Journal of Human Kinetics volume 73/2020, 115-124 DOI: 10.2478/hukin-2019-0136
Section II - Exercise Physiology & Sports Medicine

Cardiac Parasympathetic Reactivation Following Small-Sided Games, Repeated Sprints and Circuit Training in Elite Handball Players

by
Gilles Ravier[1], Philemon Marcel-Millet[1]

To compare acute parasympathetic reactivation following usual training exercises, the acute post-exercise heart rate (HR) and heart rate variability (HRV) were analysed. Fourteen elite male handball players completed three separate sessions of 16-min small-sided games (SSGs), repeated sprints (RSs) consisting of two sets of six repetitions of a 25-m sprint with a 180° change of direction (12.5 m + 12.5 m) every 25 s and 40 min of handball-specific circuit training (CT, one brief action every 40 s). The HR was recorded during the exercises; HRV was assessed 10 min before and after exercise. The exercise HR was higher for SSGs than RSs and it was higher for RSs than CT. Comparison of the baseline and acute post-exercise HRV values showed that parasympathetic indices decreased following SSG ($p < 0.01 – p < 0.0001$; large effect size) and RS ($p < 0.05 – p < 0.01$; large effect size) interventions. For CT, recovery values remained similar to the baseline (small effect size). The comparison of the acute recovery period between exercise modalities showed that the root mean square of the successive differences (RMSSD) was lower for SSGs than RSs and CT. No difference in any HRV indices was observed between RSs and CT. Time-varying of RMSSD for successive 30 s segments during the 10 min recovery period showed lower values for SSGs than CT for all tested points; the progressive increase in the beat-to-beat interval was similar for all interventions. In conclusion, SSGs caused the greatest post-exercise vagal disruption and it is likely that CT is the exercise modality that least delays over-all recovery. These results might help coaches design better training sessions by understanding athletes' recovery status after completing their conditioning exercises.

Key words: *autonomic nervous system, recovery, exercise modality.*

Introduction

Handball is a strenuous team sport that involves high intensity technical actions (jump shots, one-on-one situations and tackles) and locomotor activities (sprints, changes of direction), characterized with a large variety of work/rest combinations (Michalsik et al., 2013; Póvoas et al., 2012). Owing to the importance of the ability to repeat high intensity actions and to recover rapidly (Romaratezabala et al., 2018), repeated sprint (RS) exercise and specific circuit-training (CT) are added to regular handball training (Dello Iacono et al., 2016; Ravier et al., 2018a; Soares-Caldeira et al., 2014). More recently, a handball small-sided game (SSG) based-training program has been shown to be effective at improving repeated sprint ability, agility, jump height and sprint performance (Dello Iacono et al., 2015, 2016). Moreover, SSGs are widely used to improve match-specific aerobic and anaerobic fitness while involving technical skills (Buchheit et al., 2009; Dello Iacono et al., 2015). Because of the accumulation of training sessions and match play during the in-season period, conditioning programs may be integrated into the team's regular handball training sessions as it was previously suggested (Hermassi et al., 2017; Wagner et a., 2017). However, little is known

[1] - *Laboratory C3S (EA 4660), Department of Sport and Performance, University of Franche-Comté, Besançon, France.*

Authors submitted their contribution to the article to the editorial board.
Accepted for printing in the Journal of Human Kinetics vol. 73/2020 in July 2020.

about the acute recovery status in response to specific CT, RS exercise and SSG interventions in team handball.

Evaluation of autonomic nervous system (ANS) recovery following exercise provides insight into the transient stress placed on the cardiovascular system and the blood flow requirements needed to restore homeostasis (Stanley, 2013). The quantification of heart rate variability (HRV), defined as the fluctuations in R-wave to R-wave (R-R) intervals, is a non-invasive tool that is used to investigate ANS status (Task Force, 1996). In the context of sports training, HRV is considered to be a physiological indicator of the overall recovery following strenuous exercise. During the post-exercise period, there is a concomitant progressive parasympathetic reactivation with a sympathetic withdrawal. Heart rate recovery (HRR) after 30 s and 60 s is determined to assess the parasympathetic arm via its reactivation. Moreover, among HRV indices, the root mean square of the successive differences (RMSSD), spectral component of high frequency (HF) and scatter of points perpendicular to the line of identity of the Poincaré Plot (SD1) are currently used to assess the parasympathetic activity during acute post-exercise recovery. The magnitude and duration of HRV disruption during recovery after endurance exercises is influenced by the intensity and duration of the exercise session (Kaikkonen et al., 2010; Michael et al., 2017a; Seiler et al., 2007). Among these exercise characteristics, intensity is likely to have the greater impact on delaying post-exercise ANS recovery. Moreover, the modality of the exercise has been reported to influence the cardiac vagal recovery. For instance, Kliszczewicz et al. (2016) showed recently that 20 min of a high-intensity body weight resistance exercise caused greater disruption of parasympathetic reactivation than 20 min of treadmill running at 85% of the maximum heart rate (HR_{max}) intensity.

