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ORIGINAL ARTICLE

Ultra-short-term heart rate recovery after maximal exercise in elite European table tennis players

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Abstract

Purpose The purpose of this study was to examine heart rate (HR) responses during 10-s intervals over the first minute of recovery (i.e., ultra-short-term recovery) after table tennis-specific maximal exercise in elite and sub-elite players.

Methods Twenty-five elite (22.8 ± 6.1 years) and 18 sub-elite (20.1 ± 2.2 years) table tennis players completed a specific table tennis test performing forehand offensive strokes against balls launched from a table tennis robot by an experienced coach at a rate of approximately 60 balls/min until exhaustion. Immediately upon exercise cessation, the participants were placed in a lying position for 60 s of HR recording.

Results In general, both absolute heart rate and heart rate expressed as a percentage of the peak exercise heart rate were possibly to likely lower (50–92% likelihood of being different; magnitude-based inference), suggesting faster heart rate recovery, in elite players than in sub-elite players.

Conclusion Therefore, we conclude that elite players have faster HR recovery than sub-elite players and that ultra-short-term recovery can be used to monitor training routines.

Keywords Training · Recovery · Intermittent · Endurance · Autonomic nervous system

Abbreviations

HR	Heart rate
ANS	Autonomic nervous system
HRV	Heart rate variability
HRR	Heart rate recovery
USTHRR	Ultra-short-term heart rate recovery

Introduction

Heart rate (HR) is one of the most widely used physiological measurements for monitoring exercise workloads during exercise [1]. There are currently many inexpensive commercial devices that can provide precise and accurate HR measurements in a noninvasive, time efficient manner. These devices make it easy to monitor the status of the autonomic nervous system (ANS) via HR measures including level and variability of HR at rest, during exercise and during post-exercise recovery [1]. Like a possibility of HR measures to monitor the ANS status is the heart rate variability, which represents one of the most promising physiological markers for monitoring the status of training and recovery in sports [2–7], as well as the use of heart rate recovery after exercise (HRR).

The mechanisms contributing to changes in HR at rest, following as well as during exercise and recovery have been of interest to researchers [1]. In this way, the HRR that is assumed the rate at which the HR decreases after exercise and easy to measure and to analyze, it is dependent on the relationship between the activities of the parasympathetic and sympathetic nervous systems [8]. In general, HRR is measured in the first minute after exercise and its highly correlated with vagal reactivation [9], especially during the first 30 s of recovery, which is referred to as ultra-short-term HRR (USTHRR) [10]. In addition, the USTHRR has been shown to be associated with aerobic capacity [11], supporting the use of USTHRR to monitor physiological adaptations that occur during a training routine [12].

Table tennis is an intermittent racket sport that includes very short rallies (i.e., ~ 3.0-s) interspersed with short

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breaks (i.e., ~8-s) [13–16]. Success in table tennis requires the capability to perform high-intensity and repeated efforts and rapidly recover between rallies and matches [16–19]. Having faster dynamics of HRR is important in table tennis, where the players perform several maximal exertions in competition with a brief interval between activities to recover. Like the recovery is one of the most important stages of both training and matches in intermittent sports, the HR can be used as an indicator of recovery during this process [1] and to improve the gains in physical conditioning [20] and consequently table tennis performance. On the other hand, the lack of or inappropriate amounts of recovery can reduce the benefit that athletes achieve from their training exercises and consequently impairs performance in competitive matches [4]. Appropriate recovery decreases fatigue, accelerates the rate of physiological and psychological adaptations, promotes muscle regeneration and improves fitness levels [4]. Phosphocreatine is the energetic substrate of the primary bioenergetic pathway used during table tennis [15] and assuming that aerobic capacity is significantly associated with phosphocreatine replenishment, it is plausible that monitoring USTHRR could be useful to table tennis training routines [15].

Scientific knowledge of table tennis is lacking with regards to the physiological responses that occur during table tennis matches and training [21]. HR changes were explored during official senior competitive matches and found that average HR ranged from 162 to 172 beats/min, corresponding to 81.2% of the predicted maximum HR of the players [14, 22]. Additionally, during table tennis training, the approximate HR values were between 126 and 142 and 152–156 beats/min, depending on the type of training [22]. Junior players had an average HR of 126 ± 22 bpm during matches and 135 ± 18 bpm during training sessions [23].

However, there are no data describing the time course of HRR over 10–60 s or within the first 30–60 s of recovery immediately following exercise cessation in table tennis.

