

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

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ABSTRACT

GOROSTIAGA, E. M., C. GRANADOS, J. IBÁÑEZ, J. J. GONZÁLEZ-BADILLO, and M. IZQUIERDO. Effects of an Entire Season on Physical Fitness Changes in Elite Male Handball Players. *Med. Sci. Sports Exerc.*, Vol. 38, No. 2, pp. 357–366, 2006. **Purpose:** Fifteen elite male handball players were studied to examine the effects of an entire season of play on physical fitness and throwing velocity. **Methods:** One repetition maximal bench press (1RM_{BP}), 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 (standing and three-step running throw) were assessed on four times (T1, T2, T3, and T4), during a 45-wk season. Individual volumes and intensities of training and competition were quantified for 11 activities. **Results:** From T1 to T3, significant increases occurred in free fatty mass (1.4%), 1RM_{BP} (1.9%), standing throwing velocity (6.5%), and three-step throwing velocity (6.2%). No significant changes were observed throughout the season in endurance running and explosive strength-related variables. Significant correlations ($P < 0.05$ – 0.01) were observed between strength training time and changes in standing throwing velocity as well as between high-intensity endurance training time and changes in endurance running. In addition, linear inverse relationships were observed between low-intensity endurance training time and changes in muscle power output of the lower extremities. **Conclusion:** The handball season resulted in significant increases in maximal and specific strength of the upper-extremity but not in the lower-extremity actions. The correlations observed suggest that training time at low intensity should be given less attention, whereas the training stimuli for high-intensity endurance running and leg strength training should be given more careful attention in the full training season program. **Key Words:** MUSCLE STRENGTH, MUSCLE POWER, ARM THROWING, TRAINING SCHEDULE

Handball is a strenuous contact Olympic team sport that places emphasis on running, jumping, sprinting, arm throwing, hitting, blocking, and pushing. In addition to technical and tactical skills, it has been shown that anthropometric characteristics and high levels of strength, muscle power, and handball throwing velocity are the most important factors that give a clear advantage for successful participation in elite levels of handball leagues (8). 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 (20). Little is known, however, about the best way to improve sport-specific performance in handball and other team sports and whether some interference between different components

of physical fitness occurs when strength, sprint, endurance, sport-specific factors, and competition are trained simultaneously during an entire season (12,14,20).

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 male handball players. Examination of these relationships could be of great importance for optimal construction of the physical and sport-specific conditioning programs to improve handball performance.

We hypothesized that if the physical demands of physical conditioning, handball practice, and competition are optimized, physical performance and handball throwing velocity should be improved during an entire handball season. On the contrary, if these demands are too great, too low, or unbalanced, no increases or interference on physical performance development should occur (9,16). This study, therefore, investigated the physical fitness and throwing velocity changes that take place over a season in one of the world's leading male handball teams. We were also specifically interested in determining the influence of quantitative assessments of different training and competition modes on the changes in physical performance and throwing velocity over the course of a season in these elite handball players.

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METHODS

Experimental approach to the problem. One elite handball Spanish team, ranked as one of the world's leading professional handball teams, participated in this study. The team was monitored throughout a 45-wk handball season consisting of 50 games, using a longitudinal study design. Measures of physical characteristics (height, body mass, percent body fat, and free fatty mass), physical performance (one repetition maximal bench press ($1RM_{BP}$), jumping explosive strength, 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 was 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). Hereby, it was possible to examine the influence of a handball season on physical performance and handball throwing velocity and quantify the individual time spent in each activity and intensity of training and competition. Experimental studies recreating the training loads and time frames relevant for international class team sports athletes are absent from the literature. Understanding the effects of periodized training and competition time spent volumes and intensities may provide insights for enhancing performance and preventing injury in elite handball team sport.

Subjects. Members of one elite male handball team ($N = 15$; age: 31.0 ± 3 yr) with a regular training and competitive background in handball (20.2 ± 4 yr) participated in the study. The team can be considered as one of the world's leading professional handball teams because (a) it was the Spanish handball champion last season, and 7 months later it was runner-up in the European Champions League, (b) 12 of their players are or have been internationals and had won 18 Olympic or World Championship medals, and (c) European players are the world leaders in handball because in the last four World Handball Championships, the first three places have been won by European national teams. Table 1 gives the physical characteristics of the subjects before and throughout the experimental period.

TABLE 1. Physical characteristics of the elite male handball team at the beginning (T1) of the first preparatory period, at the beginning (T2) and at the end (T3_R) of the first competitive period, and at the end of the second competitive period (T4).

Physical Characteristics	T1	T2	T3 _R	T4
Body mass (kg)	95.6 ± 14.3	95.2 ± 13.4	95.6 ± 12.1	93.9 ± 16.9
Body fat (%)	14.9 ± 4.2	13.9 ± 2.6	13.6 ± 2.6	14.0 ± 3.1
Free fatty mass (kg)	80.7 ± 8.8	81.8 ± 9.4*	82.1 ± 8.8*	80.3 ± 11.8
Age (yr)	31 ± 4			
Height (cm)	188 ± 7			

Values are means ± SD, $N = 15$. * Significantly different ($P < 0.01$) from corresponding value at T1.

