ANALYSES OF TIME-MOTION AND HEART RATE IN ELITE FEMALE PLAYERS (U19) DURING COMPETITIVE HANDBALL MATCHES

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Abstract:

Heart rate and time-motion were examined in elite female handball players (U19) during six competitive matches. The average age of the participants was 17.9±0.3 years, the average mass was 65.4±6.9 kg, and the average height was 169.6±6.9 cm. Time-motion analyses of the players were performed using Video Manual Motion Tracker 1.0 software. The descriptive approach of the study determined the overall physical activity (distance [m]) and type of locomotion (standing, walking, jogging, medium-intensity running, high-intensity running, sprinting). The players' heart rates were monitored using TEAM Polar^{2}Pro sport testers (Polar Electro, Kempele, Finland). The maximum heart rate was measured by means of the Yo-Yo intermittent level 1 (YYIRT1) recovery test. One-way ANOVA with repeated- measures was used to compare data on heart rate, covered distance and speed. Based on the results from the time-motion analysis, the average distance covered was 113.3±8.6 m per minute per match. The average distance the players covered during the matches was 3399±362.3 m. The shortest distance (385.8±371.6 m), was traversed by standing and walking, and the longest distance (935.8±165.5 m) by jogging. The players' average heart rate was 183.7±7.3 beats·min^{-1}. The mean intensity during the matches represented 89.6±3.6% of the maximal heart rate (HR_{max}) The results of this study demonstrate that handball is a high-intensity intermittent sport. The physiological profile shows that the players spent more than 83% of the playing time per match in the high-intensity zone (>85%HR_{max}). Based on this, training focused on anaerobic exercises and interval training methods is recommended. Anaerobic training ensures that players will be ready to carry out a high intensity performance and to maintain it during the whole match. Maintaining high intensity depends chiefly on the ability to replenish energy systems during the period spent in lower-intensity locomotion. We recommend working on the improvements in anaerobic and aerobic power during practice sessions.

***Key words**: team sports, game performance, monitoring, load intensity*

Introduction

In elite sports, an athlete's technical, tactical, physiological, and psycho-social characteristics play fundamental roles in the development of match performance. In terms of physiology, the game tasks carried out during a match define the physical demands imposed on the athlete. Depending on the sport practised, these demands can be classified either in the aerobic system, or anaerobic system, or in both. In team sports such as soccer and basketball, athletes perform different types of physical movements ranging from standing still to maximal running of varying intensity (Bangsbo, Mohr, Poulsen, Gomez, & Krustrup, 2006).

Training is a critical component in the world of elite sports necessary to enhance match performance. Consequently, the quantification of training becomes a main responsibility of the coach, because it can make the difference between being perfectly ready to compete or not (Barbero-Álvarez, López, Álvarez, Granda, & Castagna, 2008). Current training trends in elite sports are based on replicating specific match performance in a non-competitive context (for example, a training camp). This requires in-depth study of the characteristics of competition to collect the information necessary to design and plan an appropriate and effective training programme (Barbero-Alvarez & Castagna, 2007; Pereira, Kirkendall, & Barros, 2007). Thus, the importance of collecting data on physical effort and athlete´s physiological response during a competition is clear (Drust, Atkinson, & Reilly,

2007). To this end, one of the most studied variables in sport science is the distance covered by athletes during matches. This information can be helpful for both improving a players' fitness during training and evaluating their performance during competition (Barros, et al., 2007). Many authors combine this variable with heart rate (HR) responses and muscular energy sources to provide an insight into the physiological demands of team sports (Coutts, Reaburn, & Abt, 2003; Krustrup, Mohr, & Steenberg, 2006; Rannou, Prioux, Zouhal, Gratas-Delamarche, & Delamarche, 2001). This information may allow coaches to plan effective training programmes and to reduce the rate of fatigue and stress on their athletes' musculoskeletal systems (McKeag, 2003).

Prior studies have monitored the heart rates of players during matches in sports such as rugby (Coutts, Reaburn, & Abt, 2003), Australian football (Veale & Pearce, 2009), women's football (Moro & López, 2005), football (Strøyer, Hansen, & Klausen, 2004), basketball (Vaquera, 2008) and women's handball (Platen & Manchando, 2011). Other studies on association football (Castagna, D'Ottavio, & Abt, 2003; Davis & Brewer, 1993; Hewitt, Withers, & Lyons, 2007; Dawn & Barry, 2007; Barros, et al., 2007), men's handball (Kotzamanidis, Chatzikotoluas, & Giannakos, 1999; Pori, Kovačič, Bon, Dolenec, & Šibila, 2005; Perš, Bon, Kovačič, Šibila, & Dežman, 2002), rugby (Deutsch, Kearney, & Rehrer, 2007; Roberts, Trewartha, Higgitt, El-Abd, & Stokes, 2008), water polo (Lupo, et al., 2009) and field hockey (Spencer, et al. 2004) have examined players' motion on a court or field during a match.