Previous research on USTHRR suggests that athletes who engage in intermittent endurance sports are likely to have faster HRR 10–20 s after maximal exercise than athletes who participate in continuous endurance sports [24]. Furthermore, research has shown that aerobic power along with autonomic modulation may play a role in ultra-short-term cardiovascular responses [11]. Buchheit et al. [25, 26] showed that short-term HRR during the first minute of recovery is lower after high-intensity and intermittent exercise sessions that it was after continuous exercise sessions. The study also reported that parasympathetic function and HRR during the first 30 s of recovery could be improved by a 9-week high-intensity interval training program [27]. Post-exercise USTHRR could be a marker of training status in intermittent-based endurance athletes [28, 29].

This information suggests that assessing USTHRR responses to maximal exercise tasks could be of particular interest for monitoring recovery in table tennis, since it is an intermittent sport requiring high-intensity activities but allowing for an average recovery time between points of only 8–20 s during competitive matches [14, 30, 31]. These data would be valuable for monitoring and creating training programs for table tennis.

Therefore, the aim of this study was to compare the USTHRR after a table tennis-specific maximal exercise task between elite and sub-elite players. We hypothesized that elite table tennis players would exhibit faster HRR during the initial phase (< 30 s) after the exercise task than sub-elite players, mainly based on athletes with higher performance have greater aerobic endurance capacity than sub-elite players.

Materials and methods

Study subjects

Initially, fifty healthy professional male table tennis players were recruited from eleven European countries (Germany, France, Slovenia, Portugal, Russia, Spain, Hungary, Belorussia, Poland, Croatia and Serbia) during the spring half-season of 2017. All participants were asked to complete a pre-competition medical examination with exercise-stress testing at the exercise physiology laboratory. Athletes who had been participating in consistent training and competitions for the past 2 years without breaks in training for more than 7–10 days because of injury or any other reason, and performed regularly 10–12 training sessions per week for a duration of 90–120 min per session. In addition, all subjects performed their training players older than 18 years of age were eligible to participate in the study. The exclusion criteria were [1] a history of heart disease [2], musculoskeletal dysfunction, [3] known metabolic disease [4], use of any performance-enhancing substance within the past 14 days [5], smoking, or [6] an impaired response to the stress test.

Players were classified into two performance level groups based on their championship results and position in the European Table Tennis Union Ranking. Specifically, they were classified as either elite [winning medals at the World, European Senior or U21 competitions [ingles, doubles, or team, in the top 20 of the ETTU rankings (senior, U21)] or sub-elite [playing for a national team or professional club that was ranked below 20th position in the European Table Tennis Union ranking (senior, U21)]. All participants were fully informed verbally and in writing about the nature and demands of the study as well as the known health risks. They completed a health history questionnaire and were informed that they could withdraw from the study at any

time, even after giving their written consent. The procedure had been previously approved by the Ethics Committee on Human Research of the Faculty of Sport and Tourism, Novi Sad (EN-01/2018) and the study was conducted in accordance with the Declaration of Helsinki. All but seven of the initial subjects met the criteria and completed the testing (7 players did not complete the tests: 3 were younger than 18 years of age, and 4 did not complete test). The final compositions of the groups were 25 players in the elite group and 18 players in the sub-elite group. The subjects had a mean age of 21.7 ± 5.0 years, a mean body mass of 74.3 ± 8.4 kg, a mean height of 180.9 ± 0.6 cm, a body mass index (BMI) of 22.7 ± 1.8, a body fat percentage of 14.0 ± 4.1% and a mean maximal oxygen uptake (VO_{2max}; all data were reported by the team coach in evaluation performed at least 3 weeks before the experiment using mainly by 20 m- shuttle run test and treadmill incremental tests) of 55.1 ± 4.7 mL/kg/min. Group characteristics are shown in Table 1 and only VO_{2max} differed between groups.

Experimental procedures

Physiological measurements were performed during the preparatory training phase for competition. Twenty-four hours prior to the experiment, participants were asked not to participate in any prolonged exercise and to refrain from consuming alcohol and/or caffeinated beverages. They reported to the training hall at 10:00 a.m. after resting for between 10:00 and 12:00 h. Prior to the experimental session, body height, body mass and body fat percentage were measured using the bioelectrical impedance analysis method (TANITA BC-601 Body Composition Monitor, Tanita, Tokyo, Japan). The testing procedure was similar to an exercise that players were performing in their training seasons. Thus, there was no need to familiarize the subjects with the testing procedure. Basic measurements were made in the training hall, where air temperature ranged from 22 to 25 °C. Measurements were taken between 11.00 a.m. and 1:00 p.m.

