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Endocrine response to high intensity barbell squats performed with constant movement tempo and variable training volume

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Abstract

OBJECTIVE: Research indicates that among the many elements of resistance exercise protocols, training volume and total training load are the key factors for post-exercise increase in the secretion of testosterone (T), growth hormone (GH), insulin-like growth factor (IGF-1) and cortisol (C). The aim of this study was to determine the effects of resistance exercises with variable volume and constant intensity and movement tempo on post-exercise concentrations of selected anabolic and catabolic hormones.

MATERIALS AND METHODS: 28 experienced powerlifters (27.8 ± 2.9 years, with 6.64 ± 1.29 years of training experience, average body mass of 85.3 ± 3.3 kg and body height of 165.8 ± 10.3 cm) who compete at the national and international level performed three repetitions of barbell squats with a constant external load of 90% 1RM and variable volume (3, 6 and 12 sets of squats) in three stages (pre-exercise, immediately post exercise, and 1h after exercise) over three consecutive weeks. Venous blood samples (10ml) were collected from the antecubital vein, to determine pre- and post-exercise values of the following variables T, GH, IGF-1, C, at rest, immediately after the cessation of the last set of squats, and after 60 minutes of recovery.

RESULTS: The T test showed that performing 6 and 12 sets resulted in increases of post exercise GH ($p<0.01$). Performing 6 sets of squats resulted in post exercise decrease ($p<0.01$) in IGF-1 and C. Performing 3 sets of squats resulted in immediate post exercise decrease of IGF-1 ($p<0.01$), which was not maintained 1h after exercise. There were no other significant differences in analysed variables, with the training volume of three sets of three repetitions, confirming previous data suggesting that low volume is the limiting factor in increased post-exercise secretion.

CONCLUSION: This study demonstrated that in terms of endocrine response, the optimal volume of high intensity strength exercise is six sets. Therefore, intentionally high volume (12 sets) or low volume (3 sets) are not an effective stimuli for endocrine responses of trained individuals. The 6 sets of squats seems to drive

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hormonal responses of GH, C and IGF-1, which may play a significant role in stimulating muscle growth and tissue regeneration.

INTRODUCTION

Resistance exercises, especially those performed with high intensity, cause significant endocrine changes, both acute and chronic (Kraemer & Ratamess, 2005; Uchida *et al.* 2009; Crewther *et al.* 2011). The endocrine system is particularly sensitive to resistance exercise and changes in anabolic and catabolic hormones have been associated with the process of post-exercise rebuilding of damaged muscle cells, and thus the magnitude and rate of the post-exercise adaptation (Kraemer & Ratamess, 2005; Sedliak *et al.* 2007; Kadi, 2008). Hormones, particularly growth hormone (GH) and testosterone, have a significant effect on the rate of protein synthesis, and the type of substrates metabolized during and immediately after exercise (Uchida *et al.* 2009). These hormones also stimulate the activation and proliferation of satellite cells which facilitate myofibrillar hypertrophy (Kadi *et al.* 2005). GH has an anabolic effect on skeletal muscles, stimulates the synthesis of proteins, facilitates the transport of amino acids into skeletal muscles, thus affecting hypertrophy of both Type I and Type II muscle fibres (Hansen *et al.* 2001). Research has demonstrated that blocking the effects of anabolic hormones reduces the rate of adaptive changes and the effectiveness of weight training programs (Kvorning *et al.* 2006). These hormones play a significant role in mediating increases in muscle mass and muscle strength (Kadi, 2008).

