ORIGINAL ARTICLE

Arch AHS

Archives of Allied Health Sciences 2021; 33(1): 9-18.

Monitoring heart rate, heart rate variability, and subsequent performance in team-sport athletes receiving hypoxic or normoxic repeated sprint training

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KEYWORDS
Altitude;
Rugby;
YoYo-Intermittent recovery;
Repeated sprint ability;
Autonomic nervous system.

ABSTRACT

Repeated sprint training (RST) in hypoxia (RSH) is becoming more popular in team sport players owing to the potential for increases in high-intensity running performance without compromising power output during training. However, as the added hypoxic stimulus also increases training load, careful monitoring is needed to avoid overtraining. The first objective of this study was to determine whether resting heart rate (RHR) and resting heart rate variability (HRV) measured following 3 weeks of training was able to detect the increased training load in the group receiving hypoxic training. A second objective was to determine whether RHR and HRV measured after 3 weeks of training were associated with post-training normoxic running performance. Amateur club rugby players completed 3 weeks of twice-weekly RST (cycling) in either hypoxia (RSH, n = 9; 20.3 ± 2.1 years; 77.1 ± 10.2 kg; 173.9 ± 4.9 cm; FIO2: 14.5%) or normoxia (RSN, n = 10; 22.0 ± 4.1 years, 88.3 ± 14.1 kg; 177.9 ± 5.4 cm, FIO2: 20.9%). Resting heart rate and HRV were monitored during normoxic rest immediately before each training session over the 3 week training period. Pre- and post-intervention aerobic endurance (Yo-Yo Intermittent Recovery Level 1 (YYIR1)) and repeated sprint ability (RSA, running) were used as performance variables before and after the training intervention. Compared to RSN, RSH demonstrated possibly lower HRV (natural log of the root mean square of successive difference, RMSSD): -8.5, ± 19.1% and standard deviation of N-N intervals: -11.5, ± 25.0%; percent change, ± 90% CL), and higher RHR (3.2, ± 4.7 bpm) post-intervention. Week 3 RHR and HRV demonstrated strong, statistically significant correlations with post-intervention performances (YYIR1, RHR: -0.82, *p*-value = 0.02; RMSSD: r = 0.58, *p*-value = 0.17; low frequency: high frequency ratio (LF/HF): r = -0.85, *p*-value = 0.01; and RSA, RHR: r = 0.73, *p*-value = 0.06; RMSSD: r = -0.53, *p*-value = 0.22; LF/HF: r = 0.77, *p*-value = 0.05) in RSH, but not RSN. In conclusion, RHR and HRV were able to detect the increased training stimulus in hypoxic compared to normoxic repeated sprint training. In addition, RHR and HRV measured after 3 weeks of RSH were correlated with post-intervention performance whereby a lower RHR or increased HRV was associated with improved YYIR1 and RSA performance.

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Received: 7 November 2020/ Revised: 28 January 2021/ Accepted: 22 March 2021

Introduction

Over the last few years the application of altitude training has extended beyond endurance athletes to include team sport athletes[1]. In particular, repeated sprint training in hypoxia may improve intermittent running performance more so than similar training performed in normoxia in team sport athletes[2]. However, while incorporating hypoxia into repeated sprint training protocols may result in improved running performance, the added hypoxic exposure increases the training stress and therefore increases the risks associated with overreaching[3]. Furthermore, not all athletes will respond to a standardized training programme in a similar fashion[4]. That is, for some of the athletes, the training programme will be well tolerated and yields performance-enhancing adaptation, while for others, the same training may result in mal-adaptation and performance decrement. The additional strain of training in hypoxia, as well as the array of individual responses anticipated from such training, means that monitoring the stress and fatigue of individual athletes is of paramount importance when it comes to ensuring optimal training and recovery, while preventing overtraining, fatigue, burnout and illness[5].

An ideal monitoring tool should be non-invasive, and able to provide readily available, time-efficient results[6]. One such tool is heart rate variability (HRV), which indicates the sympathetic and parasympathetic innervation of the heart[7]. A reduction in HRV implies reduced vagal stimulation of the sinus node and lower parasympathetic contribution while higher HRV indicates increased vagal activity and generally indicates improved health[7].