Table 1 Physical and physiological characteristics of the subjects

	Elite players ($n=25$)	Sub-elite players ($n=18$)	p value
Age (years)	22.8 ± 6.1	20.1 ± 2.2	0.068
Height (cm)	182.4 ± 0.1	178.8 ± 0.1	0.056
Body mass (kg)	75.6 ± 9.1	72.5 ± 7.2	0.247
BMI (kg/m^2)	22.7 ± 1.9	22.7 ± 1.6	0.889
Body fat (%)	13.2 ± 4.3	15.0 ± 3.8	0.164
VO_{2max} (mL/kg/min)	57.2 ± 3.9	52.1 ± 4.0*	0.001

Values are means ± SD. p value: statistical significance of a corresponding t test

*$p < 0.05$ compared with Elite players

To ensure that the testing environment was appropriately controlled, training was kept as quiet as possible during all recovery measurements.

Subjects completed two testing sessions in 1 week, performing maximal table tennis-specific tests with 24 h between tests. Prior to each test, a 5-min moderate intensity warm-up exercise was performed with tests starting 5 min after the end of the warm-up period. Thereafter, the subjects were immediately positioned in lying position for telemetric heart rate (HR) assessment and beat-by-beat HR was recorded using a V800 Polar heart rate monitor with a Polar H10 chest strap (Polar Electro Oy, Kempele, Finland). Validity of the Polar V800 in measuring beat-by-beat HR has been confirmed by Giles et al. [32]. Data were saved as RR interval data files, with intervals in milliseconds (ms). Polar HRM raw unfiltered RR data were exported from the Polar Flow web service as a space-delimited .txt file and analyzed with Kubios HRV analysis software.

Each participant performed maximal exercise tests requiring forehand offensive strokes against balls shot from a table tennis robot by an experienced coach. The ball-throwing frequency was moderate (approximately 60 balls/min) and was kept constant throughout the test (adapted from Zagatto et al. [15]).

Balls were alternately shot to 3 points on the table 30–40 cm on the forehand side (F) (from the center line), the table center line (M), the backhand side (B) and again on the forehand side, so that the ball made contact with the table 50–60 cm from the net, simulating an opponent's shot (Fig. 1), with effort performed until the voluntary exhaustion [15]. The voluntary exhaustion was defined as the moment in which the subject decided to interrupt the test in spite of strong verbal encouragement. In all of the exercises, participants were instructed when they felt that they had reached their maximal effort.

Immediately after exercise cessation (i.e., exhaustion), the participants were placed in a supine position for 60 s for

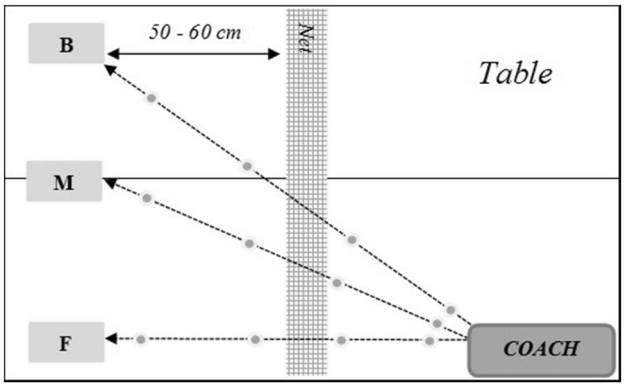

Fig. 1 Illustration scheme of table tennis and the contact areas for the balls in the specific tests

the HR assessment. The time between exercise cessation and the recovery HR measurements was kept as short as possible. The time between exercise cessation and assuming the supine body position was similar in both groups of subjects (4.0 ± 1.3 s and 4.2 ± 1.3 s for the elite and sub-elite groups, respectively; $p > 0.05$).

HR during the first minute of recovery was measured at 10 s intervals using an HR monitor. The mean of the two readings with a coefficient of variation below 15% was used in the study. HR decreases during the recovery phase were also quantified as the percent decrease in HR during the first minute of recovery from the peak exercise HR (100%).