Some research indicates that among the many variables of strength training protocols, training volume and total training load are key factors for post-exercise increase in the secretion of various hormones (Kraemer *et al.* 1991). Other research results indicate that duration of the force production and the length of rest periods between sets are the most significant factors stimulating plasma and serum cortisol (C). These hormonal responses are particularly intense in the case of high-intensity, medium or high volume training programs (Kraemer *et al.* 1991) and when the training protocol targets large muscle groups (Kraemer & Ratamess, 2005). Research on the effects of strength training on muscle hypertrophy showed an important role not only of anabolic hormones like testosterone (T), but also for growth factors, including the insulin-like growth factor-1 (IGF-1). Serum IGF-1 elevations are induced by strength training (Kraemer & Ratamess, 2005), but some studies suggested that this is the case only when resting concentrations are low (Kraemer *et al.* 1991). The divergent findings concerning the effect of strength training on the process of adaptation and response of the endocrine system may result from the fact that most procedures did not specify the movement speed for an exercise or the whole strength training session. Only a few publications have analysed the effects of movement tempo (cadence) on adaptive processes in terms of strength, power, muscle hypertrophy or endocrine responses (Wilk *et al.* 2018a; Headley *et al.* 2011; Hatfield *et al.* 2006; Sakamoto and Sinclair 2006; Hunter *et al.* 2003; Keeler *et al.* 2001; Westcott *et al.* 2001). Repetition speed is the only variable which has not been widely explored scientifically with respect to adaptation and response of the endocrine system. In most studies, the tempo of performing strength exercises is volitional, according to the natural movement rhythm. Studies have found that the lower the movement speed the more intensive decline in the generated muscle force (Hutchins 1993, Westcott *et al.* 2001, Kraemer *et al.* 2002). Wilk *et al.* (2018b) showed that the movement tempo in strength training impacts training volume, both in terms of repetitions and total time under tension (TUT). The optimal volume and intensity of training loads in resistance exercises that may most effectively stimulate the anabolic hormones while diminishing the secretion of catabolic ones has not been determined. This may be due to numerous factors such as movement speed for an exercise, age, sex, training experience, type of muscular contractions used which complicate this issue. Additional factors include type of equipment, diet, supplementation and how these factors interact with genetic endowment (Wilk *et al.* 2018c). Exceeding the optimal training volume causes the anabolic hormone peak to occur during training, and continuation of exercise results in an excess concentration of catabolic hormones (Viru & Viru, 2004; Uchida *et al.* 2009; West *et al.* 2012).

The aim of this study was to determine the effect of variable volume in squat exercise with constant intensity and constant tempo on post-exercise concentrations of selected anabolic and catabolic hormones and growth factors (GH, T, IGF-1 and C). An additional objective was to determine the range of training volume, which elicited the greatest anabolic hormone secretion while limiting the increase in C.

MATERIALS AND METHODS

Experimental Approach to the Problem

All testing was performed in the Strength and Power Laboratory at the Jerzy Kukuczka Academy of Physical Education in Katowice. The experiment was performed following a randomized cross sectional design, where each participant performed a familiarization session with a 1-RM test and three different testing protocols a week apart. During the experimental sessions, subjects performed barbell squats at low volume - 3 sets (LV_3); medium volume - 6 sets (MV_6); high volume- 12 sets (HV_{12}). In each set 3 repetitions were done using 90% 1RM and a 2/0/3/0 tempo. Subjects were required to refrain from resistance training 72 hours prior to each experimental session, were familiarized with the exercise protocol and were informed about the benefits and risks of the research before expressing their consent for participation in the experiment.

Subjects

Participants for this study were 28 experienced powerlifters who competed at the national and international level. The age of the subjects was 27.8 ± 2.9 years, with 6.64 ± 1.29 years of training experience, average body mass of 85.3 ± 3.3 kg and body height of 165.8 ± 10.3 cm. The participants were allowed to withdraw from the experiment at any moment and were free of injuries. The study protocol was approved by the Bioethics Committee for Scientific Research, at the Academy of Physical Education in Katowice, Poland, according to the ethical standards of the Declaration of Helsinki, 2013. Participants were instructed to maintain their normal dietary habits over the entire study period and did not use any dietary supplements or stimulants for the duration of the study.

Procedures

Familiarization session and one repetition maximum test

The participants arrived at the laboratory at the same time of day (in the morning between 09:00 and 11:00) and cycled on an ergometer for 5 minutes at an intensity that resulted in a heart rate of around 130 bpm, then performed a general lower body warm-up. Next, the participants completed 15, 10, 5 and 3 barbell squat repetitions using 20%, 40%, 60%, 80% of their estimated 1RM using a 2/0/2/0 cadence. Knee wraps were allowed and three spotters were present at all times during the testing protocol. The participants then executed single repetitions using a volitional cadence with 5 min of rest between successful trials. The load for each subsequent attempt was increased by 5 kg, and the process was repeated until failure.

Experimental sessions

The participants arrived at the laboratory in the morning (09:00 to 11:00 am). After completing the same warm-up as in the familiarization session, they performed 3 sets (LV_3), 6 sets (MV_6) or 12 sets (HV_{12}) of the squat with 90% 1RM (*Table 1*) using 2/0/3/0 metronome guided cadence (Korg MA-30,Korg, Melville, New York, USA). The time between experimental sessions of training was one week. The participants were verbally encouraged throughout all testing sessions. All repetitions were performed without intentionally pausing at the transition between the eccentric and concentric phases.

