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The Effects of a Peaking Protocol on Heart Rate Variability and its Predictive Associations with Wilks Coefficient in Competitive Powerlifters

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ABSTRACT

Powerlifting competition is comprised of three barbell lifts: squat, bench press, and deadlift that are all completed in a single day and summed together, ultimately normalized to the lifter's body weight via the Wilks Coefficient. This figure is then subsequently employed to determine the "best" athlete in that meet. During the competition preparation, powerlifters often undergo peaking protocols which include physiologically taxing overreach and low-volume, recovery-focused taper phases to collectively induce super-compensatory strength adaptations. Heart rate variability (HRV) has emerged as an easily accessible, user-friendly biomarker for autonomic nervous system-associated fatigue and readiness. Therefore, the purpose of this observational study was to investigate the potential impact of a peaking protocol on fatigue/readiness via HRV measurements and its possible relationship with competitive powerlifting performance. Daily measurements of HRV were taken, each morning, using the HRV4Trainning smartphone application by nineteen competitive powerlifters (26.16±4.56 years) from 14-days prior to a peaking protocol, throughout individual peaking phases, on meet day, and 14-days following competition. A quadratic regression was used to determine the predictability of HRV measurements and powerlifting performance. The change in HRV from competition day to baseline was found to be a significant predictor of Wilks coefficient ($p=0.038$, $R^2=0.336$; mean±SE log-transformed root mean square of successive R-R intervals [lnRMSSD] = -51.98±22.23). Although extrapolations of the present study are limited by inherent subject peaking protocol variability, these data suggest HRV may nonetheless represent a viable means to modulate individual athlete training programs to promote recovery.

INTRODUCTION

Powerlifting competition is comprised of three barbell lifts: squat, bench press, and deadlift that are all completed in a single day and summed together, ultimately normalized to the lifter's body weight via the Wilks Coefficient. Consequently, powerlifters often adopt specific training protocols - either self- or coach-developed – that ultimately follow periodized progression referred [1]. Periodization modulates training loads via daily, weekly, or monthly alterations

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in training load, frequency, repetition scheme, and/or exercise variation to potentially enhance strength adaptation [2], [3]. The two main guiding principles of training prescription have been developed utilizing two theories of adaptation and performance: the Selye general adaptation syndrome [4] and the fitness-fatigue theory [5]. The final block of training is considered the peaking block and is comprised of two phases: (a) overreaching and (b) taper. The overreaching phase of the peaking protocol is the period of time where the main training stimulus is applied. During this period, there are increases in training load and intensity resulting in an acute performance decrease and commensurate fatigue increase [6]. Overtraining often occurs when the training load frequency is too great or the body is not given the resources (e.g. time, nutrients) to recover [6]. Overtraining can be attributed to a decrease in performance, motivation, immune system function, and/or injury [7]. Currently, a combination of invasive tests assessing urea, uric acid, ammonia, creatine kinase and the testosterone-to-cortisone (T/C) ratio are used to help in athlete overtraining status [8]. The T/C ratio is an important marker as it can be used as an indicator of the balance of anabolic to catabolic processes and to diagnose overreaching or overtraining. Coutts et al. [9], showed that immediately following a 6-week overreaching phase, the plasma T/C ratio in rugby athletes was significantly decreased compared to pre-training levels and that following a 7-day taper phase the ratio was still significantly depressed (31.4 ± 6.6 pre-training, 22.11 ± 5.4 post-training, and 23.9 ± 3.1 taper). To combat the accumulated fatigue accrued during the overreaching phase, the taper (i.e. unloading) portion of the peaking protocol is the last phase completed prior to competition. The duration of the tapering phase typically lasts between 1-4 weeks [10]. The main objective of the tapering phase is to minimize accumulated fatigue without diminishing the strength compensations that were acquired previously [11]. This effect is achieved by training volume attenuations, elicited by reducing the total completed repetitions and/or working sets in a training session. This ultimately shortens training duration to enhance recovery speed, whilst often maintaining relative intensity as per % one-repetition maximum (1RM) [11]. The most widely used taper protocols include linear, exponential (i.e. slow decay, fast decay), and step tapers [11]. Although there are many protocols that can be employed, the overall strategies are reductions in volume (i.e., repetitions, sets) from 60-90%, while maintaining training intensity (i.e.,>80%1RM) and largely sustaining frequency [11] all with the goal of increasing performance while decreasing the fatigue level of the athlete.

