Original Article

Time-motion analysis in women's team handball: importance of aerobic performance

CARMEN MANCHADO [1], JANEZ PERS[2], FERNANDO NAVARRO[3], AHREUM HAN[4], EUNSOOK SUNG[4], PETRA PLATEN[4]

[1]*Faculty of Education, University of Alicante, Spain*
[2]*Faculty of Electrical Engineering, University of Ljubljana, Slovenia*
[3]*Faculty of Sport Sciences, University of Toledo, Spain*
[4]*Faculty of Sport Sciences, Ruhr University Bochum, Germany*

ABSTRACT

Manchado C, Pers J, Navarro F, Han A, Sung E, Platen P. Time-motion analysis in women's team handball: importance of aerobic performance. *J. Hum. Sport Exerc.* Vol. 8, No. 2, pp. 376-390, 2013. Women's handball is a sport, which has seen an accelerated development over the last decade. Data on movement patterns in combination with physiological demands are nearly nonexistent in the literature. The aim of this study was twofold: first, to analyze the horizontal movement pattern, including the sprint acceleration profiles, of individual female elite handball players and the corresponding heart rates (HRs) during a match and secondly to determine underlying correlations with individual aerobic performance. Players from one German First League team (n = 11) and the Norwegian National Team (n = 14) were studied during one match using the Sagit system for movement analysis and Polar HR monitoring for analysis of physiological demands. Mean HR during the match was 86 % of maximum HR (HRmax). With the exception of the goalkeepers (GKs, 78 % of HRmax), no position-specific differences could be detected. Total distance covered during the match was 4614 m (2066 m in GKs and 5251 m in field players (FPs)). Total distance consisted of 9.2 % sprinting, 26.7 % fast running, 28.8 % slow running, and 35.5 % walking. Mean velocity varied between 1.9 km/h (0.52 m/s) (GKs) and 4.2 km/h (1.17 m/s) (FPs, no position effect). Field players with a higher level of maximum oxygen uptake (V̇O2max) executed run activities with a higher velocity but comparable percentage of HRmax as compared to players with lower aerobic performance, independent of FP position. Acceleration profile depended on aerobic performance and the field player's position. In conclusion, a high V̇O2max appears to be important in top-level international women's handball. Sprint and endurance training should be conducted according to the specific demands of the player's position. **Key words**: ACCELERATION, FEMALE ATHLETE, PHYSICAL ENDURANCE, VELOCITY.

Corresponding author. Faculty of Education, University of Alicante, Campus San Vicente del Raspeig, 03080 Alicante, Spain.
E-mail: carmen.manchado@ua.es
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INTRODUCTION

Team handball is an Olympic sport that has been played throughout the world for many years. However, despite of growing professionalization, there is a remarkable lack of scientific information concerning movement patterns in combination with physiological demands of the individual player (Ziv & Lidor, 2009a). Even less information is available for women's handball, where data on movement patterns in combination with physiological demands are nearly nonexistent in the literature (Lidor & Ziv, 2011; Manchado et al., 2012). This is especially true for the time period of the past few years, after developing changes in rules that impact game intensity in 2002. Statistics from the 1999 and 2003 World Championships for women show that the total number of attacks increased by nearly 10 % after this rule change (Ronglan et al., 2006). As a result, top-level women's handball has increased in terms of dynamics, velocity and intensity in the past few years.

Detailed information on the movements like, the distances covered by players, the velocities of their movements and position in two-dimensional space during a game –among the analysis of vertical movements like jumps, shots or blocking- provides comprehensive assessment of the demands of competition and assists in developing specific training regimes. Data on run distances and run velocities and other movement patterns of individual players, however, are not available in the literature. This lack of information includes the physiological demands on the individual player accompanying the movements.

For many years, team sports analysis consisted mainly of human observers filling in "observation sheets" during the matches. With the emergence of widely available and low-cost computers, data manipulation and analysis have been modernized, although the principles have remained the same (Ali & Farrally, 1991), and accuracy and reliability of the obtained data have remained low. On the other hand, video-based motion acquisition was used to obtain player positions as far back as the early 1990s, using somewhat primitive techniques of camera calibration and position acquisition (Erdmann, 1992). In the past few years, a computer-vision system ("Sagit") using bird's eye video positioning has been developed and validated for the exact analysis of large-scale players' movements in sports such as handball, basketball, squash, and tennis (Pers et al., 2002). The advantages of this technology lie in its high data processing capacity along with the reliability, speed and accuracy of the acquired data. In addition, since it is entirely based on video technology, its use is completely nonintrusive and causes no disruptions to the game or the players (Erculj et al., 2008). One recent investigation used the Sagit system for match analysis for elite adolescent team handball players (Chelly et al., 2011). However, to date, this system has never been used for motion analysis of female handball players.

For about 20 years, highly developed aerobic performance, determined as maximal oxygen uptake (V̇O2max), has been considered to be a fundamental basis for team handball on the international level (Platen, 1989). This statement has been summarized for team sports in general in a recent review (Stone & Kilding, 2009). Unfortunately, the handball-specific physiological demands have not been investigated systematically, neither in the past, nor during the years following the rule changes described above. This might be due to a lack of methods that can be used during competition in order to analyze physiological reactions. Individual HR, however, is a relatively easy-to-use parameter, especially since the development of the "Polar® Team System," which allows the storage of heart rate data in a transmitter that can be worn during competition without risk of injury. Continuous measurement of heart rates allows analysis of individual physiological demands during intermittent exercise, including team sports (McInnes et al., 1995), because variations in heart rate during exercise correlate with a small time delay with alterations in exercise intensities (Achten & Jeukendrup, 2003). Only one study has investigated heart rates in female top-level handball players during competition so far (Manchado et al., 2007). This study reported a mean heart rate of 85.8 % of maximum heart rate with a broad variation of 74.7 % to 91.7 % between players. However, as no time-motion analysis was carried out during that study, interactions between movement patterns and physiological demands could not be determined.