Statistics

The data were expressed as the means ± standard deviation (SD). Initially, the Shapiro–Wilk test was performed to confirm the normality of the data. A Student's *t* test for independent samples was used to compare the heat rate values between groups (elite and sub-elite players). One-way analysis of variance (ANOVA) with repeated measures was used to test the responses over time. The Mauchly's sphericity test was applied and corrected by Greenhouse-Geisser when the sphericity was violated. The Tukey's *post hoc* was applied when significant differences were demonstrated by the ANOVA analyses. For all cases, the significance level was determined as 5% ($p < 0.05$).

Raw differences in means (with 95% confidence intervals) between the groups were also calculated. Additionally, standardized differences between the groups were calculated using Cohen's *d* coefficient, with its respective 90% confidence interval (90% CI). The magnitudes of Cohen's *d* coefficient (effect size: ES) were qualitatively interpreted using the following thresholds: < 0.2, trivial; 0.2–0.6, small; 0.6–1.2, moderate; 1.2-2.0, large; 2.0–4.0, very large; and > 4.0, extremely large. The quantitative likelihood of finding differences in the selected variables was inferred qualitatively as follows: <1%, almost certainly not; 1–5%, very unlikely; 5–25%, unlikely; 25–75%, possibly; 75–95%, likely; 95–99%, very likely; and > 99%, almost certainly. If the likelihood had a range of > 5% in both the positive and negative directions, the true difference was rated as unclear [33]. The data were analyzed using SPSS version 21.0 (SPSS Inc., Chicago, IL, USA).

Results

The time to exhaustion in the table tennis-specific test was 93.2 ± 19.1 s. No significant differences were found between the groups in with 10-s intervals stages of analyzed HR (Table 2); however, magnitude-based inference produced lower HRR in the elite group for all almost recovery times, with inferences varying from possibly to likely negative (70–83% of chance of lower response to elite players; i.e., negative inference) and with a small ES ranging from − 0.36 to − 0.49. The inferences for peak HR and HRR at 30-s were unclear (ES = − 0.29 and − 0.32, respectively) (Fig. 2a). Similar results were found when %HR dropouts were compared between the groups, with lower %HR at 10-s (likely negative; 92% of chance of lower response), at 50-s (possibly negative; 72% of chance of lower response) and at 60-s (likely negative; 80% of chance of lower response) (Table 3; Fig. 2b).

Discussion

The main purpose of study was to examine compare the HR responses over 10-s intervals during the first minute of recovery after a table tennis-specific maximal exercise task in elite and sub-elite players. The main findings of the study were that elite table tennis players had faster HR recovery times than sub-elite players as demonstrated by magnitude-based inferences, which occurred essentially throughout the recovery period, indicating the ultra-short-term heart rate recovery in elite players. In general, the elite players have lower HR responses than sub-elite

Table 2 Heart rate (HR) responses during the study (means ± SD)

	Elite players ($n = 25$)	Sub-elite players ($n = 18$)	Difference in means between groups (95% CI)	*p* value
Peak HR (beats min^{-1})	182.7 ± 7.3	185.3 ± 9.8	− 2.6 (− 8.2 to 3.0)	0.348
HRR at 10 s (beats min^{-1})	169.7 ± 6.8	174.3 ± 11.0	− 4.6 (− 10.6 to 1.4)	0.127
HRR at 20 s (beats min^{-1})	158.7 ± 7.0	162.8 ± 12.2	− 4.2 (− 10.7 to 2.4)	0.206
HRR at 30 s (beats min^{-1})	149.2 ± 8.2	152.9 ± 13.5	− 3.7 (− 11.1 to 3.6)	0.307
HRR at 40 s (beats min^{-1})	139.0 ± 12.6	144.4 ± 16.4	− 5.4 (− 14.8 to 4.0)	0.250
HRR at 50 s (beats min^{-1})	130.0 ± 19.5	137.7 ± 16.5	− 7.6 (− 18.8 to 3.5)	0.174
HRR at 60 s (beats min^{-1})	121.7 ± 17.6	130.1 ± 16.3	− 8.4 (− 18.9 to 2.1)	0.115