More complex views of players' outer and inner loads have been examined in studies addressing physiological aspects, such as heart rate monitoring and players' motion on a court during a match, in classic football (Barbero-Álvarez, López, Álvarez, Granda, & Castagna, 2008; Castagna, et al., 2003; Di Salvo, et al., 2007; Strøyer, et al., 2004; Tessitore, et al., 2005), seven-a-side football (Capranica, Tessitore, Guidetti, & Figura, 2001), futsal (Barbero-Álvarez, Soto, Barbero, & Granda, 2008; Castagna, D'Ottavio, Granda, & Barbero, 2009), rugby (Deutsch, Maw, Jenkins, & Reaburn, 1998; Cunniffe, Proctor, Baker, & Davies, 2009), women's football (Krustrup, Mohr, Ellingsgaard, & Bangsbo, 2005), beach soccer (Castellano & Casamichana, 2010), basketball (Abdelkrim, El Fazaa, & El Ati, 2007; Matthew & Delextrat, 2009; Rodríguez-Alonso, Fernández-García, Pérez-Landaluce, & Terrados, 2003) and wheelchair basketball (Bloxham, Bell, Bhambhami, & Steadward, 2001). Despite this body of research, we found only one study that focused on handball. This study, Chelly et al. (2011) examined physical and physiological profiles of players (U15) during handball matches. However, the length of the games examined was only 2 periods of 25 minutes each, and the players (n=18) were divided into three teams according to playing position. The teams played two matches in two weeks during which they played with each other with no substitution.

It is important to recognize that significant differences exist between men and women regarding their physiological responses to exercise. With regard to the specific physical demands of team sports, Kirkendall (2007) stated that differences between men and women exist as a result of unequal technique, tactics and physical conditioning. Because of this, sports training must be not only sport-specific but also gender-specific, because women's and men's responses and adaptation to the same training loads can be completely different.

The mentioned suggests that training programmes focused on improving performance in handball players must respect the specific physical and physiological demands and the athletes' response to them. Physical testing and physiology-based analyses would provide valuable data that could be used as a basis for further research and for improving sport- and gender-specific training requirements.

Hence, the main goal of this study was to evaluate physiological responses of female athletes during competitive handball matches by means of time-motion analysis and to compare these responses between the first and the secondhalf of a match. The comparison between the first half and the second half performances was intended to provide us with information about the capacity of players to sustain physical effort and maintain exertion level throughout a match and to identify any significant decrease in performance during the second half-time.

This study focused on two aspects of performance: physiological response to match loads, based on the heart rate values as measured with telemetry, and physical response, measured via the Video Manual Motion Tracker 1.0 software programm. This study represents the first effort to apply these measures to women's competitive handball matches.

Methods

The descriptive portion of the study determined the overall physical activity (distance [m]), type of locomotion (standing, walking, jogging, medium-intensity running, high-intensity running, sprinting) and physiological load: mean HR (HR_{mean}), maximal HR (HR_{max}), and percentage of HR_{max} ($\%HR_{max}$) in female players during six competitive handball matches. The first and the second half periods of each competitive match were compared and analysed from the aforementioned points of view.

All players and their parents were informed about the study and signed consent to participate.

The local ethical committee and the committee on current ethical standards in sports and exercise research of the Palacky University also approved the research.

Participants

Fourteen players from an elite women's handball team from the Czech Republic participated in this study. The players had an average of 10 years of experience in the sport. Goalkeepers were not involved in this study because their position's requirements differed from the roles of other positions in a team. All the players were fully informed about the study protocol and provided written consent to participate. The average age of the players was 17.9±0.3 years, the average height was 169.6±6.9 cm, and the average mass was 65.4±6.9 kg. The players practised five times per week for an hour and a half and played a competition match once a week. During the 2011/2012 season, six competition matches (three home and three away matches) were analysed. The team involved in this study was ranked second in the Czech Republic elite juniors' handball league. One senior and one junior player of the Czech national team were members of the explored team.