Limited data are currently available on cardiac parasympathetic reactivation following different types of exercises that are usually prescribed for team-sports, such as SSGs, RS exercise and CT (Buchheit et al., 2007; Hammami et al., 2018; Nakamura et al., 2009; Vernillo et al., 2015). Only one study compared HRR between specific CT, RSs and SSGs with elite soccer players (Dellal et al., 2015). Authors reported that after 60s recovery, HRR was significantly greater following RS exercise in comparison with SSGs and specific CT. Nevertheless, based on previous HRV findings, the RS intervention is considered to be a strenuous exercise with cardiac vagal depression similar to the exhaustive intermittent shuttle-run test (Nakamura et al., 2009) and high intensity intermittent exercise (Buchheit et al., 2007). Evaluation of ANS recovery following exercise provides insight into the restoration of cardiovascular homeostasis; thus, it might reflect an athlete's over-all recovery. It was hypothesised that parasympathetic reactivation differed between exercise modalities. Therefore, coaches should be very interested in the assessment of the parasympathetic reactivation so they can better design training sessions. The purpose of this study was to compare acute post-exercise HRV indices (in time, frequency and nonlinear domains) for SSGs, shuttle RSs and specific CT in elite handball players.

Methods

Participants

Fourteen elite male handball players (mean ± SD: age 25.4 ± 4.9 years, range 21−37 years; body mass 86.7 ± 7.0 kg; body height 189.9 ± 6.7 cm) from the same team who were involved in the professional French National Handball League (two goalkeepers, two pivots, six backcourt and four wing players) volunteered to participate in this study. Maximum aerobic performance was individually assessed within the two weeks preceding the study by the conditioning coach using the Intermittent Fitness Test (IFT) (Buchheit, 2008). Running velocity reached at the last fully completed stage was 19.4 ± 1.1 km/h and the HR_{max} recorded was 192.5 ± 6.0 beats/min. All of the athletes underwent an equal amount of training, and they were trained by the same team coach. Their handball training background was 12.3 ± 4.3 years. Each participant was medically screened and had no medical or orthopaedic problems. The experiments were carried out between the first and the second half of the competitive season. During the four months preceding the beginning of the study, each participant had trained, on average, seven times a week, including three training sessions for strength and conditioning, and they had competed on weekends. These data arose as a condition of elite player monitoring in which training is routinely measured over the course of the season. Therefore, ethics committee clearance was not required (Winter and Maughan, 2009). Nevertheless, the study conformed to the recommendations of the Declaration of Helsinki.

Experimental design

The study employed an observational within-subject repeated-measures design to compare the acute effects of SSGs, RSs and CT exercises on cardiac parasympathetic reactivation during acute recovery. The study carried out over three consecutive weeks was characterized by a similar training schedule; each week resulted in the same training volume and frequency. Conditioning drills were performed twice a week (on Monday and Tuesday evening), comprising short sequences integrated into handball training sessions to maintain the physical fitness potential, avoid overloading and then minimize accumulation of fatigue. The main objective for coaches remained to improve tactical and technical determinants of performance. The experimental sessions were undertaken on Tuesday on separate occasions seven days apart at the same time of the day (5–7 PM) on a regular indoor handball court (20 x 40 m), and they were implemented during the team's regular weekly training schedule. All participants were accustomed to the exercises used in the experiment because they were performed as part of their in-season training. Team coaches and investigators supervised each experimental session. Throughout the experimental sessions, the conditioning coach verbally encouraged participants to perform maximally.

The participants' heart rate (HR) was measured before, during and after each experimental exercise session. Initially, participants were instructed to remain seated and breathe spontaneously without speaking or making any movement for 10 min to obtain the baseline HR-derived data. A standardised 15-min warm-up was used to prepare participants for each experimental exercise session. After that, participants rested passively for 5 min before beginning the experimental exercise. Immediately after each exercise, participants remained in a seated position for 10 min to record the HR-derived data; toward that end they were given the same instructions they had received before the exercise.