In a sporting context, typically, athletes with greater high frequency, or parasympathetic components in their post-intervention HRV measures demonstrate improved performances, such as decreased 800m swim time in elite triathletes[8]. Furthermore, HRV measured in normoxia[9] or at moderate altitude[10] has been used to provide valuable predictive information on climbers likely to develop acute mountain sickness[9, 10]. Therefore, using HRV appears to be a very useful monitoring tool during both athletic training and during altitude training. However, much of its use has been centered on endurance athletes, and more research is needed on the role of resting heart rate and heart rate variability measures in monitoring fatigue in team sport athletes receiving hypoxic training.

The primary objective of this study was to determine the effect of short, repeated sprint training intervals in hypoxia vs repeated sprint training in normoxia on HRV in a team sport population. Secondly, we wanted to determine the relationship between HRV taken at rest during the training period with subsequent performance.

Materials and methods

Participants

As described elsewhere[11], 19 amateur club rugby players performing similar pre-season training and fitness routines were matched for baseline repeated sprint ability (using the cumulative time for 8 x 20m sprints), and then randomly divided using randomization software (www.randomizer.org) into groups performing repeat-sprint training in hypoxia (RSH: n = 9, age: 20.3 ± 2.1 years; weight: 77.1 ± 10.2 kg; height: 173.9 ± 4.9 cm) or normoxia (RSN: n = 10, age: 22.0 ± 4.1 years, weight: 88.3 ± 14.1 kg; height: 177.9 ± 5.4 cm). The repeat sprint protocol was designed to be as sport-specific as possible, based on sprinting bouts observed during typical rugby matches[12]. All participants continued with similar training protocols throughout the study. Written informed consent was provided by the participants in accordance with the Declaration of Helsinki. The research was approved by the local University Human Ethics Committee (2015-46).

Procedures

This was a single-blind, randomised, placebo-controlled trial with similar numbers of participants divided into placebo and hypoxic groups. The lead researcher enrolled the participants, ran the random allocation sequence, and implemented the training protocols based on the randomised groups' particular intervention. All participants were blinded to their interventions (all believed they were receiving hypoxic air). No alterations or amendments to the method were applied after the commencement of the trial. Recruitment into the study began in the second week of January, and the trial was started in the second week of February. All participants completed a familiarization session, followed 4 – 5 days later by their baseline testing session. Post-intervention testing occurred two days following the completion of the repeated sprint training. The study was concluded in the first week of April.

Participants were advised to arrive at testing sessions in a rested (no intense exercise for 24 hours) and well-hydrated stated. No caffeine was consumed for 12 hours prior to testing. Testing sessions were mirrored as closely as possible to each other to reduce the risk of the testing session or participant readiness and fatigue contributing to pre-post measurement differences. Each participant recorded their dietary intake before their baseline measurements for repetition prior to the post-intervention testing. Additionally, testing sessions were conducted at the same time of day (±1 h), and the measures were completed in the same order.

All tests were completed in a covered stadium on a slip-free floor under similar climatic conditions. Following a 15 min warm up (5-min slow jog and 5 – 10 mins of dynamic stretching), the participants completed a squat jump (data not reported here), repeated sprint test, and Yo-Yo Intermittent Recovery Level 1 test. Each test was separated by 10-15 mins of recovery.

Repeated sprint performance test

Participants completed 8 x 20 m maximal running-based sprints, timed to go every 20 s. Each sprint was recorded to the nearest 0.01 s using electronic speed-timing lights (Smartspeed, Fusion Sport, Ltd, Australia). Repeated sprint performance was assessed using mean sprint time.

Yo-Yo Intermittent Recovery Level 1 test

The Yo-Yo Intermittent Running Performance Test Level 1 is an intermittent, endurance-focused running test in which the athlete completes 2 x 20 m back-to-back shuttles interspersed by 10 s of active recovery. The test was externally paced using audible tones. As the test progressed, the tones got faster and the test was concluded when the athlete was unable to complete the shuttle before the tone sounds. The total distance (m) covered by the athlete was recorded.