95% CI 95 percent confidence intervals

p value statistical significance of a corresponding *t* test

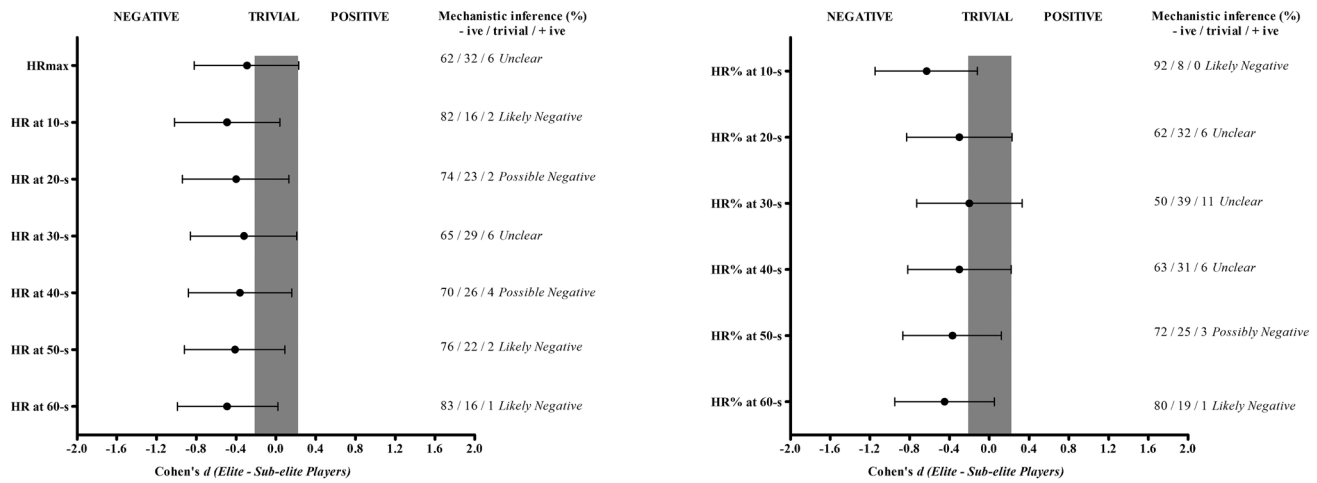

Fig. 2 Mean effect size and 90% CI for HRR (**a**) and %HR (**b**) in sub-elite and elite players and the magnitude-based inferences

Table 3 Heart rate [expressed as the percentage of the peak exercise heart rate ($\%HR_{peak}$)], in elite and sub-elite players recorded after maximal effort (means ± SD)

	Elite players ($n=25$)	Sub-elite players ($n=18$)	Difference in means between groups (95% CI)	p value
$\%HR_{peak}$ at 10 s	92.9 ± 1.8	94.1 ± 1.9*	− 1.2 (− 2.3 to − 0.02)	0.046
$\%HR_{peak}$ at 20 s	86.9 ± 2.4	87.8 ± 3.8	− 1.0 (− 3.1 to 1.1)	0.345
$\%HR_{peak}$ at 30 s	81.7 ± 3.0	82.5 ± 4.8	− 0.8 (− 3.5 to 1.8)	0.533
$\%HR_{peak}$ at 40 s	76.0 ± 5.3	77.8 ± 6.4	− 1.8 (− 5.5 to 1.9)	0.335
$\%HR_{peak}$ at 50 s	71.0 ± 9.6	74.1 ± 6.5	− 3.1 (− 8.1 to 1.9)	0.212
$\%HR_{peak}$ at 60 s	66.5 ± 8.9	70.1 ± 6.7	− 3.6 (− 8.4 to 1.2)	0.139

95% CI 95 percent confidence interval, p value statistical significance of a corresponding t test

*$p < 0.05$ compared with Elite players

players ranging to − 2.6 beat at HR_{peak} lower, and this behavior seems increase over time until 60-s with a change between groups corresponding to − 8.4 beats, reinforcing the faster HR recovery in elite athletes.

Despite the fact that table tennis athletes receive a greater contribution from the phosphagen energy pathway during high-effort periods, oxidative metabolism makes a greater contribution over the course of the entire match [15]. Additionally, due to the moderate energetic demand during table tennis matches and training [22], it is expected that important adaptations in oxidative metabolism arise with training and with increasing performance. Therefore, this greater aerobic fitness level in elite players results in faster HR recovery, as verified in the current study. In addition, the aerobic fitness (i.e., VO_{2max}) in table tennis players has been significantly associated with rally duration ($r=0.85$) and number of shots per rally ($r=0.81$) in all-round players, but it no associated for offensive players, evidencing that influence of playing style [34]. In addition to compare elite and sub-elite players such as the current study, in the future to compare the influence of playing style on HR recovery.