Blood sampling and analysis

During the experiment, 10 ml venous blood samples were collected from the antecubital vein to determine pre- and post-exercise concentrations of T, GH, IGF-1, and C at rest, immediately after the cessation of the last set of squats, and after 60 minutes of recovery. Commercially available radioimmunoassay evaluations were performed for the evaluation of T (DSL-4000), GH (DSL-1900), IGF-1 (DSL-2800), and cortisol (DSL-2100). The ICC for the biochemical analysis varied from 0,88 to 0,99 for the 4 conducted test.

Table 1. The testing protocols applied during the experiment

	Low volume (LV_3)	**Medium volume (MV_6)**	**High volume (HV_3)**
Load (%1RM)	90%1RM	90%1RM	90%1RM
Tempo	2/0/3/0	2/0/3/0	2/0/3/0
Set / repetition	3 / 3	6 / 3	12 / 3
Rest interval between sets	5 min	5 min	5 min

Statistical Analyses

Means, standard deviations, confidence levels and standard errors were calculated for all measured variables, and all variables were tested for normality by the quantile-quantile test. To identify significant group by time interactions, t test for independent trials was used for each dependent variable. When a significant interaction occurred post hoc test by Rodger's method was performed for detecting differences among groups (pair wise comparisons). Rodger's method belongs to the most powerful post-hoc tests for detecting differences among groups. This test protects against loss of statistical power as the degrees of freedom increase. The statistical significance was set at $p \le 0.05$.

RESULTS

All variables were normally distributed as determined by the quantile-quantile test results (p > 0.05). Among 28 experienced powerlifters (N = 28), there were statistically significant differences of GH concentration in MV_6, between the mean post-workout values (1.278 ± 4.89 ηg/ml) and the mean rest value (0.393 ± 0.234 ηg/ml) t(7) = 5.87, p ≤ .01, as well as between the value obtained one hour after exercise (0.573 ± 0.347 ηg/ml) t(7) = 5.01, p ≤ .01. Statistically significant difference also occurred in GH during HV_{12}, between the mean post-workout value (1.141 ± 0.432 ηg/ml) and the mean rest value (0.199 ± 0.171 ηg/ml) t(7) = 6.15, p ≤ .01, as well as the value obtained one hour after exercise (0.293 ± 0.137 ηg/ml) t(7) = 6.07, p ≤ .01. Therefore, we reject the null hypothesis that there is no difference in concentration of growth hormone at rest and post-workout in MV_6 and HV_{12} training. For LV_3 training, GH concentrations were not significantly different between mean values at rest, post-exercise and after one hour of recovery when LV_3 was applied. Significant differences were found just for GH with MV_6, and HV_{12} (*Figure 1*).

With regard to testosterone, no significant differences in concentration were observed as a result of training volume at any time point. Therefore, we fail to

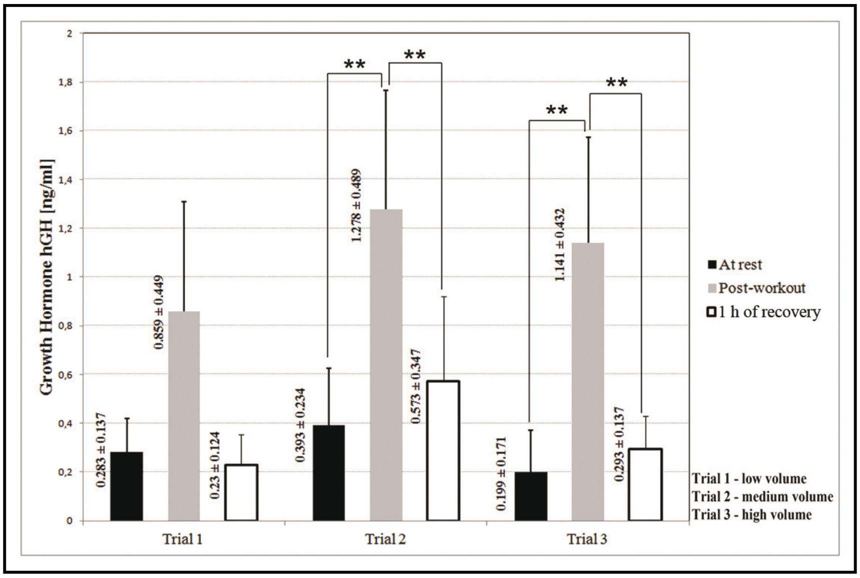

Fig. 1. The average concentration of the growth hormone at various levels of training volume. **$p<0.01$.

