Parasympathetic Nervous Activity Mirrors Recovery Status in Weightlifting Performance After Training

Jui-Lien Chen,[1] Ding-Peng Yeh,[1] Jo-Ping Lee,[1] Chung-Yu Chen,[1] Chih-Yang Huang,[2,3] Shin-Da Lee,[4,5] Chiu-Chou Chen,[1] Terry B.J. Kuo,[6] Chung-Lan Kao,[6,7] and Chia-Hua Kuo[1,4]

[1]Laboratory of Exercise Biochemistry, Taipei Physical Education College, Taipei, Taiwan; [2]Graduate Institute of Basic Medical Science, Graduate Institute of Chinese Medical Science, China Medical University, Taichung, Taiwan; [3]Department of Health and Nutrition Biotechnology, Asia University, Taichung, Taiwan; [4]Department of Physical Therapy, Graduate Institute of Rehabilitation Science, China Medical University, Taichung, Taiwan; [5]Department of Healthcare Administration, Asia University, Taichung, Taiwan; [6]School of Medicine, National Yang-Ming University, Taipei, Taiwan; and [7]Department of Physical Medicine and Rehabilitation, Taipei Veterans General Hospital, Taipei, Taiwan

Abstract

Chen, J-L, Yeh, D-P, Lee, J-P, Chen, C-Y, Huang, C-Y, Lee, S-D, Chen, C-C, Kuo, TBJ, Kao, C-L, and Kuo, C-H. Parasympathetic nervous activity mirrors recovery status in weightlifting performance after training. *J Strength Cond Res* 25(X): 000–000, 2011—Heart rate variability (HRV) and parasympathetic power are closely related to the well-being and health status in humans. The main goal of the study was to determine whether these measures can reflect recovery status after weight training. After a 10-day detraining period, 7 weightlifters were challenged with a 2-hour weight training which elicited approximately fourfold increases in circulating muscle creatine kinase level and protracted pain feeling ($p < 0.05$). Weightlifting performance was then evaluated 3, 24, 48, and 72 hours after training to determine the degree of recovery from fatigue. Heart rate variability, circulating dehydroepiandrostendione sulfate (DHEA-S), and muscle damage markers were measured before each performance test. An electrocardiogram was recorded for 5 minutes continuously at rest in seated positions. After training, weightlifting performance of the subjects decreased below baseline in paralleled with suppressed parasympathetic power (high-frequency [HF] HRV), whereas sympathetic power (normalized low-frequency HRV) was slightly elevated at 3 hours of recovery ($p < 0.05$). Both weightlifting performances and parasympathetic power returned to baseline values in 24 hours and further increased above baseline during 48–72 hours of recovery in a similar fashion ($p < 0.05$). Circulating DHEA-S level dropped at 24 hours ($p < 0.05$) and returned to normal values by 48 hours. Muscle pain increased at 3 hours after training and remained higher than baseline values for the 72-hour recovery period ($p < 0.05$). Our data suggest that parasympathetic power, indicated by HF HRV, is able to reflect the recovery status of weightlifters after training.

Key Words fatigue, weightlifter, strength performance, frequency-domain analysis, muscle power, vagal

Address correspondence to Dr. Chia-Hua Kuo, kuochiahua@gmail.com, or Dr Chung-Lan Kao, clkao@vghtpe.gov.tw.

0(0)/1–7

Journal of Strength and Conditioning Research

Introduction

For most weightlifters, who perform 3 workouts a week, recovery is the period between the end of 1 workout and the beginning of the next. The optimal time of recovery allows weightlifters to sustain a greater weight challenge on the upcoming competition event or the next workout. Conversely, inadequate recovery after training results in fatigue or underperformance. The development of a noninvasive surrogate marker would help coaches to monitor the recovery status of weightlifters in the preparation for competitions or modulation of training load.

Heart rate variability (HRV), determined by beat-to-beat time variations in heart rate, is the outcome of dynamic control of the cardiovascular system governed by the sympathetic and parasympathetic nervous activities. This noninvasive measure has attracted vast interest because of its significant correlation with health status such as cardiovascular morbidity (16), well-being state such as effort-reward imbalance (10), and all-cause mortality (15). Its association with weightlifting performance, representing the coping capability against maximal physical challenge, has not yet been reported.