Therefore, the aim of this study was twofold: first, to exactly analyze large-scale movement patterns including - for the first time in an investigation in women's handball - acceleration profiles of top-level female handball players during a match in combination with the analysis of heart rate profiles as an indicator of individual physiological demands, and secondly, to assess the influence of maximal oxygen uptake on these parameters.

MATERIAL AND METHODS

Experimental approach to the problem

This is a cross-sectional observational study investigating one of the best German First League women's handball teams and one of the world´s leading national teams, the Norwegian national women's handball team. We investigated the Norwegian National Team during one match of an international tournament, and a German First League team during a First League match. The Norwegian National Team won the European Championship in 2004 and 2006 and was the gold medalist during the Olympic Games in 2008. The German First League team was the European Challenge Cup Winner in 2005. Therefore, both teams truly represent international top level women's handball teams, and both matches are representative of a top-level women's handball match.

The most widely accepted parameter in sports medicine for objectifying endurance capacity is maximum oxygen uptake (V̇O2max) (ACSM, p73). To determine V̇O2max, all subjects performed a vita-maxima test on a motorized treadmill. As the determination of V̇O2max depends on maximum cardiopulmonary exhaustion (Uth et al., 2004), this test was also used to determine HRmax. The participants were familiar with the test protocol for the determination of V̇O2max and HRmax, since they routinely performed this test at least once per year. The Norwegian team was tested at the Norwegian Olympic Centre, Oslo, Norway, and at the Norwegian Institute of Sports Medicine (Hjelp24 NIMI), Oslo, Norway. The German team was tested at the laboratory of the Institute of Cardiology and Sports Medicine of the German Sport University, Cologne, Germany.

One generally accepted method of describing exercise intensity is the determination of the percentage of HRmax obtained during exercise (ACSM, p156ff). In accordance with Helgerud et al. (2001) individual demands were categorized into five intensity zones based on %HRmax: zone I: < 70 %; zone II: 70 – 85 %; zone III: 85 – 90 %; zone IV: 90 – 95 %, and zone V: > 95 % of HRmax.

For the time-motion analysis of player's movements, we used the Sagit computer-vision system that was developed and evaluated by engineers from the University of Ljubljana, Slovenia, for the analysis of indoor ball games, including handball (Bon, 2001; Bon et al., 2004; Pers et al., 2002). In short, video analysis included video calibration, automatic tracking and manual corrections (using the videos from the side of the playing field for controlling players' movements), manual annotation (optional), export of trajectory data and annotations to the file or export of graphical diagrams of trajectories, velocity and acceleration (Pers et al., 2002).

Participants

Twenty-five elite handball players with different positions (3 goalkeepers, 9 backs, 8 wings and 5 pivot players) from a German First League team (n=11) and the Norwegian National Team (n=14) gave their verbal consent to participate after information about the purpose and protocol of the study had been given. The study conformed to the standards set by the Declaration of Helsinki. The local Ethics Committee approved the study. As the risks for the subjects were very low because the study mainly constituted survey research, the Ethics Committee declared the study to be exempt from the usual requirement of obtaining written informed consent. Subjects' characteristics were: age: 25.2 ± 2.8 years, weight: 67.8 ± 4.8 kg, and height: 175.2 ± 6.3 cm, without any differences between the teams or between players in different positions.

Procedures

Maximum oxygen uptake and maximum heart rate

V̇O2max and HRmax were determined during an incremental maximum intensity test on a calibrated treadmill. For the German team, the following test protocol was used: The initial velocity was set at 2.4 m·s-1 and increased to 2.8 m·s-1 after 5 min; the incline of the treadmill was 1 %. After this 10-minute warm-up, inclination was increased to 2 %, and velocity was increased by 0.2 m·s-1 every 30 sec until exhaustion. For the Norwegian team, the following procedure was used: After a 20-minute, low-intensity warm-up, the incline of the treadmill was constantly set at 5 % and a step test was started with a velocity of 10 km·hr-1. Velocity was increased by 1 km·hr-1 every minute until exhaustion. Each player was instructed and verbally encouraged to give maximum effort. Duration of the tests varied between 4 min and 7 min, depending on individual aerobic performance. Prior to the study, we analyzed V̇O2max values obtained from both test protocols in physical education students (n=6, age: 23.5 ± 2.1 years, weight: 77.4 ± 5.8 kg, and height: 181.2 ± 5.1cm). Both tests resulted in significantly correlated V̇O2max values (r=0.96, p=0.002) without any significant difference between the two tests (50.6 ± 6.5 vs. 51.8 ± 5.5 mL·kg-1·min-1, for the test obtained with the German team, and the Norwegian National Team, p>0.05). Throughout the test, gas exchange was measured continuously using a ZAN spirometric system (German team) (ZAN, Oberthulba, Germany) or a Sensor Medics Vmax29 (Norwegian team) (SensorMedics Corp, Yorba Linda, CA, USA), respectively. The analyzer was calibrated daily using a 1-L calibrated syringe and a gas mixture of known concentration (5% CO2, 16 % O2, and 79 % N2). V̇O2max was determined as the highest mean value of 10 consecutive seconds. Heart rate was measured continuously using a heart rate monitor (Team System, Polar Electro Oy, Kempele, Finland). HRmax was determined as the highest value that was obtained when the subject was exhausted.

Movement analysis during matches

For the time-motion analysis, two video cameras were installed on the ceiling of the arena, approximately in the middle of each half field to record the games at 25 video frames per second, thus obtaining 25 positions for each individual player for every second of the game. Furthermore, an additional video camera was set up at the side of the playing field near the center line. After digitalization, the videos from the ceiling of the arena were further analyzed using the software program Sagit (Pers et al., 20002). The use of 25 video frames per second allowed a very detailed movement analysis resulting in 25 distinct values for velocity and acceleration per second.

