Short Communication

The effects of individualized resistance training volume by heart rate variability in collegiate football players

Gregory C. Smith, Keith Leiting, Alexander J. Koch

Objectives: We sought to determine if individualized programming by heart rate variability (HRV), improves resistance training outcomes in American football players.

Design and Methods: Twenty-seven National Collegiate Athletic Association (NCCA) Division II American football players (age 19.03 ± .98 y, height 185.50 ± 5.30 cm, body mass 100.59 ± 18.57 kg) were divided into an experimental (HVG) group (n = 11), and a control (CON, n = 16). Subjects completed 5-weeks of 3 $d \cdot wk^{-1}$ periodized resistance training during the off-season. The HVG monitored HRV on mornings before training, and their training volume was adjusted by their HRV. Specifically, on training days when HRV indicated that a subject was fatigued, the subject performed half of the originally planned repetitions for the training day. CON performed assigned workouts with no alterations. Performance was assessed via 1RM bench press (BP), power clean (PC), back squat (BS), and vertical jump (VJ) between groups using a 2 × 2 repeated measures analysis of variance (ANOVA).

Results: The HVG had an average of 4 ± 1.51 days modified over the 5 wks, but volume load lifted was similar ($p = 0.955$) between groups. Repeated measures ANOVA revealed significant increases in BP (time effect $p < .001$), BS (time effect $p < 0.001$), PC (time effect $p = 0.002$), and VJ (time effect $p = 0.042$) for both HVG and CON. There were no significant between-group differences in performance variables. The group × time interaction for PC ($p = 0.087$) trended towards a significantly greater increase in HVG (+ 8.6%) vs. CON (+ 2.6%). Conclusions: Periodized training can improve performance without monitoring HRV, but it may have an advantageous effect for highly technical movements such as the PC.

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Key words: resistance exercise ■ periodization ■ strength ■ fatigue management

INTRODUCTION

Ideal training loads apply adequate stress to produce adaptation, without leading to maladaptation. With insufficient recovery, athletes may develop overtraining or overreaching syndrome.[1,2] Managing recovery is a challenge, as recovery requirements may vary drastically between individuals.[3]

Tracking the regulation of the autonomic nervous system (ANS) via heart rate variability (HRV) presents a potentially useful noninvasive and objective measure of an individual's recovery status.[4-6] HRV is a statistical analysis of R-R intervals of the cardiac cycle. HRV represents the balance between parasympathetic and sympathetic activity within the autonomic nervous system.[7] Resting HRV measurements have been studied in the realm of endurance training. Higher resting HRV has been related to greater improvements in maximal oxygen consumption following training.[7-9] Additionally, increasing resting HRV during training periods has been linked to improvements in endurance performance.[9-13] Theoretically, tracking HRV can be used in athletes to reduce training loads when HRV readings impacted, thus enhancing recovery and reducing overwork. Prescribing endurance exercise according to HRV has also been attempted, with Kivinemi reporting greater improvements in VO2max and endurance performance when adjusting training prescriptions (i.e. reducing training volume) in accordance with a single daily HRV measure, versus subjects who performed a predefined training plan.[4,5] Likewise, Vesterinen et al.[6] found improved 3000m running performance when training was individualized according to a 7d rolling average of HRV.

Resistance exercise evokes a substantial response from the ANS,[14] which may be measured by changes in HRV[15]. HRV responds to resistance training in clinical populations,[16,17] and the HRV response to resistance exercise differs based on the relative effort and the volume of exercise completed[15]. No published studies have investigated the efficacy of individualizing resistance exercise prescription according to HRV.

Given the promising results seen from individualizing aerobic exercise prescription via HRV, an exploration of whether resistance exercise prescription can be enhanced through the use of HRV monitoring is warranted. The purpose of this study was to determine if individual fatigue management using HRV enhances resistance exercise performance outcomes in collegiate football players.