Heart rate variability (HRV) has emerged as a potential noninvasive biomarker to identify overtraining in various types of athletes [12], [13]. Morales et al. [14] consequently demonstrated that judo athletes who were exposed to a high training load had lower natural logarithm of root mean square of the squared differences between adjacent normal R-R intervals (LnRMSSD) values. Additionally, Baumert et al., [15] showed that HRV significantly decreases throughout a two-week training camp including cycling and running. With specific regards to resistance training outcomes, Thamm et al.[16], demonstrated depressed HRV up to 30-minutes following both hypertrophy and strength training sessions that subsequently return to normal. During a six-day overload microcycle Schneider et al. [17] saw LnRMSSD decrease compared to baseline, which increased during a four-day recovery period. Additionally, Kaikkonen et al. [18] recently found that during a 2-week intensive resistance training period, the nocturnal RMSSD was significantly decreased. During a 3-week protocol that consisted of a 1-week introduction microcycle, 1-week overload microcycle and a 1-week taper microcycle, LnRMSSD measured in the morning decreased from baseline to post-overload while post-taper was not different from post-overload [19]. This suggests that LnRMSSD is a sensitive marker of training fatigue during an overload microcycle. Specifically, HRV may be an especially relevant tool in competitive powerlifting. Powerlifter training protocols are similar to recreational resistance training and result in comparable physiological adaptations [20]. These athletes also commonly employ periodized peaking protocols preceding competition, which inherently involve training volume fluctuations that may reasonably impact HRV and associated performance indices. Therein, investigating the potential interaction between HRV and powerlifter peaking protocols simultaneously explores two heavily under-investigated demographics: athletes and strength-based populations. As previously mentioned, and pertaining to powerlifting, the overload or overreaching portion of a peaking protocol is characterized by an increase in training volume and intensity, which is then followed by a taper where intensity remains elevated but volume decreases. In a recent systematic review and meta-analysis, Marasingha-Arachchige et al. [21] showed that resistance training programs with higher intensities and lower training volumes allowed for an optimal training load without inducing a large

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stress on the autonomic nervous system (ANS). The authors theorized that the relatively low-volume and concomitantly higher intensities allowed for recovery, whilst also achieving the desired training adaptions to resistance training. Thus, it can be theorized that the overreaching phase of a peaking protocol for powerlifters would show lower LnRMSSD readings compared to the taper portion. In addition to monitoring athlete fatigue HRV has researched as a proxy measure for performance. Following training Ataloui et al., [22] showed that HRV indices were not changed following intense training and resistance training but normalized high-frequency measurements were positively correlated with performance. Additionally, Garet et al., [23] found that the fluctuation in global and parasympathetic ANS activity correlated with the fluctuation in performance.

To date, there is limited published literature exploring the relationship between powerlifting and HRV. Powerlifting meet performance is quantified by the highest Wilks coefficient in the athlete's weight class and the meet overall [24]. The Wilks coefficient is a standardized result of the athlete's body weight and total amount lifted in the three movements (i.e. squat, bench press, deadlift) during the course of the competition[24]. As HRV has been used to help potentially detect and prevent overtraining in athletes [12], [25] we hypothesized that a lower HRV on competition day, compared to a baseline preceding the peaking protocol, would lead to a lower Wilks coefficient on competition day. Conversely, a higher HRV on competition day compared to baseline would lead to a higher Wilks coefficient. Thus, the primary aim of this study was to determine if HRV on competition day compared to baseline average could predict Wilks coefficient. A secondary aim of this paper was to determine the ability of HRV indices to measure the effect of the overreach and taper portions of the peaking protocol of powerlifting athletes.

METHODS

Experimental Approach to the Problem

The current investigation utilized an observational approach to determine peaking protocol phase-specific impacts on HRV. Furthermore, we aimed to elucidate the extent to which HRV is able to predict powerlifting success as defined by a greater meet day Wilks Coefficient. HRV was recorded for 14-days prior to starting a peaking protocol (baseline), during the overreach and taper phases, as well as both on and 14-days post competition day. It is important to note the inherent between-subject variations in overall load-volume, considering individual peaking programs were characterized by diverse phase-specific lengths and exercise frequencies and thus not standardized.