Horizontal movements in the game were identified and assigned to five arbitrary velocity categories: stand, walk, slow run, fast run and sprint. "Stand" was defined as "the subject stands on the court without any steps" (0 m·s-1); "walk" was defined as "forward or backward movements of no greater intensity than walking" (0 – 1.3 m·s-1); "slow run" was defined as "forward or backward movements at an intensity greater than walking but without urgency" (1.4 – 3.0 m·s-1); "fast run" was defined as "forward or backward movement at an intensity greater than jogging and a moderate degree of urgency" (3.1 – 5.2 m·s-1); and "sprint" was defined as "forward movement at a high intensity, characterized by effort and purpose at or close to maximum" (>5.2 m·s-1). As no velocity categories were described earlier for female handball players, we defined the range of velocities of each of these movement categories using the mean pace of the players of the German National Handball Team who were asked to move on a straight line over a distance of 30 m in each of these categories with an individually selected speed. We decided to choose five categories similar to those used by Chelly et al. (2011), who investigated male adolescent handball players during matches. In addition to total run distance and mean velocity of the whole match and of each half of the match, we also calculated number per minute of each of the speed categories, their distance, and duration. As the run distance mainly depends on the time each player is on the field, we also calculated the sum of run distances of all players in one position.

In addition to velocity, we also analyzed horizontal sprint accelerations of the players. As no sprint acceleration data in team sports are available in the literature, we decided to use a similar number of acceleration categories as we used for categorization of velocity, namely four positive categories. Acceleration may occur as positive or negative movement. Therefore, we also analyzed movement patterns in four corresponding negative categories. The highest values were chosen according to the highest acceleration data we measured from the movements of the players. The values for the acceleration categories were: A1 < -4.5 m·s-2; A2 ≥ -4.5 < -3 m·s-2; A3 ≥ -3 < -1.5 m·s-2; A4 ≥ -1.5 < 0 m·s-2; A5 ≥ 0 < 1.5 m·s-2; A6 ≥ 1.5 < 3 m·s-2; A7 ≥ 3 < 4.5 m·s-2; A8 ≥ 4.5 m·s-2. One single acceleration was defined whenever the player changed from one acceleration category to another. For each acceleration category, we calculated mean number per minute, mean run distance, and mean duration of movement in this category.

Heart rates

Heart rates during the matches were recorded every five seconds using the Polar® Team System. The summarized measure used was the mean HR expressed by beats per minute (1·min-1) and its individual equivalent as percentage of HRmax (%HRmax).

Analysis

Statistical analyses

The results were analyzed for both teams and also based on individual playing positions and on individual aerobic performance (V̇O2max). For this purpose, players were divided into four groups: goalkeepers, backs, wings, and pivot players. As the back players interchanged their playing position frequently, no further differentiation was made between central and lateral backs. Furthermore, field players were ordered according to their V̇O2max and then divided into two same-sized groups according to either the higher-level or lower-level subgroup of V̇O2max. As only three goalkeepers took part in the investigation, no tests of significance were done for this subgroup, and data from goalkeepers are only shown descriptively.

Univariate analysis of variance (ANOVA) was used for the analysis of position-specific differences on the parameters tested. When a significant effect was detected, data were subsequently analyzed using a Newman-Keuls post hoc test. Correlation coefficients were determined and tested for significance using Pearson's product-moment test. Students' t-tests were used to compare the two teams, the two subgroups of high or low level of aerobic performance, and data from the first and second halves of the matches. Pearson's correlation coefficient was used to assess relationships between aerobic performance (V̇O2max) and percentage of distances covered in different run velocities, between V̇O2max and mean run velocity of the whole match, and between V̇O2max and the different acceleration categories, respectively. Statistical analysis was carried out using the Statistical Package for Social Sciences (Version 16.0). Data were expressed as means ± standard deviation (SD). p-values ≤ 0.05 were considered to be statistically significant. If multiple comparisons were performed, p was adjusted accordingly.

RESULTS

Performance characteristics

Players of the Norwegian National Team had a significantly higher V̇O2max compared to the players of the German First League team (mean of both teams: 53.1 ± 4.8 mL·kg-1·min-1; Norwegian team: 55.5 ± 3.9 ml·kg-1·min-1; German team: 50.2 ± 4.3 ml·kg-1·min-1; p < 0.01). Mean maximum heart rate of all players was 195 ± 1 min-1. Values did not differ between both teams. Furthermore, there were no position specific differences concerning V̇O2max and HRmax.

Heart rates during the match

%HRmax during the match was 78.4 ± 5.9 % for the goalkeepers and 86.5 ± 4.5 % for the field players. We did not find any differences between teams, between halves of the matches or between field players with different positions.

The time spent in the different heart rate zones as percentage of the whole playing time is given in Table 1. No differences were found between the teams in any of the heart rate zones. For this reason, team-specific data are not shown. With the exception of the goalkeepers, who tended to spend more time in lower intensity zones, no position-specific differences could be detected. Among the field players, time spent in heart rate zones higher than 85 % of HRmax (Zones III, IV, and V) accumulated to more than 65 % with about 9 % spent in the highest intensity zone. Total time spent in the very low intensity category only constituted about 6 %. Although mean heart rates did not differ significantly between the halves of the match, time spent in low to moderate intensities (between 70 % and 85 % HRmax, zone II) was higher, and time spent in high intensities (> 95 % HRmax, zone V) was lower in the second half of the match as compared to the first half.