Spectral analysis (frequency-domain method) on HRV provides an estimation of the quantity of variation at specific frequencies and is able to reflect changes in autonomic

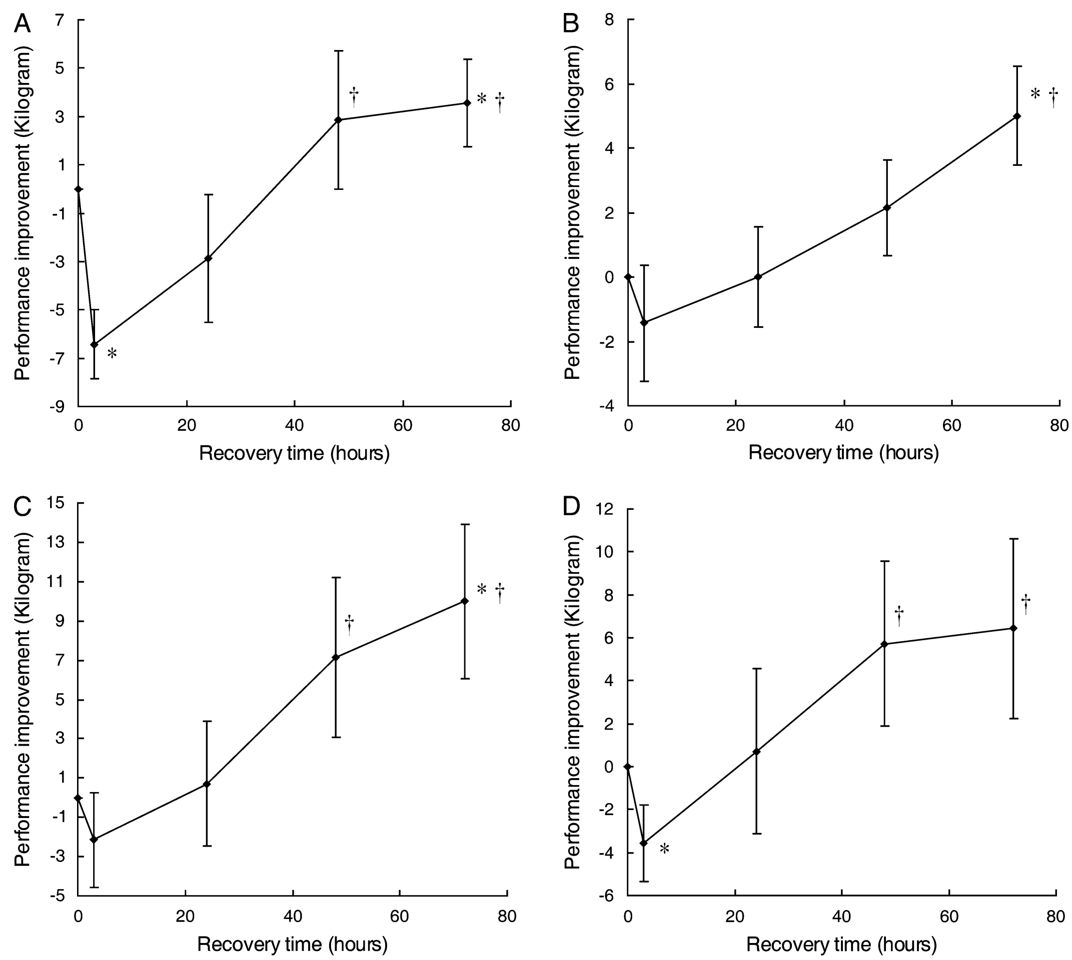

Figure 1. Weightlifting performance during recovery. Maximal weights lifted from 3 attempts were recorded for 4 types of exercise: A) back squat, B) seated shoulder press, C) dead lift, and D) front squat. *Significant difference from pre; †Significant difference from the bottom line (3-hour value) ($N = 7$, $p < 0.05$).

nervous control of the heart rate. Three major portions are geometrically distinguished in a spectrum calculated from 5-minute standardized recordings under resting condition (1,21,26): high-frequency (HF), low-frequency (LF), and very low-frequency (VLF) portions. High-frequency power is contributed by parasympathetic nervous activity, whereas LF power in normalized units is considered as a marker of sympathetic nervous activity. These are based on the experimental observations of autonomic manipulations such as electrical stimulation on vagal nerve (1), application of autonomic blocking agents (25), vagotomy (24), and exercise (21). The LF/HF ratio has been thought to reflect sympathoparasympathetic nervous balance or to reflect sympathetic nervous modulations (20). The physiological explanation for the VLF power is less clear.