Subjects

Prior to recruiting subjects, researchers obtained approval for the research protocol from the Institutional Review Board for Human Subjects (Reference #: 1389246). Electronically signed informed consent were received from each subject prior to inclusion in the study. A convenience sample of twenty-five subjects were recruited and volunteered to serve as study subjects, (24 United States, 1 New Zealand athlete). All subjects were powerlifting athletes who had competed in at least one sanctioned powerlifting (United States Powerlifting Association or USA Powerlifting) meet and obtained a Wilks coefficient greater than 350 prior to enrolling in this study. While there are no established standards for powerlifting performance, all subjects were required to have acquired the aforementioned Wilks coefficient in an effort to exclude inexperienced powerlifters from the investigation [20]. All subjects were between the ages of 18-35 years and were scheduled to compete in an upcoming sanctioned powerlifting meet in the "raw" division (limited supportive equipment) [26]. Exclusion criteria included the use of anabolic androgenic steroids within the past year, the use of any emotional or psychotropic medications (e.g., methylphenidate, 1-phenylpropan-2-amine), and no subjects could have any known metabolic disorder (e.g. heart disease, arrhythmias, diabetes, thyroid disease, hypogonadism). Recruitment efforts resulted in twenty-five athletes agreeing to participate. 21 (Males = 12, Females = 9, Age = 26.0 ± 4.5, Weight = 72.5kg ± 17.9, prior Wilks coefficient = 432.1 ± 55.4), had completed the study as a result of either training injury, not completing all of the required HRV measurements or providing necessary background information.

Protocol

HRV is defined as the oscillation in the interval between consecutive heartbeats in addition to the oscillations between consecutive instantaneous heart rates [27]. HRV measurement requires the amount of time recorded between normal R-R peaks of two subsequent QRS complexes from an ECG [28]. The most popular technique for

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analysis is the RMSSD [28]. The RMSSD can serves as insight into the overall variability of heart rate; however, it cannot distinguish the main cause for the variability [29]. The natural logarithm of RMSSD (LnRMSSD) is taken to reduce the skewness of the RMSSD [29]. HRV measurements were obtained using photoplethysmography (PPG) through a smartphone application (app) "HRV4Training", previously validated against the Polar H7 Heart Rate Strap and Electrocardiography [30]. This app was chosen as all that is required is a smartphone with a camera and a flash. Due to remotely monitoring the athletes the research team felt that this was the best solution as the PPG technology has previously been validated against techniques which require more equipment and is readily available in the Apple and Android App Store. PPG is technique that detects changes in blood volume during a cardiac cycle by illuminating the skin and measuring changes in light absorption [30]. Sampling rate is conducted at 30 frames per second and filtered using a Butterworth band pass filter [31]. Instructions on how to place the finger over the camera and to hold still while recording for the minute duration were provided by the HRV4Training smartphone app upon first use [30].To avoid circadian fluctuations due to time of day and measurement position, subjects were instructed to complete measurements every morning after waking and emptying their bladder; they did so in a seated position and the total assessment time was about one-minute in length [32], [33]. Athletes were blinded to their data displayed both on the mobile and desktop application to prevent them from modulating their training protocols based on data feedback and interpretation. HRV was recorded 14 days prior to starting a peaking protocol (baseline), during the entire peaking protocol including competition day, and 14 days post-competition. Importantly, there were inherent variations between overall load-volume and lifting day-to-day frequency between subjects, considering that peaking protocols were not standardized and unsupervised. The peaking protocols were also not standardized as the athletes were not trained by the research team. Thus, all athletes remotely trained for their respective competitions and remotely measured HRV through a smartphone app. The RMSSD was the HRV measure used for analysis; this method has been shown to have a higher reliability compared to other HRV indices with short duration measurements [34]. The RMSSD was then log transformed (LnRMSSD) to reduce the data skewness. The averages of each phase (baseline, overreach, taper and post) were taken for the LnRMSSD. The $LnRMSSD_{baseline}$ was then subtracted from the LnRMSSD the morning of the competition ($LnRMSSD_{competition}$) to obtain $LnRMSSD_{delta}$. Wilks coefficient was obtained from an open-source powerlifting record database (https://www.openpowerlifting.org/).