Repeated sprint training

Repeated sprint training started one week after the baseline testing session. All participants completed cycling repeated sprint training twice a week for 3 consecutive weeks (total of 6 training sessions). Repeated-sprint training was performed in an upright, but seated position on a calibrated Wattbike (Wattbike Pro, Nottingham, UK) set up to participant-specific dimensions (saddle and handle bar height and position). The Wattbike was selected for its high reliability and low typical error of 2.6%[13]. In weeks 1 and 3, air brake and magnetic settings were adjusted to resistance level 3. Air brake resistance was increased to level 5 in week 2 to increase overload.

Training sessions started with a 5-min warm up at 50 W with a 5s sprint at the end of each minute. Participants completed 4 sets of 5 x 5-s repeated maximal-intensity sprints interspersed with 25 s between sprints and 5 min between sets of active recovery, slowly turning their legs over at 20-50 W. In total, training sessions included 35 minutes of exercise per session, and a total of 280 minutes over the course of the study (i.e. 280 mins of hypoxic exposure for the hypoxic group).

Hypoxic dosage during training

To improve blinding, all participants were informed that they would be receiving hypoxic air. Data that may indicate separate groups, such as blood oxygen saturation or heart rate, was also hidden from the participants. Prior to training, all participants were fitted with a face mask (Hans-Rudolph 8980, Kansas City, Missouri, USA) connected to one of 2 sets of 2x100L Douglas bags connected in series and containing either hypoxic (fraction of inspired oxygen (F_IO_2) of 14.5%, approx. 3000 m) or normoxic (F_IO_2 20.9%) air. The hypoxic or normoxic air was delivered to the participant via a one-way non-rebreathing valve (Hans-Rudolph 2700). Douglas bags were continually re-supplied with hypoxic or normoxic air using the GO_2Altitude® hypoxicator system (Biomedtech, Victoria, Australia).

An F_IO_2 of 14.5% was chosen as it has been found to increase physiological stress without impacting the typical attenuation in performance that normally occurs with such exercise[14].

Stress monitoring during training: Heart rate variability

Following arrival at the training session, participants were fitted with a heart rate monitor belt (WearLink, Polar, Kempele, Finland) and wrist watch (RS800CX, Polar, Kempele, Finland) and rested in a supine position in a dimly lit, quiet room for 10 mins. Heart rate variability was recorded on the wristwatch and later downloaded to a personal computer (HP Pavilion dv6 notebook, with Windows 10) using the Polar Protrainer software (Polar Protrainer 5™, Version 5.41.002) for HRV analysis. Data was filtered using the default error correction function (moderate filter power with a minimum protection zone of 6 beats per min). Identified errors were recorded, and all participants with an error rate of >5% were excluded from the dataset (RSH: n=1). On average, data was high quality (mean error percent 0.9 ± 1.1 %). The last 5 mins of the 10 min resting recording was used to determine resting heart rate (RHR) and time-domain analyses. Time domain analyses included the root mean squared of the successive difference (RMSSD) and the standard deviation of the N-to-N intervals (SDNN) as these time-domain measures are typically more reliable and display less variance than their frequency-domain counterparts[15]. Furthermore, the accuracy of HRV measures is vastly improved when the weekly average of heart rate variables is used compared to single "on the day" measurements[16]. Therefore, the weekly average of the HRV measurements taken before the training sessions was used. The low frequency to high frequency ratio was also included as this measurement has been associated with mountain climbers likely to develop acute mountain sickness[9].

Stress monitoring during training: Power output

Power output during training sessions was assessed by downloading and then averaging the peak power recorded by the Wattbike during each sprint in the sprint training (i.e. mean peak power of the 20 repeat sprints for each training day e.g. 4 sets of 5 reps).

Statistical analysis

A total of 17 participants were included in the analysis of this study. One participant in the RSH group was excluded due to outlying performance data indicating lower athletic ability than the rest of the cohort. A second participant in the RSH group was also excluded due to >5% errors detected in the filtering algorithm of the HRV analysis. Two researchers worked to examine and analyse the outcome measures in this study. All participants tolerated the interventions well, and none of the participants needed to stop their training at any stage.