Heart rate

The players' heart rates (HR) were monitored during all the six matches in regular five-second intervals using TEAM Polar^{2}Pro sport testers (Polar Electro, Kempele, Finland). Heart rates were monitored during live playing time (i.e. the complete time that the players were on the court so the time a player was resting during the half-time, timeouts and sitting on the substitution bench was not included).

The maximal HR values were measured by means of the Yo-Yo intermittent level 1 (YYIRT1) recovery test (Bangsbo, Iaia, & Krustrup, 2008) and were established for each player individually (Krustrup, et al., 2003). The measurements were performed in a sports hall on a regular handball court. All the players were familiar with this test because they had performed it as a regular part of a conditioning test before and during the season. The values of individual HR_{max} were used as a standard against which three intensity zones were defined (<65%HR_{max}, 65 to 85% $HR_{max,}$ >85%HR_{max}). In case that any HR_{max} value during a match was higher than the rate determined by the beep test (performed prior to the study), the registered HR_{max} value was used for later computations because the registered HR_{max} values of two players were higher (1 to 3 beats·min^{-1}) than the ones measured in the YYIRT1 recovery test; the HR_{max} of the first player was higher by one beat·min^{-1}, and that of the second player was higher by three beats·min^{-1}. The relative times were divided into three zones with different load intensities. These zones were based on the Woolford and Agove (1991) classification and included supramaximal or high-intensity activities (>85%HR_{max}), aerobic zone or medium-intensity activities (65 to 85%HR_{max}) and sub-aerobic or low-intensity activities (>65 %HR_{max}). Based on these classifications, Barbero-Álvarez, Soto, Barbero and Granda (2008) presented a similar study of futsal. We computed the average time covered in each zone for each match as well as the HR_{mean} and HR_{max} values of each player. These were presented as both the absolute and relative values %HR_{max} and the percentage of average heart rate (%HR_{mean}).

Time-motion analysis

Three home and three away matches were analysed. Only three participants did not take any part in play in all the six competition matches. The 12 players who participated and were regularly substituted in each match were analysed. The average time the players spent on the court was 14.5±2.9 min (range=10–20 min) and 14.7±2.8 min (range=11–21 min) in the first and second half, respectively. The players spent an average of 29.25±4.7 min (range=21–39 min) on the court during the matches. The fact that players were substituted regularly resulted in higher HR values.

Each of the six competitive matches were recorded using two digital camcorders (Panasonic SDR-H80 and Canon HF10) placed in a static position approximately six metres from the side line and nine metres above the court; each camera recorded a half of the court. Each match was recorded by the same cameraman. The video recordings were analysed using the authorized Video Manual Motion Tracker 1.0 software (Hulka, Cuberek, & Svoboda, 2013). This technique is based on the inverse projection of the real plane of the court, recorded by a video camera, and then transferred onto the plane of an electronic tablet after importing the video into the software. The calibration processes transfer the real plane of the court onto a computer model of a handball court to ensure that the court lines overlap. An orthogonal coordinate network (with distances of 0.5 m) is then generated over the entire court, and the video recording could begin. Coordinates [*X, Y*] are assigned to each point in the real plane of the court and are then transformed into the plane coordinates on the screen. Using this procedure, a formula for an inverse projection function is determined. The domain of this function is the set of real numbers on the plane of the screen, and the range of the function is the set of real numbers on the real plane of the court (Hulka, et al., 2013). Then, the observer manually copies the movement trajectory of a player using an electronic pen on an electronic tablet during a match. The system saves each point

of the player's movement trajectory, which is defined by a set of values [*X, Y, t*], where *X* and *Y* are the orthogonal coordinate axes in the screen plane and *t* is the time variable (Hulka, et al., 2013). This method enables the recording of the total distance covered as well as the immediate and average locomotion speeds of the players during a match or a training session.

The assessment of one match took 32 hours. Only the players' motion during live playing time, precluding any interference from referee´s timeouts, team timeouts and the 10-minute half-time, was analysed. The players' motions were not analysed when they were sitting on the substitution bench.

An assistant, who operated the software program and consequently evaluated the six competition matches, was trained before the study began. To achieve relevant results, the data were transformed, synchronized and revised.

