Effects of an Entire Season on Physical Fitness in Elite Female Handball Players

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ABSTRACT

GRANADOS, C., M. IZQUIERDO, J. IBÀÑEZ, M. RUESTA, and E. M. GOROSTIAGA. Effects of an Entire Season on Physical Fitness in Elite Female Handball Players. *Med. Sci. Sports Exerc.*, Vol. 40, No. 2, pp. 351–361, 2008. **Purpose:** Sixteen elite female handball players were studied to examine the effects of an entire season on anthropometric characteristics, physical fitness, and throwing velocity. **Methods:** One-repetition-maximum bench press (1RMBP), jumping explosive strength, power–load relationship of the leg and arm extensor muscles, 5- and 15-m sprint running time, endurance running, and handball throwing velocity were assessed in four periods. Individual volumes and intensities of training and competition were quantified for 11 activities. **Results:** During the season, significant increases ($P < 0.05$–0.01) occurred in fat-free mass (1.8 ± 1.2%), 1RMBP (11 ± 7.4%), bench press (12–21%) and half-squat (7–13%) muscle power output, vertical jumping height (12 ± 7.2%), throwing velocity (8 ± 5.9%), and a significant decrease in percent body fat (9 ± 8.7%). No changes were observed in sprint and endurance running. Significant correlations ($P < 0.05$–0.01) were observed between time devoted to games and changes in velocity at submaximal loads during bench press actions, as well as between changes in muscle velocity output of the upper and lower extremities and changes in throwing velocity. Changes in percent body fat or body mass correlated ($P < 0.01$) positively with changes in maximal strength and muscle power. **Conclusion:** The handball season resulted in significant increases in anthropometric characteristics, physical fitness, and throwing velocity. The correlations observed suggest the importance of including explosive strength exercises of the knee and elbow extensions. Special attention may be needed to be paid to the mode of body fat loss, to increase endurance capacity without interfering in strength gains. Official and training games may be an adequate stimulus for enhancing certain physical fitness characteristics in female elite handball players.

Key Words: WOMEN, MUSCLE STRENGTH, MUSCLE POWER, ARM THROWING, TRAINING SCHEDULE

It has been shown that anthropometric characteristics and high levels of strength, muscle power, and handball throwing velocity distinguish elite from lower-level male handball players (7). The differences between elite and lower-level handball groups are more clearer in females because, in addition to the above-mentioned differences observed in males, elite female handball players present higher levels of vertical jump power as well as sprint and endurance running velocities, compared with amateur female players (9). From this, it is believed that, to improve their handball performance, elite-level players must arrange specific handball conditioning with some additional resistance, as well as sprint and endurance training (19). However, little is known about the optimal way to enhance sport-specific performance in handball, and to what extent some interference between different components of physical fitness occurs when strength, sprint, endurance, and sport-specific training and competition are trained simultaneously during an entire training and competitive season (11,13,19).

Only one study has investigated the relationships between the physical conditioning markers monitored during the course of a season and the quantitative assessments of training and competition (6) in elite male handball players. The results of this study show that the entire season led to significant increases in fat-free mass (FFM), maximal concentric upper-body strength, and handball throwing velocity. The findings also show linear relationships between periods devoted to strength or high-intensity endurance training and changes in endurance running, throwing velocity, and muscle power output of the lower extremities. Furthermore, significant relationships were observed between changes in percent body fat and changes in muscle power output of the lower upper extremities (6). These data suggest that 1) muscle strength and throwing velocity can increase during the season in elite handball players, 2) training stimuli for high-intensity endurance running and leg strength training should be given more attention in the full training season program (6), 3) training time at low intensity should be given less attention, and 4) dietary guidance should be recommended to reduce body fat without decreasing muscle function.

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TABLE 1. Physical characteristics of the elite handball team ($N = 16$) at the beginning (T1) of the first preparatory period, at the beginning (T2) and end (T3) of the first competitive period, and at the end of the second competitive period (T4).

	T1	T2	T3	T4
Body mass (kg)	69.6 ± 8.4	69.4 ± 7.7	69.3 ± 8.0	69.3 ± 8.2
Body fat (%)	21.1 ± 5.3	19.9 ± 5.3	19.2 ± 5.3**	19.6 ± 5.4
Fat-free mass (kg)	54.4 ± 3.9	55.0 ± 4.0	55.4 ± 4.0*	55.2 ± 4.2
Age (yr)	23 ± 4			
Height (cm)	175 ± 6			

Values are means ± SD.
* * Significantly different ($P < 0.01$) from corresponding value at T1; * significantly different ($P < 0.05$) from corresponding value at T1.

To date, no studies have investigated the relationships between the physical conditioning markers monitored over the course of a season and the quantitative assessments of training and competition in elite female handball players. Examination of associations between training data and changes in anthropometric, physical fitness, and handball velocities in elite female handball players could be of great importance for the optimal construction of the physical and sport-specific conditioning programs to improve handball performance (19), as well as for preventing injury in elite handball team sport.

We hypothesized that, as shown in elite male handball players, physical performance and handball throwing velocity should be improved in elite females during the handball season if the physical demands of physical conditioning, handball practice, and competition are adequate during the preparatory season and are maintained during the in-season to provide adequate stimuli, particularly for muscle strength enhancement (20). This study, therefore, investigated possible changes in the physical fitness and throwing velocity characteristics of elite female handball players during an entire season. We were also specifically interested in determining the influence of quantitative assessments of different training and competition modes on changes in physical performance and throwing velocity during the course of a season in these handball female elite players.