METHODS

Subjects

Thirty-two men from a NCAA Division II American Football team, volunteered (age 19.0 ± 1.0 y, height 185.5 ± 5.3 cm, body mass 100.6 ± 18.6 kg) at the outset of the study. Twelve HR monitors had been provided to the team, and these

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From the Athletics Department, Lenoir-Rhyne University, Hickory, NC 28603, USA (G.C.S.) and Health & Exercise Science Program, Lenoir-Rhyne University, Hickory, NC 28603, USA (G.C.S., K.L., A.J.K.)
Communicated by Takashi Abe, PhD
Correspondence to: Dr. Alexander J Koch, Exercise Science Program, Lenoir-Rhyne University, Hickory, NC, 28603, USA. Email: alex.koch@lr.edu

Table 1 Subject Characteristics for HVG (n = 11) and CON (n = 16) groups at Baseline

	Group		
Variable	CON (n = 16)	HVG (n = 11)	p value
Age (y)	18.8 ± 0.9	19.6 ± 1.0	0.047*
Height (cm)	184.6 ± 5.1	184.6 ± 5.11	0.949
Body Mass (kg)	98.0 ± 15.6	101.0 ± 24.6	0.693

*denotes $p \leq 0.05$ difference between groups

were distributed to volunteers on a first-come, first-served basis. The first twelve participants to receive a HR monitor formed the experimental (HVG) group, while the remaining 20 members of the team were the control (CON) group. For data analysis, an adherence rate of attending 95% of planned resistance training sessions was selected, so that subject numbers included in the analyses were n = 11 for HVG and n = 16 for CON. Subject characteristics for HVG and CON are presented in Table 1. Subjects in HVG and CON were similar in body mass and height (Table 1; $p > 0.05$). Subjects in HVG were older than those in CON ($p = 0.047$), though difference in age was small (0.8 y). Subjects in HVG and CON were similar in performance measures at the outset of the study (BP ($p = 0.053$), PC ($p = 0.140$), BS ($p = 0.312$), and VJ Power ($p = 0.728$).

All subjects were between the ages of 18-23, had a working smart phone (Apple™ or Android™) that was able to download the EliteHRV application, had no current musculoskeletal injuries, and had ≥ one year of lifting experience with the back squat (BS), bench press (BP), power clean (PC), and vertical jump (VJ). Participants provided written informed consent for use of their data, and all experimental procedures involving human subjects were approved by the University's Institutional Review Board.

Procedures

HRV data were collected in the mornings before resistance exercise sessions using the Elite HRV phone application. The HVG was instructed to record their HRV every morning upon waking and emptying of their bladder. Subjects were instructed to apply a Polar H7 Heart Rate Monitor (Polar Electro Oy, Kempele, Finland) with a sampling frequency of 1000 hz, under the xiphoid process. They then measured their HR using the Elite HRV application (www.elitehrv.com) on their cell phone lying in the supine position for 2.5min. All HVG participants were instructed in proper application of the heart rate monitor and use of the Elite HRV app. The Elite HRV app provides users with a morning readiness rating of 1-10. This score is based off of the natural log of the Root Mean Square of Successive Differences (rMSSDln), a time domain measure of HRV, and is compared to a baseline of averaged HRV readings over the past 2-10 days. Baseline HRV readings for subjects in the HVG were obtained over three days during the week prior to the 1st week of training. Natural breathing was recommended to ensure comfort for the participant and consistency throughout the study. Smart phone-generated readiness reading scores were recorded by a researcher each morning after collection throughout the study period.

Based on an analysis of the HRV readings, the day's planned resistance exercise was adjusted to each HVG player individually. The Elite HRV application provides a readiness rating based on a scale of 1 (most fatigued)-10 (most rested). Based on the readiness rating, HVG athletes modified their daily resistance exercise bout according to the following scale: HRV reading of 1-3 = static stretching and controlled breathing only; HRV reading of 4-6 = half of prescribed repetitions; HRV reading of 7-10 = maintain originally prescribed resistance exercise. Halving the prescribed number of repetitions as a means of enhancing recovery was based on the work of Pareja-Blanco et al.[15].

Controlled breathing exercises were a guided program of timed exhalation and inhalation delivered through the Elite HRV application. Each HVG participant performed the breathing exercise at a minimum of one time prior to the study beginning. The resistance training plan is detailed in Table 2. When athletes' plans were modified to perform half of the original planned repetitions, this was implemented for all lifts on that day. Odd numbers of prescribed repetitions were halved and rounded up.

After five weeks of training, three sessions per week, each session lasting 45-60 minutes, for both groups, subjects were tested for performance using the BP, BS, PC, and VJ.

