Japanese Journal of Physiology, **55**, 279–284, 2005

Hormone and Lipolytic Responses to Whole Body Vibration in Young Men

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Abstract: This study examined the effects of whole-body vibration (WBV) on the hormone and lipolytic responses. Eight male subjects performed WBV and control (CON) trials on separate days. The WBV session consisted of 10 sets of vibration for a duration of 60 s with rest periods of 60 s between each set (frequency 26 Hz). The subjects maintained a static squat position with knees bent on the platform. In the CON trial, the WBV stimulation was not imposed. Blood samples were collected before both trials and during the recovery period. In the WBV trial, the concentrations of plasma epinephrine (Epi) and norepinephrine (NE) increased immediately after the session ($P < 0.05$). Serum free fatty acids (FFA) concentration increased significantly at the 150, 180, and 210 min points of the recovery period in the WBV trial ($P < 0.01$) with the interaction between trial and time ($P < 0.01$). Serum glycerol showed no significant change in either trial. These results suggest that the WBV session causes secretions of Epi and NE, and it subsequently increases FFA concentration during the recovery period. However, because the FFA response was inconsistent with that of glycerol, we were unable to clarify the effect of WBV exposure on lipolysis. [The Japanese Journal of Physiology 55: 279–284, 2005]

Key words: growth hormone, catecholamine, free fatty acids, glycerol.

Whole-body vibration (WBV) has been developed recently as a neuromuscular training method. During WBV training, a subject stands on a platform while maintaining a static position or performing dynamic exercise with an extra load. The subject is exposed to vertical sinusoidal vibration stimuli at frequencies from 18 to 45 Hz [1, 2]. These mechanical stimuli will elicit reflex muscle activation [3] that results in neurogenic adaptation [4]. A single bout of WBV exposure improves the maximal jump height [4], power output, and muscular strength of activated muscles [5–7], and causes reduction of chair-raising time for elderly people [8]. Chronic studies have revealed significant increases in maximal strength following 12 wk [2] and 24 wk of WBV training [9], but some studies have shown no meaningful effect [10].

Resistance and endurance exercises are potent stimuli to improve muscular strength and cardiovascular fitness [11, 12]. Furthermore, the prescription of a training program with combined resistance and endurance exercises is widely recommended to control body weight and reduce body fat [13]. Lipolysis during endurance exercise is stimulated primarily by catecholamine release and is suppressed by insulin [14]. Alternatively, lipolysis is not strongly stimulated during general resistance exercise sessions. However, exercise-induced secretions of catecholamine and growth hormone (GH) might enhance lipolysis during the recovery period [15]. It has been reported that resistance exercise causes prolonged enhancements of resting oxygen consumption and lipid metabolism for several hours after a single exercise session [16, 17], and these are partially related to elevated catecholamine and residual hormone effects, including GH [15]. A GH infusion to healthy individuals increases the serum free fatty acids (FFA) and glycerol concentrations with maximal elevations of 120–160 min after infusion [18]. These findings suggest that exercise-in-