Table 1. *Percentage of total time spent in the different heart rate zones of both teams for the whole match and for each half time, and level of significance of the half time effect; values are means ± sd.*

Both teams	1st half	2nd half	Whole match	Level of sign. of half time effect
Field players (n=22)	%	%	%	
Zone I	4.7±6.3	7.6±14.9	5.5±7.5	ns
Zone II	25.6±19.3	35.4±20.5	28.9±15.9	p<0.01
Zone III	24.1±13.7	24.9±13.7	24.1±11.6	ns
Zone IV	34.8±18.5	27.7±18.5	32.4±16.4	ns
Zone V	10.4±12.9	5.7±9.8	9.2±10.4	p<0.01
Goalkeepers (n=3)	%	%	%	
Zone I	6.0±0.0	24.0±0.0	15.0±12.7	
Zone II	51.0±0.0	72.0±0.0	61.5±14.8	
Zone III	38.0±0.0	3.0±0.0	20.5±24.7	
Zone IV	5.0±0.0	0.0±0.0	2.5±3.5	
Zone V	0.0±0.0	0.0±0.0	0.0±0.0	

Zone I: <70%, zone II: <85%, zone III: <90%, zone IV: <95%, zone V: ≥95% HRmax; ns:p>0.05

Time-motion analysis

Total run distance and mean velocity

No significant differences could be detected between mean run distances and mean run velocities during the match between the teams, between the first and second halves of the match, or between the different positions of the field players. The individual run distance varied broadly between single players. Mean run distance of the field players was 2882 ± 1506 m, and 1377 ± 293 m for the goalkeepers. Sum of run distances for all field players in one position was 5251 ± 242 m, and reached 2066 ± 513 m for the goalkeeper position during one match. Mean run velocity of the field players was relatively slow with 70 m·min-1 (about 4.2 km·hr-1) and was even slower with only 31 m·min-1 (about 1.9 km·hr-1) for the goalkeepers.

Velocity categories

Absolute values of run distances and the percentage of run distances spent in each velocity category of the field players did not differ between the two teams, between the first and second halves of the match, or between the different positions of the field players. The field players covered 961 ± 539 m (30.8 ± 5.9 %) walking, 761 ± 420 m (29.1 ± 3.8 %) slow running, 752 ± 484 m (29.7 ± 3.9 %) fast running, and 272 ± 224 m (10.5 ± 4.1 %) sprinting. The goalkeepers covered 950 ± 290 m (68.5 ± 10.2 %) walking, 358 ± 100 m (26.6 ± 8.7 %) slow running, 67 ± 37 m (4.7 ± 2.3 %) fast running, and 3 ± 2 m (0.2 ± 0.2 %) sprinting.

Table 2. *Mean number of distinct velocities per minute, mean distances and mean durations in the velocity categories "walking," "slow running," "fast running," and "sprinting" of the whole matches, and for the different players' positions, and level of significance of the position effect; goalkeepers are excluded from statistical analysis; values are means ± standard deviation.*

	Goalkeeper	**Wing**	**Back**	**Pivot**	**All field players**	**Level of sign. of position effect**
n	3	8	9	5	22	
No. of velocities ($1·min^{-1}$)						
Walking	11.4±2.4	9.6±5.3	8.4±1.5	7.4±1.7	8.6±3.4	ns
Slow running	4.6±2.0	10.4±5.7	9.6±1.6	8.5±2.4	9.7±3.7	ns
Fast running	0.7±0.1	4.1±2.1	3.1±0.5	2.8±0.5	3.4±1.4	ns
Sprinting	0.0±0.0	1.2±0.4**#	0.6±0.2	0.7±0.2	0.8±0.4	p<0.01
Sum of distinct actions	16.5±3.2	25.3±13.3	21.7±3.2	19.3±4.6	22.5±8.5	ns
Mean duration (s)						
Walking	3.9±0.4	6.2±4.9	4.4±0.7	5.3±1.8	5.2±3.1	ns
Slow running	1.0±0.4	1.2±0.1	1.2±0.1	1.2±0.2	1.2±0.1	ns
Fast running	0.7±0.4	1.6±0.3	1.7±0.1	1.8±0.1	1.7±0.2	n
Sprinting	0.5±0.2	1.3±0.2**##	0.9±0.2	0.8±0.3	1.1±0.3	p<0.01
Mean distance (m)						
Walking	1.7±0.1	2.6±0.3	2.8±0.4	3.0±0.5	2.8±0.4	ns
Slow running	1.8±0.7	2.3±0.2	2.4±0.2	2.4±0.3	2.4±0.2	ns
Fast running	2.5±1.3	6.5±1.2	6.3±0.5	7.0±0.7	6.5±0.9	n
Sprinting	2.8±1.4	8.0±1.7**##	5.7±1.4	4.9±1.6	6.3±2.0	p<0.01

***: p<0.01 wing vs. back; #: p<0.05 wing vs. pivot; ##: p<0.01 wing vs. pivot; ns: p > 0.05*

Number of distinct velocities, mean distance, and mean duration in each velocity category

No significant differences could be detected between the number of distinct velocities per minute, mean distances and mean duration of each velocity category between the two teams or between the first and second halves of the matches. For this reason, only mean data of the two teams and of the whole matches are shown (Table 2). Total number of distinct velocities amounted to more than 20 per minute, with the highest number in walking. Wing players showed the highest number of sprints per minute, the longest duration of the sprints, and the longest distance covered sprinting as compared to the other field player's positions. The other velocity parameters did not differ between playing positions, apart from the fact that the goalkeepers tended to have a lower number of actions, a shorter duration, and shorter distances in all velocity categories as compared to the field players.

Aerobic performance and run velocity

We found a significant positive correlation between V̇O2max and mean run velocity during the match in the group of the field players (r=0.48, p<0.05) (Fig. 1). Furthermore, V̇O2max was negatively correlated with the percentage of the total distance covered walking (percent walking (%) = 71.0 – 0.75·V̇O2max (mL·kg-1·min-1); r = -0.63, p<0.05), while the percent values of the total distance covered for fast running and sprinting were both positively correlated with V̇O2max (percent fast running (%) = 8.6 + 0.39·V̇O2max (mL·kg-1·min-1); r=0.50, p<0.05, and percent sprinting (%) = -16.9 + 0.51·V̇O2max (mL·kg-1·min-1); r=0.62, p<0.05, respectively). None of the distinct velocity parameters (number per minute, duration of and run distance in each velocity category), however, correlated significantly with the players individual aerobic performance.