Before commencing the study, players had a physical examination by the team physician, and each was cleared of any medical disorders that might limit their participation fully in the investigation. The subjects and coach were informed 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. 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. No tests were positive for any banned substance in any of the subjects during several in or out of competition doping control tests undertaken by the Spanish or International Handball Federation under strict International Olympic Committee doping control guidelines. The subjects were not taking any medications that would have an impact on the results of the study.

Testing schedule. The 45-wk season lasted from August 2002 to May 2003 and consisted of two preparatory periods (from weeks 1 to 6 and from weeks 23 to 27) and two competitive periods (from weeks 7 to 22 and from weeks 28 to 45) (Fig. 1). During the season, the subjects were tested on four occasions (Fig. 1): The first test (T1, August, 1) was performed 3 d after the beginning of the first preparatory period. The second test (T2, September, 9), and the third test (T3_R, December, 12) were performed at the beginning and at the end, respectively, of the first competitive period of the National First Division League, whereas the fourth test (T4, May, 19) was performed at the end of the second competitive period of the National First Division League. The only incidence in the testing schedule was that the sprint and the endurance running test in T3 (T3_E), were performed at the beginning of the second competitive period of the National First Division League (January, 31), 6 wk after the T3_R, because of a coach decision (Fig. 1). The subjects were familiarized with the testing protocol because they had been tested on several occasions in previous seasons for training prescription purposes. For a given test, all of the players were assessed on the same day, and the tests were performed in the same order in the three test sessions. During the first testing session, each subject was subjected to a sprint and endurance running test. In the second test session, each subject was tested for anthropometric measurements, maximal and explosive strength, and muscle power. In the third testing session, penalty 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.

All the subjects were familiarized with the testing protocol because they had been previously tested on several occasions in previous seasons for training prescription purposes with the same testing procedures. In a pilot study, the intertest reliability for measuring maximal strength and power, anthropometric variables, as well as several

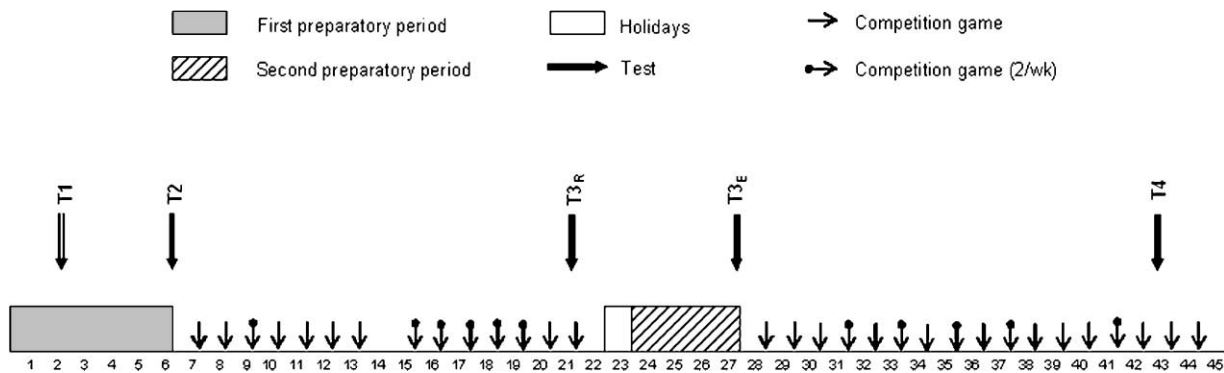


FIGURE 1—Testing and games schedule of the elite male handball season.

endurance indices was assessed on two trials separated by 7 d in a group of handball players. The test–retest intraclass correlations coefficients (ICC) of the anthropometric, maximal strength and explosive (e.g., throwing and jumping) variables used in this study were >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 $3 \text{ mmol}\cdot\text{L}^{-1}$ (V_3) were 0.94 and 2.2%, respectively.