Received on Oct 18, 2005; accepted on Nov 1, 2005; released online on Nov 8, 2005; DOI: 10.2170/jjphysiol.RP000305
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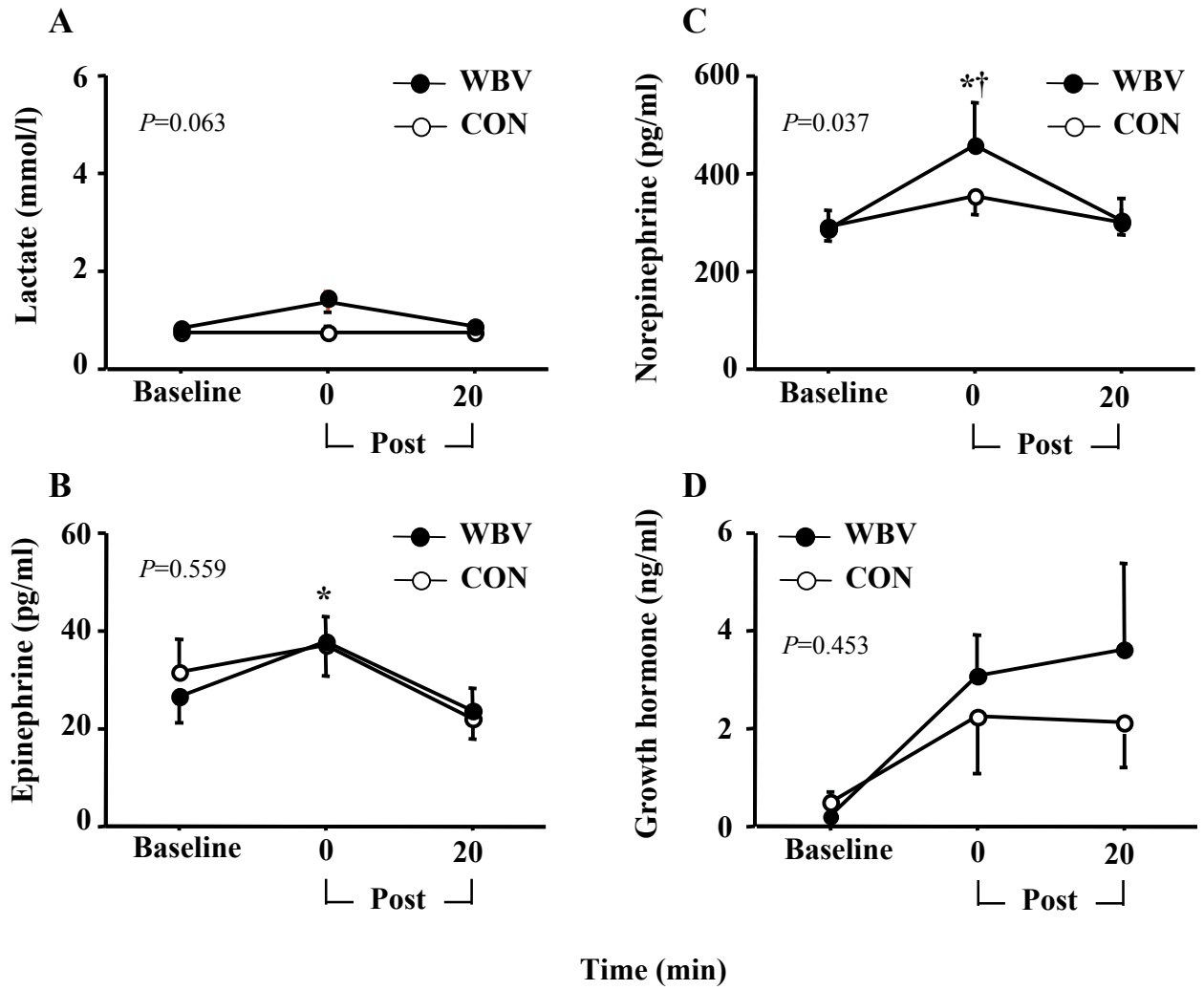

Fig. 1. Blood lactate (A), plasma epinephrine (Epi) (B), norepinephrine (NE) (C), and serum growth hormone (GH) (D) concentrations during two types of trials. Values are means ± SE, and *P* values indicate the interaction between time and trial (WBV or CON), analyzed using ANOVA. *Significant difference from baseline value in the WBV trial ($P < 0.05$). †Significant difference from corresponding value in the CON trial ($P < 0.05$). $N = 8$ for lactate and GH. One datum for Epi and NE was uncollectable ($N = 7$ for Epi and NE).

duced catecholamine and GH secretions play a role in lipolysis during the recovery period.

Bosco *et al.* [4] demonstrated that a 10 min WBV session significantly increases serum GH and testosterone. It is interesting that the magnitude of GH response to the WBV session was comparable to a sprinting exercise [19, 20], heavy resistance exercise with several exercises [21], and GH infusion resulting in marked lipolysis [22]. Thus the GH secretion following a WBV session might augment lipolysis during the recovery period. However, no studies have examined the effects of acute WBV exposure on lipid metabolism.

Therefore this study was intended to examine the effect of a single bout of a WBV session on hormone and lipolytic responses. We hypothesized that the WBV exposure would cause strong catecholamine and GH responses, subsequently increasing blood FFA and glycerol concentrations during the recovery period.