Statistical Analysis

All statistical analyses were performed in IBM SPSS Statistics for Windows, version 25 (IBM Corp., Armonk, N.Y., USA) and results are expressed as means ± *SD*s. The average LnRMSSD of each peaking phase ($LnRMSSD_{baseline}$, $LnRMSSD_{overreach}$, $LnRMSSD_{taper}$, $LnRMSSD_{competition}$, and $LnRMSSD_{post}$) were analyzed using a one-way ANOVA with repeated measures. In the case of a significant effect, a Bonferroni adjustment was employed to compare main effects whilst adjusting for multiple comparison alpha inflation. To determine the ability of $LnRMSSD_{delta}$ to predict competition day Wilk's coefficient as an index of competitive success, an ordinary least squares regression analysis was performed using both linear

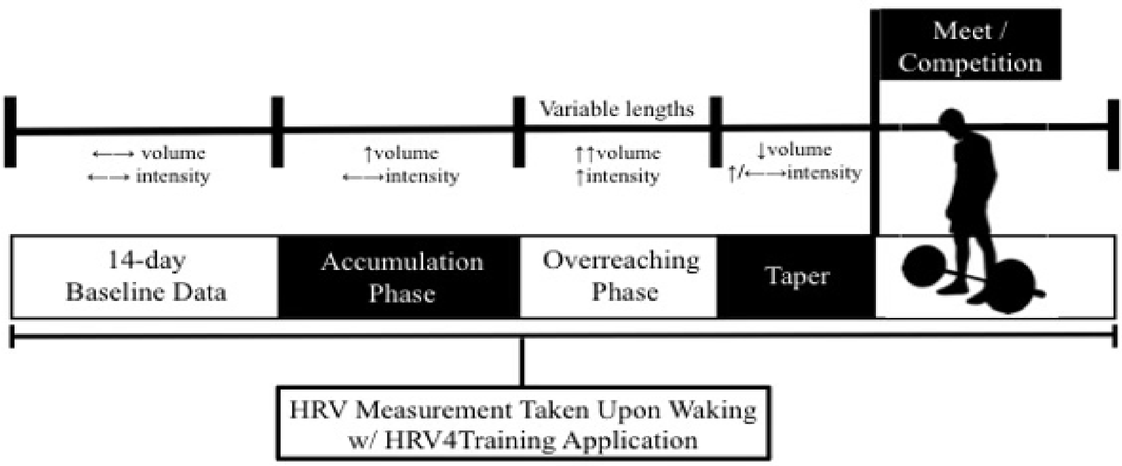

Figure 1. Study timeline/protocol visualization.

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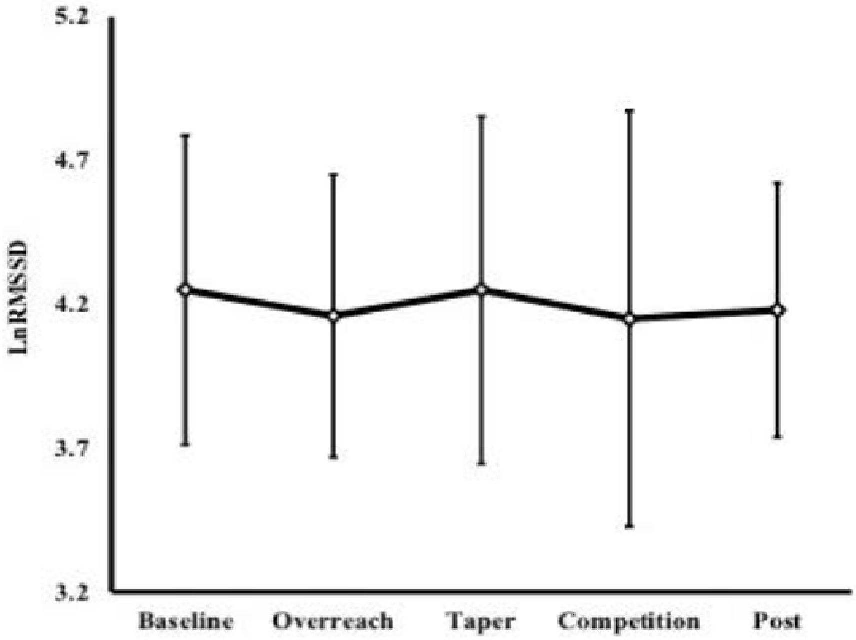

Figure 2. LnRMSSD progression from baseline (14-days prior to peaking protocol) through post-competition (14-days following each athlete's respective powerlifting meet.