Performance Testing Procedures

All 1RM tests were performed following a standard warm-up, consisting of 5 repetitions at 50% of estimated 1RM, three repetitions at 80%, one repetition at 90%, and then maximal attempts of 1 repetition repeated until failure. Rest was allowed as subjects needed between sets. All exercises (PC, BP, and BS) were performed with technique in accordance to published guidelines (18). A high degree of reliability for 1RM tests using this procedure was established at our institution (ICC = 0.91) approximately three months prior to the data collection period. Coefficients of variation for each performance test were calculated as follows: BP = 3.7%, BS = 2.6%, PC = 3.4%, and VJ = 7.3%.

The VJ was performed on a Vertec device. Athletes performed two counter movement vertical jumps. The best score of two trials was recorded to the nearest 1.27 cm. Best jump height was converted to an estimated power output using the Sayers formula, where VJ power (W) = [60.7 × jump ht (cm)] + [45.3 × body mass (kg)] - 2055.[19]

Table 2 Five-Week Resistance Exercise Program completed by HVG (n = 11) and CON (n = 16) subjects

Week 1

Monday	Intensity	Set 1	Set 2	Set 3	
Military Press	ML	10	10	10	
Hang Clean	70	5	5	5	
Clean Pull	90	5	5	5	
GHR	BW	10	10	10	
DB Bench Press	ML	10	10	10	
Wed.		Set 1	Set 2	Set 3	
Drop Under	50	5	5	5	
Back Squat	70	10	10	10	
RDL	ML	10	10	10	
Incline Bench Press	70	10	10	10	
Friday		Set 1	Set 2	Set 3	Set 4
Snatch Pull	70	3	3	3	
ECC Front Squat	80	5	5	5	5
Bench Press	70	10	10	10	

Week 2

Monday	Intensity	Set 1	Set 2	Set 3	Set 4	Set 5
Push Press	55	4	4	4	4	
Pull + Clean	70-75	3+2	3+2	3+2	2+1	2+1
GHR	BW	10	10	10		
SA DB Bench	M	×6	×6	×6		
Wed.	Intensity	Set 1	Set 2	Set 3		
3 Position Clean	60	3	3	3		
Back Squat	75-80	8	8	8		
ECC Inc Bench Press	70	5	5	5		
Friday	Intensity	Set 1	Set 2	Set 3		
Drop SN + OH Squat	50	3+3	3+3	3+3		
Front Squat	75-80	10	8	8		
Bench Press	75-80	8	8	8		
RDL	ML	10	10	10		

Week 3

Monday		Set 1	Set 2	Set 3	Set 4	Set 5	Set 6
Power Jerk	65	3	3	3	3		
Clean	80-85	3	3	3	3	3	3
Snatch Pull	75	5	5	5			
Wed.	Intensity	Set 1	Set 2	Set 3	Set 4	Set 5	
Floor Pull + Hang Clean	75	3+2	3+2	3+2			
Back Squat	75-85	10	8	6	6		
RDL	M-MH	8	8	8	6		
DB Incline Bench Press	MH	5	5	5	5	5	
Friday		Set 1	Set 2	Set 3	Set 4		
Hang Snatch	ML	4	4	4	4		
Front Squat	85	5	5	5			
Bench Press	75-85	10	8	6	6		
GHR	BW	×8	×8	×8			

Week 4

Monday	Intensity	Set 1	Set 2	Set 3	Set 4	Set 5	
Push + Split Jerk	65-70	3+2	3+2	3+2	3+2		
Clean	75-85	4	4	3	3	3	
Snatch Pull	MH	5	5	5			
Front Squat	85-90	3	3	3	3	3	
DB Floor Press	H	3	3	3	3		
Wed.	Intensity	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6
Back Squat	85-90	5	5	4	4	4	3
Bench Press	85-90	5	5	4	4	4	3
RDL	MH-H	5	5	4	4	4	
Friday	Holiday - Off						

Week 5

Monday	Holiday - Off						
Wednesday	Intensity	Set 1	Set 2	Set 3	Set 4		
Hang Pull+ Clean	70-75	3+1	3+1	2+1	2+1		
Front Squat	75-80	5	5	5			
RDL	H	5	5	5	5		
Friday	Intensity	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6
Hang Squat Clean	80-85	3	3	3			
Back Squat	80-95+	3	3	2	2	1	1
Bench Press	80-95	3	3	2	2	1	1

DB = Dumbbell, ECC= 4s eccentric movement , GHR = glute hamstring raise, OH = overhead, RDL = Romanian Deadlift, SA = Single arm, SN = Snatch; Intensities are listed numbers (%1RM) or ratings of perceived effort where L = 70-75%, ML = 75-80%, M = 75-80%, MH = 80-85%, H = 85-90% of maximum effort or bodyweight (BW).