METHODS

Subjects. Eight healthy male students (mean ± SE: age 23.4 ± 0.9 years; height 175.2 ± 1.1 cm; body mass 77.8 ± 3.3 kg; body fat 22.1 ± 1.1%, BMI 24.6 ± 2.2) participated in this study. All subjects were physically healthy, but were not involved in a regular exercise program. They were informed about the experimental procedure and the purpose of this study. Subsequently, their written informed consent was obtained. This

study was approved by the Ethics Committee for Human Experiments at the Institute of Health and Sport Sciences, University of Tsukuba.

Vibration procedure. The subjects visited the laboratory on three occasions during the experiment period. The first session was prepared for familiarization with the WBV equipment. During the second and third sessions, the subjects came to the laboratory at 8:00 a.m. following overnight fasting. They performed two trials (WBV or CON) in random order, separated by approximately seven days. In the WBV trial, the subjects maintained a static squat position on the platform with a knee angle of 120° (180° at full extension) and were exposed to a vertical WBV stimulus by using a special device (Galileo 900, Novotec Medical GmbH, Germany). The vibration frequencies were set at 26 Hz (amplitude 2.5 mm). The stimulation protocol consisted of 10 sets of vibrations for 60 s with rest periods of 60 s between sets [4]. During the rest periods, the subjects rested on chairs. In the CON trial, they completed the same protocol as in the WBV trial, but the WBV stimulation was not imposed. The vibration stimulation was conducted from 8:30 to 8:50 a.m. All subjects were asked to wear gymnastic-type shoes to avoid bruises.

Blood sampling and protocol for measurements. The subjects rested for 30 min before the first blood collection. Venous blood samples were obtained from an indwelling cannula in the antecubital vein before (baseline), at 0 min (immediately after the session), and at 20, 60, 90, 120, 150, 180, and 210 min after each session. From the obtained samples, blood lactate, plasma epinephrine (Epi) and norepinephrine (NE), and serum GH were measured at baseline and at 0 and 20 min after the session. The concentrations of serum FFA, glycerol, and lipase were measured at baseline and at 60, 90, 120, 150, 180, and 210 min after each session (the FFA concentration was also measured at 0 and 20 min after each session). Plasma and serum samples were stored frozen at –85°C until analyses. Plasma concentrations of Epi and NE were measured by high-performance liquid chromatography (Tosoh Corp., Japan). The sensitivity of these assays and interassay and intra-assay coefficients of variation (CV) were 6.0 pg/ml, 2.7, and 2.0% for Epi and 6.0 pg/ml, 2.4, and 1.3% for NE. The serum GH concentration was measured by radioimmunoassay (RIA) with kits from Daiichi Radioisotope Laboratories, Ltd., Japan. The GH assay sensitivity was 0.5 ng/ml, and the interassay and intra-assay coefficients of CV were 3.6% and 3.4%, respectively. Serum FFA and glycerol were measured by use of the enzymatic method (Eiken Chemical Co. Ltd., Japan, and Wako Pure Chemical Industries Ltd., Japan). These interassay and intra-assay coefficients of CV were 0.2% and 0.9% for FFA and less than 5.0% for glycerol. Blood lactate concentration was measured with an automatic lactate analyzer (YSI1500 Sport; Yellow Springs Instrument Co. Inc., USA).

Statistical analysis. Data are expressed as means ± SE. A two-way (trial × time) analysis of variance (ANOVA) was used with repeated measure followed by Tukey's post hoc test. The responses of serum FFA, glycerol, and lipase were also assessed with the area under the time-concentration curve (AUC). The AUC were calculated by using a trapezoidal method from the 60- to 210-min points of the recovery period. For the AUC data, paired *t*-tests were applied. $P < 0.05$ was considered significant.