Physical characteristics. The anthropometric variables of height (m), body mass (kg), body fat (%), and free fatty mass (kg) were measured in each subject. Height and body mass measurements were made on a leveled platform scale (Año Sayol, Barcelona, Spain) with an accuracy of 0.01 kg and 0.001 m, respectively. Body mass index (BMI) was calculated from body mass and body height ($\text{kg}\cdot\text{m}^{-2}$). Percentage of body fat was calculated from measurements of seven skinfold thickness (19). Free fatty mass (FFM; kg) was calculated as a difference between body mass 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 (18). Basically, maximal strength of the upper extremity was assessed using one repetition concentric maximal bench press action (1RM_{BP}). Bench press (elbow extension) was chosen because it seems most specific to the overhand throwing technique (6). 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 supported by the bottom stops of the measurement device. The subject was instructed to perform a purely concentric action from a lower starting position, maintaining the shoulders in a 90° abducted position to ensure consistency of the shoulder and elbow joints throughout the testing movements (18). 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 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 half-squat position, respectively, using the relative loads of 30, 45, 60, and 70% of 1RM for bench press exercise, and 60, 80, 100, and 125% of body mass for half-squat exercise. For comparison purposes, the subject's power–load relationship was tested through the experimental period with the same absolute pretraining loads. In half-squat position, shoulders were in contact with a bar and the starting knee angle was 90° (18). 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 the loads of 40–60% of the body mass. 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 part of the bar. The rotary encoder recorded the position and direction of the bar within accuracy of 0.0002 m. Customized software (JLML I+D, Madrid, Spain) was used to calculate the power output for each repetition of the half-squat and bench press performed throughout the whole range of motion. Average power output for each repetition of the half-squat and bench press was determined. Power curves were plotted using average power over the whole range of movement as a most representative mechanical parameter associated with a contraction cycle of leg and arm extensor muscles participating in the half-squat (i.e., hip, knee, and ankle joints) and bench press (i.e., elbow and shoulder joints) performances. In all neuromuscular performance tests, strong verbal encouragement was given to each subject to motivate maximal and rapid performance of each test action. The reproducibility of the measurements has been reported elsewhere (18).

Jumping test. Subjects were asked to perform a maximal counter-movement vertical jump on a contact platform (Newtest OY, Oulu, Finland). Using a preparatory counter movement, subjects performed the jump from an extended leg position, down to the 90° knee flexion, and then immediately followed by a subsequent concentric action where the subject jumps for maximal height. Subjects could move their arm freely, but were instructed to land on the contact platform in a position similar to that of the take-off. The jumping height was calculated from the flight time (1). Two sets of two maximal jumps were recorded, interspersed with an approximately 10-s rest between jumps and 90-s 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. Time was recorded 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. 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 10, 12, 14, and 16 km·h⁻¹. Time for each stage was 5 min. To assure a 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 were obtained from hyperemic earlobe to determine lactate concentrations. 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 mmol·L⁻¹). 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 polynomial function. From the equation describing the exercise blood lactate curve, the velocity associated with a blood lactate concentration of 3 mmol·L⁻¹ (V₃) was

interpolated. The submaximal velocity associated with a given absolute blood lactate concentration has been shown to be an important determinant of endurance performance capacity (29).

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 480 g, circumference 58 cm) as fast as possible through 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 3.4 m from the penalty mark and contained five vertically distributed photocells (range: 1.49–2.10 m above the ground). The second tripod was placed 6.4 m from the penalty mark and contained four vertically distributed photocells (range: 1.37–1.89 m above the ground). To simulate a real handball game action, the players were told to throw to the upper right corner of the goal with maximal velocity and were allowed to put resin on their hands to throw the ball. The first tripod was located slightly higher than the second one because some of the tallest handball players released the ball at a vertical height slightly higher than the goal height (2.00 m). The time was automatically activated as the handball passed the photocells of the first tripod and 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 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 the individual match and training time exposure (i.e., player participation for every training and competition session, including the duration of each activity). Individual training volume was determined as the amount of time each player participated in 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).

The endurance training was divided into the low (E1; average heart rate corresponding to $<80\%$ of $V_{3\text{mmol}\cdot\text{L}^{-1}}$), medium (E2, average heart rate corresponding to $80\text{--}90\%$ of $V_{3\text{mmol}\cdot\text{L}^{-1}}$), and high (E3; average heart rate corresponding to $>90\%$ of $V_{3\text{mmol}\cdot\text{L}^{-1}}$ or interval training) intensity 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 $<80\%$ of $V_{3\text{mmol}\cdot\text{L}^{-1}}$); medium (B2; average heart rate corresponding to $80\text{--}90\%$ of $V_{3\text{mmol}\cdot\text{L}^{-1}}$); and high (B3; average heart rate corresponding to $>90\%$ of $V_{3\text{mmol}\cdot\text{L}^{-1}}$) 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 training (Sw; with free weights and machines) and sport-specific strength training (Ss; running uphill, multijumps, medicine ball throwing). Briefly, Sw consisted of two main exercises with barbells: dynamic half-squat lift and bench press, and two main secondary exercises: power clean and pullover. The load in the squat-lift exercises (2–5 sets, 2–5 repetitions) ranged from 85 to 110% of the load with the maximal power output that was attained in the power-load test in half-squat actions. This corresponds to a load ranging approximately from 51 to 77% of one maximal concentric repetition in the squat lift exercise (18). The load in the power clean lift exercises (3–5 sets, 3–6 reps) ranged from 65 to 95% of six maximal concentric repetitions (6RM). This corresponds to a load ranging approximately from 41 to 76% of one maximal concentric repetition in the power clean exercise. The load in the dynamic bench press lift exercise (2–4 sets, 1–5 repetitions) ranged from 85 to 100% of one maximal concentric repetition (1RM_{BP}). Loads were adjusted based on 1RM testing through the season. The load in the dynamic pullover lift exercise (3–4 sets, 5–10 repetitions) ranged from 15 to 25% of body mass (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 between 55 and 120 min per session. Training was periodized from a high-volume, low-intensity phase during the preparatory periods to a low-volume, high-intensity phase toward the competitive periods.