Data reconstruction was necessary because the recorded coordinates were distorted by the camera angle. Data synchronization allowed us to adjust the recorded data and minimize possible errors caused by imprecise digitalization. The errors may be levelled using digital filters. The cameraman's accuracy and reliability with this data reconstruction method was addressed in the protocol; the same cameraman assisted with all digital phases. Before the data were gathered, the cameraman received a detailed training in processing the data using the Video Manual Motion Tracker 1.0 software. During this training, he also had to analyse ten hours of recordings of handball players' gross-movements. To guarantee reliability, the cameraman had to record five minutes of different motions at different speeds (walking, jogging and running) ten times. The computing module, which was specifically devised and developed to calculate kinematic data, enabled the generation of results using numerical or graphical parameters.

All the six monitored competition matches were played on high-quality indoor courts with either parquet or polyurethane (synthetic rubber) floors. The temperature in the sporting hall was 21 to 23°C during the matches. Every match consisted of two 30-minute periods with a 10-minute half-time. Full-time scores of the matches were: 23:22, 37:23, 22:23, 29:23, 42:28, and 34:21. The monitored team varied between playing two defensive systems (0:6 and 1:5) and preferred the attack system with one pivot.

Based on the recommendations of other authors (Hernandez, 2001; Van Gool, Van Gerven, & Boutmans, 1988), we categorized the players' gross-movements into standing, walking, jogging, medium-intensity running, high-intensity running and maximal speed running (sprinting). We merged standing and walking into a single category – walking – because of the minimal and marginal average of the distances covered (2.2 m) during the matches. Castellano and Casamichana (2010) made a similar decision in their study. As in our study, Barbero-Alvarez, Soto et al. (2008) and Gabett and Mulvey (2008) categorized the activity intensity as high intensity (medium-intensity running, high-intensity running) and maximal speed running (sprinting) and low intensity (standing, walking and jogging).

Statistical analyses

The Statistica 10cz software package (StatSoft Inc., Tulsa, OK, USA) was used to compute all statistical characteristics. The data are presented as the mean and standard deviation(s). The average distance covered and HR values measured during the matches were compared. To compare data on HR, covered distance and speed, one-way ANOVA with repeated-measures was used. The threshold for statistical significance was set at $p<.05$.

Results

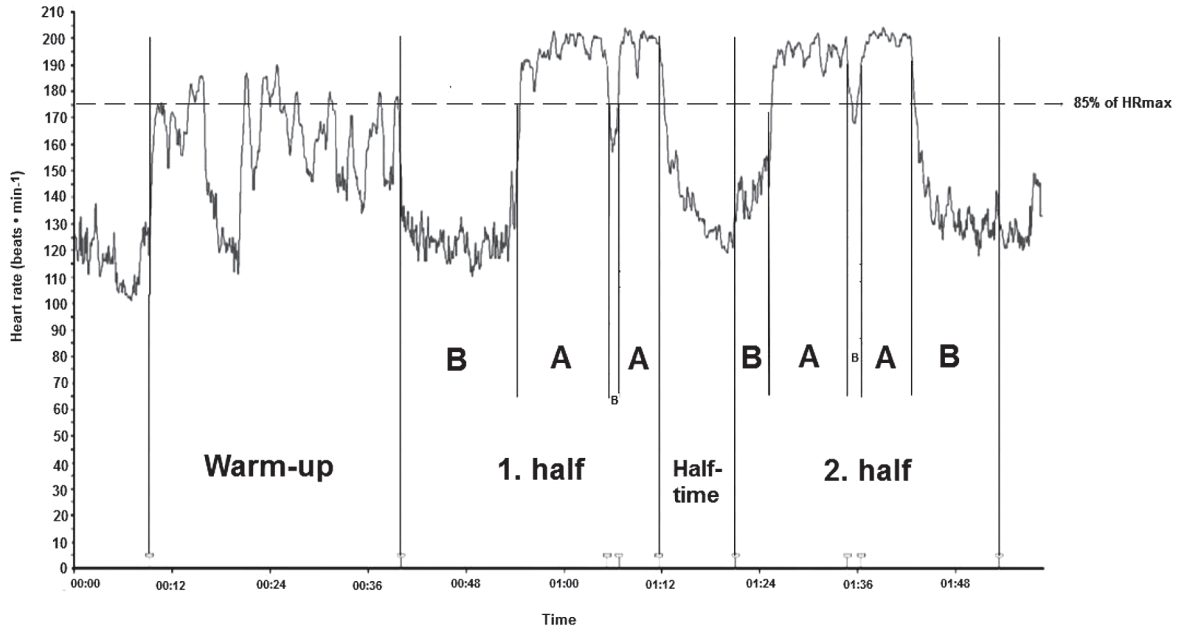
Heart rate

The players' average HR during the monitored competitive matches was 183.7±7.3 beats·min^{-1}. The mean intensity during the matches represents 89.6% of the maximal heart rate (%HR_{max}). In the competitive matches, the players spent 83±3.6% (50 minutes out of the standard match duration) above the anaerobic threshold. Figure 1 shows an example of a player's HR during a competitive match.