RESULTS

Figure 1 shows acute changes in blood lactate, plasma Epi and NE, and serum GH concentrations during two types of trials. No significant difference was seen in the baseline values (before each session) of lactate and hormones between trials. Blood lactate concentration increased slightly after the WBV session (0.8 ± 0.1 mmol/*l* to 1.4 ± 0.2 mmol/*l*, ns), but no significant difference was observed at any point between the WBV and CON trials. In the WBV trial, the concentrations of Epi and NE showed significant increases immediately after the session (Epi, 26.7 ± 5.4 pg/ml to 38.0 ± 5.0 pg/ml, $P < 0.05$; NE, 288.0 ± 38.7 pg/ml to 456.4 ± 89.8 pg/ml, $P < 0.05$), with a significant difference in NE between trials ($P < 0.05$). No significant difference was found in Epi and NE concentrations in the CON trial. Although serum GH concentration increased slightly after the session in both trials, no significant difference was found at any point between trials. Moreover, no significant difference was apparent in the peak values of GH between trials (WBV trial, 4.6 ± 1.7 ng/ml; CON trial, 2.8 ± 1.2 ng/ml).

Figure 2 shows changes in serum FFA concentration during two types of trials. No significant difference was found in the baseline value of FFA between trials (WBV trial, 0.39 ± 0.04 mEq/*l*; CON trial, 0.41 ± 0.05 mEq/*l*). In the WBV trial, FFA concentration showed a gradual increase after the 60-min point, with significant differences at the 150-min, 180-min, and 210-min points compared to the baseline value ($P < 0.01$). In the CON trial, no significant change

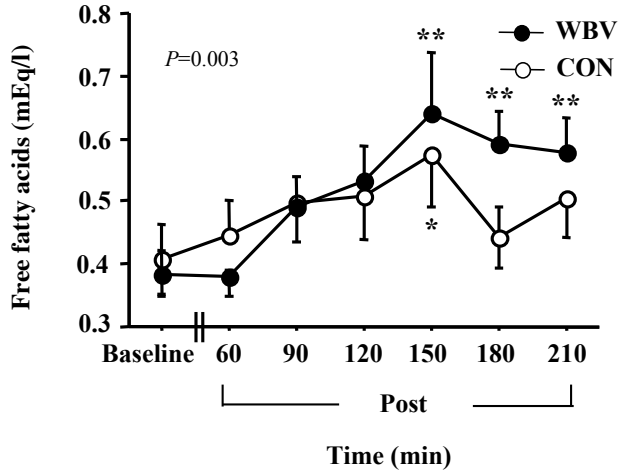

Fig. 2. Serum free fatty acids (FFA) concentration during two types of trials. Values are means ± SE, and *P* value indicates the interaction between time and trial (WBV or CON), analyzed using ANOVA. **Significant difference from baseline value ($P < 0.01$). *Significant difference from baseline value ($P < 0.05$). Although the values at 0 min and 20 min after each session are not shown, these are included in the statistical analysis using ANOVA.

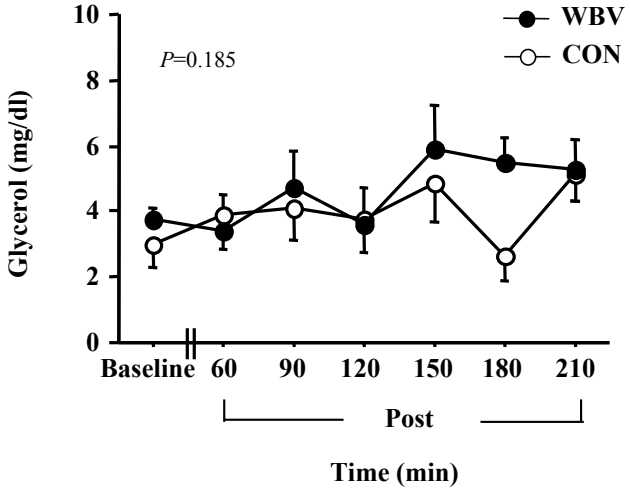

Fig. 3. Serum glycerol concentration during two types of trials. Values are means ± SE, and *P* value indicates the interaction between time and trial (WBV or CON) analyzed using ANOVA.

was found in FFA throughout the recovery period except for the 150-min time point ($P < 0.05$). As a result, a significant interaction effect (time × trial) was found for the FFA response ($P < 0.01$). No significant difference was found between trials (WBV trial, 104.5 ± 10.2 mEq/*l*; CON trial, 101.6 ± 12.5 mEq/*l*) when the total FFA response during the recovery period was assessed with the AUC.