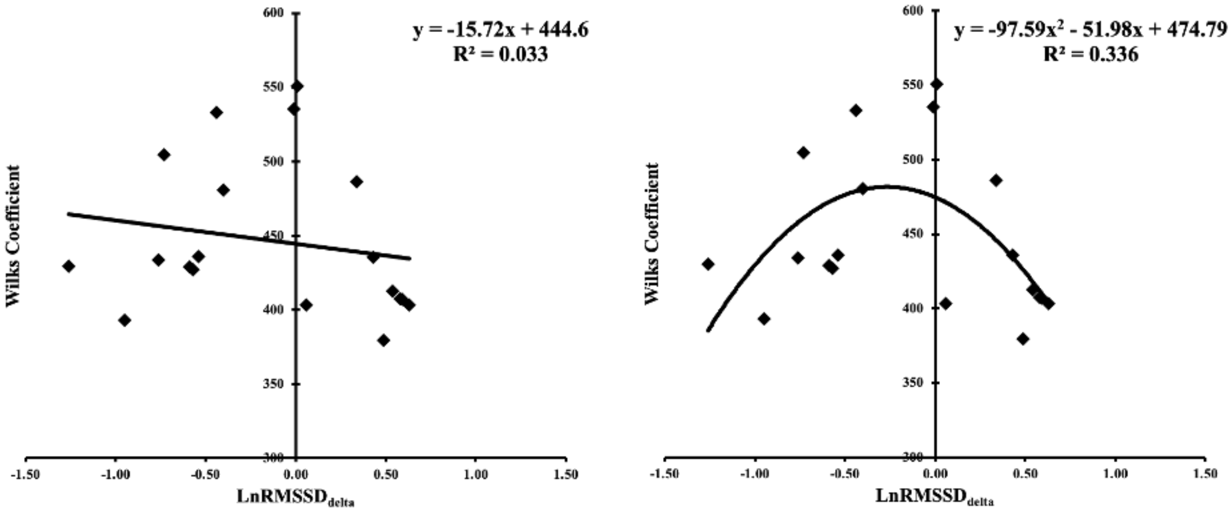

Figure 3. Linear (A) and quadratic (B) functions depicting LnRMSSDdelta and its ability to predict competition day performance (as defined by Wilks Coefficient).

and quadratic equations to predict Wilks Coefficient using $LnRMSSD_{delta}$. The quadratic regression was calculated using the square of $LnRMSSD_{delta}$ ($LnRMSSD_{delta}^2$). The coefficient of determination (R^2) was used to estimate the proportion of variance in the dependent variables explained by the independent variable, whereby R^2=.01, small, R^2=.09, medium, R^2=.25, large effects [35]. Statistical significance was set at $p \leq 0.05$.

RESULTS

LnRMSSD ($\chi2$ [9] = 37.190, p<0.001) repeated measures ANOVA analyses violated Mauchly's Test of Sphericity. Thus, the Greenhouse-Geisser correction was used to compare means. LnRMSSD (F[1.851, 29.623] = 0.922, p = 0.402) did not differ significantly with time (see Figure 2).

The linear regression predicting Wilk's coefficient using $LnRMSSD_{delta}$ was not significant (R^2 = 0.033, F = 0.575, p = 0.459). However, the quadratic regression using the square of $LnRMSSD_{delta}$ as well as its linear term, was found to be significant (R^2 = 0.335, F = 4.035, p = 0.038). The graphs showing the linear and quadratic (Figure 3A and 3B) models are shown as well as the summary of values in Table 2.

