Parasympathetic nervous activity mirrors recovery status in weight lifting performance after training

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Running title: Weight lifting performance and HRV

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ABSTRACT

Heart rate variability (HRV) and parasympathetic power are closely related to wellbeing and health status in humans. The main goal of the study was to determine whether these measures can reflect recovery status during a weight training recovery. 7 weightlifters were challenged with a 2-h weight training after a 10-d detraining period, which elicited ~4-fold increases in circulating muscle creatine kinase (CK) level and protracted pain feeling ($P< 0.05$). Weight lifting performance was then evaluated 3, 24, 48, and 72 h following training to determine the degree of recovery from fatigue. HRV, circulating DHEA-S (dehydroepiandrostendione sulphate), and muscle damage markers were measured before each performance test. Electrocardiogram was recorded for 5 min continuously at rest in seated positions before each performance assessment. Weight lifting performance substantially decreased below baseline in paralleled with suppressed parasympathetic power (high frequency HRV), while sympathetic power (normalized low frequency HRV) slightly elevated at 3 h after training ($P < 0.05$). Both weight lifting performances and parasympathetic power were returned to baseline in 24 h, and were further increased above baseline by 48-72 h of recovery in similar fashion ($P< 0.05$). Circulating DHEA-S level dropped at 24 h ($P <0.05$) and returned to normal by 48 h. The muscle pain feeling was increased 3 h after training and remained higher than baseline for the entire 72-h recovery period ($P< 0.05$). **CONCLUSIONS:** Our data suggest that parasympathetic power, indicated by high frequency HRV, is able to reflect recovery status for elite weightlifters after an intensive training.

Keywords: fatigue, weightlifter, strength performance, frequency domain analysis, muscle power

INTRODUCTION

For most of weightlifters, who perform 3 workouts a week, recovery is the period between the end of one workout and the beginning of the next. Optimal time of recovery allows weightlifter to sustain greater weight challenge on the coming competition event or the next workout. Conversely, inadequate recovery after training results in fatigue or underperformance. To develop a non-invasive surrogate marker would be helpful for coaches and weightlifters to monitor recovery status in preparation for competition or modulation of training load.

Heart rate variability (HRV), determined by beat-to-beat time variations in heart rate, are the outcome of dynamic control of the cardiovascular system by the sympathetic and parasympathetic nervous activities. This non-invasive measure has attracted vast interest due to its significant correlation with health status such as cardiovascular morbidity (16), wellbeing state such as effort-reward imbalance (10), and all-cause mortality (15). Its association with weight lifting 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, is able to reflect changes in autonomic nervous control of heart rate. Three major portions are geometrically distinguished in a spectrum calculated from 5-min standardized recordings under resting condition (1, 20, 25): high frequency (HF), low frequency (LF), and very low frequency (VLF) portions. The HF power is contributed by parasympathetic nervous activity; whereas the LF power in normalized units is considered as a marker of sympathetic nervous activity. This is based on the experimental observations of autonomic manipulations such as electrical stimulation on vagal nerve (1), use of autonomic blocking agents

(24), and vagotomy (23), and exercise (20). The LF/HF ratio has been thought to reflect sympatho-parasympathetic nervous balance or to reflect sympathetic nervous modulations (19). 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 recovery status in aerobic type of performance during a training/competition cycle. However, it has been reported in one 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 to 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 weight lifting performance changes during a 72-hour recovery period after training.

Furthermore, the neurosteroid DHEA-S has been found required for repair process after damage in the nervous system (13). Tsai et al reported a protracted reduction in circulating DHEA-S level during recovery phase after resistance training and many other types of stress (28, 29, 30). Intervention that enhances DHEA-S level has been found to increases HRV (21). Therefore, changes in circulating DHEA-S were also measured in line with HRV and weight lifting performance during the same recovery period.

METHODS

Experimental Approach to the Problem

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

Subjects. Male weightlifters (19.3±0.3 years, N=7), with more than 6-year training history of national or international-level competitions, were voluntarily participated in this study. This present study was conducted in accordance with the guidelines in the Declaration of Helsinki. Subjects were informed of the experimental risks and signed an informed consent prior to the investigation. This study was approved by the Human Subject Committee of 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 2-hour weight lifting training program after 10 days of detraining. 4 types of exercises were given for the training: back squat, seated shoulder press, dead lift, and front squat. The intensity for each training started from 60% maximal effort for 3 times, 70% maximal effort for 3 times, 80% maximal effort for 3 times, 90% maximal effort for 2 times, 95% maximal effort for 1 times with ~90 second rest on each pull. All sessions were supervised by coach to monitor the appropriate amount of exercises and time of rest intervals. They were then recovered in sedentary condition for 72 h. Assessments for HRV and weight lifting performance were performed before training, and 3 h, 24 h, 48 h, and 72 h during recovery. Their normal daily living schedules including sleeping and eating was remained unchanged. Weight lifting performance was recorded 5 min after

HRV assessments at each time point. Blood samples were collected immediately after each HRV assessment. Weight lifting performance represents the maximal weight lifted (back squat, seated shoulder press, dead lifts, and front squat) from 3 attempts was recorded.