Figure 3 shows changes in serum glycerol concentration during two types of trials. No significant difference was found between trials for the baseline values of glycerol (WBV trial, 4 ± 1 mg/dl; CON trial, 3 ± 1 mg/dl). Glycerol concentrations showed no significant change throughout the recovery period in either trial, with no significant difference at any point between trials (interaction effect, $P = 0.185$). Furthermore, when assessed with the AUC, no significant difference between trials was apparent (WBV trial, 722 ± 122 mg/dl; CON trial, 596 ± 13 mg/dl).

No significant difference was found between trials for the baseline values of serum lipase concentration. During the recovery period, the concentration of lipase showed significant decreases after the 60-min point in both trials (WBV trial, 32 ± 4 to 27 ± 3 IU/*l*, $P < 0.01$; CON trial, 29 ± 5 to 25 ± 4 IU/*l*, $P < 0.01$), whereas no significant difference was apparent at any point between trials (interaction effect, $P = 0.274$). No significant difference was found between trials when it was assessed with AUC (WBV trial, 4084 ± 462 IU/*l*; CON trial, 3848 ± 527 IU/*l*).

DISCUSSION

The major finding of this study was that a single bout of a WBV session enhanced acute Epi and NE secretions and subsequently increased serum FFA concentration during the recovery period. However, no significant difference was apparent in glycerol response between trials. In this study, although the WBV protocol resembled that of a previous study [4], no marked GH secretion was observed after the WBV session.

Bosco *et al.* [4] demonstrated that a 10-min WBV session increased concentrations of serum GH and testosterone significantly and reduced cortisol concentration. Among these hormones, GH is known to have a powerful lipolytic effect [22]. It is responsible for a gradual increase of blood FFA and glycerol concentrations and a concomitant shift of metabolism toward fat oxidation [15, 23]. The present study used a similar device, frequency and duration for vibrations as Bosco's study [4]. Moreover, the WBV session was conducted at a similar time of day (8:30 a.m.) to reduce the effects of diurnal variation of GH secretion between studies. As a result, the value of serum GH was increased slightly after the WBV session. However, no significant change was found in comparison to the baseline value (Fig. 1). Both the central nervous system and the peripheral factors (e.g., metabolite accumulation within working muscles) might be involved in the regulation of hypothalamic hormones, including GH [24, 25]. During the WBV session, enhancements of hormone secretions might be primarily

caused by central factors because the metabolic stress within working muscles is not great. The reason for different results between previous and present studies remains unclear, but the subjects' characteristics might be related. In Bosco's study [4], physically active athletes participated as subjects, whereas the subjects of the present study were not engaged in regular physical activities or sports training. The exercise-induced hormonal responses would be strongly affected by physical characteristics [26] and training status [19]. Some studies have shown that the trained men can induce larger responses of GH compared to untrained men [27]. It is therefore possible that the magnitude of central activation to the WBV stimuli differs between athlete subjects and nonathlete subjects. These might be responsible for a smaller GH response in the present subjects. However, the greater individual variation of GH response in Bosco's study [4] should be noted.

We anticipated that a WBV session would stimulate secretions of catecholamine and GH and subsequently enhance lipolysis, resulting in increased FFA and glycerol concentrations of blood. In the WBV trial, serum FFA concentration increased gradually after the 60-min point of the recovery period, with a significant interaction effect (trial × time, Fig. 2). These results are partially consistent with our hypothesis and suggest that the WBV session stimulates lipolysis during the recovery period. This lipolysis enhancement might be caused by Epi and NE secretions seen immediately after the WBV session (Fig. 1). However, the secretions of these hormones were not great in comparison to those of heavy resistance exercise [28] or prolonged cycle ergometer exercise [29]. Moreover, the delayed time course of FFA response was consistent with that seen after the GH administration, rather than catecholamine [18]. Figure 1 shows that no significant increase was found in GH concentration after a WBV session, but we could not determine its peak level attributable to the frequency of blood sampling for GH concentration. Thus we were unable to exclude the gradually increased circulating GH level after the 20-min point of the recovery period in the WBV trial. On the other hand, the response of glycerol showed no significant interaction effect (trial × time; Fig. 3). The inconsistent responses between FFA and glycerol remain unexplained, but these indicate that the interpretation of lipolysis in the WBV trial needs precaution. Moreover, FFA in the CON trial slightly increased after the session, with significant difference at the 150-min point compared to baseline ($P < 0.05$). Serum lipase decreased significantly during the recovery period in both trials. These were unexpected results, and more research with measurements of other hormones (e.g., insulin) should be conducted.