METHODS

Experimental approach to the problem. An elite female handball Spanish team, one of the leading Spanish professional handball teams, participated in this study. The team was monitored throughout a 45-wk handball season consisting of 29 games, using a longitudinal study design. Measures of physical characteristics (height, body mass (BM), percent body fat, and FFM), physical performance (one-repetition-maximum bench press ($1RM_{BP}$), jumping explosive strength (VJ), power–load relationship of the leg and arm extensor muscles, 5- and 15-m sprint running time, running endurance), and handball throwing velocity (standing and three-step running throw) were assessed four times during the course of the season. In addition, the individual time spent and intensity of training and competition were quantified by means of the time used in 11 activities (endurance running at low, medium, and high intensities, ball exercise at low, medium, and high intensities, weight training and sport-specific strength training, sprint running, training game, and competition game). It was thus possible to examine the influence of a handball season on physical performance and handball throwing velocity while quantifying the individual time spent on each activity and the intensity of training and competition. Experimental studies recreating the training loads and time frames relevant to international-class team sports athletes are absent from the literature. Understanding the effects of periodized training and competition time spent and intensities may provide insights for enhancing performance and preventing injury in elite handball team sport.

Subjects. Members of one elite female handball team ($N = 16$; age: 23.1 ± 4 yr) with a regular training and competitive background in handball (11.7 ± 5 yr) participated in the study. The team played in the Spanish National First Division League, and all its players were professional. The team can be considered an elite handball team because 1) it finished fourth in the Spanish handball champion last season, 2) seven of its players are or have been internationals and had won 15 Olympic and/or World Championship medals, and 3) the team qualified for the European Handball Cup during the ongoing season. Table 1 shows the physical characteristics of the subjects before and throughout the experimental period.

Before commencing the study, players underwent physical examination, and each was cleared of any medical disorders that might limit their full participation in the investigation. The subjects and coach were informed in detail about the experimental procedures and the possible risks and benefits of the project, which was approved by the institutional review committee of the Instituto Navarro de Deporte y Juventud and carried out according to the Declaration of Helsinki. Each subject signed a written informed consent form before participation in the study.

The subjects were not taking exogenous anabolic–androgenic steroids or other drugs or substances expected to affect physical performance or hormonal balance during this study. There were no positive tests for any banned substance in any of the subjects during several in- or out-of-competition doping-control tests undertaken by the Spanish Handball Federation under strict International Olympic Committee doping-control guidelines.

Testing schedule. The 45-wk season lasted from August 2002 to May 2003 and consisted of two preparatory periods (from weeks 1 to 7 and from weeks 20 to 24) and two competitive periods (from weeks 8 to 19 and from weeks 25 to 42) (Fig. 1). During the season, the subjects were tested on four testing periods (Fig. 1). The first testing period (T1, August 12) was performed during the first week after of the beginning of the first preparatory period. The second testing period (T2, September 10) and the third testing period (T3, November 26) were performed at the beginning and the end, respectively, of the first competitive period of the National First Division League, whereas the fourth testing period (T4, May 6) was performed at the end of the second competitive period of the National First Division League. The subjects were familiarized with the testing protocol in detail, as they had been previously tested on several occasions in previous seasons for training prescription purposes. For a given testing period, the subjects completed a 3-d experimental protocol. All of the players were assessed on the same day, and the tests were always performed in the same order in the 3-d experimental protocol of a given testing period. During the first day session of a given testing period, each subject was subjected to a sprint and endurance running test. In the second day session of a given testing period, each subject was tested for anthropometric measurements, maximal and explosive strength, and muscle power. In the third day session of a given testing period, standing and three-step-running-throw velocities were measured. The subjects were given strong verbal encouragement to perform all the tests as best as they could. Testing was integrated into weekly training schedules.

In a pilot study, the intertest reliability for measuring maximal strength and power, anthropometric variables, and several endurance indices were assessed in two trials, which were separated by 7 d, in a group of handball players. The test–retest intraclass correlation coefficients (ICC) of the anthropometric, maximal strength, and explosive (e.g., throwing and jumping) variables used in this study were greater than 0.91, and the coefficients of variation (CV) ranged from 0.9 to 7.3%. Similarly, the ICC and CV for the velocity associated with a blood lactate concentration of 3 mM (V_3) were 0.94 and 2.2%, respectively.

Physical characteristics. The anthropometric variables of height (m), BM (kg), body fat (%), and FFM (kg) were measured in each subject. Height and BM measurements were made on a leveled platform scale (Año Sayol, Barcelona, Spain) with an accuracy of 0.01 kg and 0.001 m, respectively. BM index (BMI) was calculated from BM and body height (kg·m^{-2}). Percent body fat was calculated from measurements of seven skinfold thickness (18). FFM (kg) was calculated as a difference between BM and body fat.

Maximal strength and muscle power output test. A detailed description of the maximal strength and muscle power testing procedures can be found elsewhere (17). Basically, maximal strength of the upper extremity was assessed using 1RM_{BP}. Bench press (elbow extension, shoulder flexion, and horizontal adduction) was chosen because it seems most specific to the overhand throwing technique (5). The test was performed in a squatting apparatus in which the barbell was attached to both ends, with linear bearings on two vertical bars allowing only vertical movements. The bar was positioned 1 cm above the subject's chest and was supported by the bottom stops of the measurement device. The subject was instructed to perform a purely concentric action from the starting position, maintaining the shoulders in a 90° abducted position to ensure consistency of the shoulder and elbow joints throughout the testing movements (7). No bouncing or arching of the back was allowed. Warm-up consisted of a set of five repetitions at loads of 40–60% of the perceived maximum. Thereafter, four to five separate single attempts were performed until the subject was unable to reach the full extension position of the arms. The last acceptable extension with the highest possible load was determined as the 1RM. The rest period between attempts was always 2 min.