Heart Rate Variability (HRV). The HRV was analyzed by the frequency domain methods. ECG data were obtained while the subjects rested quietly, breathing spontaneously in seated positions after 5 min 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 analogue to digital conversion (eight-bit) at a sampling rate of 256 Hz and the R-R intervals (ms) 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 nonparametric method of fast Fourier transform (FFT). 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. Determination of VLF, LF and HF power portions is generated in absolute values of power (ms^2). LF 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. DHEA-S was measured using an ELISA kit from Diagnostic Systems Laboratories (Webster, Texas, USA). CK 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 ten 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 ANOVA with repeated measures was used to compare the differences among all dependent variables 24 h before and 24 h, 48 h, 72 h after the exercise training. Mann-Whitney U test was used to compare the differences between pre and post values. A level of $P < 0.05$ was considered significant on all tests, and all values are expressed as means ± standard errors.

RESULTS

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

Subjective muscle pain was measured since this is associated with the fatigue feeling. Muscle pain feeling was significantly elevated approximately 4 folds above baseline at 24 h and remained higher from 48 to 72 h without a significant recovery (Figure 2). Plasma muscle creatine kinase level, as an indicator of muscle damage, was elevated

from 132±6 to 485±103 U/L for the first 3 hour and returned to 254±115 U/L at 72 hour (Figure 3). DHEA-S was significantly dropped from 3.0±0.4 to 2.0±0.4 μ g/mL and returned normal at 48 h (Figure 4).

Frequency domain spectral analysis for HRV is presented in Figure 5. HF (A), VLF (C), and mean variance (D) were dropped significantly within 24 hour of post-training recovery and return to baseline by 72 hour. LF in normalized unit (B) was marginally elevated in 24 hour, and return to normal within 48 h.

DISCUSSION

In this study, 2-h weight lifting training produced ~4-fold increases in circulating CK level and muscle pain feeling, which reflects a considerable amount of muscle damage elicited by the current training protocol. During recovery, these damage markers were unable to return to baseline within 72 h of recovery period. However, the weight lifting performance was quickly recovered in line with parasympathetic rebound by day 1. The training effect on enhancing weight lifting performance became apparent from 48 to 72 h of recovery period when parasympathetic power (HRV-HF) reached plateau. To the best of our knowledge, this is the first time-course study delineating the covariations in autonomic modulation and weight lifting performance during recovery after weight lifting training. Our data provides novel evidence, which suggests that increases in parasympathetic nervous activity can mirror the degree of performance recovery for weightlifters after training.

While fatigue was apparent at 3 h after weight lifting 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 daily training load was increased (14). In the present study, the time required for the parasympathetic reactivation was much slower than what has been reported in the Iellamo's study after submaximal endurance type of training. The discrepancy is probably because that weight lifting training consists of mainly anaerobic type of muscle contraction, which causes greater amount of muscle damage than endurance exercise. A well-controlled study has shown that parasympathetic reactivation during the first 10 min of recovery was significantly more delayed after two 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 damage repair and compensation of oxygen debt. For muscle-damaging exercise like weight lifting training, neuromuscular repair after training can demand more energy consumption and thus longer recovery time can be resulted.

To determine the effect of weight training on autonomic nervous activity, time tracking on HRV measurements for 72 h is required. In the present study, 3 hour after training had lowest and 72 hour after training had the highest parasympathetic power in reference to baseline value. Without time tracking, contradictory conclusion can be made if post-exercise recording time is different. It has been reported an increased parasympathetic nervous activity by strength training (7, 27). However, some other studies had also reported either unchanged (5, 6) or decreased (22) parasympathetic nervous activity by strength training. In addition, resting sympathetic activity is either increase (Sinoway et al. 1992; Melo et al., 2009) or unchanged (4) following 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 modulation is influenced by pain feeling, supported by the evidence of increased sympathetic nervous activity with severe pain induced by acute intramuscular injection of hypertonic saline (5%) (3). In our data, the pain feeling was substantially increased after training and sustained above baseline during the entire period of 72-hour recovery, while HF had already returned above baseline.

Reduction in circulating DHEA-S level found in the present study is most likely due to increased rate of DHEA-S consumption during recovery, which is also found after many types of stress conditions such as trauma and disease (9, 26, 29). This neurosteroid has been documented required for damage repair in nerve (13). Interventions that increase circulating DHEA-S level has been found to improve HRV in human (21). DHEA administration can enhance functional recovery following various tissue damage conditions in human (12) and animal (17, 18). Similar to the result of this study, muscle damage induced by resistance exercise causes a marked reduction in serum DHEA-S level, occurred 48 h and 72 h after exercise in 1-month detrained athletes (28). The subjects in the present study were weightlifters with 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 endocrine system, 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 periphery, which typically occurs during and after external challenge. Apparently, recovery time required for a challenged individual to be returned to the basal physiological setpoint (or wellbeing state) is depending on the magnitude and the type of the challenge. Weight lifting 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 and neuromuscular damage can also be generated. Therefore, lowered resting parasympathetic nervous activity after weight training suggests a greater energy demand for recovery.