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Table 1. Unstandardized coefficients for the linear and quadratic regression models

	LINEAR MODEL	QUADRATIC MODEL
$LNRMSSD_{DELTA}$	-15.72 (20.72)	-51.98 (22.23) *
$LNRMSSD_{DELTA}{}^2$	-	-97.59 (36.16) *
CONSTANT	444.60 (12.43)	474.79 (15.42)
R^2	0.03	0.34

Standard errors shown in parentheses

*Significant regression predictor $p \leq 0.05$

DISCUSSION

The present investigation aimed to determine how HRV is impacted by powerlifting competition preparation and evaluate the extent to which this biomarker may predict meet day performance. Interestingly, LnRMSSD did not significantly vary between any phase of the peaking protocol. However, it is worth noting that the means illustrated in figure 2 favored (although not significant) an expected direction, whereby HRV indices decrease during the fatiguing volume-intensive overreach phase before rebounding upwards in response to the lower-volume taper period [11], [16], [17], [19]. While allowing athletes to perform their individualized peaking protocols ultimately enhanced participation and external validity, we contend that this freedom promoted widespread variability amongst our data and subsequently limited any opportunity to detect significant between-phase differences. Furthermore, we were unable to supervise each participant's training to ensure that the reported protocols were accurate. Future studies should therein aim to better standardize subject peaking phase length and quantify their diverse stressors across the investigative timeline in an observable laboratory setting; these modifications may ultimately clarify the variability in both between-phase and baseline-to-competition HRV indices.

Contrary to our original hypothesis, a higher HRV was not associated with a higher Wilks Coefficient in this sample. Nevertheless, our data substantiate a significant strong relationship between HRV and competitive powerlifting performance as $LnRMSSD_{delta}$ nears 0, demonstrated via the quadratic regression model. The highest Wilks Coefficients, 550.58 and 535.23, were both associated with an $LnRMSSD_{delta}$ of 0.01 and -0.01 respectively. To our knowledge, this is the first study to discover a predictive interaction between LnRMSSD and powerlifting performance. Consequently, the individuals who did not re-approach their baseline HRV may have not recovered fully from their respective overreaching phases, possibly hindering their competition day performance. This effect was similarly evident in LnRMSSD measures reported by Williams et al.[19], whereby 1-week post-overload and taper microcycle values were statistically equivocal. A meta-analysis conducted by Kim et al. [36]illustrated that HRV is sensitive to stress-mediated changes in ANS activity. This stress can come from professional sources and travel [37]–[39] which would ultimately decrease the athlete's competition day HRV. For example, HRV indices were found to be affected by anticipatedly higher-versus-lower demanding matches in female soccer athletes, which were associated with changes in cognitive anxiety [40]. Furthermore, it is possible that the performance anxiety of subjects could have led to the currently displayed attenuated LnRMSSD average. A recent meta-analysis demonstrated that acute mental stress has been shown to significantly decrease HRV in healthy adults [41]. Although the acute stressors in the aforementioned meta-analysis included academic stresses and not athletic tests, it can be theorized that acute competition day stress could lead to the same effect (i.e. decreased HRV).

The inverted "U-shape" of the quadratic model is unmistakably reminiscent of the arousal-performance curve. Incidentally, the latter can reliably predict performance in an inverted U-shape curve [42] and this over arousal could have been due to the performance anxiety mentioned previously [40]. Additionally, the downward slope (primarily present on the positive x-axis) of the quadratic regression raises the question as to why the higher HRV levels were associated with a lower Wilks Coefficient as well. A potential explanation may be that these athletes' taper lengths were too long, thus sacrificing sport specificity and fostering subsequent performance decrement. Consequently, the optimal taper length for an athlete is highly individualistic as shown by a previous mathematical model [10]. Through this aforementioned study, it was found that a group of international level swimmers had optimal taper lengths varying from 12 to 32 days [10]. The variability illustrated among this demographic suggests that powerlifting tapers may require an individualized approach. This notion is further evidenced by prior findings that describe the latency to HRV recovery following a single resistance training session, let alone a full, multi-session periodized peaking protocol [17]. Thus, coaches and athletes are left to follow the more generalized scientific recommendations of a varied 1-4 week timeframe

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PRACTICAL APPLICATIONS

Individual athletes respond uniquely to a set peaking protocol. Older, more experienced athletes will need longer recovery times following an overreach protocol due to the high loads needed to induce super compensatory effects. For competitive powerlifters, protocol customization has mostly been employed subjectively, using a coach's visual assessment and inferences predicated upon previous experience. The ability to gain insight into quantitative, athlete-specific training responses is therefore invaluable to both the athlete and the coaching professional. Competition day HRV analysis relative to baseline measurements may provide data regarding a powerlifter's recovery and commensurate preparedness for putting forth optimal meet-day performance. Therein, implementing a mock peaking protocol prior to a competition-intended variation could impart insight into more appropriate, individualized program lengths, loads, and timing.

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