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Original article

Seasonal Changes in Selected Physical and Physiological Variables in Male Handball Players

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SUMMARY

Literature search shows that there is a shortage of studies that 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 handball players. Thus, the aim of our work was to follow changes in speed, strength, power and endurance of elite male handball players during an entire season. The study was performed within a group of 14 elite male senior handball players who were tested four times during season (T1, T2, T3, T4). The testing consisted of the following procedures: 1) measuring anthropometric characteristics (body height, body weight, body fat, % of fatty tissue), 2) measuring motorical (physical) capabilities (maximal muscle force and power, speed, explosive strength), 3) measuring physiological characteristics (anaerobic capacity, cardiorespiratory endurance). Explosive strength decreased at the end of season compared to the first part of season (T1 vs T4: $p = 0.00$, T2 vs T4: $p = 0.00$), as well as the total work done on modified Wingate test (T1 vs T4: $p = 0.01$). In contrast, blood lactate levels after the third (T1 vs T2: $p = 0.00$, T1 vs T3: $p = 0.02$; T1 vs T4: $p = 0.00$) and fourth (T1 vs T3: $p = 0.02$) stage of endurance test were the highest at the beginning of the season. Our results suggest that anaerobic capabilities of players were the ones mostly affected by long season and inadequate training program, while on the other side, aerobic capabilities improved by the end of season. Explanation for such results may be found in insufficient strength training or interference of endurance training with strength development.

Key words: **handball, strength, speed, endurance**

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INTRODUCTION

Handball is an Olympic team sport with increasing popularity and number of players in both male and female category (1). It is a very complex and multi-factorial sport with specific requirements for anthropometric characteristics, technical skills, tactical understanding and physical capabilities (2). Despite its popularity, the knowledge regarding the physiological demands in elite team handball is scarce (3). Furthermore, previously published studies are contradicting and inconclusive regarding the role and importance of different physical characteristics according to playing level and positions in male elite handball (4).

The ability of handball players to develop explosive efforts (e.g. sprinting, jumping, changing direction) is crucial to success (5). Handball may be described as a strenuous intermittent team sport with lots of contacts, pushing and pulling between players, together with accelerations/decelerations, changes of direction, jumping, arm throwing, hitting, blocking, etc. (6). After rules modifications in 2002 and the adoption of the „quick throw-off" style of play, the rest time between phases of attack and defense has been reduced, which increased the speed of the game. It requires the performance of high-intensity actions and many substitutions during match, where some coaches have „specific" players for either phase of attack or defense, in order to maintain high intensity and avoid fatigue accumulation in players. Based on recent study (7), an average running pace (53 ± 7 to 90 ± 9 m min^{-1}) during handball games tends to be lower than in the majority of other team sports, while blood lactate and heart rate responses tend to be similar and slightly lower, respectively. All this suggests that the physical conditioning of handball players is a complex process and a hard task.

Besides the need for more studies of high performing athletes tested in order to get a clearer overview of the physical, physiological and anthropometrical demands in handball (4), performing studies on the changes of the detected capabilities during season seems to be even more necessary. More research in this area is needed to obtain information that should be useful for the design of effective training programs and to define specific test batteries (8). This is especially important if problems regarding the interference between different components of physical fitness, which occurs when strength, sprint, endurance, sport-specific factors, and competition are trained simultaneously, are taken into consideration (5, 6).

Literature search shows that there is a shortage of studies that 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 handball players. To the best of the authors' knowledge, only one study investigated the effects of the entire season on physical fitness in elite male (6) and one in elite female handball players (9). Examination of these relationships could be of great importance for optimal construction of the physical and sport-specific conditioning programs to improve handball performance (10). Thus, the aim of our work was to follow changes in speed, strength, power and endurance of elite male handball players during an entire season, and suggest ways to improve the overall physical condition of handball players.

MATERIAL AND METHODS

PARTICIPANTS

The study was performed within a group of 14 elite male senior handball players, members of the team which participated in highest national level of competetion. Before the beginning of the study, participants were informed of the nature, risks and benefits of participation in the study, and their written consent for participation in the study was obtained. All participants underwent a physical examination performed by a sports medicine specialist before every testing session. None of the participants had an indication that may exclude him from the participation in this study.

The presented procedures were in accordance with the ethical standards on human experimentation. The Institutional Review Board approved of the study.

PROTOCOL

The study consisted of performing the following procedures:

1) measuring anthropometric characteristics of subjects (body height, body weight, body fat, percentage of fatty tissue);

2) measuring motorical (physical) capabilities of subjects (maximal muscle force and power, speed, explosive strength);

3) measuring physiological characteristics of subjects (anaerobic capacity, cardiorespiratory endurance).