PRACTICAL APPLICATIONS

Our data provide strong evidence that parasympathetic power mirror weight lifting performance following a 72-h recovery from weight training. The time required for optimal recovery after training takes more than 48 h for typical Olympic style weightlifters. Furthermore, the recoveries in weight lifting performance and HRV appear to be unrelated to pain feeling and circulating muscle CK levels. In conclusion, HRV is a non-invasive tool which can be used by coach to monitor recovery status from fatigue for a weightlifter during training period and before competition.

ACKNOWLEDGEMENTS

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

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TABLE AND FIGURE LEGENDS

FIGURE 1. Weight lifting performance during recovery. Maximal weights lifted from 3 attempts were recorded for 4 types of exercise: back squat (A), seated shoulder press (B), dead lift (C), and front squat (D). * denotes significant difference from Pre; † denotes significant difference from bottom line (3 h value) (N=7, P< 0.05).

FIGURE 2. Subjective pain feeling during recovery. * denotes significant difference from Pre (N=7, P< 0.05).

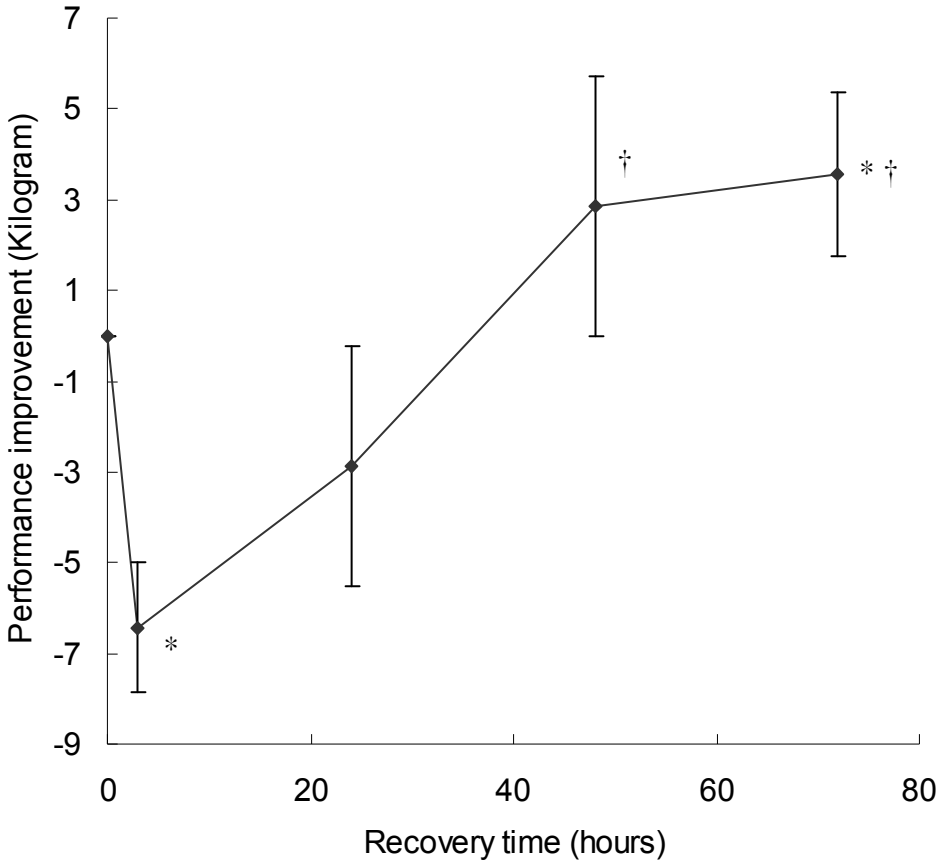
FIGURE 3. Plasma creatine kinase levels. * denotes significant difference from Pre (N=7, P< 0.05).

FIGURE 4. Plasma DHEA-S levels. * denotes significant difference from Pre (N=7, P< 0.05).