Statistical Analysis

Data were analyzed using the SPSS software (version 21, IBM) and were found to be normally distributed ($p > 0.05$) using Kolmogorov-Smirnov tests. Subject characteristics between HVG and CON were compared at baseline using independent samples t-tests. Changes in performance (1RM and VJ) were compared between groups using a repeated measures analysis of variance (ANOVA). A Pearson Product-Moment correlation tested the relationship between volume load lifted and improvements in performance variables. Statistical significance was set at the $p \leq 0.05$ level of confidence, trends towards significance were defined as any p value between 0.05 and 0.10.[20]

RESULTS

Training completed

Volume load lifted over the 5-week period was also similar ($p = 0.955$) between groups (HRV = 138,614 ± 22645 kg vs. CON 139,028 ± 15,605 kg). The HVG averaged 4 ± 1.51 $d \cdot person^{-1}$ modified, with a range of 2-7 total training days modified among the HVG. During the 5-week period, no HVG participant produced a HRV readiness rating < 4. Following modified training days, HVG subjects displayed an average 2.3 ± 2.2 increase in the next day's readiness rating, compared to an average change in readiness reading of 0.0 ± 1.7 between successive days that were not modified. Day to day changes in HRV readiness rating ranged from -2 to + 6, with positive changes in HRV readiness occurring in 28 of 38 instances after training was modified.

Performance measures

Table 3 displays pre- and post-1RM and vertical jump power measures. There were no significant group × time interactions for changes in performance variables (BP = 0.640; BS = 0.387; VJ = 0.970). The group × time interaction for power clean displayed a trend towards significance (group × time interaction $p = 0.087$), with power clean increasing + 8.6% in HVG vs. + 2.6% in CON. Percent changes for all performance variables for HVG and CON are displayed in Figure 1. For both groups ($n = 27$) significant increases in BP (123.1 ± 19.9 kg to 128.6 ± 17.3 kg, time effect $p < .001$), BS (175.0 ± 28.5 kg to 183.5 ± 29.1 kg, time effect $p < 0.001$), PC (115.2 ± 14.1 kg to 120.9 ± 14.9 kg, time effect $p = 0.002$), and VJ (time effect $p = 0.029$) were observed after training. There were no correlations between volume load lifted and changes in performance variables ($p \geq 0.265$).

Table 3 Performance Measures for HVG (n = 11) and CON (n = 16) groups at Baseline after after 5 wks training

Variable	CON (n = 16)	HVG (n = 11)	time effect p value	group × time effect
1RM Bench Press (kg)				
Baseline	128.8 ± 18.2	114.6 ± 17.2		
Post	134.0 ± 16.0	120.8 ± 16.6	<0.001	0.640
1 RM Back Squat (kg)				
Baseline	179.7 ± 25.6	168.2 ± 32.2		
Post	189.2 ± 29.6	175.0 ± 29.2	<0.001	0.387
1 RM Power Clean (kg)				
Baseline	118.5 ± 15.6	110.3 ± 10.3		
Post	121.6 ± 15.3	119.8 ± ± 15.4	0.002	.087
Vertical Jump (W)				
Baseline	7,016 ± 507	6,915 ± 1,028		
Post	7,136 ± 544	7,031 ± 1,071	0.029	.970