Those tests were performed four times during the 2014/2015 handball season that consisted of 18 matches:

1) T1: in the middle of the first part of league (after six matches),

2) T2: by the end of the first part of league (after 10 matches),

3) T3: in the middle of the second part of the league (after 14 matches),

4) T4: by the end of the second part of the league (after 17 matches). Preparatory period between the first and the second part of the league lasted two months.

The testing protocol was conducted in the same order all four times, with the use of the same equipment and performed by the same investigators.

Participants were instructed not to engage in any exhausting exercise (significantly different from regular handball training) for a period of 48-hours prior to testing. They were also warned to refrain from eating or drinking energy or caffeine drinks for two hours prior to the testing. The participants were allowed to drink non-caffeinated liquids ad libitum before testing.

ANTHROPOMETRIC MEASUREMENTS

Body height was measured using the anthropometer GPM 101 (GPM GmbH, Switzerland), in accordance with standardized procedure. The results of the measurements were accurate within 0.1 cm. Body weight was measured by electronic scales with an accuracy within 0.1 kg. Body structure was analyzed using bioelectrical impedance device Omron BF 511 (Omron Healthcare Co, Kyoto, Japan). Percentage of fatty tissue was measured with an accuracy of 0.1%.

PHYSICAL CAPABILITIES TESTING

Prior to testing, participants were exposed to two familiarization sessions, where they were instructed the proper technique of all exercises. Prior to testing, the participants warmed up for approximately 10-15 minutes (submaximal intensity aerobic activity on stationary bikes and/or step machines and short bouts of dynamic muscle stretching).

MUSCULAR FORCE, STRENGTH AND POWER TESTING

Maximal muscular force and power were measured while participants performed two exercises: squat and bench press. The load for 1 repeated maximum (1RM) was determined for each subject in each exercise using the protocol suggested by (11). Maximal muscular force was expressed as maximal number of kilograms that participants lifted with regular technique.

For power measurement, the load was set at 70% of previously determined 1RM for both exercises, and participants performed six repetitions. The participants were instructed to accelerate the barbell as much as possible during the concentric phase of motion, during which the peak power and velocity of movement were measured by means of a computer-interfaced Fitrodyne premium (Fitronic, Bratislava, Slovakia) attached to the barbell via a tether. The validity and reliability of the device has been confirmed by (12). Maximal power was expressed in Watts (W).

Explosive strength was tested using Counter movement jump (CMJ) test. Participants were equipped with Velcro waist belt and wireless Myotest accelerometer device (Myotest SA, Switzerland) while performing five consecutive CMJs. At the end of the procedure, software of the device analyzed the data (13). Results are expressed as maximal height that participant achieved (in centimeters).

SPEED TESTING

Speed was measured using 15 m sprint test on an indoor handball court. Before running, subjects performed three submaximal acceleration runs. The running speed of players was measured by means of infrared photocells gates (Chrono jump, Boscosystem, Spain). Speed was measured to the nearest 0.01 second.

ENDURANCE RUNNING TEST

Endurance running test was performed around handball court (40 x 20 m), clearly marked by cones at the corner. Each player performed a four-stage submaximal discontinuous progressive running test interrupted by three minutes passive recovery between each run (6). Velocities for the 1st, 2nd, 3rd and 4th stage were set at 10, 12, 14 and 16 km/h, respectively, and each stage lasted five minutes. Preprogrammed audio signal was defined to assure a constant velocity during each stage.

Immediately after each stage, capillary blood samples (~ 0.5 μL) were drawn from hyperemic earlobe to determine lactate concentrations. The Lactate Scout analyzer (LS, SensLab GmbH, Germany) was used for lactate analysis. Blood lactate analyzer was calibrated before measurement with a 1-level calibration solution (range 9.5–12.5 mM) that is used as a quality control to ensure that the analyzer and test strips are functioning properly (14).

ANAEROBIC CAPACITY TEST

Anaerobic capacity was estimated using modified Wingate test on an arm ergometer Monark Rehab Trainer 881E (Monark Exercice AB, Sweden), and with telemetric control of heart rate (HR) with Polar RS400 (Polar Electro, Finland). Warming up included three series of 30 s of submaximal work and 30 s of rest, and it was considered that participant was well warmed up if after the third series his HR was 150-160 bpm. After three minutes of rest, participants started the test by turning the pedals with maximal speed for 30 s. The results are presented as total work in Joules (J) and average power in Watts (W) converted into relative values (power per kilogram of body mass).