Exercise interventions

For RSs, participants performed two sets of six repetitions of a 25-m sprint with a 180° change of direction (12.5 m + 12.5 m) every 25 s. Two minutes of passive standing recovery were allowed between the two sets. Three seconds before starting each sprint, participants were asked to assume the ready position and await the start signal. They were instructed to pair up for all the sprints in order to ensure that they ran as swiftly as possible.

For CT, participants completed four 10-min period of the handball-specific circuit separated by 1 min of rest during which they were allowed hydration *ad libitum*. Each period consisted of performing high-intensity short duration activities based on explosive exercises separated by a rest period (walking) with a start signal every 40 s. CT consisted of: a) one two-legged jump (0.5 m height) immediately followed by a 15-m maximum sprint, b) one linear W-sprint (alternating forward and backward) around eight cones (spaced at 2 m), c) eight plyometric single-leg jumps (marks on the ground spaced at 1.4 m) followed by a handball jump shot, and d) one agility ladder (4 m length) immediately followed by a 4-m shuffle sideways (right and left). Participants were instructed to pair up to complete the a, b and d drills so as to maintain their involvement and motivation throughout CT.

The SSG session consisted of two match play periods of 8 min, with 2 min of passive recovery between periods during which participants were allowed hydration *ad libitum*. The SSG followed the procedures outlined by Ravier et al. (2018b). Briefly, it was completed as an intermittent regimen consisting of 30 s of match play interspersed with 30 s of passive recovery. The SSG comprised goalkeepers and three-a-side field players. Each team consisted of six field players; three of them played the match while three others watched. This status was reversed every 30 s. Immediately after the timekeeper blew the whistle, participants that were playing left the court and the other participants took their place on the handball court. Before leaving, the ball carrier passed the ball to one of his teammates entering the court. This rotation of participants minimised interruption of the game. The official rules of the

International Handball Federation were applied with the following exceptions: 1) a throw-in after a goal was immediately made by the goalkeeper from his 6-m area, 2) coaches were available to replace the ball when it was thrown out of the playing court, 3) any infringement of the rules of the game were sanctioned. However, 2-min exclusions were not allowed. When the referee awarded a penalty, it was performed at the end of the two 10-min periods of playing time and the fault was immediately sanctioned with a free-throw, and 4) ball dribble was avoided during the SSG to increase physiological demand. These adaptations of the rules by the team coaches minimised interruption of the game.

HR-derived data recording

Data acquisition was performed with a HR monitor (memory belt, Suunto, Vantaa, Finland). The participants' HR was continuously recorded at 2 s intervals 10 min before, during and 10 min after each exercise session. The mean HR at rest (HR_{rest}) was analysed during the final 5 min of the 10 min period (Task Force, 1996). During each exercise, peak HR (HR_{peak}), mean HR (HR_{mean}) and HR registered at the end of the exercise (HR_{end}) were analysed. HR_{mean} included the absolute value relative to the maximum HR determined at the final stage of the IFT. Heart rate recovery (HRR) was assessed immediately at the end of each exercise during the 10 min recovery period as the difference between HR_{end} and after 30 s (HRR_{30}), 60 s (HRR_{60} and $nHRR_{60}$ when expressed in % of HR_{end}), 300 s (HRR_{300}) and 600 s (HRR_{600}) (Del Rosso, 2017).

The HRV value was registered with a sampling rate of 1000 Hz, and it was analysed using Kubios HRV analysis software, version 3.0.2 (Biosignal Analysis and Medical Imaging Group, University of Kuopio, Kuopio, Finland). Artefact noise was automatically replaced with the interpolated adjacent R-R interval value by applying the "medium" filter of the Kubios software. HRV indices were analysed during the last 5 min of the 10 min pre- and post-exercise recovery period. The time-domain dependant variables were the RMSSD (ms) and the standard deviation of normal R-R intervals (SDNN, ms). In the frequency domain, analysis included low frequency (LF) (0.04–0.15 Hz) and HF (0.15–0.4 Hz) presented in normalised units (n.u.). Furthermore, SD1 (ms) was analysed. A time-varying vagal-related index was calculated for successive 30 s segments ($RMSSD_{30s}$, ms) during the 10 min recovery period to assess the progressive increase in the R-R interval (Goldberger et al., 2006).