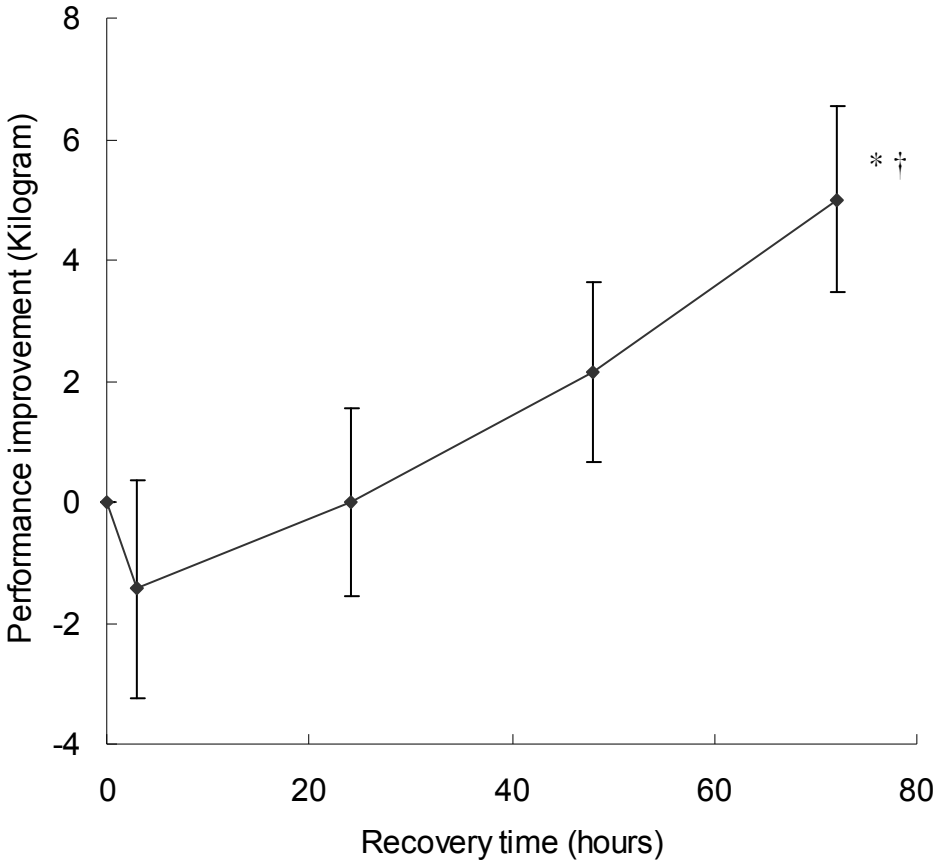
FIGURE 5. Heart rate variability. HF reflects parasympathetic modulation (A), LF in normalized unit (n. u.) reflects sympathetic modulation (B), VLF (C), Variance reflects both sympathetic and parasympathetic modulations (D). * denotes significant difference from Pre (N=7, P< 0.05); † denotes significant difference from bottom line (N=7, P< 0.05).

FIGURE 1.

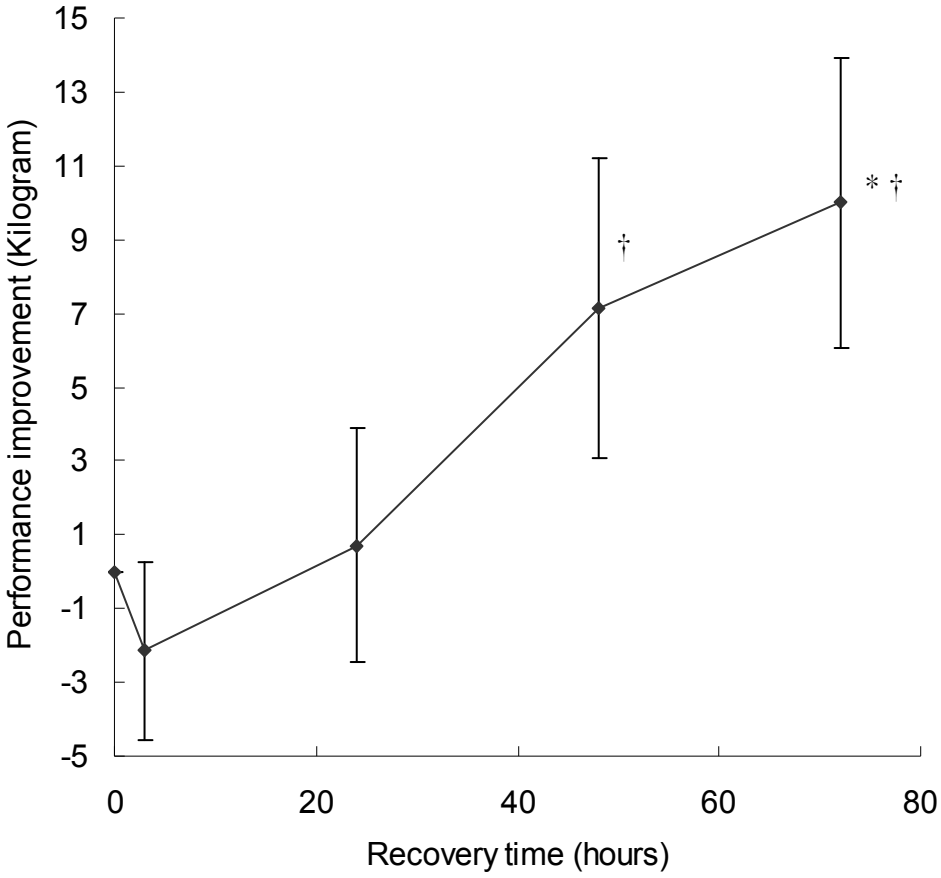
A.