Table 1. **Average weekly training load during the season.**

Type of training load	Duration (min)	Percentage of total training time (%)
Endurance running – low intensity (< 80% HRmax)	25.4	3.8 %
Endurance running – medium intensity (80% - 90% HRmax)	37.5	5.7 %
Endurance running – high intensity (> 90% HRmax)	50.5	7.6 %
Exercises with ball – low intensity (< 80% HRmax)	62.8	9.5 %
Exercises with ball – medium intensity (80% - 90% HRmax)	127.3	19.3 %
Exercises with ball – high intensity (> 90% HRmax)	83.5	12.7 %
Sprinting	42.7	6.4 %
Strength training with free weights or machines	100.4	15.2 %
Sport-specific strength training (medicine ball throws, jumping, uphill running, etc.)	37.9	5.7 %
Training matches	38.1	5.7 %
Official matches	51.3	7.8 %
Total	**657.4 min**	**100%**

TRAINING PROCESS

Experimental program of this study was plan and program of training of HC Red Star for the entire season. We classified training load as time spent in one of 11 activities (5, 9) presented in Table 1.

STATISTICAL ANALYSIS

Data analysis was performed using the Statistical Package for the Social Sciences (v20.0, SPSS Inc., Chicago, IL, USA). The differences between investigated motorical and physiological parameters were analyzed using multivariate analysis of variance (MANOVA). Changes in performance parameters between the first, second, third and fourth testing were compared using a univariate analysis of variance (ANOVA). When a significant value was achieved, an appropriate post hoc procedure was used to locate the difference between the means. Statistical significance was set at $p < 0.05$.

RESULTS

The age of participants in our study was 19.79 ± 2.08 years. Average body height was 188.74 ± 6.15cm. Changes in body mass and fat percentage during season is presented in Table 2. Those anthropometric parameters did not significantly change during season.

The results that participants achieved on motorical and physiological tests are presented in Table 2 and Table 3. MANOVA showed that both motorical ($p = 0.01$) and physiological ($p = 0.00$) parameters did significantly differ during season. Explosive strength estimated through counter movement jump decreased at the end of season compared to the first part of season (T1 vs T4: $P = 0.00$, T2 vs T4: $P = 0.00$; ANOVA - Bonferroni Post Hoc).

Table 2. **Values (X±SD) of measured anthropometric and physical parameters of participants on four different testings during season**

Parameter	T1	T2	T3	T4	ANOVA
Body mass (kg)	88.79 ± 10.42	88.14 ± 9.59	88.87 ± 7.02	88.33 ± 8.96	p = 0.99
Fat mass (%)	20.13 ± 4.02	19.81 ± 3.72	18.32 ± 2.11	18.86 ± 2.18	p = 0.40
1RM Bench press (kg)	87.11 ± 4.09	87.48 ± 3.99	87.70 ± 3.14	87.50 ± 4.75	p = 0.98
5RM Bench press (W)	510.15 ± 96.1	488.58 ± 87.88	503.77 ± 79.32	481.08 ± 88.11	p = 0.81
1RM Squat (kg)	100.50 ± 5.14	101.6 ± 5.23	102.00 ± 6.37	101.14 ± 6.72	p = 0.92
5RM Squat (W)	947.21 ± 186.33	880.69 ± 204.86	971.30 ± 151.58	958.02 ± 131.73	p = 0.66
Sprint 15m (s)	2.77 ± 0.42	2.98 ± 0.20	2.84 ± 0.27	2.75 ± 0.13	p = 0.09
Countermovement jump (cm)	40.49 ± 3.12	38.99 ± 4.65	37.62 ± 2.39	34.32 ± 2.25	p = 0.00
Anaerobic capacity (W/kg BM)	6.86 ± 0.46	6.84 ± 0.42	6.91 ± 0.57	6.82 ± 0.44	p = 0.96
Anaerobic capacity (J)	328.91 ± 23.88	319.67 ± 6.75	313.49 ± 13.62	306.44 ± 22.66	p = 0.01

Table 3. **Blood lactate levels (X±SD) of participants after each endurance test stage on four different testings during season**

Blood lactate (mmol·L^{-1})	T1	T2	T3	T4	ANOVA
Stage 1	2.72 ± 1.26	2.85 ± 0.89	2.71 ± 0.09	2.60 ± 0.72	p = 0.94
Stage 2	3.84 ± 2.01	2.73 ± 1.06	2.61 ± 0.75	2.83 ± 1.11	p = 0.06
Stage 3	6.63 ± 2.15	4.50 ± 1.09	4.93 ± 1.13	4.14 ± 1.23	p = 0.00
Stage 4	8.09 ± 2.39	6.18 ± 1.78	5.41 ± 2.89	6.02 ± 2.08	p = 0.02

Total work done on modified Wingate test on an armerometer was lower at the end of season compared to the first part of the season (T1 vs T4: P = 0.01, ANOVA -Bonferroni Post Hoc). Finally, blood lactate levels after the third (T1 vs T2: P = 0.00, T1 vs T3: P = 0.02; T1 vs T4: P = 0.00, ANOVA - Bonferroni Post Hoc) and fourth (T1 vs T3 > P = 0.02) stage of endurance test were the highest at the beginning of the season.