An association between concurrent gains in parasympathetic power and maximal aerobic capacity has been reported in endurance athletes (11). Recent investigation has further shown that the rebound in autonomic nervous activity after a 2-week recovery was associated with performance enhancement in swimmers (8). These studies suggest that HRV measurements could be a useful tool for monitoring the recovery status in aerobic type of athletic performance during a training/competition cycle. However, it has been reported in 1 study that anaerobic exercise significantly attenuates fast recovery in autonomic control (2), suggesting that exercise mode can affect the recovery time. The current knowledge regarding the link between autonomic nervous modulation and weight training performance is lacking. Thus, the main goal of the study was to determine the covariations in HRV modulations and weightlifting performance changes during a 72-hour recovery period after training.

Furthermore, the neurosteroid dehydroepiandrostendione sulfate (DHEA-S) has been found to be required for repair process after damage in the nervous system (13). Tsai et al. reported a protracted reduction in circulating DHEA-S level

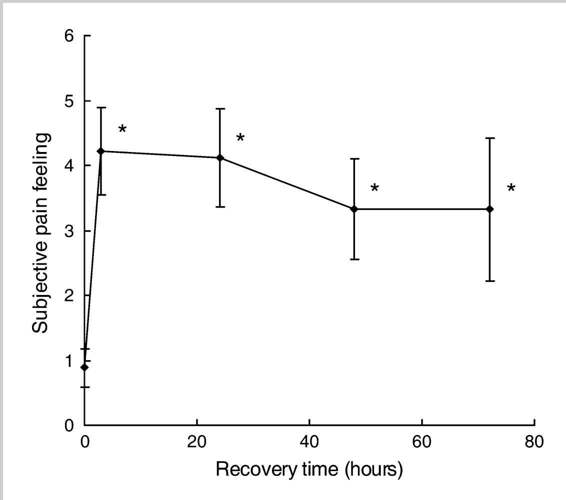

Figure 2. Subjective pain feeling during recovery. *Significant difference from pre ($N = 7$, $p < 0.05$).

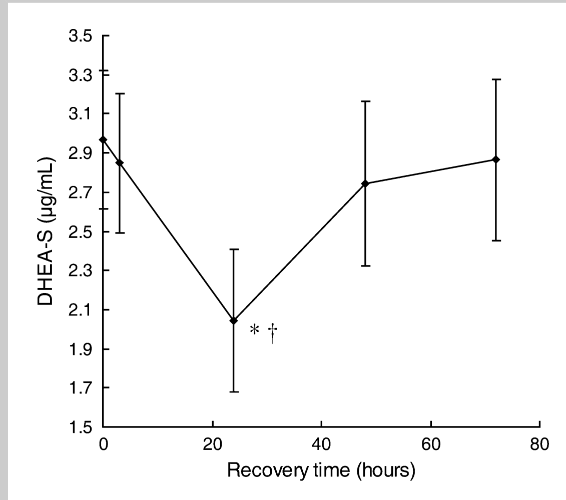

Figure 4. Plasma DHEA-S levels. *Significant difference from pre ($N = 7$, $p < 0.05$).

during recovery phase after resistance training and many other types of stress (29–31). Intervention that enhances DHEA-S level has been found to increase HRV (22). Therefore, changes in circulating DHEA-S were also measured in line with HRV and weightlifting performance during the same recovery period.

Methods

Experimental Approach to the Problem

This study was designed to examine the covariations in HRV modulations and weightlifting performance changes during a 72-hour recovery period after training. The hypothesis was that parasympathetic nervous activity can reflect recovery status in weightlifting performance after training.

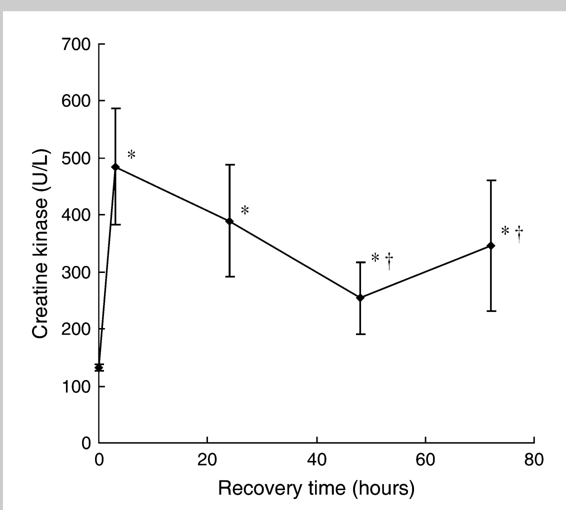

Figure 3. Plasma creatine kinase levels. *Significant difference from pre ($N = 7$, $p < 0.05$).

