energy systems. The present data obtained during a large number of Danish Premier Male Team Handball League matches revealed indications of temporary fatigue onset during match-play. Physical profiles differed between playing positions, with wing players covering a greater total distance during the Yo-Yo test and showing superior jumping performance and repeated sprint running capacity compared to both backcourt players and pivots. The present observations of positional differences in physiological capacity and demand profile should be taken into account when planning physical training in elite team handball players.

Perspectives

The substantial positional differences in the physical demands that were revealed in the present study challenge the traditional way of conducting physical training in modern team handball. Consequently, differential and specific physical training in male elite team handball should be implemented at the various playing positions to ensure optimal development of the physical capacity of the individual players. Such individualized training may be divided into separate exercises related to the specific requirements in defence and offence, respectively. The increased knowledge regarding the physical demands of male elite team handball players is important for recommendations for the future planning and execution of physical training. Future studies should be conducted to identify how different tactical playing styles affects the physical demands imposed on the players during match-play and the resulting consequences for the development of fatigue at the various playing positions. Moreover, it would be of major interest to investigate the impact of different training regimens (strength vs. anaerobic vs. aerobic exercise) for increasing the physical fitness in elite team handball players and to provide improved fatigue resistance during elite team handball match-play.

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