Difference between hypoxic and normoxic repeat-sprint ability on stress markers

A pre-post parallel-groups spreadsheet[17] was used to assess the between-group differences in change scores from weeks 1 – 3 for measures of HRV. Cohen's value of 0.2 of the between-subject standard deviation was used to assess the smallest worthwhile change. Prior to analysis, data were log-transformed to reduce non-uniformity of error. Results are displayed as a percent change ± 90 % confidence interval, and qualitatively assessed using the clinical inference[18]. In this regard, an odds ratio of benefit: harm was only accepted if it was above 66%; if not, the effect was considered "unclear". For clear results, the magnitude of the change was reported using the following scale <0.5% = most unlikely; 0.5-5% = very unlikely; 5–25% = Unlikely; 25–75% = possibly; 75–95% = likely, 95–99.5% = very likely, >99.5% = most likely[18]. The direction of the change (increase, trivial or decreased) was determined, and interpreted according to the variable. In addition, *p*-values have been added to broaden the usefulness and scope of these results, particularly for those who do not use magnitude-based inferences.

Relationship between stress markers and post-intervention performance.

The athletes' week 3 HRV was correlated with the post-intervention performance using the Proc Corr procedure in the Statistical Analysis

System (Version 9.3; SAS Institute, Cary, NC). Correlations were interpreted using Cohen's scale of <0.10, 0.10, 0.30, 0.50, 0.70, and ≥0.90 for trivial, small, moderate, large, very large, and extremely large respectively[18].

Results

Blinding was effective as when questioned post-intervention only 20% of the participants in the control group suspected they were receiving either a higher oxygen dose or a placebo. All participants in the hypoxic group tolerated the hypoxia well, and no interruptions or cessations were necessary during the repeated sprint training in hypoxia.

Differences in stress markers in hypoxic vs normoxic groups

Compared to the participants who trained in a normoxic environment, the participants training in hypoxia had higher RHR and possibly lower HRV in week 3 compared to Week 1 (results are presented in Table 1). The higher LF/HF (%) values in the RSH group were driven by an increase in low frequency as well as a reduction in high frequency (ms) over weeks 1 – 3 (data not presented) in the RSH group compared to the RSN group.

Relationship between HRV variables and post-intervention exercise performance

The correlations between RHR, LnRMSSD and LF/HF ratio taken during Week 3 of the training period and post-intervention performance are presented in Figure 1. For the RSH group, measures with the strongest correlation with post-intervention performance change were resting heart rate, LF/HF ratio, and RMSSD. The correlation between heart measures and post-intervention performance were weaker in the RSN group.

There were likely trivial differences in the change in power output (-1.3, ± 7.5%, between-group difference in the week 3 – week 1 of the log-transformed change in performance) in the hypoxic (baseline: 824.4 ± 220.9 W to post-intervention: 826.3 ± 215.2 W) and normoxic (baseline: 990.2 ± 162.0 W to post-intervention: 1012.7 ± 203.0 W) repeated sprint training.

Table 1 The between-group differences in the physiological stress markers

			Week 1	**Week 3**	**Between-group difference[a] (Week1-Week3)**
HRV marker	Group	(n)	Mean ± SD	Mean ± SD	Change, ± 90% CL (%)
RHR (bpm)	RSN	10	74.8 ± 13.0	71.9 ± 10.1	3.2, ± 4.7%
	RSH	7	75.2 ± 12.1	74.9 ± 11.1	Possibly higher in RSH
RMSSD (ms)	RSN	10	48.2 ± 31.0	51.1 ± 27.1	-8.5, ± 19.1%
	RSH	7	37.0 ± 20.2	37.4 ± 21.0	Possibly lower in RSH
SDNN (ms)	RSN	10	73.7 ± 29.2	82.8 ± 25.9	-11.5, ± 25%
	RSH	7	69.2 ± 28.5	70.4 ± 26.9	Possibly lower in RSH
LF/HF (%)	RSN	10	301.7 ± 174.7	313.6 ± 151.8	-6.4, ± 42.3%
	RSH	7	469.9 ± 239.2	508.9 ± 301	Unclear