Subjects

Male weightlifters (19.3 ± 0.3 years, $N = 7$), with >6-year training history of national- or international-level competitions, voluntarily participated in this study. This study was conducted in accordance with the guidelines of the Declaration of Helsinki. Subjects were informed of the experimental risks, and they signed an informed consent before the investigation. This study was approved by the Human Subject Committee of the Taipei Physical Education College, and the subjects gave informed consent.

Procedures

To determine HRV modulation during a training recovery, all weightlifters attended an acute bout of a 2-hour weightlifting training program after 10 days of detraining. Four types of exercises were performed: back squat, seated shoulder press, dead lift, and front squat. The intensity for each training started from 60% maximal effort 3 times, 70% maximal effort 3 times, 80% maximal effort 3 times, 90% maximal effort 2 times, 95% maximal effort 1 time with ~90-second rest on each pull. All sessions were supervised by the coach to monitor the appropriate amount of exercises and time of rest intervals. The participants were then made to recover in sedentary conditions for 72 hours. Assessments for HRV and weightlifting performance were performed before training, and 3, 24, 48, and 72 hours during recovery. The participants' normal daily living schedules, including sleeping and eating, remained unchanged. Weightlifting performance was recorded 5 minutes after HRV assessments at each time point. Blood samples were collected immediately after each HRV