All works were supervised by team coaches. Diets or lifestyles were not controlled significantly during the course of the season, although the coaches encouraged some of the players to maintain body weight, under threat of economic fine.

Statistical procedures. Standard statistical methods were used to calculate the mean and standard deviations. ANOVA with repeated measures was used to determine the differences between tests. When a significant *F* value was achieved, appropriate Scheffé *post hoc* tests pro-

cedures were used to locate the difference between means. The test–retest reliabilities for the experimental test demonstrated intraclass correlations of $R \geq 0.95$. Pearson product–moment correlation coefficients (*r*) were used to determine association 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 $P \leq 0.05$ criterion was used to establish statistical significance.

RESULTS

Times spent at training and competition modes.

During the 5-wk first preparatory period (from T1 to T2), each player participated in an average of 37 training sessions (8.4 training sessions per week), and played seven training games for a total average duration of 3048 min distributed as follows: endurance training (31%), strength training (29%), sprint training (0.3%), ball exercise (31%), and training game (7%) (Fig. 2). From T2 to T3_R (15 wk), each player participated in an average of 77 training sessions (5.1 training sessions per week), and played 1 training game and 20 competition games for a total average duration of 6326 min distributed as follows: endurance training (25%), strength training (10%), sprint training (0.2%), ball exercise (52%), training game (3.4%), and competition game (8%). From T3_R to T4 (22 wk), each player participated in an average of 119 training sessions (5.5 training sessions per week), and played 22 competition games for a total average duration of 5757 min distributed as follows: endurance training (25%), strength training (17%), sprint training (0.1%), ball exercise (48%), training game (2.5%), and competition game (8%). Average training and competition time decreased from $649 \pm 16 \text{ min}\cdot\text{wk}^{-1}$ (from T1 to T2) to $369 \pm 41 \text{ min}\cdot\text{wk}^{-1}$ (from T2 to T3_R), and to $263 \pm 121 \text{ min}\cdot\text{wk}^{-1}$ (from T3_R to T4).

Physical characteristics. Some slight changes occurred in physical characteristics during the experimental period (Table 1). No changes occurred in body mass and percent body fat during the season. Free fatty mass significantly increased 1.3% ($P < 0.01$) from T1 ($80.7 \pm 8 \text{ kg}$)

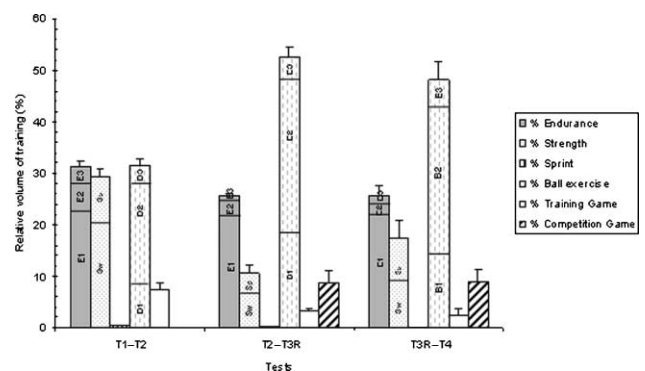


FIGURE 2—Relative volumes (mean \pm SD) of the different training and competition modes between tests during the entire season. Low- (E1), medium- (E2), and high-intensity (E3) endurance training; weight strength training (Sw) and sport-specific strength training (Ss); low (B1), medium (B2), and high-intensity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

to T2 (81.8 ± 9 kg) and 1.4% ($P < 0.01$) from T1 to T3 (82.1 ± 8 kg).

Maximal strength and muscle power output.

Maximal $1RM_{BP}$ values increased during the season. Thus, $1RM_{BP}$ increased 2% at T2 (106.9 ± 11.6 kg, $P < 0.05$) and 1.9% at T3 (106.8 ± 11.3 kg, $P < 0.01$) compared with T1 (104.8 ± 15.6 kg). The data of the values of the average bilateral concentric half-squat and bench press power-load curve in absolute values during the experimental period are presented in Table 2. Muscle power output of the lower extremities at all loads examined remained unaltered during the whole season. Similarly, bench press power output at all loads examined remained unaltered during the season.

Jumping test.

No significant changes were observed in vertical jumping height at any time during the whole season (45.2 ± 7.0 , 46.8 ± 7.7 , 48.2 ± 7.2 , and 47.5 ± 7.0 cm at T1, T2, T3_R, and T4, respectively).

Maximal sprint and endurance running.