Note: [a]The between-group difference is the difference between RSN and RSH in week 1 compared to Week 3 using log-transformed means. CL, confidence limits; SD, standard deviation; RHR, Resting heart rate; HRV, heart rate variability; RSN, Group receiving a normoxic placebo during the repeated sprint intervention; RSH, group receiving hypoxic during the repeated sprint intervention; RMSSD, Root Mean Square of the Successive Differences; SDNN, Standard Deviation of the N-N interval; LF/HF, Low frequency to high frequency ratio expressed as a percent.

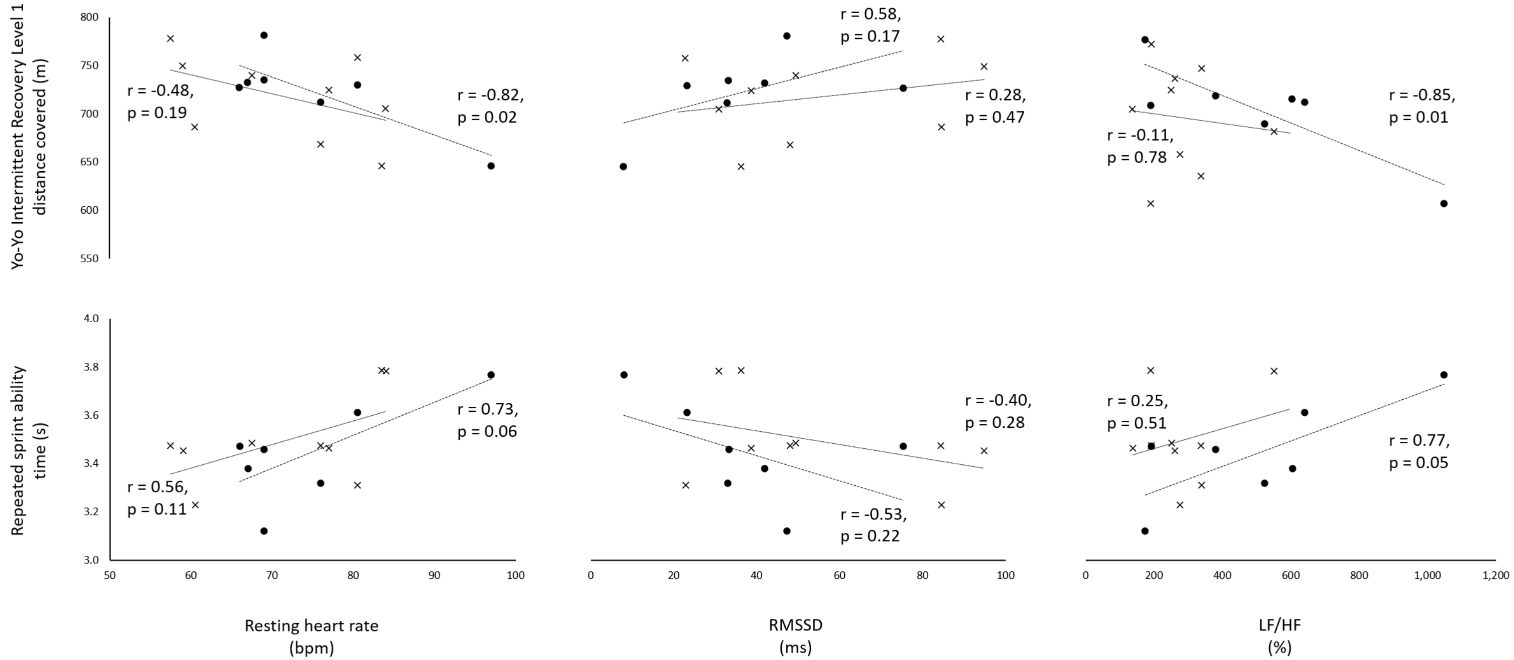

Figure 1 Correlations between heart rate and heart rate variability measurements and Yo-Yo Intermittent Recovery Level 1 and repeated sprint ability performances following repeated sprint training in hypoxia (circles, short dashes trendline) and normoxia (crosses; fine dots trendline). m, meters; s, seconds; bpm, beats per minute; RMSSD, root mean squared of the successive difference in heart beat intervals; ms, milliseconds; LF/HF, low frequency to high frequency ratio expressed as a percent.