Some evidence exists in relation to the effects of WBV training on enhancing neuromuscular performance [2, 6]. Also, a recent study has addressed favorable effects on bone density, indicating its potential availability for preventing and treating osteoporosis [30]. However, no previous studies have established the long-term effects of WBV training on the improvement of body composition, especially reducing body fat. In fact, no significant reduction in body fat was found after 24 weeks of WBV training [9]. Verschueren *et al.* [30] examined the effects of WBV training with squat exercises on body composition. Results have shown that the WBV training group did not engender a greater reduction of fat mass compared to that of another group after a 6-month training period. Previous and present findings indicate that WBV training is unlikely to cause a great reduction of body fat. This is not unexpected because cardiovascular stress during the WBV session is mild and the energy expenditures might be equal to those during walking at moderate intensity [3, 9].

In conclusion, this study showed that a WBV session caused moderate secretions of Epi and NE, and subsequently increased FFA concentration during the recovery period. In contrast, no effect of WBV sessions was noted on the responses of GH and glycerol. Although WBV training appears to be a simple and useful exercise intervention for enhancing neuromuscular performance, we were unable to clarify its effectiveness on lipolysis.

REFERENCES

1. Cardinale M and Bosco C: The use of vibration as an exercise intervention. Exerc Sport Sci Rev 31: 3–7, 2003
2. Delecluse C, Roelants M, and Verschueren S: Strength increase after whole-body vibration compared with resistance training. Med Sci Sports Exerc 35: 1033–1041, 2003
3. Rittweger J, Beller G, and Felsenberg D: Acute physiological effects of exhaustive whole-body vibration exercise in man. Clin Physiol 20: 134–142, 2000
4. Bosco C, Iacovelli M, Tsarpela O, Cardinale M, Bonifazi M, Tihanyi J, Viru M, De Lorenzo A, and Viru A: Hormonal responses to whole-body vibration in men. Eur J Appl Physiol 81: 449–454, 2000
5. Bosco C, Cardinale M, and Tsarpela O: Influence of vibration on mechanical power and electromyogram activity in human arm flexor muscles. Eur J Appl Physiol 79: 306–311, 1999
6. Bosco C, Colli R, Introini E, Cardinale M, Tsarpela O, Madella A, Tihanyi J, and Viru A: Adaptive responses