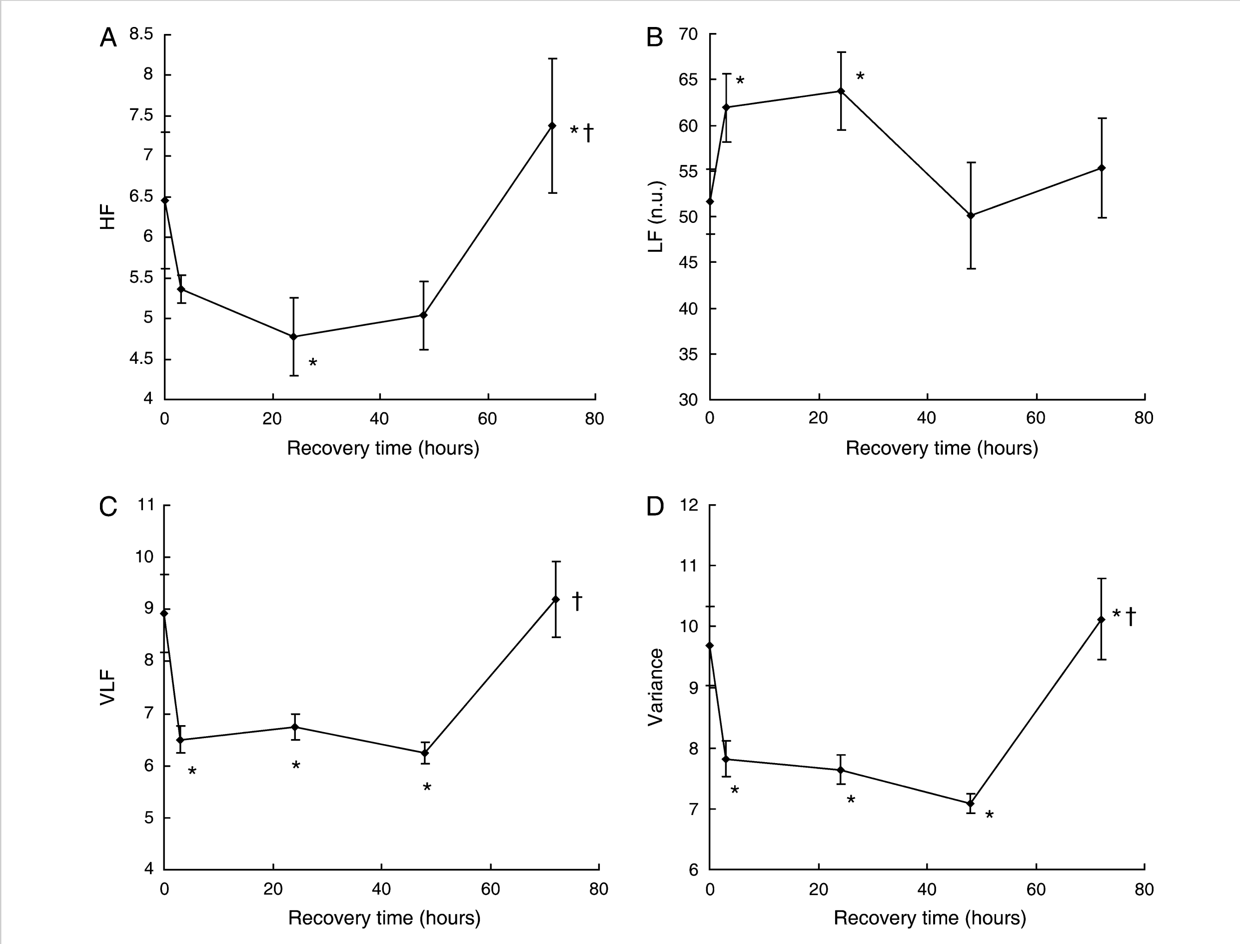

Figure 5. Heart rate variability. A) High frequency reflects parasympathetic modulation; B) low frequency in normalized unit (n. u.) reflects sympathetic modulation; C) very low frequency; D) variance reflects both sympathetic and parasympathetic modulations. *Significant difference from pre ($N = 7$, $p < 0.05$); †Significant difference from the bottom line ($N = 7$, $p < 0.05$).

assessment. Weightlifting performance, representing the maximal weight lifted (back squat, seated shoulder press, dead lifts, and front squat) from 3 attempts, was recorded.

Heart Rate Variability

The HRV was analyzed using the frequency-domain methods. Electrocardiogram (ECG) data were obtained while the subjects rested quietly, breathing spontaneously in seated positions after 5-minute rest. During the assessment period, subjects were monitored at the lead to record heart rate and R–R intervals (intervals between R waves on ECG). The signals were recorded in real time after analog-to-digital conversion (8-bit) at a sampling rate of 256 Hz. R–R intervals (milliseconds) were calculated on a beat-to-beat basis using customized software programmed by Dr. Terry B. J. Kuo. Frequency-domain analysis was performed using the non-parametric method of fast Fourier transform. The direct current portion was deleted, and a Hamming window was used to attenuate the leakage effect. The power spectrum was corrected for attenuation resulting from the sampling and the Hamming window. The power spectrum was then quantified into various frequency-domain measurements. VLF, LF, and HF power portion was generated in absolute values of power (ms^2). Low frequency (in normalized units [n.u.]) was normalized by the percentage of total power except for VLF to detect sympathetic influence on HRV. All HRV parameters were expressed in natural logarithmic form with correction of possible skewness.

Biochemical Analysis

Dehydroepiandrostendione sulfate was measured using an enzyme-linked immunosorbent assay kit from Diagnostic Systems Laboratories (Webster, TX, USA). Creatine kinase was directly measured on a Reflotron Plus Analyzer according to its standard procedure provided by the manufacture (Roche Diagnostic, Basel, Switzerland).

Muscular Pain Assessment

Before and after training, all subjects were instructed to rate the pain perception on a 10-point category scale. The even numbers of the scale had the following verbal anchors: 0, no pain; 2, uncomfortable; 4, very uncomfortable; 6, painful; 8, very painful; and 10, extremely painful.

Statistical Analyses

One-way analysis of variance with repeated measures was used to compare the differences among all dependent variables 24 hours before and 24, 48, and 72 hours after the exercise training. The Mann–Whitney U test was used to compare the differences between pre and post values. A level of $p \leq 0.05$ was considered significant on all tests, and all values are expressed as mean $\pm$ SE.

Results

Three hours after completion of the training program, weightlifting performance (maximal weight lifted from 3 attempts) was significantly dropped below baseline, and gradually regained during the rest of the 72 hours. Figure 1 shows the regain in weight lifting performance for the back squat (A), seated bench press (B), dead lift (C), and front squat (D) during the 72-hour time course of recovery. Weightlifting performance for the back squat, seated bench press, and dead lift was recovered exceeding baseline and reaching the maximum at 72 hours.

Subjective muscle pain was measured because this is associated with the fatigue. Muscle pain was significantly elevated approximately fourfolds above baseline at 24 hours and remained higher from 48 to 72 hours without a significant decline (Figure 2). Plasma muscle creatine kinase (CK) level, as an indicator of muscle damage, was elevated from 132 $\pm$ 6 to 485 $\pm$ 103 $U \cdot L^{-1}$ for the first 3 hours and returned to 254 $\pm$ 115 $U \cdot L^{-1}$ at 72 hours (Figure 3). Dehydroepiandrostendione sulfate significantly dropped from 3.0 $\pm$ 0.4 to 2.0 $\pm$ 0.4 $\mu g \cdot ml^{-1}$ and returned to normal values at 48 hours (Figure 4).