Reliability of performance measures

The typical error between the familiarization and baseline tests for all participants for the RSA and YYIR were 0.7% (90% Confidence limit = 0.6 – 1.1%) and 7.5% (90% Confidence limit = 5.8 – 10.8) respectively.

Discussion

The objective of this study was first to determine the effect of short, repeated sprint training intervals in hypoxia vs repeated sprint training in normoxia on heart rate variability in a team sport population. Subsequently, the relationship between the post-intervention heart rate variability with subsequent performance was determined. Our study indicates that while RHR and HRV are sensitive enough to discriminate between participants receiving hypoxic training vs those receiving normoxic training, the effect of RSH on HRV is characterised more by an absence in HRV response, rather than an increase in HRV (suggesting increased parasympathetic innervation)[7] as was observed following RSN. Regarding the second objective, RHR and LF/HF had strong, statistically significant correlations with post-intervention aerobic and repeated sprint performance following RSH. These correlations were stronger than the correlations observed following RSN.

The absence of any change in HRV following RSH (in contrast to the increased HRV seen following RSN) may provide support for Schmitt and colleagues'[3] caution of an increased risk of overtraining with hypoxic repeated sprints compared to repeated sprint training in normoxia. That is, in the present study we increased the training stress in the RSH group but did not increase the recovery period more so than the RSN group, effectively increasing the overall workload and training stress[5,19] in RSH compared to RSN. As altitude training appears to be a particularly fatigue-inducing form of stress[3], this increased stress state would theoretically result in an increase in sympathetic innervation and a resultant reduction in HRV[7]. However, power output during training from week 1 to week 3 was either maintained or gradually increased indicating that over-reaching was avoided[8], and that it is unlikely that the training-stress was accumulating towards an elevated stress state[5]. What is likely is that the addition of hypoxia to the repeated sprint training intensified their normal preseason training, sustaining a higher level of training stress along the stress-adaptation continuum[19]. Continuation of such high-stress training over a longer timeframe may ultimately push the athletes further along the stress-adaptation continuum resulting in overtraining. Fortunately, the short time frame of the study, and low frequency of the RSH training allowed the hypoxic group to recover quickly and ultimately improve their repeated sprint ability compared to the normoxic group[11]. Indeed, following the cessation of the repeated sprint training intervention, and therefore with more relative rest, the hypoxic group continued to improve their repeated sprint ability compared to the control group[11] suggesting supercompensation occurred[5].

The RMSSD and SDNN values from the athletes in this study were in-line with healthy HRV values reported by Nunan et al.[20]. When taken together with the absence in power output drop-off during the repeat-sprint training in hypoxia, it is likely that RSH appeared to induce autonomic nervous system stress responses to a greater extent than when training in normoxia, but not to the extent that the additional physiological stress was detrimental to the athlete.

Correlation between HRV during training and post-training performance

The overall correlations between Week 3 HRV and post-intervention performance supports others who have found lower HRV to be associated with reduced performance[21]. In our study, the correlations between lower RHR, increased RMSSD and lower LF/HF values, all of which are typically due to increased vagal innervation[22], were all associated with improved performance in both the hypoxic and normoxic groups (see Figure 1).

Our findings support previous research which demonstrated an increase in HRV with an increase in YYIR1 performance following normoxic repeated sprint training in team sport athletes[23].