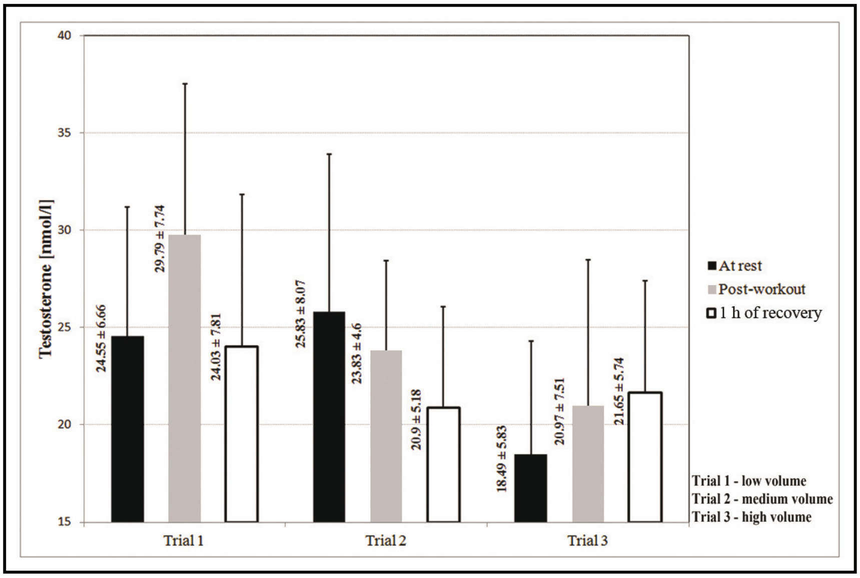

Fig. 2. The average concentration of the testosterone at various levels of training volume.

reject the null hypothesis that there is no difference in concentration of testosterone between training volume at each time point (*Figure 2*).

For IGF-1, there were no significant differences in HV12 between the mean rest concentration and the post-exercise value. In the moderate volume trial, significant differences were found between the mean rest value (657.29 ± 205.36 ηg/ml) and the value obtained one hour after exercise (534.77 ± 102.3 ηg/ml) t(7) = 3.10, $p \leq .01$. Statistically significant differences also occurred in LV_3s, between post-exercise value (476.43 ± 197.82 ηg/ml) and the mean rest value (573.42 ± 169.76 ηg/ml) t(7) = 3.69, $p \leq .01$. Therefore, we reject the null hypothesis that there is no difference in concentration of the IGF-1 between values at rest and post-exercise in LV_3s, as well as between rest and after one hour of recovery in MV_6s (*Figure 3*).

For C, only the MV_6 trial yielded significant differences between the concentrations at rest (673.76 ± 251.32 ηmol/l) and after one hour of recovery (320.28 ± 114.17 ηmol/l) t(7) = 6.89, $p \leq .01$, as well as post-exercise (479.54 ± 218.24 ηmol/l) t(7) = 4.17, $p \leq .01$. Therefore, we reject the null hypothesis that there is no difference in concentration of the cortisol between training volume at every time point (*Figure 4*).

DISCUSSION

The main finding of this study is that the different training volume (LV_3, MV_6, HV_{12}) with constant movement tempo in resistance exercise doesn't impact on post-exercise concentrations of T, only MV_6 and HV_{12} can elicit anabolic GH post-exercise response, and only HV_6 can elicit post-exercise IGF-1 response