The power–load relationship of the arm and leg extensor muscles was tested in bench press and parallel squat position, respectively, using relative loads of 30, 45, 60, and 70% 1RM for bench press exercise, and 60, 80, 100,

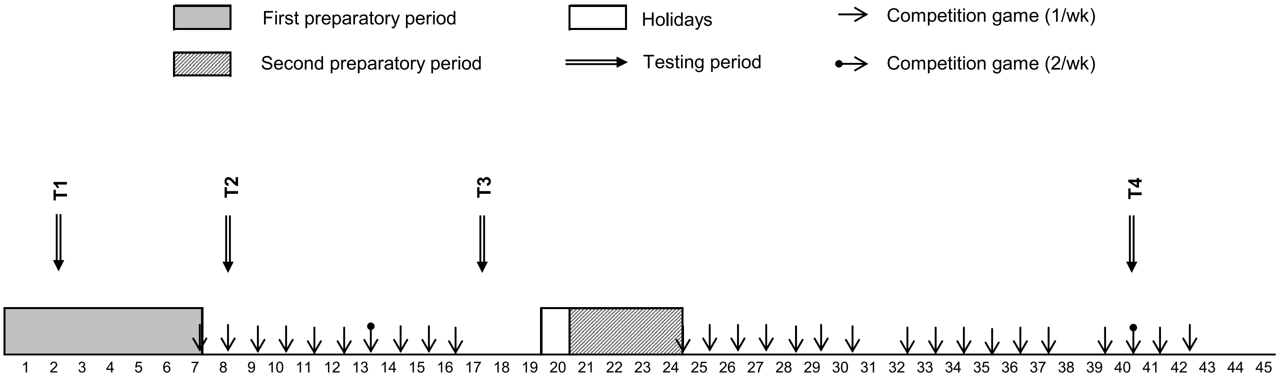

FIGURE 1—Testing periods and games schedule for the elite female handball season.

and 125% BM for parallel squat exercise. For comparison purposes, the subject's power–load relationship was tested through the experimental period with the same absolute pretraining loads. No weight release was allowed during the leg or arm extension movements. In parallel squat position, the shoulders were in contact with a bar, and the starting knee angle was 90° (17). On command, the subject performed a concentric leg extension (as fast as possible), starting from the flexed position to reach the full extension of 180° against the resistance determined by the weight plates added to both ends of the bar. The trunk was kept as straight as possible. The subjects were allowed to use a weight training belt. Warm-up consisted of a set of five repetitions at loads of 40–60% BM. Two testing actions were recorded, and the best reading (with the best velocity) was taken for further analysis. The time period of rest between each trial and set was always 1.5 min.

During the lower- and upper-extremity test actions, bar displacement, average velocity ($\text{m}\cdot\text{s}^{-1}$), and mean power (W) were recorded by linking a rotary encoder to the end of the bar. The rotary encoder recorded the position and direction of the bar to an accuracy of 0.0002 m. Customized software (JLML I+D, Madrid, Spain) was used to calculate the power output for each repetition of the parallel squat and bench press performed throughout the whole range of motion. Average power output for each repetition of the parallel squat and bench press was determined. Power curves were plotted using average power over the whole range of movement, as the most representative mechanical parameter associated with a contraction cycle of leg and arm extensor muscles participating in the parallel squat (i.e., hip, knee, and ankle joints) and bench press (i.e., elbow and shoulder joints) exercises. In all neuromuscular performance tests, strong verbal encouragement was given to each subject to motivate them to perform each test action as maximally and as rapidly as possible. The reproducibility of the measurements has been reported elsewhere (17).

Jumping test. The jumping test was performed on an indoor court and consisted of four maximal countermovement jumps with arm swing on a contact platform (Newtest OY, Oulu, Finland). The subjects were asked to perform a maximal jump on the contact platform from standing position with a preparatory movement from the extended leg position down to the 90° knee flexion, followed by a subsequent concentric action. Subjects could move their arm freely but were instructed to land on the contact platform in a position similar to that of take-off. The jumping height was calculated from the flight time (2). Two sets of two maximal jumps were recorded, interspersed with approximately 10 s of rest between jumps and 90 s of rest between sets. The best reading was used for further analysis.

Maximal sprint and endurance running test. After a nonstandardized 15-min warm-up period that included low-intensity running, several acceleration runs, and stretching exercises, the subjects undertook a sprint running test consisting of three maximal sprints of 15 m with a 90-s rest period between each sprint on an indoor court. During the 90-s recovery period, the subjects walked back to the starting line. The recording of running time was done using photocell gates (Newtest OY, Oulu, Finland) placed 0.4 m above the ground, with an accuracy of 0.001 s. The subjects commenced the sprint when ready from a standing start, 0.5 m behind the start. Stance for the start was consistent for each subject. The time was automatically activated as the subject passed the first gate at the 0-m mark, and split times were recorded at 5 and 15 m. The run with the lowest time was selected for further analysis.

The endurance running test was performed 5 min after the end of the sprint running test on an indoor court. Each subject performed a four-stage submaximal discontinuous progressive running test around the handball court (40 × 20 m), with a 3-min rest between each run. The running velocities for the four stages were 8.5, 10, 11.5, and 13 $\text{km}\cdot\text{h}^{-1}$. The time for each stage was 5 min. To assure constant velocity for each running stage, subjects were instructed to even pace their running through an audio signal connected to a preprogrammed computer (Balise Temporelle, Bauman, Switzerland). During the test, heart rate was recorded every 15 s (Sportester Polar, Kempele, Finland) and averaged for the last 60 s of each stage. Immediately after each exercise stage, capillary blood samples for the determination of lactate concentrations were obtained from hyperemic earlobe. Samples for whole-blood lactate determination (100 μL) were collected in a preservative collection kit (YSI Preservative Collection Kit), stored at 4°C, and analyzed within the following 24–72 h (YSI, 1500 Sport L-Lactate Analyzer).

The blood lactate analyzer was calibrated after every fifth blood sample dose with three known controls (5, 15, and 30 mM). Individual data points for the exercise blood lactate values were plotted as a continuous function against time. The exercise lactate curve was fitted with a second-degree polynomic function. From the equation describing the exercise blood lactate curve, V_3 was intrapolated. The submaximal velocity associated with a given absolute blood lactate concentration has been shown to be an important determinant of endurance performance capacity (31).