The division of all field players into two equal-size subgroups of either lower (< 54.0 mL·kg-1·min-1) or higher (> 54.0 mL·kg-1·min-1) V̇O2max revealed a clear trend for a higher percentage of total distance spent sprinting in the players with a higher V̇O2max compared to those with a lower V̇O2max (12.1 ± 4.8 % vs. 8.9 ± 2.4 %, p=0.07, respectively), while percentage of total distance spent walking tended to be lower in this subgroup (28.6 ± 4.4 % vs. 32.9 ± 6.5 %, p = 0.08). The two subgroups did not differ in their distances in the run categories "slow running" and "fast running", in their mean %HRmax, and in the percentage of time spent in the different heart rate zones. Furthermore, none of the distinct velocity parameters (number per minute, duration of and run distance in each velocity category) differed between the two subgroups of either high or low aerobic performance.

Acceleration data

We did not find any significant differences in any of the acceleration data between the 1st and second halves of the matches. For this reason, only mean values of the whole matches are shown. The total number of accelerations per minute was quite high with an amount of nearly 200 (Table 3). The Norwegian National Team had a significantly lower number of total accelerations as well as number of accelerations in most of the different acceleration categories as compared to the German First League team. There was no team effect on the number of accelerations in the different playing positions. There was, however, a clear position effect on the number of accelerations with the wing players showing the highest numbers of all positions, and the goalkeepers with clear trends towards a lower number in the high-acceleration categories A1-A3 and A6-A8.

Table 3. *Total number of accelerations per minute in the different acceleration categories of both teams of the whole match, and level of significance of the team effect and the position effect; goalkeepers are excluded from analysis; values are means ± standard deviation.*

Number per minute (min^{-1})	German First League team	Norwegian National Team	Both teams	Level of sign. of team effect	Goalkeeper	Wing	Back	Pivot	All field players	Level of sign. of position effect
n	11	14	23		3	8	9	5	21	
A1	0.9±0.5	0.4±0.3	0.6±0.5	p<0.01	0.3±.4	1.1±0.5##	0.5±0.2	0.4±0.2	0.7±0.5	p<0.01
A2	4.4±2.7	2.6±1.1	3.4±2.1	p<0.05	1.1±0.9	5.2±2.7##	3.0±0.7	2.4±0.5	3.7±2.0	p<0.01
A3	17.6±9.4	14.1±3.8	15.6±6.9	ns	7.8±1.5	21.6±9.0#	14.2±2.5	13.3±2.0	16.7±6.7	p<0.05
A4	89.4±27.2	58.7±14.5	72.2±25.9	p<0.01	71.2±14.0	89.0±35.0#	63.9±17.5	60.9±17.0	72.4±27.3	p<0.05
A5	93.0±28.4	60.2±15.0	74.6±27.1	p<0.01	72.6±15.3	91.3±36.9#	66.8±19.0	63.1±17.9	74.9±28.6	p<0.05
A6	22.5±11.4	16.2±4.4	19.0±8.6	ns	9.7±2.3	25.7±11.9#	17.6±3.9	16.3±1.5	20.2±8.4	p<0.05
A7	5.8±3.4	3.5±1.4	4.5±2.7	p<0.05	1.8±1.0	7.2±3.3##	3.6±0.9	3.4±0.5	4.9±2.7	p<0.01
A8	1.1±0.6	0.6±0.4	0.8±0.5	p<0.01	0.4±0.4	1.3±0.5##	0.5±0.2	0.8±0.5	0.8±0.5	p<0.01
∑A1-A8	235±82	156±35	191±71	p<0.05	165±31	243±99##	170±43	160±37	194±74	p<0.01

Acceleration categories: A1: < -4.5 $m \cdot s^{-2}$; A2: ≥ -4.5 < -3 $m \cdot s^{-2}$; A3: ≥ -3 < -1.5 $m \cdot s^{-2}$; A4: ≥ -1.5 < 0 $m \cdot s^{-2}$; A5: ≥ 0 < 1.5 $m \cdot s^{-2}$; A6: ≥ 1.5 < 3 $m \cdot s^{-2}$; A7: ≥ 3 < 4.5 $m \cdot s^{-2}$; A8: ≥ 4.5 $m \cdot s^{-2}$; #: p<0.05 and ##: p<0.01 for the comparison between wing and all other positions; ns: p > 0.05

Table 4. *Mean duration (s) (Dur.) of each acceleration category and mean distance (m) (Dist.) in each acceleration category of both teams of the whole match, and level of significance of the team effect and the position effect; goalkeepers are excluded from analysis; values are means ± standard deviation.*