Maximal sprint running velocity for 5 m (17.3 ± 1.2 , 17.4 ± 1.1 , 17.2 ± 0.8 , and 17.2 ± 1.1 m·s⁻¹ at T1, T2, T3_E, and T4, respectively) and for 15 m (21.9 ± 1.3 , 21.9 ± 1.1 , 21.9 ± 0.8 , and 21.8 ± 1.3 m·s⁻¹ at T1, T2, T3_E, and T4, respectively) did not change during the experimental period. Similarly, no statistically significant changes occurred in the mean running velocity that elicited a blood lactate concentration of 3 mmol·L⁻¹ (V₃) during the season (11.9 ± 0.9 , 11.8 ± 0.9 , 12.3 ± 0.9 , and 12.4 ± 0.5 km·h⁻¹ at T1, T2, T3_E, and T4, respectively).

Handball throwing velocity.

Measures in average handball throwing velocity showed significant increases during the season for both types of throwing. Thus, a significant ($P < 0.001$) increase was observed in standing throw at T3_R (26.0 ± 2.2 m·s⁻¹) compared with T2 (23.8 ± 1.9 m·s⁻¹) and T1 (24.3 ± 2.3 m·s⁻¹). Similarly, a significant ($P < 0.01$) increase was observed in the average velocity of handball throwing with three-step running at T3_R (27.6 ± 2.2 m·s⁻¹) compared with T2 (25.3 ± 2.2 m·s⁻¹) and T1 (25.9 ± 1.9 m·s⁻¹). No changes in standing or three-step throwing were observed between T3_R and T4.

Relationships between training and competition times, physical performance, throwing velocity, and physical characteristic changes during the training season. Statistically significant correlations were observed from T1 to T2 between training times and physical performance and throwing velocity changes as well as between relative changes in physical characteristics

TABLE 2. Absolute power values in the elite male handball team, at the beginning (T1) of the first preparatory period, at the beginning (T2) and at the end (T3_R) of the first competitive period, and at the end of the second competitive period (T4).

Power	T1	T2	T3 _R	T4
Lower extremity				
P 60% (W)	645 ± 114	649 ± 105	625 ± 133	598 ± 108
P 80% (W)	763 ± 101	767 ± 106	766 ± 84	755 ± 131
P 100% (W)	845 ± 103	840 ± 112	883 ± 100	840 ± 137
P 125% (W)	763 ± 243	866 ± 108	929 ± 127	898 ± 136
Upper extremity				
P 30% (W)	440 ± 84	437 ± 58	452 ± 55	431 ± 97
P 45% (W)	476 ± 73	487 ± 70	500 ± 74	481 ± 96
P 60% (W)	449 ± 77	468 ± 81	455 ± 81	441 ± 109
P 70% (W)	394 ± 72	416 ± 91	391 ± 107	364 ± 110

Values are means ± SD, $N = 15$.

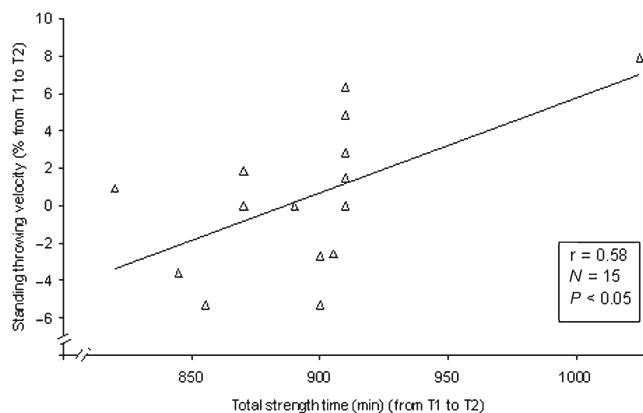


FIGURE 3—Relationship between the total time devoted to strength training and the individual changes of standing throwing velocity, from T1 to T2.

and relative changes in physical performance. Thus, from T1 to T2, the individual total strength training time ($S_w + S_s$) correlated with the individual relative changes in standing throwing velocity ($r = 0.58$, $P < 0.05$, $N = 15$) (Fig. 3). Significant inverse correlations were observed from T1 to T2 between the individual total endurance running and ball exercise training times at low intensities ($E1 + B1$) and the individual relative changes of concentric power production at the load of 125% of body mass during half-squat action, expressed relative to kilograms of body mass ($r = -0.79$, $P < 0.01$, $N = 10$) (Fig. 4). Finally, from T1 to T2, the individual relative changes in percent body fat correlated significantly ($r = 0.70$, $P < 0.01$, $N = 14$) (Fig. 5) with the individual relative changes in concentric power production at the load of 30% of $1RM_{BP}$.