Statistical analysis

Data are reported as mean ± SD. The normality and equality of variance were verified using the Shapiro-Wilk's test and the Bartlett's test, respectively. According to the distribution, the HR data (recorded at baseline, during exercise and recovery) were tested with one-way repeated measures analysis of variance to determine for each variable the effects between the exercise modalities (SSGs, RSs, CT). Because some HRV indices (*i.e.* for RS modality) were skewed, all the HRV data were log-transformed (natural logarithm, ln) to allow for parametric statistical comparison. A mixed-design factorial analysis of variance was used to determine the significant mean effects of the HRV indices (lnRMSSD, lnSDNN, lnSD1, lnHF and lnLF) changes over time (baseline and recovery) and the interaction effects between the exercise modalities (SSGs, RSs, CT). Comparison of the $lnRMSSD_{30s}$ changes over time (exercises: SSGs, RSs, CT; time: 30 s segments during 10 min recovery) was performed with two-way analysis of variance. Pairwise comparisons were tested using the post-hoc Tukey's test. Furthermore, Cohen's *d* effect size (ES) analysis was performed to determine the qualitative difference between exercise modalities for all HRV indices. An ES <0.20 was classified as trivial, 0.20–0.49 as small, 0.50–0.79 as moderate, and >0.80 as large (Cohen, 1988). Relationships between HR_{mean}, HRR indices and LnRMSSD; between HR_{end}, HRR indices and LnRMSSD; as well as between HRR indices and LnRMSSD were tested with Pearson's correlation. The $p \leq 0.05$ criterion was used for establishing statistical significance.

Results

The HR and HRR data for SSGs, RSs and CT are reported Table 1. Because of a technical problem, the HRV data reported in this section were obtained from 13 of 14 participants. Table 2 shows the HRV indices at baseline and during the recovery period following each exercise, changes between baseline and the post-exercise recovery for each exercise which were analysed separately, and differences between CT, SSGs and RSs for the baseline and post-exercise values. The magnitude of these comparisons expressed as ES is shown in Table 3.

For CT, the HR_{mean} was not correlated neither with HRR indices nor with LnRMSSD, whereas HR_{end} correlated with $nHRR_{60}$ ($r = 0.69$; $p < 0.01$) and HRR_{60} ($r = 0.88$; $p<0.0001$). For RS, the HR_{mean} was not correlated neither with HRR indices nor with LnRMSSD, whereas HR_{end} correlated with $nHRR_{60}$ ($r = 0.76$; $p < 0.01$), HRR_{60} ($r = 0.85$; $p < 0.001$) and HRR_{30} ($r = 0.80$; $p < 0.001$). The SSG modality showed significant correlation between HR_{mean} and LnRMSSD ($r = -0.62$; $p < 0.05$). The HR_{end} was not correlated neither with HRR indices nor with LnRMSSD. None of the HR indices was correlated with LnRMSSD in CT, RSs and SSGs.

The time-varying of lnRMSSD measured on successive 30 s segments during the 10 min recovery period resulted in differences between the three exercise interventions ($p < 0.001$); time was found to have a statistically significant effect ($p < 0.0001$). However, no interaction effect was observed between time and exercise interventions. The $lnRMSSD_{30s}$ following SSGs had lower values at the 120 to 600 s and 150 to 510 s time points in comparison to CT and RSs, respectively. No significant difference was observed between RSs and CT.

Table 1

Heart rate data

Comparisons between training exercises for the heart rate at rest, during exercise (mean in absolute value and relatively to maximum and peak value) and recovery after 30, 60, 300 and 600 s post-exercise. Values are mean ± standard deviation.

	SSGs	RSs	CT
HR_{rest} (bpm)	54.6 (7.8)	54.4 (6)	52.9 (7.1)
HR_{mean} (bpm)	164.9 (8.3)	146.4 (7.7) §c, #c	129.2 (12) §c
HR_{mean} (% HR_{max})	85.7 (3.7)	76.1 (4) §c, #c	67.2 (6.3) §c
HR_{peak} (bpm)	179.9 (8.3)	161.4 (7.3) §c	162 (11.2) §c
HR_{end} (bpm)	171.1 (7.6)	153.0 (6.6) §c	147.6 (14.8) §c
HRR_{30} (bpm)	27.6 (7.2)	35.3 (9.8) #a	24.6 (8.7)
HRR_{60} (bpm)	50.0 (10.2)	53.1 (9.0) #b	39.8 (8.3) §a
$nHRR_{60}$ (% HR_{end})	29.2 (5.3)	34.6 (4.8) §a, #c	26.8 (4.0)
HRR_{300} (bpm)	75.9 (8.4)	70.1 (11.7)	66.8 (13.1)
HRR_{600} (bpm)	80.9 (7.1)	73.6 (10.9)	74.6 (11.1)