7
5
3
1
-1
-3
-5
-7
-9
Performance improvement (Kilogram)
0
20
40
60
80
Recovery time (hours)
*
†
* †

B.


8
6
4
2
0
-2
-4
Performance improvement (Kilogram)
0
20
40
60
80
Recovery time (hours)
* †

C.


15
13
11
9
7
5
3
1
-1
-3
-5
Performance improvement (Kilogram)
0
20
40
60
80
Recovery time (hours)
†
* †

D.

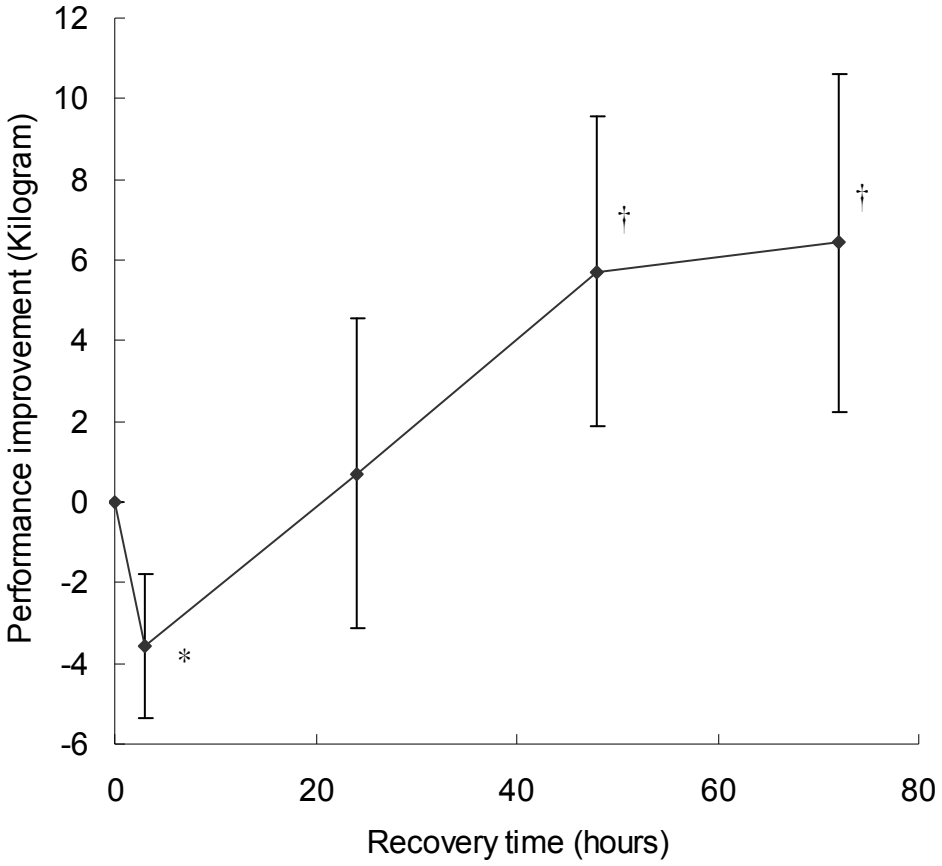

12
10
8
6
4
2
0
-2
-4
-6
Performance improvement (Kilogram)
0
20
40
60
80
Recovery time (hours)
*
†
†

FIGURE 2.