Handball throwing velocity test. Specific explosive strength production in handball was evaluated on an indoor handball court by an overarm throw, in two situations: a standing throw (penalty throw), and a three-step running throw. After a 10-min standardized warming up, the subjects were instructed to throw a standard handball (mass 370 g, circumference 52 cm) as fast as possible thorough a standard goal, using one hand and their own technique. In the standing throw, one of the feet had to be in contact with the floor behind the line 7 m from the goal (penalty mark); in the three-step running throw, the players were allowed to do a preparatory run, limited to three regular steps, before releasing the ball behind the line 9 m from the goal. The recording of throwing time was done with an accuracy of 0.001 s, using photocell gates (Newtest OY, Oulu, Finland) placed on two tripods located parallel to the throwing trajectory, in front of the left post of the goal. The first tripod was located slightly higher than the second because some of the tallest handball players released the ball at a vertical height slightly higher than the goal height (2 m). The time was automatically activated as the handball passed the photocells of the first tripod, and it was stopped when the handball passed the photocells of the second tripod. Average throwing velocity was calculated from the time and the distance (3 m) covered by the ball. The coaches supervised the entire throwing test to ensure that the subjects were using the right handball technique. For each type of throw, each subject performed trials until three correct throws were recorded, up to a maximum of three sets of three consecutive throws. A 1- to 2-min rest period elapsed between sets of throws, and 10–15 s elapsed between two throws of the same set. As motivation, athletes were immediately informed of their performance. The throw with the highest average ball velocity was selected for further analysis.

Training and competition data analysis. During the experimental period, the coaches recorded individual match and training exposure (i.e., player participation for every training and competition session), including the duration of each activity. Player participation was split into 11 activities: endurance running at low, medium, and high intensities, ball exercise at low, medium, and high intensities, weight training, sport-specific strength training, sprint running, training game, and competition game.

Endurance training was divided into low-intensity (E1: average heart rate corresponding to $< 80\%\ V_3$), medium-intensity (E2: average heart rate corresponding to 80–90% V_3), and high-intensity (E3: average heart rate corresponding to $> 90\%\ V_3$, or interval training) running, based on the relationships observed between running velocity, heart rate, and blood lactate concentration during the endurance running test. In the same way, ball exercise training was divided into low (B1: average heart rate corresponding to $< 80\%\ V_3$), medium (B2: average heart rate corresponding to 80–90% V_3), and high (B3: average heart rate corresponding to $> 90\%\ V_3$, or interval training) ball intensity. Heart rate was periodically monitored (Polar, Oulu, Finland) through several endurance running and ball exercise training sessions to verify the exercise training intensities.

The strength training time was divided into weight strength training (Sw; with free weights and machines) and sport-specific strength training (Ss; running uphill, multijumps, medicine ball throwing, etc). Briefly, Sw consisted of two main exercises with barbells: dynamic parallel squat lift and bench press; and two main secondary exercises: power clean and pullover. The load in the squat lift exercises (three to four sets, three to four reps) ranged from 60 to 110% of the load, with the maximal power output attained in the power–load test in parallel squat actions. This corresponds to a load ranging from approximately 36 to 77% 1RM in the squat lift exercise (17). The load in the power clean lift exercises (three to four sets, three to six reps) ranged from 65 to 95% of six maximal concentric repetitions (6RM). This corresponds to a load ranging from approximately 41 to 76% 1RM in the power clean exercise (17). The load in the dynamic bench press lift exercise (three to four sets, one to four reps) ranged from 85 to 100% $1RM_{BP}$. Weight loads were adjusted according to 1RM (bench press), 6RM (power clean lift), and maximal power output (parallel squat) testing through the season. The load in the dynamic pullover lift exercise (three to four sets, 5–10 reps) ranged from 15 to 25% BM (BM_P). The players also performed some light strengthening exercises for the calf, hamstring, leg adductor, and deep abdominal muscles to prevent injuries. Strength training frequency was one to two sessions per week and lasted from 45 to 90 min per session. Training was periodized from a low-volume, low-intensity phase during the preparatory periods to a high-volume, high-intensity phase towards the competitive periods.

All work was supervised by team coaches. Diets or lifestyles were not controlled significantly during the course of the season. Nevertheless, some nutrition guidelines were given to some players to reduce body fat.

Statistical procedures. Standard statistical methods were used for the calculation of the means and standard deviations. One-way analysis of variance with repeated measures was used to determine the differences between tests. When a significant F value was achieved, appropriate Scheffé *post hoc* test procedures were used to locate the difference between means. The test–retest reliabilities for the experimental test demonstrated intraclass correlations of $R \geq 0.91$. Pearson product–moment correlation coefficients (r) were used to determine associations between handball training and competition variables and anthropometric, physical fitness, and throwing velocity parameters. Statistical power calculations for t-test correlation ranged from 0.69 to 0.95 in this study. The $P < 0.05$ criterion was used for establishing statistical significance.