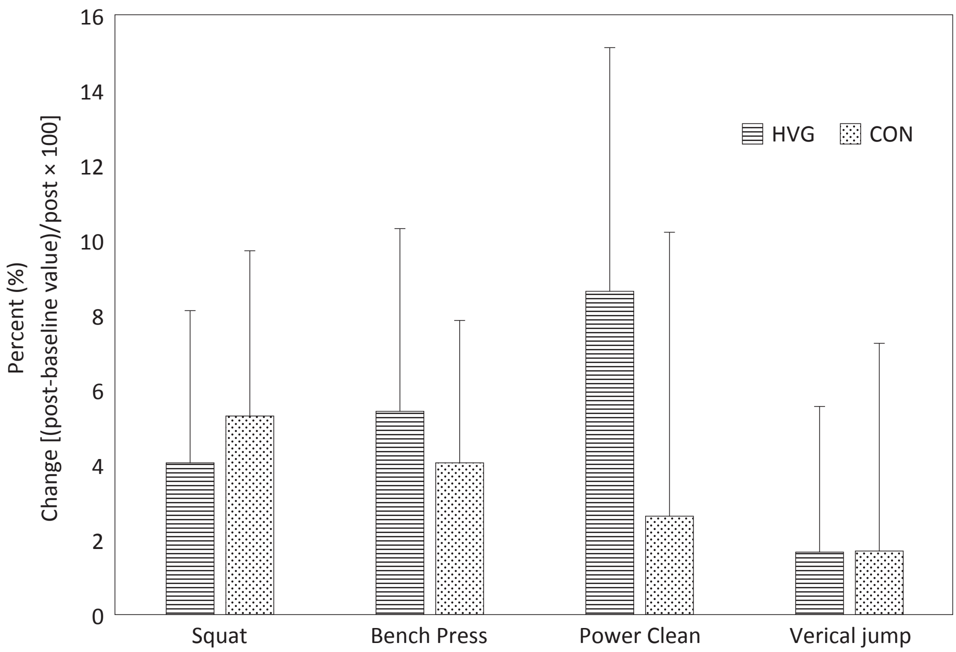

Figure 1 Percent Change in Performance Variables (Bench Press, Back Squat, Power Clean, and Vertical Jump) after 5 wks of Periodized Training between HVG (n = 11) and CON (n = 16).

DISCUSSION

The present study adjusted resistance training volume according to HRV readings in attempt to promote better performance outcomes. The CON group and the HVG group completed a similar volume load at the end of the five week period, and achieved similar improvements in performance for all variables measured. The average amount of days modified from HVG throughout the 5-week period 4 ± 1.51 days per person.

Despite the between-group similarities in improvements in BP, BS, and VJ, the HVG did trend towards producing a greater increase in the 1RM PC (group × time interaction p = 0.087, approaching a medium effect size). If this trend were to prove meaningful, it could indicate that multi-joint, high velocity, highly technical movements such as the PC will stress the ANS more so than simpler, lower-velocity exercises, and thus performance on these exercises could prove more sensitive to an athlete's state of fatigue.[21]

The present study is the first to employ individualized programming via HRV in resistance training. Previously, Kiviniemi[4,5] and Vesterinin et al.[6] prescribed individualized training in endurance athletes. Kiviniemi found adjusting daily training according to HRV accomplished greater[5] or equal[4] improvements in maximum running velocity than following a preprogrammed plan, while completing lesser training load to achieve their results. Vesterinin et al.[6] examined running training via heart rate variability for eight weeks in recreational athletes, and found that, compared to a preprogrammed plan, modifying training via HRV produced significantly greater improvements in 3000m run times. The HRV-modified training group enjoyed this enhanced running performance after completing significantly fewer high and moderate intensity training sessions than the preprogrammed training.[6] In contrast, the present data did not find significant differences between HVG and CON, though 1RM PC trended (group × time interaction $p = 0.087$) towards a greater improvement in the HVG. Possible reasons for this the lack of performance differences between HVG and CON include the length of the intervention, and the type of resistance training that was being performed. Specifically, the present study examined an intervention period of 5wks duration. Vesterinin et al.'s study examined an 8wk training period, providing more time for training adaptation between groups.[6] Further, the training period examined by Vesterinin et al. was described as a period of intensified training, in which subjects were asked to perform high intensity intervals (4 sets × 4 min @ 90% + VO2max) and hard (85% + VO2max) constant runs in weekly training.[6] Such intense training is likely to challenge recovery and produce measurable changes in HRV.[22]

Limitations

The training program employed in the current study was intended to promote optimal performance gains and allow adequate restitution for both groups, as the chief priority for our strength staff was maximizing performance in these competitive athletes, regardless of group assignment. Thus, the preprogrammed plan examined in the present study was not ideal to observe advantages of individualizing training via HRV. Future studies, examining a preprogrammed plan with extended periods of high volume and high intensity resistance training, where inducing an overreached state in athletes is likely, would provide an environment more conducive to revealing advantages of individualizing exercise prescription according to HRV.

Despite the relative ease of using the EliteHRV app, there were instances of athletes arriving for lifting sessions late, and citing difficulty with the HRV measure as their cause of tardiness. Distributing the HR monitors and having the athletes lie down and take the HRV reading at the training facility is suggested as an antidote to this problem.[23]

In conclusion, modifying resistance exercise according to HRV did not produce increases in performance above those seen following a periodized training plan. Programming resistance training according to HRV may prove useful for longer, more intense training periods.

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