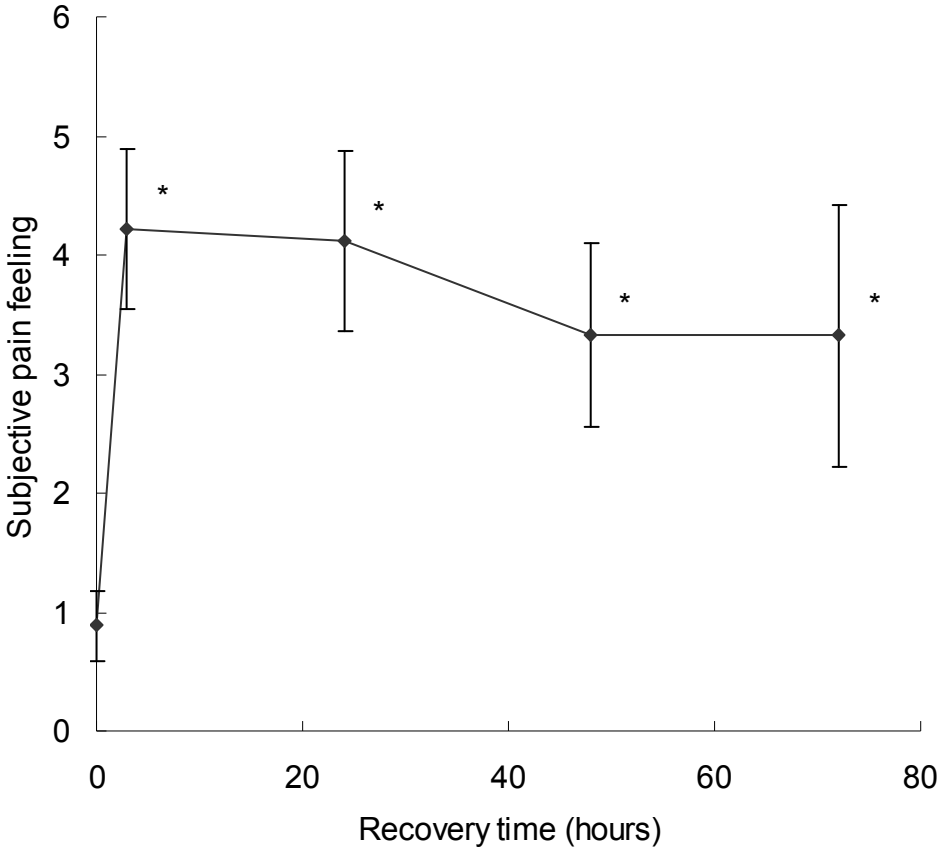

Subjective pain feeling
Recovery time (hours)
0
1
2
3
4
5
6
0
20
40
60
80
*
*
*
*

FIGURE 3.

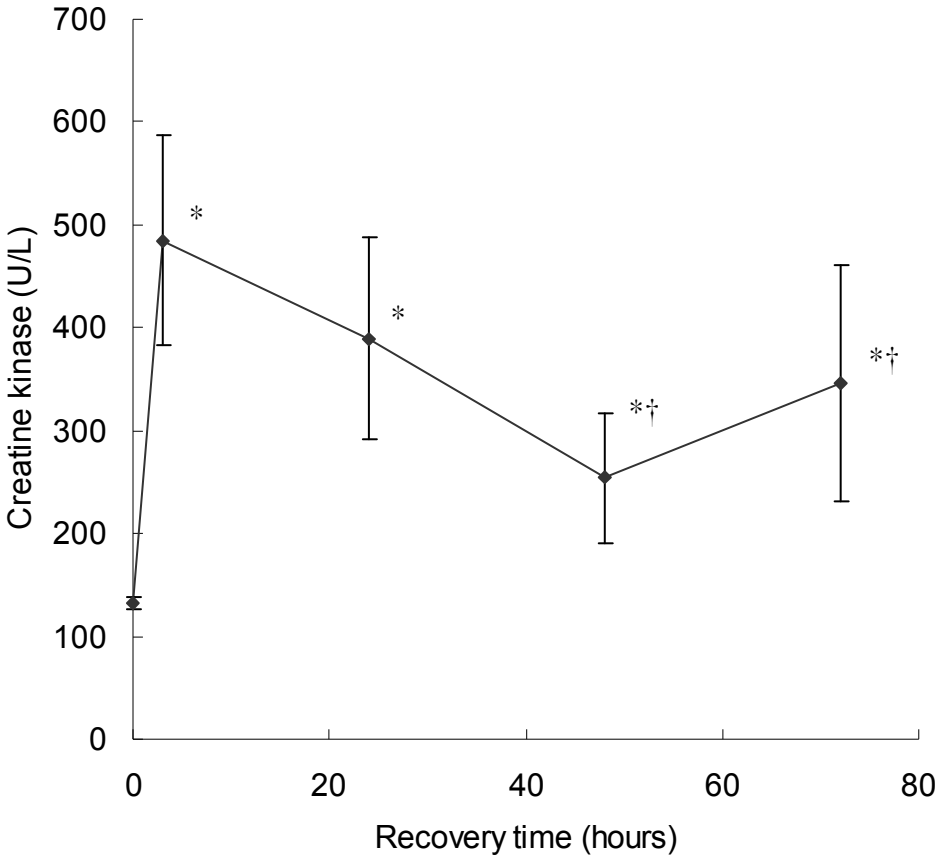

700
600
500
400
300
200
100
0
Creatine kinase (U/L)
0
20
40
60
80
Recovery time (hours)
*
*
*†
*†

FIGURE 4.