Dur. (s)	German First League team	Norwegian National Team	Both teams	Level of sign. of team effect	Goalkeeper	Wing	Back	Pivot	All field players	Level of sign. of position effect
n	11	14	23		3	8	9	5	21	
A1	0.20±0.04	0.20±0.07	0.20±0.06	ns	0.15±0.07	0.22±0.03	0.21±0.07	0.18±0.04	0.21±0.05	ns
A2	0.17±0.02	0.21±0.02	0.19±0.03	p<0.01	0.18±0.04	0.18±0.02	0.20±0.03	0.20±0.02	0.19±0.02	ns
A3	0.20±0.02	0.24±0.04	0.22±0.04	p<0.01	0.20±0.05	0.20±0.02**##	0.24±0.03	0.24±0.03	0.22±0.03	p<0.05
A4	0.25±0.02	0.38±0.08	0.32±0.09	p<0.01	0.31±0.13	0.30±0.08	0.34±0.09	0.35±0.09	0.32±0.09	ns
A5	0.35±0.07	0.48±0.09	0.43±0.10	p<0.01	0.49±0.08	0.35±0.06**##	0.44±0.10	0.48±0.13	0.42±0.10	p<0.01
A6	0.21±0.02	0.25±0.03	0.23±0.03	p<0.01	0.21±0.05	0.21±0.02**##	0.25±0.03	0.25±0.03	0.24±0.03	p<0.01
A7	0.17±0.02	0.22±0.02	0.20±0.03	p<0.01	0.18±0.06	0.19±0.02	0.21±0.03	0.21±0.02	0.20±0.03	ns
A8	0.21±0.04	0.17±0.5	0.19±0.05	p<0.05	0.17±0.12	0.20±0.02	0.19±0.02	0.17±0.05	0.19±0.03	ns
Dist.(m)										
A1	0.46±0.13	0.64±0.29	0.56±0.24	ns	0.26±0.18	0.68±0.24	0.58±0.22	0.50±0.21	0.60±0.24	ns
A2	0.36±0.05	0.56±0.13	0.47±0.15	p<0.01	0.30±0.09	0.53±0.17	0.41±0.02	0.40±0.01	0.49±0.14	ns
A3	0.38±0.06	0.44±0.10	0.41±0.09	p<0.01	0.22±0.02	0.43±0.05	0.44±0.05	0.46±0.07	0.44±0.06	ns
A4	0.28±0.07	0.43±0.12	0.37±0.12	p<0.01	0.18±0.08	0.36±0.10	0.40±0.09	0.42±0.13	0.39±0.10	ns
A5	0.33±0.08	0.45±0.11	0.39±0.12	p<0.01	0.20±0.06	0.38±0.08	0.44±0.07	0.44±0.12	0.42±0.09	ns
A6	0.38±0.07	0.45±0.10	0.42±0.10	p<0.01	0.22±0.05	0.43±0.05	0.46±0.07	0.46±0.09	0.45±0.07	ns
A7	0.36±0.07	0.55±0.10	0.46±0.13	p<0.01	0.32±0.08	0.52±0.14	0.47±0.14	0.45±0.08	0.48±0.12	ns
A8	0.52±0.14	0.49±0.18	0.50±0.16	ns	0.35±0.30	0.56±0.11	0.54±0.08	0.42±0.21	0.52±0.14	ns

Acceleration categ.: A1: <-4.5$m \cdot s^{-2}$; A2: ≥-4.5<-3$m \cdot s^{-2}$; A3: ≥-3<-1.5$m \cdot s^{-2}$; A4: ≥-1.5<0$m \cdot s^{-2}$; A5: ≥0<1.5$m \cdot s^{-2}$; A6: ≥1.5<3$m \cdot s^{-2}$; A7: ≥3<4.5$m \cdot s^{-2}$; A8: ≥4.5$m \cdot s^{-2}$; #: p<0.05 and ##: p<0.01 for the comparison between wing and all other positions; ns: p>0.05.

Mean duration in each acceleration category was significantly higher in the Norwegian team in nearly all categories as compared to the German First League team (Table 4). In the highest positive category (A8), the value was higher in the German team, and did not differ in the lowest negative category (A1) between both teams. There was no team effect on the duration in each acceleration category in the different groups of playing positions. The wing players of both teams had significantly lower duration values in the middle acceleration categories A3, A5 and A6 as compared to the back and pivot players, and the goalkeepers' values were similar to the duration values of the field players. Mean distance covered in each acceleration category was higher for the Norwegian National Team as compared to the German First League team in all but the fastest categories (A1 and A8) (Table 4), while there was no position effect on the distance in any of the eight acceleration categories beside the fact that the goalkeepers had lower distances in all eight categories.

We found significant negative correlations between individual V̇O2max values and the number of accelerations per minute in nearly all acceleration categories, including the total number of accelerations per minute (Table 5). Furthermore, we found significant positive correlations between V̇O2max and the duration of the acceleration and the covered distance in all acceleration categories except for the highest and lowest categories (A1 and A8). Duration of the highest acceleration category A8 was negatively correlated with V̇O2max.

***Table 5**. Correlations between maximal oxygen uptake ($\dot{V}O_{2max}$) and the acceleration parameters in the different acceleration categories*

Acceleration parameter and category	Equation of correlation, correlation coefficient, and level of significance
No. of accelerations (min^{-1})	
A1	$y=3.60-0.06\cdot\dot{V}O_{2max}$;r=-0.56;p<0.01
A2	$y=15.1-0.21\cdot\dot{V}O_{2max}$;r=-0.51;p<0.01
A3	$y=41.1-0.46\cdot\dot{V}O_{2max}$;r=-0.34;ns
A4	$y=245.8-3.24\cdot\dot{V}O_{2max}$;r=-0.59;p<0.01
A5	$y=259.3-3.44\cdot\dot{V}O_{2max}$;r=-0.60;p<0.01
A6	$y=59.6-0.74\cdot\dot{V}O_{2max}$;r=-0.43;p<0.05
A7	$y=19.0-0.26\cdot\dot{V}O_{2max}$;r=-0.49;p<0.05
A8	$y=3.9-0.06\cdot\dot{V}O_{2max}$;r=-0.57;p<0.01
∑A1-A8	$y=653.0-8.6\cdot\dot{V}O_{2max}$;r=-0.55;p<0.05
Duration of category (sec)	
A1	$y=0.18+0.001\cdot\dot{V}O_{2max}$;r=0.04;ns
A2	$y=0.02+0.003\cdot\dot{V}O_{2max}$;r=0.66;p<0.01
A3	$y=0.03+0.004\cdot\dot{V}O_{2max}$;r=0.51;p<0.05
A4	$y=-0.25+0.011\cdot\dot{V}O_{2max}$;r=0.61;p<0.01
A5	$y=-0.15+0.011\cdot\dot{V}O_{2max}$;r=0.50;p<0.05
A6	$y=0.04+0.004\cdot\dot{V}O_{2max}$;r=0.60;p<0.01
A7	$y=0.02+0.003\cdot\dot{V}O_{2max}$;r=0.61;p<0.01
A8	$y=0.41-0.004\cdot\dot{V}O_{2max}$;r=-0.57;p<0.01
Distance of category (m)	
A1	$y=-0.19+0.015\cdot\dot{V}O_{2max}$;r=0.32;ns
A2	$y=-0.36+0.016\cdot\dot{V}O_{2max}$;r=0.57;p<0.01
A3	$y=0.21+0.004\cdot\dot{V}O_{2max}$;r=0.38;ns(p=0.08)
A4	$y=-0.39+0.015\cdot\dot{V}O_{2max}$;r=0.69;p<0.01
A5	$y=-0.29+0.013\cdot\dot{V}O_{2max}$;r=0.72;p<0.01
A6	$y=0.07+0.007\cdot\dot{V}O_{2max}$;r=0.51;p<0.05
A7	$y=-0.19+0.013\cdot\dot{V}O_{2max}$;r=0.50;p<0.05
A8	$y=0.85-0.006\cdot\dot{V}O_{2max}$;r=-0.22;ns