From T2 to T3_R, significant correlations were observed between the individual changes of concentric power production at the load of 125% of body mass during half-squat action and the individual changes in the average running velocity over 15-m sprint running ($r = 0.95$, $P < 0.01$, $N = 6$). From T2 to T3_E, significant correlations were observed between the individual total endurance running and ball exercise training times at high intensities ($E3 + B3$) and the individual relative changes of mean running

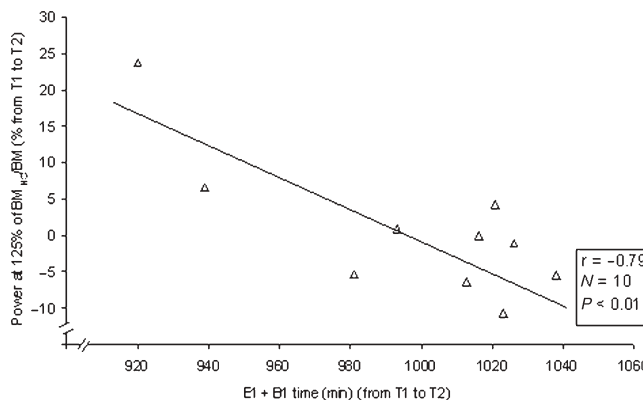


FIGURE 4—Relationship between the time devoted to endurance (E1) and ball exercise (B1) training at low intensity and the individual changes of relative concentric power production at load of 125% of body mass during half-squat action, from T1 to T2.

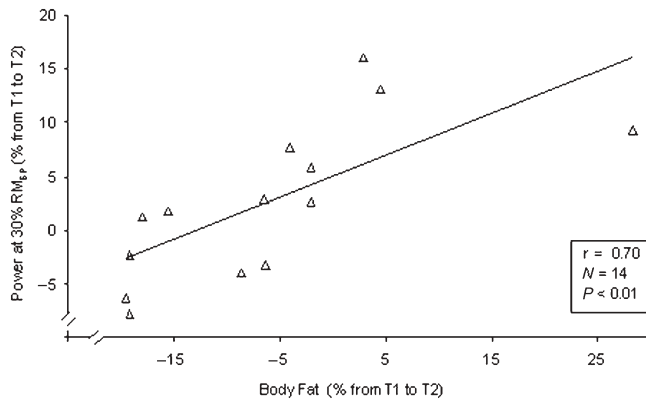


FIGURE 5—Relationship between the individual changes of percentage of body fat and the individual changes of power at 30% of 1RM of bench press, from T1 to T2.

velocity that elicited a blood lactate concentration of 3 mmol·L⁻¹ (V₃) ($r = 0.68$, $P < 0.05$, $N = 10$) (Fig. 6).

From T3 to T4, the number of subjects who could perform all the tests was low, because of injuries. Consequently, the associations between variables could be studied in few subjects ($N = 5$ – 9) and should be viewed with caution. Similar trends to those found in previous training and competition periods were observed between variables. Thus, significant inverse correlations were observed from T3_R to T4, between the individual total endurance running and ball exercise training times at low intensities (E1 + B1) and the individual relative changes in velocity at the load of 125% of body mass during half-squat action, expressed relative to kilogram of body mass ($r = -0.93$, $P < 0.05$, $N = 5$). Finally, significant correlations were observed from T3_E to T4 between the individual total endurance running training times at medium and high intensities (E2 + E3) and the individual relative changes of mean running velocity that elicited a blood lactate concentration of 3 mmol·L⁻¹ (V₃) ($r = 0.95$, $P < 0.05$, $N = 5$).

DISCUSSION

This is the first study to document the physical fitness changes over an entire season and the relationships between durations of different training and competition modes and changes in physical performance, in one of the world's leading elite male handball teams. The primary findings of the present study demonstrated that the entire season in elite male handball players led to significant increases in free fatty mass, maximal concentric upper-body strength, and handball throwing velocity. No changes, however, occurred during the season in maximal sprint and endurance running or in muscle power output of the upper and lower extremities at all loads examined. The present findings additionally demonstrated that linear direct relationships were observed between strength training time and changes in standing throwing velocity, between high-intensity endurance training time and changes in endurance running, as well as between changes in percent body fat and changes in muscle power output of the upper extremities. In

addition, linear inverse relationships were observed between low-intensity endurance training time and changes in muscle power output of the lower extremities.

The elite male handball players had significant increases from T1 to T3 in free fatty mass, upper-body maximal strength, and standing throwing velocity, but no changes occurred in sprint running, endurance running, and upper- and lower-extremity muscle power. These minor changes in physical fitness during the season are consistent with the results obtained in male elite handball (23), soccer (21), bandy (14), and basketball players (11). It is not known why minor changes are observed in physical fitness in elite players, despite using an in-season conditioning program. They may be related, however, to low training intensity or motivation, the distribution of different training and competition modes for different phases, interfering effects between training modes, and that their handball-related physical performance is probably approaching their genetic limits. The findings of minor changes in physical fitness during the season in handball players raises the question of the appropriate training stimulus required to elicit improvements in physical fitness and performance in elite team sports participants.