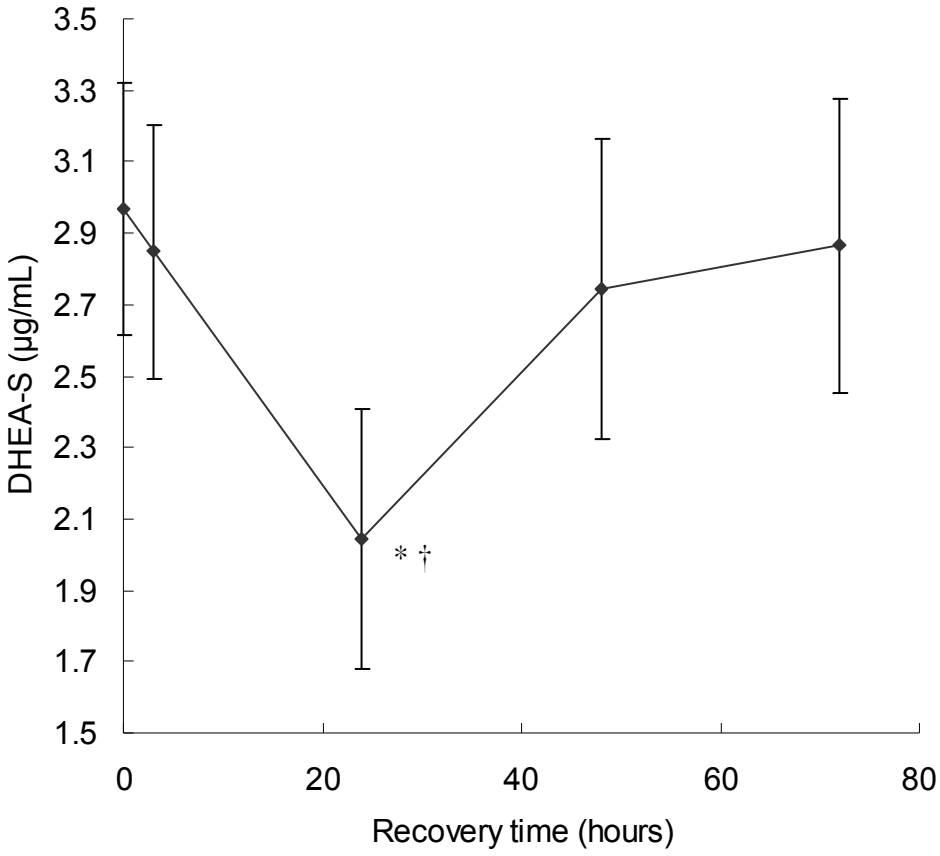
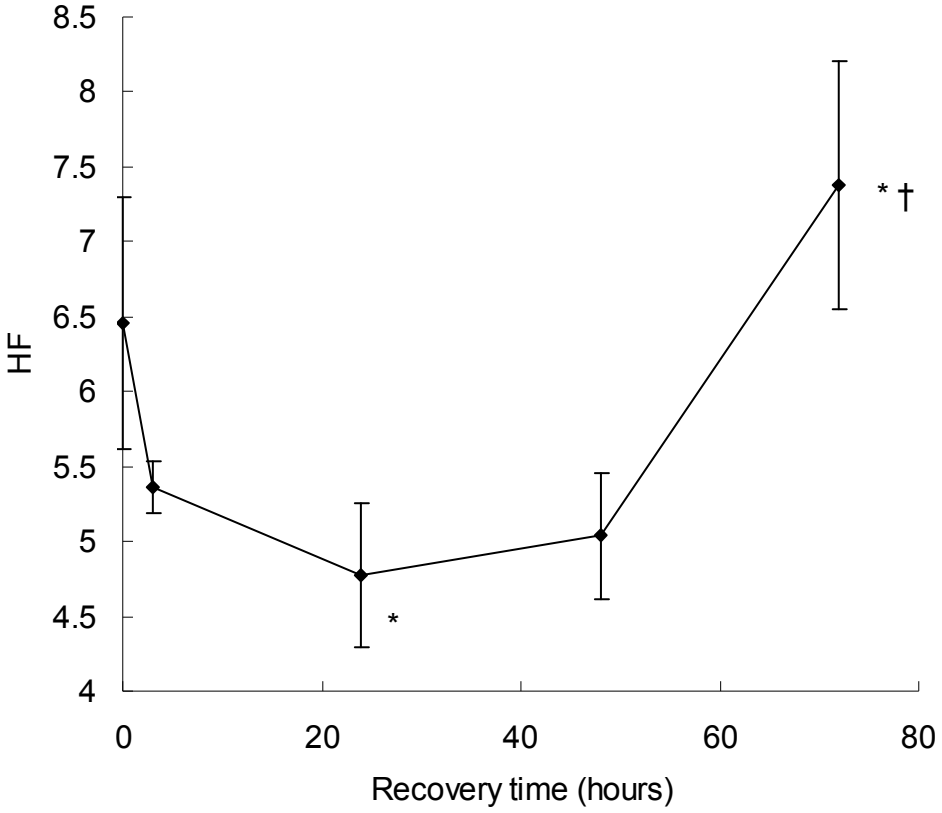

3.5
3.3
3.1
2.9
2.7
2.5
2.3
2.1
1.9
1.7
1.5
DHEA-S (µg/mL)
* †
0
20
40
60
80
Recovery time (hours)

FIGURE 5.

A.