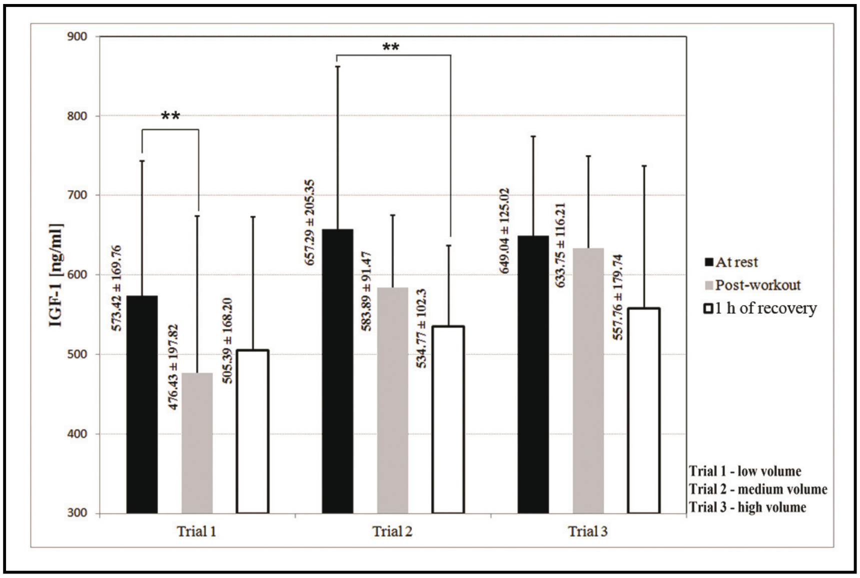

Fig. 3. The average concentration of the IGF-1 at various levels of training volume. $^{**}p<0.01$.

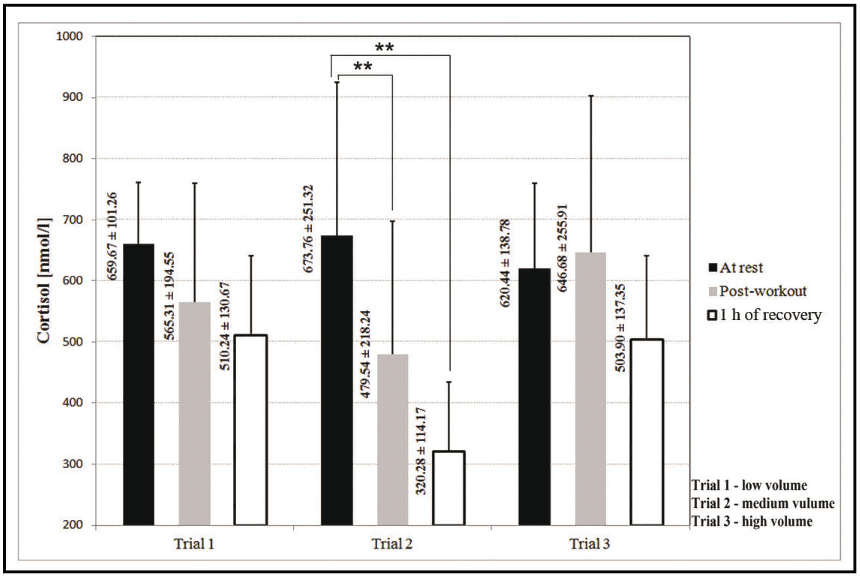

Fig. 4. The average concentration of the cortisol at various levels of training volume. $^{**}p<0.01$.

with decreased post-exercise C level. Therefore, the MV_6 resulted in most efficient hormonal post-exercise response in terms of post exercise recovery.

Despite our use of variable-volume of exercise (LV_3, MV_6, HV_{12}) in the present study, no significant differences in post-exercise plasma testosterone levels were observed, contrary to previous findings (Crewther *et al.* 2008). While Kraemer and Ratamess (2005) suggested that strong increases in serum testosterone levels occur in participants with a relatively high baseline levels of this hormone, this was not confirmed by the results of the present study. The absence of significant differences between resting and post-exercise values may have resulted from high initial resting testosterone levels in these young participants (mean age 24), extensive training experience (mean of 6 years), and/or time of day of sampling (9 am). It is possible that circadian rythym changes masked exercise-related changes of in testosterone (Sedliak *et al.* 2007; Cook and Crewther, 2012). It is also possible that the lack of significant differences in post-exercise testosterone levels could have been due to the length of rest periods between sets (5 minutes), since Kraemer *et al.* (1991) suggested that the length of rest periods between sets determines the effective impact of strength training on the elevation of testosterone levels and should not exceed two minutes. Kraemer *et al.* (1991) also suggested that exercise-induced changes in testosterone may be influenced by the type of exercise performed. While an increase in plasma testosterone levels was observed when powerlifting exercises targeting several muscle groups were performed at the same time (Kraemer *et al.* 1991), the present study did not find this association with just one exercise being used (back barbell squat), even at varying exercise volumes.