In the first half of the match, the mean heart rate was 184.8±7.4 beats·min^{-1}, corresponding to 90.2±3.6%HR_{max}. In the second half, the mean heart rate was lower, at the level of 182.5±7.2 beats·min^{-1}, which corresponded to 89.1±3.5%HR_{max}. We did not find significant differences ($F=2.15$; $p=.15$) between the average heart rates in the first and second half. During a match, the players spent 83% of the play time above 85% HR_{max}, 15% of the play time was spent in the moderate load intensity zone (65 to 85% HR_{max}), and only 2% in the low load intensity zone (<65%HR_{max}) (Figure 2). There was no statistically significant difference between each half and among the zones.

Distances covered

On average, the distance covered during the matches was 3399.2±362.3 m. The average distance the players covered per minute was 113.3±9.7 m·min^{-1} based on the time-motion analysis. The average distance the players covered during the matches while walking was 385.8±371.6 m. The average distance covered while jogging was 935.8±165.5 m; during medium-intensity and high-intensity running the average distances were 824.9±165 m and 556.3±115.7 m, respectively. The average distance the players covered while sprinting was 696.04±177.8 m.



Note. A = player in play; B = player on the substitution bench; HR_{max} = maximal heart rate.

Figure 1. Heart rate responses during one of the games for a player who played the competition match.

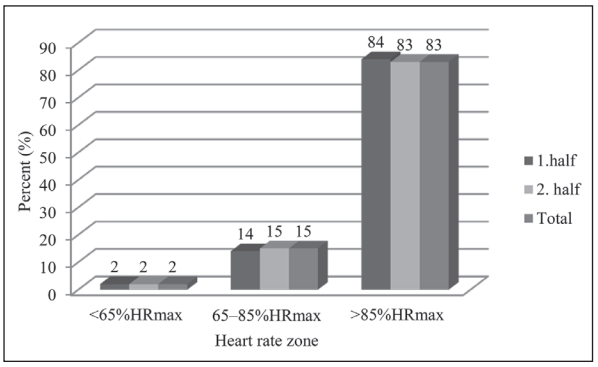


Figure 2. Percentages of time spent in low activity (<65 % HR_{max}), moderate activity (65 to 85 % HR_{max}) and high activity (>85 % HR_{max}) during the competitive matches.

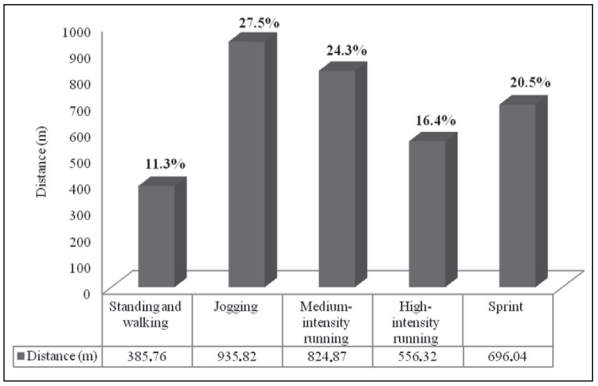


Figure 3. Percentages, standard deviations and mean distances covered during the different motion categories established in this study.

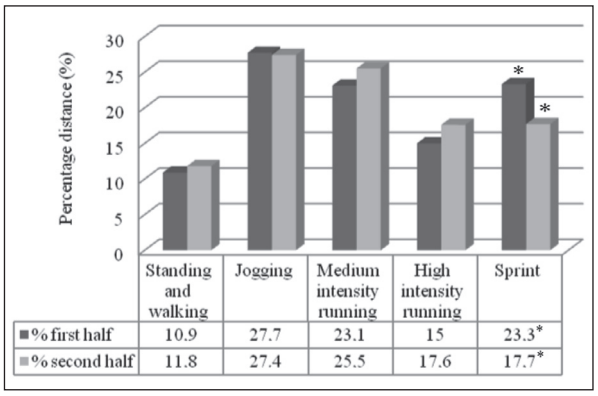


Figure 4. Percentage of distance covered in the categories in the first and second halves.