APPLIED SCIENCES

RESULTS

Time spent in training and competition modes. During the 6-wk first preparatory period (from T1 to T2), each player trained an average of 21 training sessions (3.5 training sessions per week) and played nine training games and two competition games, for a total average duration of 2738 min, distributed as follows: endurance training (14%), strength training (8%), sprint training (0.3%), ball exercise (50%), training game (11%), and competition game (2%) (Fig. 2). From T2 to T3 (9 wk), each player trained an average of 39 training sessions (4.3 training sessions per week) and played one training game and nine competition games, for a total average duration of 4317 min, distributed as follows: endurance training (19%), strength training (11%), sprint training (0.2%), ball exercise (61%), training game (1%), and competition game (4%). From T3 to T4 (24 wk), each player trained an average of 98 training sessions (4.1 training sessions per week) and played 2

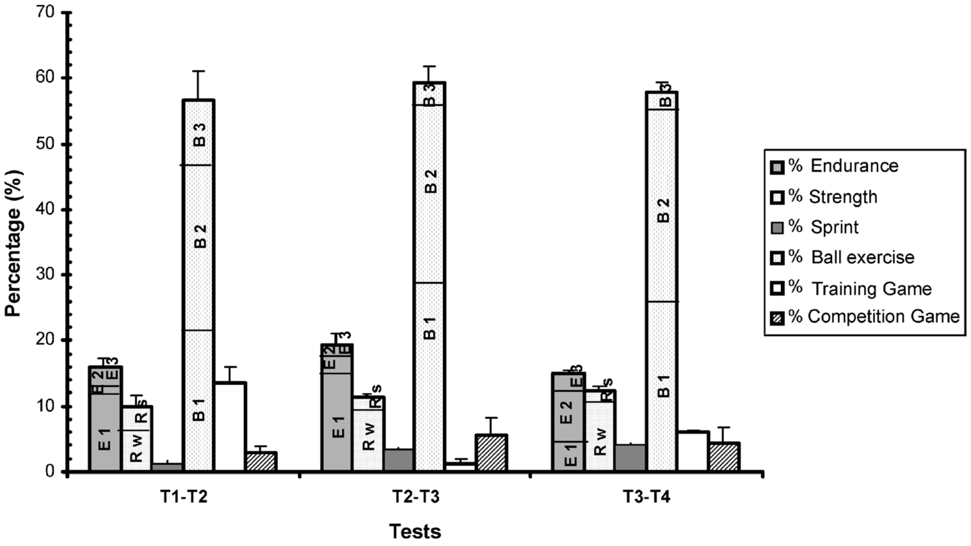

FIGURE 2—Relative volumes (mean ± SD) of the different training and competition modes between tests during the entire season. Low- (E1), medium- (E2), and high-intensity (E3) endurance training; weight strength (Sw) and sport-specific strength (Ss) training; low- (B1), medium- (B2), and high-intensity (B3) ball exercise training; training game (TG) and competition game (CG).

training games and 16 competition games, for a total average duration of 11,432 min, distributed as follows: endurance training (14%), strength training (12%), sprint training (0.1%), ball exercise (57%), training game (6%), and competition game (2%). Average training and competition time progressively increased ($P < 0.05$) from 399 ± 84 $\text{min}\cdot\text{wk}^{-1}$ (from T1 to T2) to 458 ± 29 $\text{min}\cdot\text{wk}^{-1}$ (from T2 to T3), and to 482 ± 15 $\text{min}\cdot\text{wk}^{-1}$ (from T3 to T4).

Physical characteristics. No changes occurred in BM during the season. FFM significantly increased by 1.8% ($P < 0.05$) from T1 (54.4 ± 3 kg) to T3 (55.4 ± 4 kg), and percent body fat significantly decreased ($P < 0.01$) from T1 (21.1 ± 5%) to T3 (19.2 ± 5%) (Table 1).

Maximal strength and muscle power output. Maximal 1RM_{BP} values increased 6.4% at T3 (48.9 ± 6.5 kg, $P < 0.01$) and 11.3% at T4 (51.6 ± 6.7 kg, $P < 0.001$) compared with T1 (45.8 ± 5.7 kg). The data of the values of the average bilateral concentric parallel squat and bench press power–load curve in absolute values during the experimental period are presented in Table 2. Bench press muscle power output at all loads examined were 12–21% higher ($P < 0.001$–0.05) at T4, T3, and T2 compared with T1, and at T4 compared with T3 and T2 for 30, 45, and 70% 1RM_{BP}. Muscle power output of the lower extremity was 7–13% higher ($P < 0.01$–0.05) at T4, T3, and T2, compared with T1 for loads of 100 and 125% BM, whereas it remained unaltered during the whole season for loads of 60 and 80% BM.

Jumping test. Vertical jumping height increased significantly by 12.2% ($P < 0.001$) from T1 (33.7 ± 5.5 cm) to T3 (38.4 ± 4.4 cm) and 9.1% ($P < 0.05$) from T2 (34.9 ± 4.6 cm) to T3.

Maximal sprint and endurance running. Maximal sprint running velocities for 5 m (16.3 ± 0.6, 16.2 ± 0.8, 16.1 ± 0.6, and 16.6 ± 0.8 $\text{m}\cdot\text{s}^{-1}$ at T1, T2, T3, and T4, respectively) and for 15 m (20.1 ± 0.7, 20.4 ± 0.8, 20.4 ± 0.8, and 20.7 ± 0.8 $\text{m}\cdot\text{s}^{-1}$ at T1, T2, T3, and T4, respectively) remained unaltered during the experimental period. Similarly, no statistically significant changes occurred in V_3 during the season (10.8 ± 0.9, 11.1 ± 0.8, 11.3 ± 0.9, and 10.9 ± 0.8 $\text{km}\cdot\text{h}^{-1}$ at T1, T2, T3, and T4, respectively).

TABLE 2. Absolute power values in the elite female handball team at the beginning (T1) of the first preparatory period, at the beginning (T2) and end (T3) of the first competitive period, and at the end of the second competitive period (T4).

Power	T1	T2	T3	T4
Lower extremity				
P 60% (W)	374 ± 28	377 ± 35	385 ± 48	388 ± 35
P 80% (W)	426 ± 39	453 ± 42^{a}	450 ± 70	451 ± 16
P 100% (W)	462 ± 60	500 ± 56^{a}	497 ± 78^{a}	494 ± 66^{a}
P 125% (W)	466 ± 78	506 ± 93^{a}	514 ± 88^{a}	527 ± 15^{a}
Upper extremity				
P 30% (W)	178 ± 26	188 ± 27^{a}	193 ± 27^{a}	200 ± 28^{a,b,c}
P 45% (W)	191 ± 38	208 ± 34^{a}	213 ± 34^{a}	219 ± 36^{a,b,c}
P 60% (W)	182 ± 44	204 ± 37^{a}	208 ± 41^{a}	214 ± 40^{a}
P 70% (W)	169 ± 42	186 ± 42^{a}	196 ± 42^{a,b}	204 ± 44^{a,b}

Values are mean ± SD, $N = 16$.