However, the findings in the present study indicate that an increase in HRV may not be evident immediately following repeated sprint training in hypoxia (see Table 1), possibly due to the increased training intensity in the hypoxic group[24]. Despite the hypoxic group's absence of improvement in HRV, the relationship between HRV variables and post-intervention performance was stronger compared to those receiving normoxic training (see Figure 1). This heightened relationship could possibly indicate the presence of responders and non-responders to hypoxic training[25]. That is, the response to hypoxic training can be quite binary, if the athlete tolerates the hypoxia well (and demonstrates increased HRV), they are likely to perform much better than if they had received similar training at sea-level. Conversely, if the hypoxic training is not tolerated, the athlete may enter a period of physiological distress which overwhelms the athlete's adaptive capabilities resulting in a reduction in resting HRV and worsened performances than had they trained at sea-level[8]. On the other hand, resting HRV during a period of repeated sprint training in normoxia, was not as strongly related to post-intervention performance as was noted in the hypoxic group. As the repeated sprint training was only held twice per week, it is possible that the normoxic training may have had less of an impact on the stronger or fitter athletes (yielding either a maintained or small increase in HRV). On the other hand, the weaker athletes in the normoxic group may have demonstrated a higher level of increased fitness and performance, with an associated increase in resting HRV. If this were the case, it may explain the overall increase in HRV seen in the RSN group (compared to the static HRV in the RSH group, see Table 1) as well as the weaker correlation between HRV and post-intervention performances in the RSN group (see Figure 1).

Of particular interest is that RHR had the strongest correlation with post-intervention performance. While more information[7] can be gleaned about a person's autonomic nervous system by means of HRV analysis, the more complex nature of the measurement, and the range in HRV outputs means that it is also more susceptible to breathing[26], technical and analytical[27] artefact compared to the more simple RHR measure. The increase in the risk of measurement artefact in the HRV outputs compared to the more straight-forward RHR measurement may be the reason for the higher correlation between RHR and post-intervention performance.

There were only small differences in the associations between the HRV variables and either repeated sprint ability and YYIR1. As repeated sprint ability and YYIR1 outcomes are not strongly associated with each other in team sport players[28], an improved autonomic balance appears to influence performance in a non-specific manner. For example, master and elite athletes typically have higher levels of HRV compared to similar-aged sedentary controls[29] regardless of whether the athlete are endurance- or sprint-athletes[30]. Therefore, it is unclear whether improved HRV is the driver of, or reflection of, generally improved performance.

Limitations

A correlation does not indicate causality, which, when combined with the small group sizes in our study, means that caution is needed inferring meaning from our results.

While the study of HRV is usually presented in a straight-forward manner, the results can be considerably more complex to interpret. This is particularly relevant in elite athletes where a decrease in HRV can be associated with improved performance[22]. The athletes in this study were all club-level athletes, as such, more research is needed before our findings can be asserted more confidently.

Conclusion

Our research supports the use of RHR and HRV measures to monitor training-related stress, particularly during repeated sprint training in hypoxia in club rugby players. Athletes in the RSH group demonstrated higher RHR and lower HRV during the training period when compared to the RSN group. While elevated RHR and lower HRV typically indicate higher levels of physiological stress, there were no reductions in training or post-intervention performance in the hypoxic group compared to the normoxic group, and overtraining was likely avoided in RSH.

Our study demonstrated moderate to strong correlations between RHR and HRV measures taken immediately before training in Week 3, and both repeated sprint ability and YoYo intermittent recovery performance post-training. These findings support previous research in suggesting that higher HRV is predictive of better subsequent athletic performance, while extending the typical participant reach to include club-level rugby players receiving hypoxic exposure during repeated sprint training. Should future research support our findings, RHR and HRV could be useful tools in the prediction of post-training performance.

Take home messages

Monitoring resting heart rate and heart rate variability during the last week of repeated sprint training may predict YoYo-intermittent recovery and repeated sprint ability in club-level athletes after training. Lower resting heart rate and higher heart rate variability were associated with improved post-training performance.

Conflicts of interest

The authors declare no conflict of interest.

Acknowledgements

The authors acknowledge the Lincoln University Research Fund (reference 2014-16E/INTF044) and Ara Institute of Canterbury for financial support for this project. The authors thank the player volunteers and their coaches for their assistance.

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