HR_{rest} = heart rate at rest; HR_{mean} = mean heart rate during exercise; HR_{max} = maximum heart rate; HR_{peak} = peak heart rate during exercise; HR_{end} = heart rate at the end of exercise; HRR_{30} = heart rate recovery at 30 s post-exercise; HRR_{60} = heart rate recovery at 60 s post-exercise; $nHRR_{60}$ = heart rate recovery at 60 s post-exercise expressed in percentage of the HR_{end}; HRR_{300} = heart rate recovery at 300 s post-exercise; HRR_{600} = heart rate recovery at 600 s post-exercise.

SSGs = small-sided games; RSs = repeated-sprints; CT = circuit training.

§ indicated differences compared with SSGs and # indicates differences between RSs and CT (a= $p < 0.05$; b = $p < 0.001$; c = $p < 0.0001$).

Table 2

Heart Rate Variability indices at baseline and during recovery
Values are mean (± standard deviation) at baseline and recovery for small-sided games, repeated-sprint and circuit training.

	SSGs		RSs		CT	
	Baseline	Recovery	Baseline	Recovery	Baseline	Recovery
lnRMSSD (ms)	4.10 ±0.37	2.94*d ±0.69	3.99 ±0.38	3.38*b, §a ±0.60	3.89 ±0.51	3.65§b ±0.50
lnSDNN (ms)	4.37 ±0.30	3.54*d ±0.35	4.32 ±0.28	3.83*c, §a ±0.44	4.23 ±0.47	4.11§d ±0.39
lnSD1 (ms)	3.75 ±0.37	2.59*d ±0.71	3.72 ±0.41	3.04*b ±0.58	3.55 ±0.51	3.30§c ±0.51
lnHF (n.u.)	3.59 ±0.30	3.10*b ±0.77	3.58 ±0.37	3.18*a ±0.54	3.48 ±0.34	3.07*a ±0.43
lnLF (n.u.)	4.11 ±0.23	4.22 ±0.33	4.10 ±0.23	4.25 ±0.29	4.17 ±0.18	4.33 ±0.12

lnRMSSD = the natural logarithm of the root mean square of the successive differences between R-waves; lnSDNN = the natural logarithm of the standard deviation of normal R-R intervals; lnSD1 = the natural logarithm of the scatter of points perpendicular to the line of identity of the Poincaré Plot; lnHF = the natural logarithm of the spectral component of high frequency; lnLF = the natural logarithm of the spectral component of low frequency.
SSGs = small-sided games; RSs = repeated-sprints; CT = circuit training.
** indicates significant difference between baseline and recovery for each exercise analyzed separately. § indicates significant difference compared with SSG for recovery values (a = $p < .05$; b = $p < 0.01$; c = $p < 0.001$; d = $p < 0.0001$).*

Table 3

Qualitative comparisons for heart rate variability indices
Effect size (descriptor) between the small-sided game, repeated-sprint and circuit training for heart rate variability indices determined at baseline and during recovery.

	Recovery			Baseline vs Recovery		
	SSGs vs. RSs	RSs vs. CT	SSGs vs. CT	SSGs	RSs	CT
lnRMSSD (ms)	0.67 (moderate)	0.49 (small)	1.17 (large)	2.10 (large)	1.22 (large)	0.48 (small)
lnSDNN (ms)	0.74 (moderate)	0.67 (moderate)	1.53 (large)	2.53 (large)	1.33 (large)	0.26 (small)
lnSD1 (ms)	0.70 (moderate)	0.47 (small)	1.15 (large)	2.05 (large)	1.35 (large)	0.48 (small)
lnHF (n.u.)	0.13 (trivial)	0.22 (small)	0.03 (trivial)	0.85 (large)	0.86 (large)	1.05 (large)
lnLF (n.u.)	0.08 (trivial)	0.36 (small)	0.44 (small)	0.41 (small)	0.56 (moderate)	1.00 (large)

lnRMSSD = the natural logarithm of the root mean square of the successive differences between R-waves; lnSDNN = the natural logarithm of the standard deviation of normal R-R intervals; lnSD1 = the natural logarithm of the scatter of points perpendicular to the line of identity of the Poincaré Plot; lnHF = the natural logarithm of the spectral component of high frequency; lnLF = the natural logarithm of the spectral component of low frequency. SSGs = small-sided games; RSs = repeated-sprints; CT = circuit training.