[a] Significantly different ($P < 0.05$) from corresponding value at T1.

[b] Significantly different ($P < 0.05$) from corresponding value at T2.

[c] Significantly different ($P < 0.05$) from corresponding value at T3.

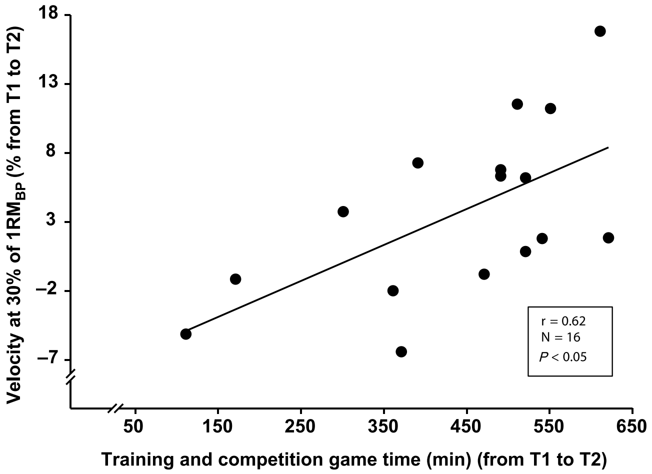

FIGURE 3—Relationship between the total time devoted to training games and competition games and the individual changes of velocity at 30% 1RM for bench press, from T1 to T2.

Handball throwing velocity. Measures in average handball throwing velocity showed significant increases during the season for both types of throwing. Thus, a significant ($P < 0.01$) increase was observed in standing throw at T4 (20.5 ± 1.3 m·s^{-1}), at T3 (20.2 ± 1.7 m·s^{-1}), and at T2 (19.5 ± 1.2 m·s^{-1}) compared with T1 (19.0 ± 0.9 m·s^{-1}). Similarly, a significant ($P < 0.01$) increase was observed in the average velocity of handball throwing with three-step running at T4 (21.8 ± 1.4 m·s^{-1}), at T3 (21.5 ± 1.4 m·s^{-1}, $P < 0.01$), and at T2 (21.1 ± 1.3 m·s^{-1}, $P < 0.05$) compared with T1 (20.0 ± 1.3 m·s^{-1}).

Relationships between training and competition times, changes in physical performance, and physical characteristics during the training season. From T1 to T2, the individual total training game and competition game times correlated with the individual changes of velocity at 30% 1RM$_{BP}$ ($r = 0.62$, $P < 0.05$, $N = 16$, Fig. 3), as well as with the individual relative changes in FFM ($r = 0.58$, $P < 0.05$, $N = 16$).

Relationships between changes in strength and changes in sprint running. From T3 to T4, significant correlations were observed between individual changes in velocity at 60% BM during parallel squat action and individual changes in the average running velocity for 5-m sprint running ($r = 0.66$, $P < 0.05$, $N = 10$).

Relationships between strength and throwing velocity. At T3, the individual standing-throw-velocity values correlated ($P < 0.05$) with the individual values of concentric power production at the load of 45% 1RM$_{BP}$ ($r = 0.61$, $N = 16$) and with the individual values of concentric power production at the load of 80% BM ($r = 0.65$, $N = 16$) during parallel squat action.

Statistically significant correlations were also observed from T1 to T4 between throwing-velocity changes and relative changes in physical performance. Thus, from T2 to T3, the individual relative changes in velocity at 100% BM during parallel squat action correlated with the individual relative changes of standing throw velocity ($r = 0.66$, $P < 0.05$, $N = 11$, Fig. 4). Significant correlations were observed from T3 to T4 between individual relative changes in velocity at the load of 70% 1RM$_{BP}$ and individual relative changes in three-step-throwing velocity ($r = 0.64$, $P < 0.05$, $N = 13$).

Relationships between changes in physical characteristics and changes in strength and running endurance. Individual relative changes in percent body fat correlated significantly with individual changes in maximal 1RM$_{BP}$ values from T1 to T2 ($r = 0.52$, $P < 0.05$, $N = 16$) and from T2 to T3 ($r = 0.65$, $P < 0.01$, $N = 15$). From T2 to T3, individual relative changes in BM correlated significantly ($r = 0.75$, $P < 0.01$, $N = 11$) with individual relative changes in concentric power production at the load of 60% BM during parallel squat action (Fig. 5). Finally, significant inverse correlations were observed from T1 to T2 between individual relative changes in BM and individual changes in mean V_3 ($r = -0.74$, $P < 0.01$, $N = 12$).

DISCUSSION

The present study is the first to document physical fitness changes over an entire season and to examine the relationships between durations of different training and competition modes and changes in physical performance, in one elite female handball team. The primary findings of the present study demonstrate that the entire season led to significant improvements in anthropometric characteristics, jumping performance, handball throwing velocity, maximal concentric strength of the upper extremity, and muscle power output production of the upper and lower extremities. No systematic changes occurred, however, during the season in maximal sprint and endurance running. The present findings also demonstrate that linear direct relationships were observed between total time devoted to games

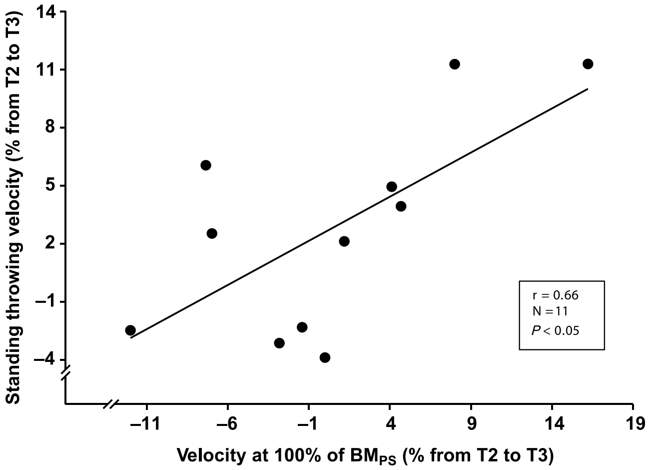

FIGURE 4—Relationship between the individual changes of standing throw velocity and the individual changes of concentric velocity production at load of 100% of body mass during parallel squat action, from T2 to T3.