Data of the frequency-domain spectral analysis for HRV are presented in Figure 5. High frequency (A), VLF (C), and mean variance (D) dropped significantly within 24 hours of posttraining recovery and returned to baseline values by 72 hours. Low frequency in normalized units (B) was marginally elevated in 24 hours and returned to normal values within 48 hours.

Discussion

In this study, 2-hour weightlifting training produced approximately fourfold increases in circulating CK level and muscle pain, which reflects a considerable amount of muscle damage elicited by the present weight training protocol. During recovery, these damage markers were unable to return to baseline values in 72 hours. However, the weightlifting performance was quickly recovered in parallel with parasympathetic rebound by day 1. The training effect on enhancing weightlifting performance above pretrained baseline became apparent from 48 to 72 hours of the recovery period when parasympathetic power (HRV-HF) reached a plateau. To the best of our knowledge, this is the first time-course study delineating the covariations in autonomic modulation and weightlifting performance during recovery after weightlifting training. Our data provide novel evidence, which suggests that increases in parasympathetic nervous activity can mirror the degree of performance recovery for weightlifters after training.

Although fatigue was apparent at 3 hours after the weightlifting training, marginally elevated sympathetic nervous activity and reduced parasympathetic nervous activity were also observed. This result is similar to the study by Iellamo et al. who reported a shift from vagal to sympathetic predominance in rowing athletes when the daily training load was increased (14). In this study, the time required for the parasympathetic reactivation was much slower than what has been reported in Iellamo's study after submaximal endurance type of training. The discrepancy is probably because weightlifting training consists mainly of anaerobic type of muscle contraction, which causes a greater amount of muscle damage than endurance exercise does. A well-controlled study has shown that parasympathetic reactivation during the first 10 minutes of recovery was significantly more delayed after 2 types of anaerobic exercise than aerobic exercise with a similar energy expenditure (2). For endurance exercise, increased sympathetic nervous activity and decreased parasympathetic nervous activity might help to stimulate catabolic response aimed to increase the rate of ATP resynthesis to sustain greater energy expenditure for repairing tissue damage and compensating oxygen debt. For muscle-damaging exercise such as weightlifting training, neuromuscular repair after training can demand more energy consumption, thus resulting in a longer recovery time.

To determine the effect of weight training on autonomic nervous activity, time-course design on HRV measurements for 72 hours is required. In the present study, 3 hours after training had the lowest, whereas 72 hours after training had the highest parasympathetic power in reference to baseline value. Without postexercise time-course measurements, a contradictory conclusion can be made if single time recording is different among studies. An increased parasympathetic nervous activity by strength training has been reported (7,28). However, some other studies have also reported either unchanged (5,6) or decreased (23) parasympathetic nervous activity by strength training. In addition, resting sympathetic activity is either increased (23) or unchanged (4) after a long-term weight training program. In this study, we provide evidence to elucidate the importance of recording time for HRV measurements during a training recovery.

The result of the study suggests that HRV (total variance and HF) was unaffected by muscle pain. It has been generally thought that autonomic nervous modulation is influenced by pain, supported by the evidence of increasing sympathetic nervous activity with severe pain induced by acute intramuscular injection of hypertonic saline (5%) (3). In our subjects, the pain was substantially increased after training and sustained above baseline during the entire period of the 72-hour recovery, whereas HF and performance had already returned above baseline.

Reduction in circulating DHEA-S level found in the present study is most likely because of the increased rate of DHEA-S consumption during recovery, which is also found after many types of stress conditions such as trauma and disease (9,17,27,30). This neurosteroid has been documented to be required for damage repair of nerves (13). Interventions that increase circulating DHEA-S level has been found to improve HRV in humans (22). Dehydroepiandrostendione sulfate administration can also enhance functional recovery after various tissue damage conditions in humans (12) and animals (18,19). Similar to the result of this study, muscle damage induced by resistance exercise causes a marked reduction in DHEA-S level, which occurred 48 and 72 hours after exercise in 1-month detrained athletes (29). The subjects in this study were weightlifters who had undergone only 10 days of detraining; thus, the rapid recovery in DHEA-S level may reflect the residual training effect from the last weight training bout.