Discussion

While RSs, CT and SSGs are exercise modalities that are usually prescribed for conditioning with team handball players, little is known about the athletes' acute post-exercise cardiac autonomic response. This is the first study to report greater disruption in post-exercise parasympathetic reactivation after handball SSGs in comparison to RSs and CT. Moreover, parasympathetic indices remained decreased during the acute recovery period for both SSG and RS modalities, while the HF index was the only one to indicate HRV disruption for CT. Although the HRR30 and HRR60 have been previously used to reflect the vagal activity (Peçanha et al., 2017), the present results failed to confirm the relationships between HRR and HRV parasympathetic indices. The magnitude of HRV disruption during recovery was different between exercise modalities. This result can be explained by the different cardiovascular and energetic stress (non-oxydative energy contribution) induced by SSG, CT and RS drills (Buchheit et al., 2007; Michael et al., 2017b). Thus, the magnitude of parasympathetic depression has been found to be related to the exercise heart rate (HR) and blood lactate accumulation (Buchheit et al., 2007; Michael et al., 2017a; Seiler et al., 2007).

The present HRV data confirm that the magnitude of the parasympathetic depression during acute recovery is related to the exercise HR (Table 1) as it was previously reported with traditional aerobic exercises (Michael, 2017a; Seiler et al., 2007). CT was the exercise modality showing the lowest post-exercise vagal perturbation, solely observed with the HF index (Table 3). This result can be related to the low value of the exercise HR (Table 1), which suggests that CT moderately elicited the participants' cardiorespiratory function. In the present study, CT consisted of high-intensity and short duration activities (i.e. explosive actions, agility drills and short sprints) with a start every 40 s. Such an exercise modality with these time characteristics has been shown previously to mainly induce neural fatigue and moderate impairment in neuromuscular performances (Ravier et al., 2018a; Thorlund et al., 2008). It seems reasonable to assume that the work/rest combination implies energetic metabolism that induces a moderate blood lactate accumulation with inter-repetition recovery allowing removing part of the lactate production and resynthesizing of phosphocreatine. During recovery, the low metabolite clearance requirements involved a reduced metaboreflex input that contributed to a rapid parasympathetic reactivation (Michael et al., 2017b).

The RS session resulted in marked vagal perturbation with a large decrease in acute post-exercise HRV indices in comparison to the baseline values (Table 3). Moreover, in RSs the magnitude of the parasympathetic depression during recovery was lower than in SSGs and higher than in CT. The significant disruption of the parasympathetic function reported in the present study with RSs is consistent with previous studies (Buchheit et al., 2007; Nakamura et al., 2009). Indeed, cardiac vagal depression after RSs was reported to be as large as that observed for exhaustive incremental shuttle running (Nakamura et al., 2009), and a 12-min high intensity intermittent exercise performed at 105% of maximum aerobic velocity (Buchheit et al., 2007). Previously, vagal perturbation has been reported to be related to the exercise HR and blood lactate accumulation (Buchheit et al., 2007; Michael et al., 2017a). In the present study, RSs resulted in moderate mean HR values (Table 1). Therefore, the present HRV results might be further explained by a significant blood acidosis. Although the present study did not measure the participants' blood lactate accumulation, it is likely that RS exercise induced high concentrations of blood lactate (≈ 10 mmol/L) as previously reported (Buchheit et al., 2010; Nakamura et al., 2009). The acute effects of RS exercise on lactic acidosis and the resulting vagal perturbation have been previously reported (Nakamura et al., 2009).

The present study demonstrates a high decrease in RMSSD, SD1, and HF indices 10 min after the SSG when compared to baseline. This result was in accordance with a previous study conducted with professional female soccer players (Mascarin et al., 2018). In addition, the present HRV data showed that SSGs resulted in the greatest vagal perturbation when compared with CT and RS (Tables 2 and 3). The first reason is that the mean HR was higher during SSGs than during the two other exercises (Table 1). The present HRmean observed with SSGs was close to the value (89% of HRmax) previously reported with the same experimental SSGs in elite handball players (Ravier et al., 2018b). Since the exercise HR has been previously reported to be related to the magnitude of the parasympathetic depression during acute recovery (Michael et al., 2017a), the present high HR values observed with SSGs can explain the magnitude of the decrease of the parasympathetic function. It has been previously reported that such a handball SSG elicited similar HR response to an equivalent high-intensity 30 s – 30 s running session (Ravier et al., 2018b), which is known to induce significant cardiorespiratory stress and greatly disturb parasympathetic reactivation (Cipryan et al., 2015). Moreover, previous data reported that the same experimental SSG resulted in blood lactate concentrations of 7 mmol/L and 48% of the total time spent in the intensity zone higher than 90% of the maximum HR (Ravier et al., 2018b). It is reasonable to assume that SSGs involved high energetic demands with an important contribution of aerobic and anaerobic metabolism that contributed to the delayed parasympathetic reactivation. However, the lack of measuring blood lactate concentration is a limitation of the study. Thus, the relationship between the contribution of the glycolytic energetic pathways and HRV disruption should be considered with caution.