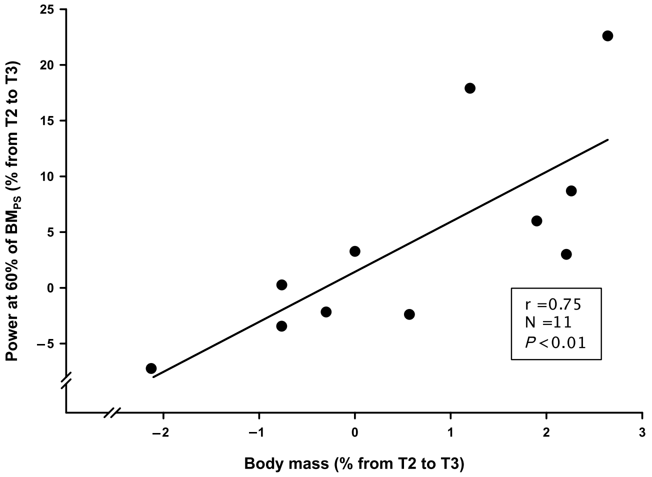

FIGURE 5—Relationship between individual changes of body mass and individual changes of concentric power production at load of 60% of body mass during parallel squat action, from T2 to T3.

and changes in FFM and in velocity at submaximal loads during bench press actions, as well as between changes in muscle velocity output of the upper and lower extremities and changes in throwing velocity. In addition, changes in percent body fat or BM correlated positively with changes in maximal strength and muscle power, but they correlated negatively with changes in running endurance.

The elite female handball players had significant increases (8–21%) in upper-body maximal strength, vertical jumping performance, and standing throw velocity during the season. The magnitude of these changes in physical fitness over the season is consistent with the results obtained in female elite (19) and amateur-level (15) handball and basketball (11) players, but these changes are higher than those observed in our laboratory in male elite handball players (1–4% $1RM_{BP}$) (6). The higher relative changes in physical fitness and throwing velocity observed in elite female compared with elite male players may be related to differences in initial fitness level, amount of training carried out during the previous off-season period, training intensity and/or motivation, interfering effects between training modes, and differences in the upper limits of physiological adaptation possible in these competitive handball players. Thus, a reduction or a cessation of physical activity during the 10-wk uncontrolled off-season period could have induced a pronounced decrease in physical fitness. In this case, decreased physical fitness during the beginning of the season might explain, in part, the high relative increases in physical fitness observed in this group of female players during the season. Furthermore, changes in training periodization could also explain the differences observed between both groups of players. Thus, the elite male handball team used a more traditional training periodization (from a high-volume, low-intensity phase during the preparatory periods to a low-volume, high intensity phase towards the competitive periods) (6), whereas the female group, because of a coach decision, used a linear training periodization model (from a low-volume, low-intensity phase during the preparatory periods to a high-volume, high intensity phase towards the competitive periods). The finding of different magnitudes of changes in physical fitness during the season in elite male versus elite female handball players raises the question of the appropriate training strategy and periodization required to elicit improvements in physical fitness and performance in elite team sports.

The handball season resulted in significant increases in upper-body maximal strength and absolute muscle power of the upper and lower extremities. Increases in maximal strength after dynamic, heavy-resistance training have been found in elite female handball players (19). These results confirm that it is possible to increase maximal explosive strength in elite female handball players over a season, even though many sessions of handball are performed in addition (19). Such changes are likely to be considered a positive result on the playing ability of the team, because the increase in maximal upper-body strength and jumping power should give the whole team an advantage to sustain the forceful muscle contractions required during some handball game actions, such as hitting, blocking, pushing, holding, and jumping. In addition, the low relative training intensity (range: 36–77% $1RM_{PS}$) used in the lower extremity in the present study may provide a positive stimulus for improving adaptations during short-term training periods in female handball players. It is also likely that using heavier training loads might further increase maximal strength and muscle power values of the lower extremities.

The handball season led to 8–9% increases in handball throwing velocity. Changes of this magnitude have also been observed in elite male handball players (6). The increase in handball throwing velocity observed during the season is of major importance to success in handball, because elite handball players have 8–9% (males) (7) and 10–11% (females) (9) higher handball throwing velocities than lower-level players. Additionally, one should take into consideration that the combination of ball velocity and accuracy in throwing is one of the most important factors for success in handball (7,28). Although the neurophysiological mechanisms for increasing handball throwing velocity are unknown, they have been suggested to be related to improvements in neural activation (12), selective increase of the fast-twitch-muscle-fiber area (12), augmentation of intrinsic muscular properties (4), increase in myosin–adenosine triphosphatase activity (1), synchronization of motor units (23), and/or higher firing frequency (10).