In contrast to the endocrine system, the autonomic nervous system is a fast component of signaling system controlling the whole-body metabolic homeostasis by coordinating different organs and tissues, aimed to precisely match oxygen demand and supply in response to external challenges. Increasing resting sympathetic nervous activity with reciprocally decreasing resting parasympathetic nervous activity reflects an elevated oxygen demand for ATP generation in the periphery, which typically occurs during and after external challenge. Apparently, recovery time required for a challenged individual to return to the basal physiological set point (or well-being state) depends on the magnitude and the type of the challenge. Weightlifting can be considered as a maximal physical effort against external challenge for most humans, which demands a huge amount of ATP resynthesis within a brief period of time. Neuromuscular damage generated afterward will further demand an extra amount of energy cost for repair. Therefore, lowered resting parasympathetic nervous activity after weight training suggests a greater energy demand for recovery.

Practical Applications

Our data provide evidence that parasympathetic power mirrors recovery status in weightlifting performance after training. The time required for optimal recovery from fatigue takes >48 hours for typical Olympic style weightlifters. Furthermore, the strength recovery and parasympathetic nervous activity appear to be unrelated to pain and circulating muscle CK levels. In conclusion, HRV is a noninvasive tool that can be used by coaches to monitor recovery status from fatigue for a weightlifter during the training period and before competition.

Acknowledgments

This work was partly sponsored by a grant from the National Science Council (grant number: NSC 96-2413-H-154-003-MY3), Taipei, Taiwan. Conflict of interest: N/A.

References

1. Akselrod, S, Gordon, D, Ubel, FA, Shannon, D, Berger, AC, and Cohen, RJ. Power spectrum analysis of heart rate fluctuation: A quantitative probe of beat-to-beat cardiovascular control. *Science* 213: 220–222, 1981.
2. Buchheit, M, Laursen, PB, and Ahmaidi, S. Parasympathetic reactivation after repeated sprint exercise. *Am J Physiol* 293: H133–H141, 2007.
3. Burton, AR, Birznieks, I, Bolton, PS, Henderson, LA, and Macefield, VG. Effects of deep and superficial experimentally induced acute pain on muscle sympathetic nerve activity in human subjects. *J Physiol* 587: 183–193, 2009.
4. Carter, JR, Ray, CA, Downs, EM, and Cooke, WH. Strength training reduces arterial blood pressure but not sympathetic neural activity in young normotensive subjects. *J Appl Physiol* 94: 2212–2216, 2003.
5. Collier, SR, Kanaley, JA, Carhart, R, Frechette, V, Tobin, MM, Bennett, N, Luckenbaugh, AN, and Fernhall, B. Cardiac autonomic function and baroreflex changes following 4 weeks of resistance versus aerobic training in individuals with pre-hypertension. *Acta Physiol* 185: 339–348, 2009.
6. Cooke, WH and Carter, JR. Strength training does not affect vagal–cardiac control or cardiovagal baroreflex sensitivity in young healthy subjects. *Eur J Appl Physiol* 93: 719–725, 2005.
7. Figueroa, A, Kingsley, JD, McMillan, V, and Panton, LB. Resistance exercise training improves heart rate variability in women with fibromyalgia. *Clin Physiol Funct Imag* 28: 49–54, 2008.
8. Garet, M, Tournaire, N, Roche, F, Laurent, R, Lacour, JR, Barthélémy, JC, and Pichot, V. Individual interdependence between nocturnal ANS activity and performance in swimmers. *Med Sci Sports Exerc* 36: 2112–2118, 2004.
9. Gudemez, E, Ozer, K, Cunningham, B, Siemionow, K, Browne, E, and Siemionow, M. Dehydroepiandrosterone as an enhancer of functional recovery following crush injury to rat sciatic nerve. *Microsurgery* 22: 234–241, 2002.
10. Hanson, EK, Godaert, GL, Maas, CJ, and Meijman, TF. Vagal cardiac control throughout the day: The relative importance of effort-reward imbalance and within-day measurements of mood, demand and satisfaction. *Biol Psychol* 56: 23–44, 2001.
11. Hedelin, R, Bjerle, P, and Henriksson-Larsén, K. Heart rate variability in athletes: Relationship with central and peripheral performance. *Med Sci Sports Exerc* 33: 1394–1398, 2001.
12. Herbert, J. Neurosteroids, brain damage, and mental illness. *Exp Gerontol* 33: 713–727, 1998.
13. Hoffman, SW, Virmani, S, Simkins, RM, and Stein, DG. The delayed administration of dehydroepiandrosterone sulfate improves recovery of function after traumatic brain injury in rats. *J Neurotrauma* 20: 859–870, 2003.
14. Iellamo, F, Pigozzi, F, Spataro, A, Lucini, D, and Pagani, M. T-wave and heart rate variability changes to assess training in world-class athletes. *Med Sci Sports Exerc* 36: 1342–1346, 2004.
15. Karemaker, JM and Lie, KI. Heart rate variability: A telltale of health or disease. *Eur Heart J* 21: 435–437, 2000.
16. Kristal-Boneh, E, Raifel, M, Froom, P, and Ribak, J. Heart rate variability in health and disease. *Scand J Work Environ Health* 21: 85–95, 1995.
17. Lee, W, Chen, S, Wu, M, Hou, C, Lai, Y, Laio, Y, Lin, C, and Kuo, C. The role of dehydroepiandrosterone levels on physiologic acclimatization to chronic mountaineering activity. *High Alt Med Biol* 7: 228–236, 2006.