DISCUSSION

Despite being an Olympic sport since 1972, and one of the most popular team sports for men worldwide, scientific knowledge regarding the physical and physiological demands in elite team handball is scarce, especially after changes in game rules. The increase in speed of game has put pressure on coaches and other responsible persons to consider athletic and performance parameters in more detail as important factors for team success (15). Regarding the importance of specific conditional factors in professional handball, several qualitative and quantitative studies have been published (2, 16). Based on them, it can be concluded that sprinting, jumping, throwing velocity, and anaerobic endurance capacity are the most important for success (17, 18), while aerobic endurance is not of such importance, but well developed endurance capacity might be helpful for recovering between high intensity bouts on the game, and increasing frequencies of games during the entire season (19). Testing the abovementioned physical and physiological capabilities is essential for talent identification, designing and individualization of conditioning programs (4).

In order to improve and maintain performance, coaches manipulate with training content and load during different phases of preparation and competition. Fluctuations in sports form are inevitable, and desirable, if coach knows how to induce and control them. So far, only one Spanish research team has dealt with changes in physical capabilities of handball players during season (6, 9). They found that the entire season led to significant increases in fat-free mass, maximal concentric upper-body strength (bench press), and handball throwing velocity (6). The correlations that they observed between physical capabilities and training load suggested 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. This is especially important if we know that high level of leg strength is one of the characteristics of top level handball players (20).

The results of our study showed that explosive strength (estimated through the height of vertical jump) and anaerobic capacity (estimated through the total work done during modified Wingate test) decreased in the second part of competitive season. On the other side, aerobic endurance increased, if levels of blood lactates after later stages of discontinuous endurance test are considered as indicators of aerobic capacity. If taken into account that body composition and muscular force and power did not significantly change during season, it might be indirectly concluded that the decrease of explosive strength of lower extremities is a result of decreased speed of movement, i.e. neuromuscular execution, and/or fatigue that the whole season induced. The fact that average power produced during modified Wingate test did not significantly change during season, but that the total work executed during this test decreased at the end of season, may also be explained by the same factors as for explosive strength in handball. The decrease of blood lactate levels during endurance-based running is a clear indicator of increased cardiorespiratory fitness, which per se is positive, but when analyzed in the light of the importance of aerobic capacity for handball success, this result shows that applied training program had some missteps. It seems that preparatory training program did not induce sufficient level of basic physical capabilities, i.e. aerobic endurance and muscular force, which are necessary for adequate development and execution of more sophisticated capabilities such as power, strength and anaerobic endurance. Average value of 1RM bench press in our subjects was around 87 kg, which is closer to the values noticed in amateur players (82.5 ± 14.8 kg) than to the levels observed in professional players, who lift more than 100 kg (21, 4). Also, 1RM squat of our players was about 102 kg, while, for example, Norwegian elite players lift 125-130 kg (4). Such low levels of maximal muscular force measured in our study may be explained by the age of players, i.e. the absence of serious strength training with young players, which is common in handball school. Taking into account the importance of muscular force for such a contact sport as handball, our results imply that it is necessary to dedicate many more trainings to work with external weights, especially in the preparatory period. This suggestion is certainly backed up by the study of Marques et al. (19) who showed that 12 weeks of strength training lead to the improvement in 1RM squat from 93.5 ± 13.9 kg to 134.1 ± 19.4 kg, which also led to the improvement in explosive strength, i.e. height of the vertical jump of players. Strength training also significantly affects throwing velocity of handball players, which is one of the main characteristics that distinguish players of different level (22-24). Since there is no study on handball players that measured power that players produce during bench press and squat, we cannot directly compare our results with others, however, the importance of power for handball success is unquestionable. The same is with speed: although we cannot directly compare our results with other studies, since in no study the test of sprint 15m was applied, speed, especially speed of wings and backs in counter attacks, may be the decisive characteristic of winning teams. For example, Krüger et al. (2) showed that handball players from the 1st German league are significantly faster and jump higher than those playing in the 2nd league. Although speed, vertical jump, throwing velocity and all other specific handball activities based on alactic anaerobic energy system are crucial for scoring a goal, the ability to perform all those activities numerous times during match is even more important. Thus, anaerobic capacity, as well as aerobic capacity, must also find their place in a complete conditioning program for handball. Average power during modified Wingate test did not significantly change in our research, which is not positive, since average power that our participants produced is also lower than reported in other studies (25). However, it must be taken into account that our subjects performed Wingate test on an arm ergometer, while Casartelli et al. (25) used cycle ergometer. Anyway, significant decrease of the total work done during the test of anaerobic capacity implies that fatigue or inadequate strength training during season affected this capability. Anaerobic capacity in one of the most important physiological indicators of physical condition necessary for playing handball, since explosive breakthroughs in handball and efficacy of counter-attack, which depend on anaerobic capacity, are the factors that distinguish between more and less successful teams (26, 27). Studies have also shown that players on higher level have greater anaerobic capacity (28), and that the capability to perform explosive actions many times during match, and in conditions of fatigue, is of great importance for handball success (29). In order to delay fatigue and recover fast, a player must also have an adequate level of cardiorespiratory endurance. Generally, handball players do not possess high levels of maximal oxygen consumption, but differences in aerobic endurance in relation to the playing level were observed even in adolescent players (30). Certain minimal, but sufficient, level of cardiorespiratory fitness is important since even negligible fatigue may hinder an athlete's performance due to the decrease in muscle strength, increase in reaction time, decrease of speed, agility and neuromuscular coordination, as well as mental concentration (31). When fatigued, a player returns to the best-trained moves and automated actions and activities, which neutralizes upgraded positive factors, such as player's intelligence, improvisation and creativity (32, 33). Coaches who smartly rotate players on the court avoid excessive physiological load of players, prevent fatigue and improve player's efficacy during game (3). We hypothesize that improved cardiorespiratory fitness in our participants is not a result of training program designed to improve this capability, but rather a consequence of deficiency of players to be rotated during games, since from 23 players who started the season, nine of them did not finish it (and they did not enter our study) due to injuries, suspensions or other factors.