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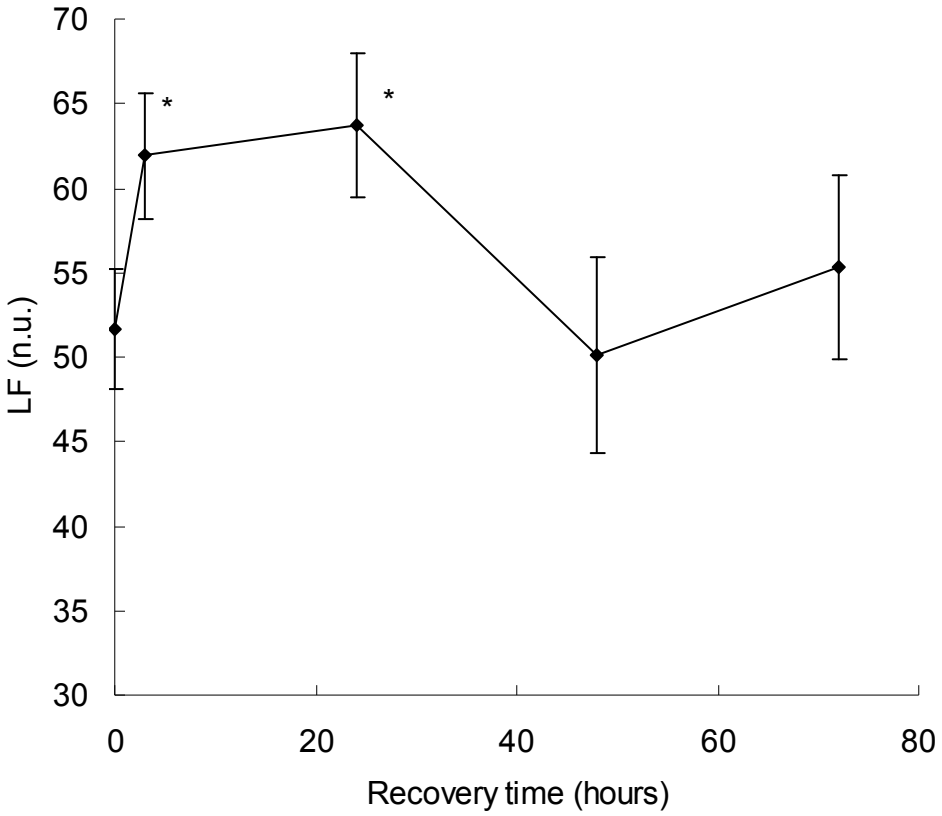
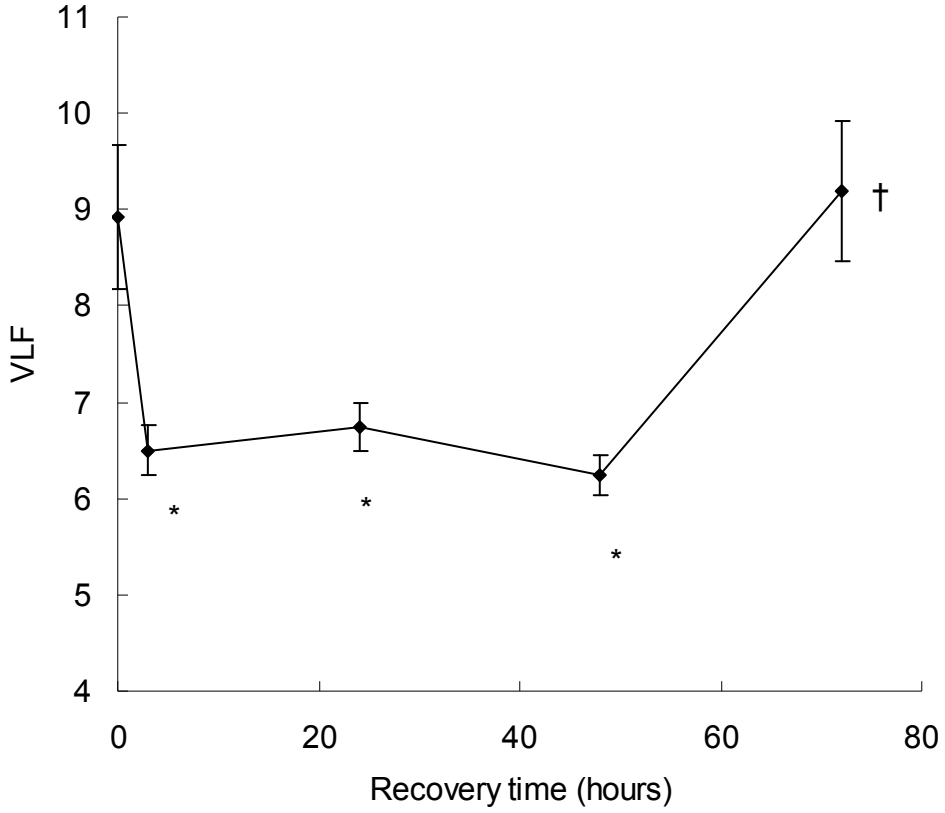


C.



D.