In the present study, individual values of muscle power at submaximal loads during bench press or parallel squat actions at T3 correlated significantly with individual values of ball throwing velocity. It was also interesting to observe significant associations between individual relative changes of velocity at the load of 100% BM during parallel squat actions (from T2 to T3) or individual relative changes of velocity at the load of 70% $1RM_{BP}$ (from T3 to T4), and individual relative changes in throwing velocity. This indicates that 1) higher values of muscular power at submaximal relative loads during bench press or parallel squat actions are associated with higher throwing velocity values, and 2) elite female handball players with higher increases in muscular velocity at submaximal relative loads during bench press or parallel squat actions may be more likely to produce major improvements in handball throwing velocity. Taken together, these correlations strongly suggest that the muscle power and velocity of elbow and knee extensions during low-loads action are important factors in acquiring high ball velocities in overarm throwing (28). Furthermore, the present correlations suggest that, in addition to specific overloading throwing exercises using variably weighted handballs (26,28), traditional resistance programs inducing improvements in muscle velocity and power during submaximal-load bench press and parallel squat actions should be able to be transferred into enhanced handball throwing velocity (15).

Significant relationships were observed from T1 to T2 between the individual values of time devoted to games (training and competition) and individual changes in FFM, as well as with individual changes in velocity production at the load of 30% $1RM_{BP}$. It indicates that female handball players playing more minutes during games may be likely to produce major gains in FFM and the capacity to quickly extend the upper extremities than those playing fewer minutes during games. Increases in FFM can be considered a positive adaptation in elite female handball players, because elite female handball players have 10% more FFM than lower-level players (9), and because higher FFM produces more force and velocity during throwing (27). Furthermore, high FFM values allow handball players to better sustain the forceful muscle contractions required during handball game actions (7). As it has been pointed out, increases in muscular velocity at submaximal loads during bench press actions can also be considered a positive adaptation in handball, because they may produce major improvements in handball throwing velocity. These relationships suggest that competitive handball play may provide positive stimuli for getting a more powerful build and for enhancement in muscular velocity production of the upper-extremity muscles in elite female handball players.

Sprint running performance remained unchanged during the entire competitive season. This must be considered a nonpositive result on the playing ability of the whole team, because sprint running is an important neuromuscular performance characteristic for successful participation in elite female handball (9). Increases in sprint running performance have been observed in elite female handball players after a reduction in training volume (19). The progressive increase in training volume during the season in the present study, as well as the short time (< 0.3% of the total time) dedicated to sprint training, might explain the absence of changes observed in sprint running performance. In addition, although muscle power output at the load of 60% BM during parallel squat actions remained unaltered during the whole season, significant correlations were observed from T3 to T4 between individual relative changes of velocity at this load and individual relative changes in 5-m average sprint running velocity. Relationships between running velocity and strength or muscular power of the knee extensor muscles have been found in elite male (6) and female (19) handball players, suggesting a possible transfer from the gain in leg muscle power into enhanced sprint performance. These findings emphasize the importance of increasing the time dedicated to sprint training and leg muscular strength and power, as well as decreasing training volume for improving short-distance sprint performance (3,8).

Given that 15–20% of total training and competition time was devoted to endurance running and, particularly, to low-intensity endurance running (E1, Fig. 2), an increase in endurance capacity during the season was expected. In contrast, it was interesting to observe no changes in running associated with a blood lactate concentration of 3 mM, a good predictor of aerobic capacity (31), during the entire handball season. Several studies have shown that additional high-intensity endurance training without the ball is needed to increase aerobic capacity in elite male (6,19) and female (19) handball players and other team sports, such as elite male soccer (14). In addition, in elite male handball players it has been shown that the training time at low intensity interferes with the development of muscle power of the leg extensor muscles (6). These observations strongly suggest that the magnitude and/or frequency of the training stimuli for high-intensity endurance running should be given more attention and that the training time at low-intensity running should be given less attention during the full handball season.

During the season, but particularly during the first preparatory period (from T1 to T2), coaches urged all players to obtain an "adequate" BM and percent body fat based on the individual competitive BM observed in previous seasons. Therefore, the majority of players reduced fat mass ($N = 13$) and BM ($N = 7$) from T1 to T2. The individual negative relationship observed from T1 to T2 between individual changes in BM and individual changes in V_3 can be considered positive in handball, considering that one's level of handball performance is, in part, determined by a large aerobic capacity (9,22). However, a finding in this study was that from T1 to T2, and from T2 to T3, individual relative changes in BM or percent body fat correlated with individual relative changes in maximal concentric strength of the upper extremities as well as with individual relative changes in concentric power production at the load of 60% BM during parallel squat actions. It indicates that female handball players who developed larger decreases in percent body fat or BM showed larger decreases in maximal strength or muscle power of the upper and lower extremities. Decreases in muscle power associated with decreases in body fat have also been observed in elite male handball players and can be considered disadvantageous for handball playing (6).

Although the mechanisms of maximal strength and muscle power losses associated with body fat reductions are unknown, they could involve (6) 1) a negative protein balance, 2) impaired ability in force production associated with the use of rapid body-weight–reduction techniques (16,25,29), and 3) detrimental effects of low dietary fat on endogenous anabolic hormone production such as testosterone (30) and IGF-I (24), resulting in decreased neural capacity to generate muscular strength and power (21).

CONCLUSION AND PRACTICAL APPLICATION

In summary, the present data indicate that an entire season led to significant increases in FFM, explosive strength of the lower extremity, maximal concentric strength and muscle power output of the upper and lower extremities, and handball throwing velocity, as well as a significant decrease in percentage of body fat, in female handball players. Although endurance and resistance training of the lower extremities were performed, no changes were observed in sprint and endurance running. The changes observed in ball throwing and its correlation with strength variables suggest that high ball throwing velocity depends on explosive strength of both extremities, the upper and the lower, and highlight the importance of including explosive strength exercises in bench press and parallel squat actions for success in elite female handball. To increase endurance capacity without interfering with strength gains, special attention may be need to be paid to the mode of weight loss and body fat. Finally, competition and training games should be considered as a high-intensity stimulus for enhancing certain physical fitness and anthropometric characteristics in elite female handball players.

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