Figure 3 shows that the observed handball players covered 11.3±12.8% of the average distance while walking and 27.5±4.2% while jogging. Medium-intensity running accounted for 24.3±3.1% of the total distance covered. High-intensity running and sprinting accounted for 16.4±2.4% and 20.5±4.3% of the average distance, respectively. We found statistically significant differences between the first and second half with regard to sprinting (F=5.44; p=0.02) (Figure 4). Other categories were not significantly different.

Discussion and conclusions

The aim of this study was to determine the physical and physiological responses of female handball players during six competitive matches in the elite junior (U18) league in the Czech Republic. The players' average HR during the monitored competitive matches was 183.7±7.3 beats·min^{-1}, corresponding to 89.6±3.6%HR_{max}. The players spent 83±3.6% of playing time above 85%HR_{max}. The average distance players covered during the matches was 3399.2±362.3 m.

Only one published study (Chelly, et al., 2011) has examined the physical and physiological profile of players during handball matches. However, the participants in that study were U15 boys, and the warm-up matches (tournaments) lasted only 2 x 25 minutes.

Because the conditions of our study differ from those of the research performed by Chelly et al. (2011), it may be more reasonable to compare our results with the studies on other team sports (basketball, futsal and beach soccer), because they have similar characteristics in terms of players' profiles, field, number of players and rules.

Considering the load intensity from a physiological point of view, our HR results were higher (183.7±7.3 beats·min^{-1}; corresponding to 89.6±3.6% of HR_{max}) compared to similar studies, such as Platen and Manchando (2011). Platen and Manchando (2011) found a slightly lower average HR of 161.7±11.9 beats·min^{-1}. However, when they measured older players, the HR_{mean} was higher (185.8±3.2 beats·min^{-1}). The study by Platen and Manchando (2011) analysed only one match – a friendly one. We attribute various results of different studies to the age- and gender-differences of the participants and the regular substitution of players during matches; differences in older studies (prior to 2004) may be attributable to recent handball rule changes that have greatly increased the dynamism of the game (Platen & Manchando, 2011). The HR_{mean} was slightly higher in the first half (184.8±7.4 beats·min^{-1}) in comparison with the second half (182.5±7.2 beats·min^{-1}), but this difference was not significant. We attribute the decrease in the HR values to the regular substitution of players during the entire match. The higher heart rate in female handball is most likely a result of the high load on the anaerobic metabolism. Regarding the comparison between the first and the second half, the HR decreased, although not significantly. Nonetheless, it is possible that this drop depended on the significant reduction in the number of sprints in the second half. In any case, we urge caution in interpreting this result, because HR can be affected by several factors not considered in this study. These include nutrition; hyperthermia; dehydration; many psychological factors, such as anxiety and motivation; performance; and regular substitutions. Conflicting results have been reported in the literature, showing either a significant decrease or no change in HR between the first and the second half of games in various team sports (Bangsbo & Lindquist, 1992; Coutts, et al., 2003). No significant decrease of HR in the total high-intensity activity was found in the second half (>85% HR_{max}). Although it was lower in the studies mentioned below, the HR_{mean} corresponded to the mean intensity. We attribute this fact to the age of participants and to the unlimited substitutions during the matches. Comparison of results from other studies for basketball (170±8 beats·min^{-1}; corresponding to 92.5% of HR_{max} (Matthew & Delextrat, 2009); 171±4 beats·min^{-1}; corresponding to 91±2% of HR_{max} (Abdelkrim, et al., 2007); 186±6 beats·min^{-1}; corresponding to 94.6% of HR_{max} and 175±13 beats·min^{-1}; corresponding to 90.8% of HR_{max} (Rodríguez-Alonso, et al., 2003), futsal (174±7 beats·min^{-1}; corresponding to 90±2% of HR_{max} (Barbero-Álvarez, Soto et al., 2008; Castagna, et al., 2009)), water polo (158±11 beats·min^{-1}; corresponding 70% of HR_{max} (Lupo, et al., 2009) and beach soccer (165.2±20 beats·min^{-1}; corresponding to 86.5% of HR_{max} (Castellano & Casamichana, 2010), where substitutions are unlimited. Considering the physical analysis, it should be noted that the average distance the players in our study covered during the matches was 3399±362.3 m. In comparison with the results of similar studies in men's handball (4464 to 5088 m per match (Perš, et al. 2002), 4700-5600 m per match (Šibila, Vuleta, & Pori, 2004), the values we found were similar to the reported ones. The difference in results may be caused by the fact that in our study the players were substituted regularly, therefore the average distance covered was lower. We attribute the differences mainly to rule changes, age and gender, the playing system of the participants, the number of substitutions and the length and nature of the matches.