ns: p>0.05

DISCUSSION

To our knowledge, this study is the first in team sports to distinctly analyze running profile including acceleration data by using computer-assisted motion analysis and physiological reactions simultaneously, and to correlate the data with the individual aerobic performance of the players. Furthermore, handball studies using time-motion analysis alone without any other physiological data are also rare (Chelly et al., 2011; Ziv & Lidor, 2009a).

The individual run distances of the female players during the matches varied broadly between single players. This is at least partly due to remarkable differences the individual playing time. Mean run distance of the players was similar to the distance covered by male top-level players during the World Championship in 2007 (2702 ± 1497 m for the female players and 2939 ± 1404 m for the male players) (Luig et al., 2008). The men's World Championship matches were analyzed with the same motion-analysis technique (Sagit system) as in this investigation. Other studies also using the Sagit system reported a mean total distance averaging 1777 ± 264 m per game in adolescent male handball players (Chelly et al., 2011), while male adult professional players covered 4464 – 5088 m (Pers et al., 2002), and male national players 4700 – 5600 m (Sibila et al., 2004). Differences between studies are probably mainly due to differences in playing time of one single player. As no data corrected for playing time are available from these studies, no direct comparisons can be made. With an average of 5251 ± 242 m for all field players in one position, however, the female top players of our study fit well with the run distances of elite male handball players.

The total distances covered by the male field players during the 2007 World Championship (Luig et al., 2008) consisted of 34.3 ± 4.9% walking (0 - 1.5 m/s), 44.7 ± 5.1% slow running (1.5 - 4 m/s), 17.9 ± 3.5% fast running (4 - 6 m/s) and 3.0 ± 2.2% sprinting (v > 6 m/s). While the distance covered for running slowly was shorter in the female players (29.1 ± 3.8%), the distances covered for fast running (29.7 ± 3.9%) and for sprinting (10.5 ± 4.1%) were clearly longer. The distance covered for walking was comparable (30.8 ± 5.9%). The differences in the high-velocity categories may be due to the fact that the velocity categories we used for the female players differed from the velocity categories for the male players. Therefore, the distances are not directly comparable.

The most important finding of the present study is that the running performance of elite female handball players during a match varied in close association with differences in individual V̇O2max. The field players with a higher V̇O2max not only ran with a higher mean velocity during the match, but also sprinted more. We assume that mainly because of their higher V̇O2max, individual physiological reactions (e.g. heart rates) remained in the same range as compared to those of the players with a lower aerobic performance (about 86 % of HRmax).

In an earlier analysis of six successive matches with elite female handball players during an international handball tournament, we were able to demonstrate that mean %HRmax of the field players during the matches showed a higher inter-individual variation as compared to the present study and was negatively correlated with aerobic performance (Manchado et al., 2007). In that investigation, however, we were not able to analyze distinct individual motion profiles such as run velocities or accelerations. As mean %HRmax of all players was in the same range as in the present investigation (87% of HRmax), we conclude that in the earlier study run distances or velocities were probably similar between the players with higher and lower aerobic performance. In that top-level international tournament (European Championship) only eight field players had a mean playing time of more than 30 minutes per match, e.g. very few players played during most of the time of the tournament. They were engaged in most playing actions which included all six actual field players nearly simultaneously. Under this condition the fitter players profited from their fitness level by lowering their physiological reactions (e.g. heart rates and probably also blood lactate concentrations). Whether such lowering of physiological reactions results in higher handball-specific performances, such as higher scoring efficacy or lower number of technical mistakes, has to be analyzed in further studies.

No other study to date has analyzed heart rate profile of female top handball players during matches. In one investigation on male handball, players had a somewhat lower mean %HRmax with values between 75 % and 80 % of HRmax (Chirosa et al., 1999), while another earlier study with experienced male handball players reported higher mean values of 85 % of HRmax (Loftin et al., 1996). The above mentioned recent study on male adolescent handball players reported a slightly lower mean HR of 82 ± 3 % of HRmax during a game, while another study with young adolescent players found values of 87 % of HRmax during matches (Chelly et al., 2011). In women's field hockey matches, players showed a slightly lower mean %HRmax (82 % - 87 %) than the handball players in the present investigation (Sunderland et al., 2006) while female soccer players had a somewhat higher mean %HRmax (89 % - 91 %) during three league matches in one study (Brewer, 1994), but comparable mean %HRmax (87 %) in another more recent study (Krustrup et al., 2005). In male soccer, players have mean HRmax values between 80 % and 93% with a mean of about 85 % of HRmax (Stolen et al., 2005), while in male basketball, intensity tends to be slightly higher with HRmax values around 86 % - 89 % (McInnes et al., 1995; Ziv & Lidor, 2009b). Altogether, these data indicate that women's handball is as physically demanding as men's handball and other women's and men's team sports.