CONCLUSION

The results of our study showed that anaerobic capabilities of players were the ones mostly affected by long season and inadequate training program, while on the other side, aerobic capabilities improved by the end of season. We hypothesize that the main reason for such variations in physical capabilities during season is insufficient strength training, both general and sport-specific, and too much of tactical and technical work in low intensity manner. Our results may also be explained by interference of endurance training with strength development in the legs, since some studies have found that simultaneous training for strength and endurance might reduce the capacity to develop strength, especially during prolonged training period.

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Original article

Sezonske promene određenih fizičkih i fizioloških varijabli kod rukometaša

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SAŽETAK

Pretraga literature pokazuje da postoji nedostatak studija koje su istraživale odnose između određenih parametara fizičke pripremljenosti nadgledanih tokom sezone i kvantitativnih ocena treninga i takmičenja kod vrhunskih rukometaša. Cilj rada bio je praćenje promena brzine, sile, snage i izdržljivosti vrhunskih rukometaša tokom takmičarske sezone. Istraživanje je sprovedeno na grupi od 14 vrhunskih rukometaša koji su testirani četiri puta tokom sezone (T1, T2, T3, T4). Testiranje se sastojalo od sledećih procedura: 1) merenja antropometrijskih karakteristika (visina tela, telesna masa, procenat masnog tkiva); 2) merenja motoričkih sposobnosti (maksimalna mišićna sila i snaga, brzina, eksplozivna snaga); 3) merenja fizioloških parametara (anaerobni kapacitet i kardiorespiratorna izdržljivost). Eksplozivna snaga bila je niža na kraju sezone u odnosu na prvi deo sezone (T1 vs T4: p = 0,00, T2 vs T4: p = 0,00), kao i ukupan rad na modifikovanom Wingate testu (T1 vs T4: p = 0,01). Nasuprot tome, nivo laktata u krvi nakon trećeg (T1 vs T2: p = 0,00, T1 vs T3: p = 0,02; T1 vs T4: p = 0,00) i četvrtog (T1 vs T3: p = 0,02) merenja tokom testa izdržljivosti, bio je najviši na početku sezone. Naši rezultati ukazuju na to da su anaerobne sposobnosti igrača uglavnom negativno pogođene dugačkom sezonom i neadekvatnim treningom, dok se aerobne sposobnosti poboljšavaju tokom takmičarske sezone. Objašnjenje za ovakve rezultate nalazimo u nedovoljnom treningu snage ili u negativnom preklapanju efekata treninga izdržljivosti sa programom za razvoj snage.

Ključne reči: **rukomet, snaga, brzina, izdržljivost**