Regarding the distance covered, many variables may have influenced the results. These variables include changes in the intensity of activity (low to high), as well as motivation and other factors. High-intensity activities were related to fast breaks and defensive tasks. The following facts may, in our opinion, have influenced our results. The game of the monitored team was based on fast transition into attack (the first and second wave fast-break and fast throw-off after a conceded goal). Quickly putting the ball into play almost always followed a conceded goal. Almost every gain of the ball in defence was followed by a fast attack of all players coupled with maximal player acceleration, mainly of the wings and backs. The team was trained to get into the basic defence system position as fast as possible after any loss of the ball. These were the main factors which differentiated the monitored players from other teams in the competition,

and that is why this specific play style was one of the most effective and the most successful in this particular elite junior competition. The team had 79 attacks in a match on average, out of which 29 fast-breakwere finished: finished by shooting – a goal scored, ball caught by the goalkeeper, the goalpost hit, shot into a defensive block, shot missing the goal, and 13 fast-break unfinished: interrupted by a foul (free throw awarded, 7-m throw awarded, two minutes exclusion of the opponent won), technical error or game interruption tactics were counted on average. The players covered the field with maximal speed mainly in the fast attacking play and in returning to defence, and they covered the largest distances with sprints. The results were highly influenced by the balls gained in defence (14 in one match on average), which was played very effectively and aggressively. According to the official statistics for the Female Junior Championships (U19) in 2012, the obtained average values per match were higher than with those of the best teams of that championship with regard to the following parameters: 11 attacks more, nine fast-breaks-finished more and eight gains of balls in defence more. We suggest our higher results are influenced by the opponents' quality, tactics, game style and performance. At least 4-5 players were always involved in the transition to fast break with respect to game situations. Regular substitution of the players during the matches helped maintain this high intensity of running. The players were prepared for such a fast game with alternating intensity in training in which exercises of interval character and small-sided games often occurred. The players accomplished high level fitness results in the tests that examined their sports preparedness before the beginning of the season. That is why we concluded that the players were well prepared for a high intensity play in competition.

Another factor that influenced maximal performance of the observed players was their motivation: they wanted to be the best team in the competition and win gold medals.

One reason why high-intensity activities did not decrease significantly in the second halves in our study may be due to the increase in medium and high-intensity running even though the number of sprints decreased. According to Chelly et al. (2011), the decrease in sprinting could depend on muscular fatigue, and a reduction in glycogen reserves in the leg muscles (Saltin, 1973), although other factors such as dehydration and physiological changes within the muscle cell could be implicated (Bangsbo, 1994; Saltin, 1973).

According to Barbero-Álvarez, Soto et al. (2008), in sports that allow an unlimited number of substitutions, the distance covered per minute is determined using a scale of a generic load intensity that can provide a complex index of load intensity in a match. In our case, the load intensity index was 113.3±9.7 $m \cdot min^{-1}$. The data obtained on the distances covered is comparable with that found in studies of other sports (futsal, basketball): 117.3 $m \cdot min^{-1}$ (Barbero-Álvarez, et al., 2008); 121 $m \cdot min^{-1}$ (Castagna, et al., 2009); 118 $m \cdot min^{-1}$ (Barbero-Álvarez & Castagna, 2007); 108 $m \cdot min^{-1}$ (Molina, 1992); 113 $m \cdot min^{-1}$ (Oliveira, 1999); 117.3 $m \cdot min^{-1}$ (Matthew & Delextrat, 2009); and 113 $m \cdot min^{-1}$ (Abdelkrim, et al., 2007). In a study by Pori et al. (2005) that focused on handball, the measured distance was 87.6 $m \cdot min^{-1}$; however, the examined matches were non-competitive, their duration was only 2 x 20 minutes and the data were collected before the official rules were changed to increase the game's intensity.

We see the limits of this study particularly in the small number of monitored matches and also in the impossibility of taking blood lactate samples, which was not approved by the players' parents. It would be helpful to assess this specific marker in future studies. With a higher number of competitive matches, it would also be beneficial to compare individual playing positions in terms of their game specifications.

Combined physiological and kinematic analysis of female handball players during competition using the modern rules has never been carried out prior to this study.