Conclusions

In elite team handball, CT, RSs and SSGs are prescribed as part of a handball training session and combined with technical and tactical training sequences. Handball training has evolved toward a more integrated type of physical training, it should be noted yet that SSGs cause greater disruption of parasympathetic reactivation than traditional CT and RSs. CT was the exercise modality showing the lowest post-exercise vagal perturbation. Training programming requires integrating workloads induced by training sessions and individual variables (current mental and physiological state and training background). As a recovery status indicator, HRV during acute post-exercise is useful to consider individual variation in how the athlete responds to training. The present results may be helpful to complement other variables to control individual training adaptations throughout the handball season and in programming training loads for handball teams.

Acknowledgements

The study was part of the European program for cross-border cooperation (Interreg France-Suisse 2014-2020) and was supported by the European funding for regional development (FEDER).

References

Buchheit M. The 30-15 Intermittent Fitness Test: accuracy for individualizing interval training of young intermittent sport players. *J Strength Cond Res*, 2008; 22: 365-374

Buchheit M, Laursen PB, Ahmaidi S. Parasympathetic reactivation after repeated sprint exercise. *Am J Physiol Heart Circ Physiol*, 2007; 293: H133-H141

Buchheit M, Laursen PB, Kuhnle J, Ruch D, Renaud C, Ahmaidi S. Game-based training in young elite handball players. *Int J Sports Med*, 2009; 30: 251–258

Buchheit M, Bishop D, Haydar B, Nakamura FY, Ahmaidi S. Physiological responses to shuttle repeated-sprint running. *Int J Sports Med*, 2010; 31: 402-409

Cipryan L, Laursen PB, Plews DJ. Cardiac autonomic response following high-intensity running work-to-rest interval manipulation. *Eur J Sport Sci*, 2016; 16(7): 808-817

Cohen J. *Statistical Power Analysis for the Behavioral Sciences* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates Publishers, 20-27; 1988

Dellal A, Casamichana D, Castellano J, Haddad M, Moalla W, Chamari K. Cardiac parasympathetic reactivation in elite soccer players during different types of traditional high-intensity training exercise modes and specific tests: interests and limits. *Asian J Sports Med*, 2015; 6(4):e25723. doi: 10.5812/asjsm.25723

Dello Iacono A, Eliakim A, Meckel Y. Improving fitness of elite handball players: small-sided games vs high-intensity intermittent training. *J Strength Cond Res*, 2015; 29(3): 835–843

Dello Iacono A, Ardigo LP, Meckel Y, Padulo J. Effect of small-sided games and repeated shuffle sprint training on physical performance in elite handball players. *J Strength Cond Res*, 2016; 30(3): 830-840

Del Rosso S, Nakamura FY, Boullosa DA. Heart rate recovery after aerobic and anaerobic tests: is there an influence of anaerobic speed reserve? *J Sports Sci*, 2017; 35(9): 820-827

Goldberger JJ, Le FK, Lahiri M, Kannankeril PJ, Ng J, Kadish AH. Assessment of para- sympathetic reactivation after exercise. *Am J Physiol Heart Circ Physiol,* 2006; 290: H2446-H2452

Hammami A, Kasmi S, Yousfi N, Bouamra M, Zouhaier T, Bouhlel E. Cardiac parasympathetic reactivation after small-sided soccer games and repeated sprints in untrained healthy adolescents. *J Sports Med Phys Fitness*, 2018; 58(3): 341-347

Hermassi S, Wollny R, Schwesig R, Shephard RJ, Chelly MS. Effects of in-season circuit training on physical abilities in male handball players. *J Strength Cond Research*, 2019; 33(4): 944-957

Kaikkonen P, Hynynen E, Mann T, Rusko H, Nummela A. Can HRV be used to evaluate training load in constant load exercises? *Eur J App Physiol*, 2010; 108: 435-442