Strength training which results in a significant increase in C levels generally involves a higher number of repetitions than three and significantly shorter rest intervals between sets than were performed in the present study (Smilios *et al.* 2003). Our findings suggest that a five-minute rest period between sets, despite a large number of sets performed at 90% of the 1RM load, does not stimulate glycolysis significantly, and thus does not result in a significant increase in C levels. Research showed that when the resting concentration of C is high, no post-exercise elevation was found (Beaven *et al.* 2008), and in some cases a post-exercise decrease in concentrations of this hormone was observed, compared to resting levels. This study demonstrated a significant difference in cortisol concentrations only in the MV_6 where exercise-induced C levels were significantly lower than baseline values prior to exercise.

The present study demonstrated that the volume of 12 sets (HV_{12}) did not result in a greater GH secretion in comparison to the LV_3 and MV_6. Thus, we suggest that the unfavorable increase in C levels associated with a higher volume indicates that the MV_6 could be more beneficial with respect to post-exercise endocrine adaptation. Previous research suggested that when the optimal volume is exceeded, the GH peak occurs already during the training session (Schwarz *et al.* 1996; West el al., 2012). It is possible that this was the case during the maximal volume protocol (HV_{12}), yet no measurements were performed between particular sets to confirm this hypothesis.

Analyses of changes in IGF-1 concentrations during our different strength training protocols demonstrated decreases in the LV_3 and MV_6 trials, and despite comparable training variables, the results we obtained were contradictory to those reported in earlier research (Kraemer *et al.* 1991). Some research results indicate that when anabolic processes in the body are predominant, strength training stimulates the exercise-induced elevation of IGF-1 concentrations, as demonstrated by previous research Forbes *et al.* (1989). The results of the present research, may be indicative of the predominance of catabolic environment in the subjects (with exception of decreased C level in MV6), which could partly explain the absence of exercise-induced increase in IGF-1 levels. It is known that the metabolic state of the body and the level of target cell sensitivity to the released IGF-1 is the essential stimulating mechanism for changes in IGF-1 concentrations (Ambrosio *et al.* 1996). In this study, a significant elevation of IGF-1 concentrations was not observed, and even decreased significantly after the low volume training protocol (Figure 3). A significant decrease also occurred between the concentrations measured prior to exercise and after one hour of recovery, in the moderate training volume trial. Resting IGF-1 levels were high in this study, what confirms a previous hypotheses that the exercise-induced elevation of IGF-1 levels are more likely to be observed when baseline concentrations are low (Kraemer *et al.* 1991). The high resting concentration of IGF-1 may be associated with the effects of nocturnal GH secretion (Ohlsson *et al.* 2009). The measurement of resting IGF-1 concentration was performed at approximately 9 am. Research showed that the duration of IGF-1 secretion due to the influence of GH can be approximately 12 hours long (Kraemer & Ratamess, 2005), which may partly explain the high resting IGF-1 concentrations.

A negative correlation between the concentrations of cortisol and testosterone has been reported (Brownlee *et al.* 2005). The study by Brownlee *et al.* (2005) also show a positive correlation between concentrations of cortisol and free testosterone. In addition to the effects of testosterone, the important post-training role of GH or IGF-1 should be taken into account. Anabolic hormones were identified as having a significant impact on muscle tissue remodelling (Viru & Viru, 2004). Hansen *et al.* (2001) suggested that the adaptation is dependent on the exercise-induced concentrations of anabolic hormones, therefore optimizing the volume may be crucial for maximal training effects. Research suggests that the first hour of recovery is critical for the endocrine response. After this period, the concentration of hormones and growth factors generally returns to resting levels (Tremblay *et al.* 2005; West *et al.* 2014) which was confirmed by the present study but not in IGF-1 and cortisol. The results of global research also indicate that there are significant differences in individual hormonal responses to specific types of exercise, (McGuigan *et al.* 2004; Beaven et al. 2008).

PRACTICAL APPLICATION

This study demonstrated that in terms of anabolic hormone response, the most effective volume is close to 6 sets. It has been established that performing 12 sets resulted in an increase of cortisol concentrations, while 6 sets led to a significant decrease in exercise-induced cortisol levels compared to baseline. We believe it is reasonable to suggest the volume of training which should not be exceeded, since our data did not demonstrate any favorable changes in hormone response with higher volume training in experienced powerlifters.

CONCLUSIONS

This research indicates that among the many variables of strength exercise, training volume and total training load are the key factors stimulating the secretion of various hormones, both anabolic and catabolic. The conducted study demonstrated that in terms of endocrine response, the optimal volume of high intensity strength exercise is about 6 sets in experienced powerlifters.

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