The handball season resulted in slight (1–4%) but significant increases in maximal concentric upper-body strength, standing throw, and three-step running throw. These results indicate that the combination of a strength training program, handball training, and competition skills training contributed to significant enhancements in maximal and specific-explosive strength of the upper extremity during the season. The increase in maximal upper-body strength should give the whole team an advantage to sustain the forceful muscle contractions required during some handball game actions such as hitting, blocking, pushing, and holding. The increase in handball throwing velocity is of major importance in handball because elite handball players have 8–9% higher handball throwing velocity than lower-level players (8) and because the combination of ball velocity and accuracy at throwing is one of the most important factors for success in handball (25). The significant correlation observed between

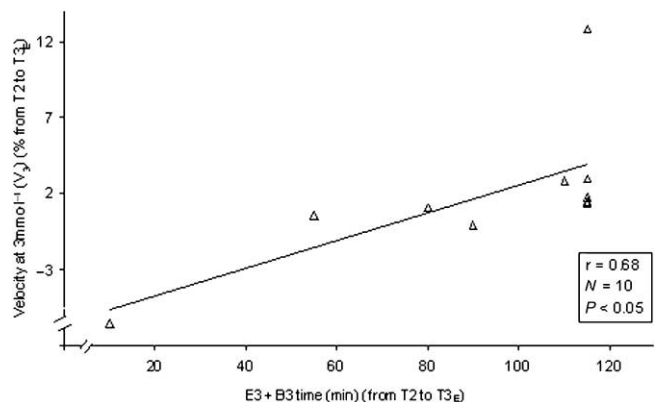


FIGURE 6—Relationship between the time devoted to endurance (E3) and ball exercise (B3) training at high intensity and the individual changes of velocity associated with a blood lactate concentration of 3 mmol·L⁻¹ (V₃), from T2 to T3_E.

the individual values of training time devoted to total resistance training time and the individual changes in handball standing throwing velocity further supports a need for careful and significant attention to the individual resistance training programs in elite handball players.

With the use of an in-season conditioning program, leg extensor strength and sprint velocity gains might be expected. Muscle power output of the half-squat actions, vertical jump, and sprint running performance, however, remained unchanged during the entire competitive season. This must be considered as a negative result on the playing ability of the whole team because muscle power output of the leg extensor muscles, absolute jumping power, and sprint running are important neuromuscular performance characteristics for successful participation in elite levels of handball (8). The differences observed for the strength gains between the upper-extremity muscles and the leg extensor muscles as a result of resistance training have been found in other studies with untrained (5), aged (13), prepubescent (26), and adolescent handball players (9). These differences have been explained by a difference in initial conditioning between knee extensors and upper-body muscles (26), related to differences in the pattern of quantity or intensity of daily physical use in normal life (5,9,13). The quadriceps muscle, owing to its weight-bearing role during habitual physical activity, would be more likely to be at a higher initial level of conditioning than the upper-body muscles, which have been shown to be used habitually less frequently (26). This explanation, however, seems to be uncertain for the present group of elite experienced players because they are probably approaching their genetic limits based in their handball and weight training history. Another explanation for the different strength gains observed between the upper and the lower extremities could be related to differences in weight training regimens. Thus, relative weight training intensity in the lower extremity (range: 50–80% $1RM_{HS}$) was lower than in the upper-extremity muscles (range: 85–100% of $1RM_{BP}$). In this case, the loads utilized in the present lower-extremity strength training program were probably not sufficient to improve the level of knee extensors strength and muscle power. From this, it appears that the use of a heavier resistance-training program might be essential for optimizing muscle strength and power of the leg extensor muscles.

Finally, an alternative explanation could be related to some interference of endurance training with strength development in the legs. Some studies have found that simultaneous training for strength and endurance might reduce the capacity to develop strength, especially during prolonged training periods (4,9,11,16). These results agree with the present study, in which significant inverse correlations were observed, from T1 to T2 and from T3_E to T4, between the individual values of training time devoted to low-intensity endurance running and ball exercises and the individual changes in concentric power and velocity production at the load of 125% of body mass during half-squat actions. This strongly suggests that

lower-extremity strength, muscle power, and sprint running velocity development may be inhibited by the low-intensity, aerobic-type training used during the entire season. The present observation agrees with other studies performed with elite basketball players (11) and suggests that overall volume of low-intensity running and low-intensity training drills of aerobic nature during the season could have had some negative effects on the muscle power performance gains of the legs. It is suggested, therefore, that the magnitude and the frequency of these specific low-intensity, aerobic-type of training should be reduced in the full training program.

Although no changes were observed in leg extensor muscle performance during the season, significant correlations were observed from T2 to T3_R between the individual relative changes of concentric power production at the load of 125% of body mass during half-squat actions and the individual relative changes in 15-m average sprint running velocity. It indicates that handball players with higher increases in concentric power production of the lower extremities may more likely produce major running sprint performance gains than those with lower increases of muscle power production. This relationship suggests a possible transfer from the gain in leg muscle power into enhanced sprint performance and emphasizes the importance of increasing leg muscular strength and power to improve short-distance sprint performance (3,10).