During the table tennis match, the effective playing time is also dependent on player performance level. Zagatto et al. [14] reported that in Brazilian players, only 44% of game time was effective playing time (i.e., effort), with 3.4 s of rally time and 8.1 s of rest time [14]. However, Leite et al. [31] reported that in elite players competing in the Olympic Games and World Championships, the effective playing time was approximately 15%, with little change in rally time (i.e., 3.3 s) but with relevant increases in rest time (i.e., ~ 19 s). Additionally, rest time differed depending on the competition phase, with greater values being verified during semifinals and final matches. This information, assuming that several matches are played by an athlete during a tournament, reinforce the idea that a fast recovery process is essential for performing well in table tennis. It also suggests that aerobic fitness is significantly associated with the recovery process.

Therefore, several studies have highlighted the importance of aerobic fitness to the recovery process between rallies of table tennis players [19].

In this way, the use of USTHRR seems to be relevant for monitoring the recovery process. The post exercise heart rate recovery represents in general to hemodynamic adjustment

in relation to body position, blood pressure and metaboreflex activity, which in part drives sympathetic withdrawal and parasympathetic reactivation [1, 24]. Furthermore, a faster decline in HR during the first second of recovery is influenced by parasympathetic reactivation and a marker of cardiac parasympathetic outflow [24, 35].

The fast HRR is associated to athletes with elevate aerobic capacity [24] and, therefore, the USTHRR has been reported to be an appropriate and practical measure for evaluating autonomic adaptations in athletes [29]. Boullosa et al. [12] reported significant correlations between USTHRR and field performance parameters in professional soccer players after 8 weeks of training. Furthermore, Ostojic et al. [24] and Buchheit et al. [25, 26] reported that athletes engaged in intermittent sports have faster heart rate recovery times after maximal effort than athletes training in continuous efforts. This finding reinforces our results because table tennis is an intermittent sport and this kind of effect is required in the training programs, thus increasing the time spent performing intermittent efforts among elite players and resulting in faster heart rate recovery. In addition, the high-intensity interval training can be a strategy to improve the physical fitness in table tennis [16] and Buchheit et al. [27] also reported that 9-weeks of high-intensity interval training improve the sympathetic function and heart rate recovery during the 30-s of recovery, reinforcing the information that a faster USTHRR with higher training level and that USTHRR could be interesting for monitoring training in intermittent sports [24, 27], such as table tennis.

To date, only a few recent studies have examined elite and non-elite athletes in the ultra-short term of heart rate recovery (USTHRR) in a supine recovery position [11, 24]. These findings agree with those of previous studies [3, 11, 36] that have reported faster HRR after exercise tasks during supine recovery, particularly over the first 10 and 20 s. Similar to our study, the study by Buchheit et al. [26] indicated that lying in a supine position during recovery might be an effective way of transiently restoring HR and inducing vagal modulation after exercise.

While our study produced a set of rather novel data, it was also constrained by several limitations. The relatively small number of the tested subjects could have led to an overestimation of the differences between the elite and sub-elite groups.

Based on shown values, the VO_{2max} between groups were different, but due to different methodology used to estimate the VO_{2max} (20-m multi-stage shuttle run test and treadmill VO_{2max} protocols by a progressive speed protocol and a progressive incline protocol), we have adopted only to use as descriptive data instead to test correlations, which we assumed as a study limitation.

In addition, it is well known that training affects HRR [8], and although we selected subjects who had similar training programs prior to the experiment (i.e., training session duration and weekly frequency), the athletes came from of different country and teams, and perform training with different coaches methodology and with different level of partners, which can affect the workload despite of similar training sessions duration and weekly frequency. In this way, data on the absolute and relative workloads in pretesting were not available that is also assumed as study limitation.

A passive recovery mode was used in the present study. This method does not reflect real-life match conditions, in which the athlete jogs or walks during recovery. Therefore, in future the methodologic procedure should be performed to compare the measure of HRR in both post-exercise positions (standing upright at rest and laying down) to see whether there was not significant difference in the two recovery modalities.

Numerous factors can affect HR measurements: the emotional state, digestion, noise, infection, and pharmacological and nonpharmacological substances known to influence the autonomic nervous system [37]. Therefore, minimizing the influence of these variables may decrease the measurement error.

Conclusion

Elite players have faster HR recovery than sub-elite players, and ultra-short-term recovery can be used to monitor training routines.

Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

Ethics approval All procedures performed in this study were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration and its latter amendments or comparable ethical standards.

Informed consent All participants provided written, informed consent after being informed about the protocol and purpose of the study. It was approved by the Ethics Committee on Human Research of the Faculty of Sport and Tourism, Novi Sad, Serbia that personal rights were respected in this study.

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