18. Liu, TC, Kuo, CH, and Wang, PS. Exercise and testosterone. *Adapt Med* 1: 24–29, 2009.
19. Malik, AS, Narayan, RK, Wendling, WW, Cole, RW, Pashko, LL, Schwartz, AG, and Strauss, KI. A novel dehydroepiandrosterone analog improves functional recovery in a rat traumatic brain injury model. *J Neurotrauma* 20: 463–476, 2003.
20. Malik, M, Bigger, JT, Camm, AJ, Kleiger, RE, Malliani, A, Moss, AJ, and Schwartz, PJ. Heart rate variability: Standards of measurement, physiological interpretation, and clinical use. *Eur Heart J* 17: 354–381, 1996.
21. Malliani, A, Pagani, M, Lombardi, F, and Cerutti, S. Cardiovascular neural regulation explored in the frequency domain. *Circulation* 84: 482–492, 1991.
22. McCraty, R, Barrios-Choplin, B, Rozman, D, Atkinson, M, and Watkins, AD. The impact of a new emotional self-management program on stress, emotions, heart rate variability, DHEA and cortisol. *Integr Physiol Behav Sci* 33: 151–170, 1998.
23. Melo, RC, Quitério, RJ, Takahashi, AC, Silva, E, Martins, LE, and Catai, AM. High eccentric strength training reduces heart rate variability in healthy older men. *Br J Sports Med* 42: 59–63, 2008.
24. Montano, N, Cogliati, C, da Silva, VJD, Gnecchi-Ruscone, T, Massimini, M, Porta, A, and Malliani, A. Effects of spinal section and of positive-feedback excitatory reflex on sympathetic and heart rate variability. *Hypertension* 36: 1029–1034, 2000.
25. Pomeranz, B, Macaulay, RJ, Caudill, MA, Kutz, I, Adam, D, Gordon, D, Kilborn, KM, Barger, AC, Shannon, DC, Cohen, RJ, and Herbert B. Assessment of autonomic function in humans by heart rate spectral analysis *Am J Physiol* 248: H151–H153, 1985.
26. Sayers, BM. Analysis of heart rate variability. *Ergonomics* 16: 17–32, 1973.
27. Straub, RH, Lehle, K, Herfarth, H, Weber, M, Falk, W, Preuner, J, and Scholmerich, J. Dehydroepiandrosterone in relation to other adrenal hormones during an acute inflammatory stressful disease state compared with chronic inflammatory disease: Role of interleukin-6 and tumour necrosis factor. *Eur J Endocrinol* 146: 365–374, 2002.
28. Taylor, AC, McCartney, N, Kamath, MV, and Wiley, RL. Isometric training lowers resting blood pressure and modulates autonomic control. *Med Sci Sports Exerc* 35: 251–256, 2003.
29. Tsai, YM, Chou, SW, Lin, YC, Hou, CW, Hung, KC, Kung, HW, Lin, TW, Chen, SM, Lin, CY, and Kuo, CH. Effect of resistance exercise on dehydroepiandrosterone sulfate concentrations during a 72-h recovery: Relation to glucose tolerance and insulin response. *Life Sci* 79: 1281–1286, 2006.
30. Wang, HT, Chen, SM, Lee, SD, Chen, KN, Liu, YF, and Kuo, CH. The role of DHEA-S in the mood adjustment against negative competition outcome in golfers. *J Sports Sci* 27: 291–297, 2009.
31. Wang, JS, Chen, SM, Lee, SP, Lee, SD, Huang, CY, Hsieh, CC, and Kuo, CH. Dehydroepiandrosterone sulfate linked to physiologic response against hot spring immersion. *Steroids* 7: 945–949, 2009.