To our knowledge, acceleration profiles during matches have never been analyzed in handball or any other team sports so far. Maximum velocity is frequently associated with successful performance in field sports; however, during competition, the athlete rarely covers the necessary distance to achieve top speed. Accordingly, the ability to accelerate, defined as the rate of change in velocity, is more important to successful performance than maximum velocity (Upton, 2011). Dividing horizontal movements into eight different acceleration categories revealed a high mean number of distinct accelerations per minute for the players of the two teams. With about 200 separate accelerations per minute, nearly three accelerations occurred per second. This finding suggests that top-level women's team handball is a game in which changes from one type of action to another are very frequent, and hence agility and speed are extraordinary important.

In our study we could demonstrate for the first time that acceleration profiles of horizontal movements in female top level handball players are related to V̇O2max. The fitter the players are, the fewer number of acceleration actions they have, but the longer they perform in all but the fastest of the different acceleration categories. This means that the fitter players are characterized by "calmer" movements and longer-lasting constant accelerations as compared to the less fit players. Whether these acceleration characteristics are associated with better handball-specific performance has to be analysed in further studies. We could also demonstrate that the wing players differed significantly from all other playing positions in their acceleration profile: their higher number of accelerations per minute and their lower duration in each category is also an indicator for less "calm" movement behavior. Furthermore, players in this position were characterized by a higher number of single sprints per minute, a longer duration of each sprint, and a longer distance covered during each sprint. Again, this finding has to be confirmed in further studies.

PRACTICAL APPLICATIONS

This study provides the first detailed analysis of movement patterns and the resulting physiological demands placed upon elite female handball players. Altogether, our results underline the importance of a high VO2max in women's team handball. Furthermore, wing players are characterized by remarkable differences in their acceleration and sprinting profiles as compared to other field players. This would mean that training programs should address 1) a superior level of aerobic performance and 2) the development of position-specific movement characteristics. Intermittent high-intensity endurance development must be carefully considered.

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APPENDIX

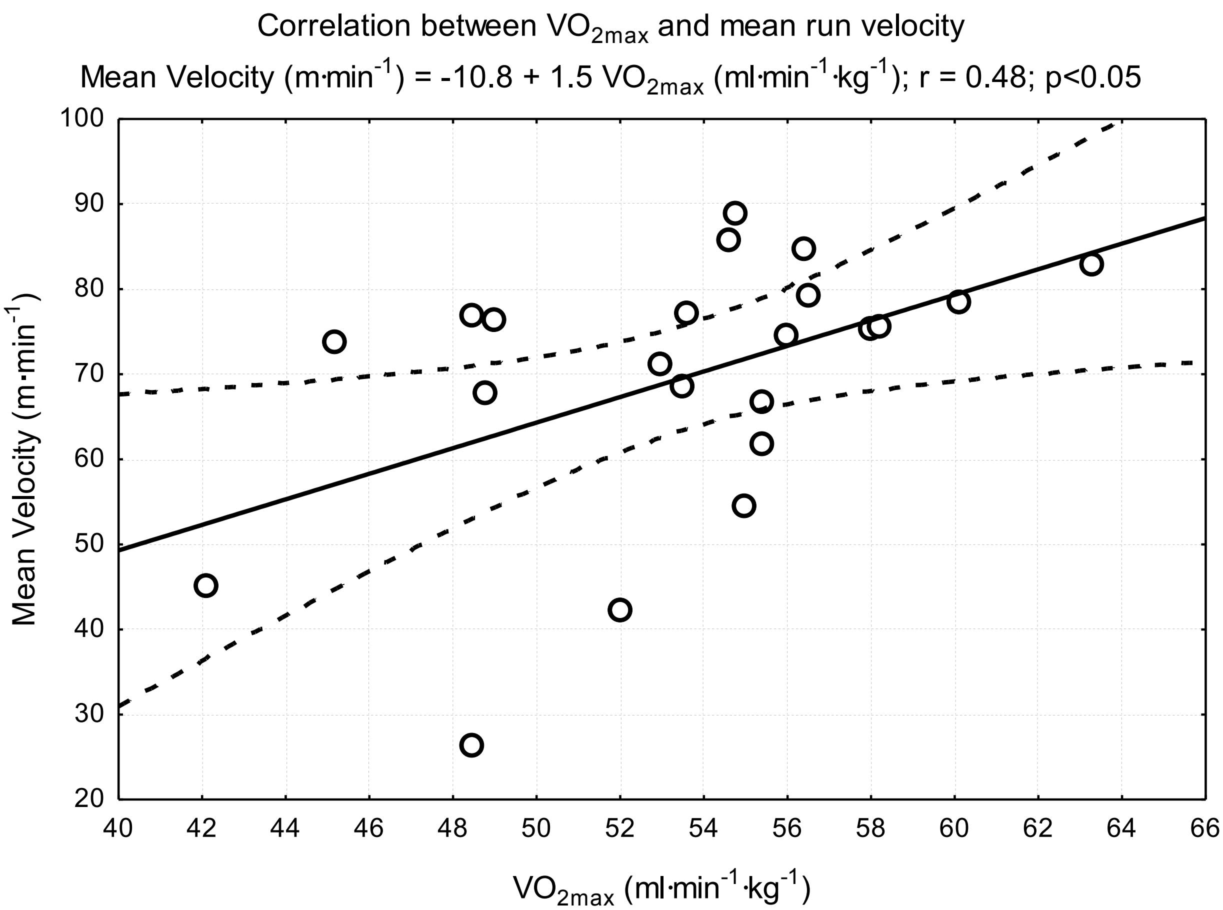

Figure 1. *Correlation between maximum oxygen uptake (VO2max) and mean run velocity during the match; only data of the field players are included. Solid and broken lines indicate the regression and prediction lines (95 % CI), respectively.*