Kliszczewicz BM, Esco MR, Quindry JC, Blessing DL, Oliver GD, Taylor KJ, Price BM. Autonomic responses to an acute bout of high-intensity body weight resistance exercise vs. treadmill running. *J Strength Cond Research*, 2016; 30(4): 1050-1058

Mascarin RB, De Andrade VL, Barieri RA, Loures JP, Kalva-Filho CA, Papoti M. Dynamics of recovery of physiological parameters after a small-sided game in women soccer players. *Front Physiol*, 2018; 9: 887

Michael S, Jay O, Graham KS, Davis GM. Higher exercise intensity delays postexercise recovery of impedance-derived cardiac sympathetic activity. *Appl Physiol Nutr Metab*, 2017a; 42(8): 834-840

Michael S, Graham KS, Davis GM. Cardiac autonomic responses during exercise and post-exercise recovery using heart rate variability and systolic time intervals – A review. *Front Physiol*, 2017b; 8: 301

Michalsik L, Aagaard P, Madsen K. Locomotion characteristics and match-induced impairments in physical performance in male elite team handball players. *Int J Sports Med*, 2013; 34: 590-599

Nakamura FY, Soares-Caldeira LF, Laursen PB, Polito MD, Leme LC, Buchheit M. Cardiac autonomic responses to repeated shuttle sprints. *Int J Sports Med*, 2009; 30: 808-813

Peçanha T, Bartels R, Brito LC, Paula-Ribeiro M, Oliveira RS, Goldberger JJ. Methods of assessment of the post-exercise cardiac autonomic recovery: a methodological review. *Int J Cardiol,* 2017; 227: 795-802

Póvoas S, Seabra A, Ascensão A, Magalhães J, Soares J, Rebelo A. Physical and physiological demands of elite team handball. *J Strength Cond Res*, 2012; 26(12): 3366-3376

Ravier G, Bouzigon R, Beliard S, Tordi N, Grappe F. Benefits of compression garments worn during handball-specific circuit on short-term fatigue in professional players. *J Strength Cond Res*, 2018a; 32(12): 3519-3527

Ravier G, Hassenfratz C, Bouzigon R, Groslambert A. Physiological and affective responses of elite handball players to 30-30s intermittent small-sided game: comparison with 30-30s intermittent running and match play. *J Hum Sport Exerc*, 2018b; 14(3): 538-548

Romaratezabala E, Nakamura F, Ramirez-Campillo R, Castillo D, Rodriguez-Negro J, Yanci J. Differences in physical performance according to the competitive level in amateur handball players. *J Strength Cond Res*, 2018; epub ahead-of-print, doi: 10.1519/JSC.0000000000002533

Stanley J, Peake JM, Buchheit M. Cardiac parasympathetic reactivation following exercise: implications for training prescription. *Sports Med*, 2013; 43: 1259-1277

Seiler S, Haugen O, Kuffel E. Autonomic recovery after exercise in trained athletes: intensity and duration effects. *Med Sci Sports Exerc*, 2007; 39(8): 1366-1373

Soares-Caldeira LF, De Souza EA, De Freitas VH, De Moraes MF, Leicht AS, Nakamura FY. Effects of additional repeated sprint training during preseason on performance, heart rate variability, and stress symptoms in futsal players: a randomized controlled trial. *J Strength Cond Res*, 2014; 28(10): 2815-2826

Task Force. Heart rate variability: standards of measurement, physiological interpretation and clinical use. Task force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. *Circulation*, 1996; 93: 1043-1065

Thorlund JB, Michalsik LB, Madsen K, Aagaard P. Acute fatigue-induced changes in muscle mechanical properties and neuromuscular activity in elite handball players following a handball match. *Scand J Med Sci Sports*, 2008; 18: 462–472

Vernillo G, Agnello L, Barbuti A, Di Meco S, Lombardi G, Merati G, La Torre A. Postexercise autonomic function after repeated-sprint training. *Eu J Appl Physiol*, 2015; 115(11): 2445-2455

Wagner H, Gierlinger M, Adzmija N, Ajayi S, Bacharach DW, Von Duvillard SP. Specific physical training in elite male team handball. *J Strength Cond Research*, 2017; 31(11): 3083-3093

Winter EM, Maughan RJ. Requirements for ethics approvals. *J Sports Sci*, 2009; 27: 985

Corresponding author:
Gilles Ravier
Address: Unit of Formation and Research in Sports, 31 chemin de l'Epitaphe, 25000 Besançon, France
Telephone number: +33 381 666 362; ORCID: 0000-0001-5169-5808
Email: gilles.ravier@univ-fcomte.fr