Based on studies measuring heart rate and blood lactate levels during 30- to 60-min handball games, it has been estimated that handball level performance demands a high aerobic capacity (2,22,23). Because a considerable amount of training time was devoted to endurance running and, specially, to low-intensity endurance running (E1, Fig. 2), an increase in endurance capacity during the season was expected. No changes in running associated with a blood lactate concentration of 3 mmol·L⁻¹, a good predictor of aerobic capacity (29), however, were observed during the entire handball season. The present results suggest that a lot of low-intensity running (E1) does not increase endurance capacity in handball players. In addition, significant correlations were observed in T2–T3 and T3–T4 between the individual training time at high-intensity endurance running (E2,E3) and the individual relative changes in average running velocity associated with a blood lactate concentration of 3 mmol·L⁻¹. This agrees with previous studies showing that handball training alone does not increase aerobic capacity (23) and that additional high-intensity endurance training is needed to increase aerobic capacity in elite handball (20) and other team sports such as elite soccer (15). These observations suggest that the magnitude or frequency of the training stimuli for high-intensity endurance running should be given more attention during the full season. It also strongly suggests that the training time at low-intensity running should be given less attention because it does not increase endurance capacity and, as it has been pointed out, it interferes with the development of muscle power of the legs extensor muscles.

During the season, but specially, during the first preparatory period (from T1 to T2), coaches pressed all the players to obtain an “adequate” body mass based in the individual competitive body mass observed in previous seasons. Most of players ($N = 11$), therefore, reduced fat mass from T1 to T2 under threat of economic fine and weekly control of body weight. An unexpected finding of this study was that from T1 to T2 the individual relative changes observed in percent body fat correlated with the individual relative changes in concentric power production at the load of 30% of 1RM during bench press action (Fig. 5). It indicates that handball players who had a greater decrease in the percent body fat from T1 to T2 had greater decreases in muscle power during high-velocity contractions of the upper extremity than did those with minor or with even some increases in percent body fat. Decreases in muscle power production of the upper-extremity muscles during very fast movements can be considered as disadvantageous for handball throwing because it has been shown that faster handball elite throwers are able to better and more quickly activate fast muscles of the upper extremity during high-velocity, low load-contractions (8,23). Although the mechanisms of muscle power losses associated with body fat reductions are unknown, they might involve: (a) A negative protein balance and reduced muscle mass. It is plausible that a hypoglucidic hypocaloric diet combined with continuous high-intensity and volume training during the precompetitive season, could contribute to a negative energy balance in some players. Such condition may have contributed to the subsequent increase in muscular protein catabolism and concomitant losses in muscle mass and power function. Increased muscular protein catabolism, however, seems improbable because during the precompetitive season body mass and percent body fat did not change and significant increases in free fatty mass were observed. This suggests indirectly that an increase in muscle mass occurred from T1 to T2. A decrease in muscle power production associated to an increased muscular protein catabolism, therefore, seems slightly probable.

(b) An alternative explanation could be related to the methods used by some players for body weight reduction. To achieve a target body weight during a short period without being fined, at least three players used rapid body weight reduction techniques (dehydration in 12–96 h)

several times during the precompetitive season, typically with food and fluid restriction and exercising in rubber or plastic suits (7). Using these methods, 2–5% decreases in body weight during 1 d have been reported (27). The effects of rapid body weight reduction on strength characteristics are complex and not clear (7,27). Some studies, however, have reported an impairment in the capability of the neuromuscular system to produce force after rapid body weight loss (17,27,28) and even after a short (1–3 h) rehydration period (27). The factors responsible for the impaired capability in force production after weight reduction are unknown, but they could be related to the considerable amount of electrolytes lost through sweating and mood alterations (reduction in aggression) (24). In this hypothesis, gradual and reasonable individual programs of body fat reduction with professional guidance should be recommended in some handball players to avoid losses in muscle function.

Conclusion and practical application. In conclusion, the present findings demonstrate that the entire season in elite male handball players led to slight but significant increases in free fatty mass, maximal strength in bench press actions and handball throwing velocity. Although a considerable amount of time was devoted to endurance and resistance training of the lower extremities, no changes were observed in sprint and endurance running, explosive strength, and muscle power output of the leg extensor muscles. Strength training utilized contributed to significant gains in upper-body maximal strength and handball throwing velocity. The absence of changes observed for the strength gains in the leg extensor muscles may be explained by the interfering effects of low-intensity endurance and playing training or by the differences in initial conditioning between knee extensors and upper-body muscles. To increase endurance capacity without interfering in lower-extremity strength gains, it is suggested that the training time at low-intensity running should be given less attention, whereas the magnitude or frequency of the training stimuli for high-intensity endurance running and leg strength training should be given more careful attention in the full training program. Professional dietary guidance should be recommended to reduce body fat without decreasing muscle function. Further studies are required to determine the appropriate training stimulus required to enhance the physical fitness and handball performance in elite players.

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