of human skeletal muscle to vibration exposure. Clin Physiol 19: 183–187, 1999
7. Torvinen S, Kannu P, Sievanen H, Jarvinen TA, Pasanen M, Kontulainen S, Jarvinen TL, Jarvinen M, Oja P, and Vuori I: Effect of a vibration exposure on muscular performance and body balance. Randomized cross-over study. Clin Physiol Funct Imaging 22: 145–152, 2002
8. Runge M, Rehfeld G, and Resnicek E: Balance training and exercise in geriatric patients. J Musculoskelet Neuronal Interact 1: 61–65, 2000
9. Roelants M, Delecluse C, Goris M, and Verschueren S: Effects of 24 weeks of whole body vibration training on body composition and muscle strength in untrained females. Int J Sports Med 25: 1–5, 2004
10. de Ruiter CJ, van der Linden RM, van der Zijden MJ, Hollander AP, and de Haan A: Short-term effects of whole-body vibration on maximal voluntary isometric knee extensor force and rate of force rise. Eur J Appl Physiol 88: 472–475, 2003
11. Hakkinen K, Pakarinen A, Kraemer WJ, Hakkinen A, Valkeinen H, and Alen M: Selective muscle hypertrophy, changes in EMG and force, and serum hormones during strength training in older women. J Appl Physiol 91: 569–580, 2001
12. Evans EM, Racette SB, Peterson LR, Villareal DT, Greiwe JS, and Holloszy JO: Aerobic power and insulin action improve in response to endurance exercise training in healthy 77–87 yr olds. J Appl Physiol 98: 40–45, 2005
13. van Aggel-Leijssen DP, Saris WH, Hul GB, and van Baak MA: Short-term effects of weight loss with or without low-intensity exercise training on fat metabolism in obese men. Am J Clin Nutr 73: 523–531, 2001
14. Stallknecht B, Lorentsen J, Enevoldsen LH, Bulow J, Biering-Sorensen F, Galbo H, and Kjaer M: Role of the sympathoadrenergic system in adipose tissue metabolism during exercise in humans. J Physiol 536: 283–294, 2001
15. Pritzlaff CJ, Wideman L, Blumer J, Jensen M, Abbott RD, Gaesser GA, Veldhuis JD, and Weltman A: Catecholamine release, growth hormone secretion, and energy expenditure during exercise vs. recovery in men. J Appl Physiol 89: 937–946, 2000
16. Melby C, Scholl C, Edwards G, and Bullough R: Effect of acute resistance exercise on postexercise energy expenditure and resting metabolic rate. J Appl Physiol 75: 1847–1853, 1993
17. Schuenke MD, Mikat RP, and McBride JM: Effect of an acute period of resistance exercise on excess post-exercise oxygen consumption: implications for body mass management. Eur J Appl Physiol 86: 411–417, 2002
18. Moller N, Jorgensen JO, Alberti KG, Flyvbjerg A, and Schmitz O: Short-term effects of growth hormone on fuel oxidation and regional substrate metabolism in normal man. J Clin Endocrinol Metab 70: 1179–1186, 1990
19. Nevill ME, Holmyard DJ, Hall GM, Allsop P, van Oosterhout A, Burrin JM, and Nevill AM: Growth hormone responses to treadmill sprinting in sprint- and endurance-trained athletes. Eur J Appl Physiol 72: 460–467, 1996
20. Stokes KA, Nevill ME, Hall GM, and Lakomy HK: Growth hormone responses to repeated maximal cycle ergometer exercise at different pedaling rates. J Appl Physiol 92: 602–608, 2002
21. Kraemer WJ, Marchitelli L, Gordon SE, Harman E, Dziados JE, Mello R, Frykman P, McCurry D, and Fleck SJ: Hormonal and growth factor responses to heavy resistance exercise protocols. J Appl Physiol 69: 1442–1450, 1990
22. Gravholt CH, Schmitz O, Simonsen L, Bulow J, Christiansen JS, and Moller N: Effects of a physiological GH pulse on interstitial glycerol in abdominal and femoral adipose tissue. Am J Physiol 277: E848–E854, 1999
23. Kanaley JA, Dall R, Moller N, Nielsen SC, Christiansen JS, Jensen MD, and Jorgensen JO: Acute exposure to GH during exercise stimulates the turnover of free fatty acids in GH-deficient men. J Appl Physiol 96: 747–753, 2004
24. Kjaer M, Secher NH, Bach FW, Sheikh S, and Galbo H: Hormonal and metabolic responses to exercise in humans: effect of sensory nervous blockade. Am J Physiol 257: E95–E101, 1989
25. Goto K, Ishii N, Kizuka T, and Takamatsu K: The impact of metabolic stress on hormonal responses and muscular adaptations. Med Sci Sports Exerc 37: 955–963, 2005
26. Kanaley JA, Weatherup-Dentes MM, Jaynes EB, and Hartman ML: Obesity attenuates the growth hormone response to exercise. J Clin Endocrinol Metab 84: 3156–3161, 1999
27. Ahtiainen JP, Pakarinen A, Alen M, Kraemer WJ, and Hakkinen K: Muscle hypertrophy, hormonal adaptations and strength development during strength training in strength-trained and untrained men. Eur J Appl Physiol 89: 555–563, 2003
28. Kraemer WJ, Noble BJ, Clark MJ, and Culver BW: Physiologic responses to heavy-resistance exercise with very short rest periods. Int J Sports Med 8: 247–252, 1987
29. Ronsen O, Haug E, Pedersen BK, and Bahr R: Increased neuroendocrine response to a repeated bout of endurance exercise. Med Sci Sports Exerc 33: 568–575, 2001
30. Verschueren SM, Roelants M, Delecluse C, Swinnen S, Vanderschueren D, and Boonen S: Effect of 6-month whole body vibration training on hip density, muscle strength, and postural control in postmenopausal women: a randomized controlled pilot study. J Bone Miner Res 19: 352–359, 2004