As our study shows, handball is a game of intermittent high intensity with a physiological profile demonstrating that more than 83% of the playing time of each match players spend in load-intensity above 85% $HR_{max,}$ and players' $\%HR_{mean}$ is 89.6±3.6% of HR_{max}. Consequently, team handball requires a high amount of anaerobic energy. The distance covered per minute is approximately 113 metres. In the training process, it would be beneficial to use specific exercises of an anaerobic character and interval training methods. The players' physical condition should be adapted to a high intensity load, which is necessary to maintain the same intensity throughout the first and second halves of a match. Based on the results of this study, we confirm that handball is a multiple-sprint sport characterised by high-intensity tasks. Consequently, training must be conducted as a high-intensity work-out and take into account repetitive specific exercises focusing on acceleration, deceleration, and changes of direction. The overall aim of high-intensity training is to increase work rate during competition and to minimize a decrease in technical performance as well as lapses in concentration induced by fatigue. The specific aim of high-intensity training in team sports is to improve the players' ability to recover after a period of high-intensity exercise. As a result, athletes should be able to recover after high-intensity actions more quickly and consequently be fit to perform at this intensity level throughout the whole match (Bangsbo, et al., 2006).

Due to a relatively small number of competitive matches, we decided not to focus on specific tactical or playing positions. In the future, we recommend taking this aspect into account, because it has been shown that physical demands of each playing position can vary to a comprehensive extent (Di Salvo, et al., 2007). A study focusing closely on each playing position would certainly help us to improve the sports training process in terms of its specificity. Only then may the knowledge gained about physical and physiological sport demands be successfully applied.

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NOTACIJSKA ANALIZA I FREKVENCIJA SRCA VRHUNSKIH RUKOMETAŠICA (U19) ZABILJEŽENA TIJEKOM NATJECATELJSKIH UTAKMICA

U ovom istraživanju provedena je notacijska analiza te je zabilježena frekvencija srca vrhunskih rukometašica (U19) tijekom šest natjecateljskih utakmica. Prosječna dob ispitanica bila je 17,9±0,3 godina, tjelesna masa 65,4±6,9 kg, a prosječna tjelesna visina 169,6±6,9 cm. Notacijska analiza igračica provedena je pomoću *Video Manual Motion Tracker 1.0 software*. Opisana je ukupna tjelesna aktivnost tijekom utakmica (prijeđena udaljenost [m]) kao i kategorija kretanja (stajanje, hodanje, kaskanje, umjereno trčanje, visokointenzivno trčanje, sprint). Frekvencija srca praćena je sustavom TEAM Polar^{2}Pro (Polar Electro, Kempele, Finska). Maksimalna frekvencija srca utvrđena je pomoću jo-jo testa (*Yo Yo Intermittent Recovery Test)*. Jednostruka analiza varijance za ponovljena mjerenja je korištena za uspoređivanje rezultata frekvencije srca, prijeđene udaljenosti i brzine kretanja. Na temelju rezultata notacijske analize, saznali smo da je prosječna prijeđena udaljenost iznosila 113,3±8,6 metara u minuti tijekom jedne utakmice. Prosječna prijeđena udaljenost tijekom utakmice iznosila je 3399±362,3 metra. Najmanja udaljenost (385,8±371,6 m) prijeđena je u kategorijom stajanje i hodanje, dok je najveća udaljenost (935,8±165,5) prijeđena u kategorijom kaskanje (jogging). Prosječna frekvencija srca iznosila je 183,7±7,3 o/min. Prosječni intenzitet tijekom utakmica bio je 89,6±3,6% od maksimalne frekvencije srca. Rezultati ovog istraživanja pokazuju da je rukomet visokointenzivan diskontinuiran sport. Fiziološki profil igračica tijekom utakmica pokazuje da su igračice provele više od 83% vremena igre u zoni visokog intenziteta (frekvencija srca veća od 85% od maksimalne). Na temelju navedenoga, rukometašicama se preporuča trening usmjeren na anaerobne vježbe koje se provode intervalnom metodom treninga. Anaerobni trening će osigurati kvalitetnu pripremu za uspješnu izvedbu visokointenzivnih aktivnosti tijekom igre, kao i za zadržavanje visoke razine intenziteta igre tijekom cijele utakmice. Zadržavanje visokog intenziteta igre tijekom utakmice najviše ovisi o sposobnosti obnavljanja energetskih izvora tijekom perioda niskointenzivnih aktivnosti. Autori stoga preporučuju rad na unapređenju i anaerobne i aerobne snage tijekom treninga.

Ključne riječi: *ekipni sportovi, igračka izvedba, praćenje, intenzitet opterećenja*