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The Effect of High-Intensity Interval Training on Testosterone, Growth Hormone, and Cortisol in Athletes: A Review

Emine Kübra AY[1] **Bahar ANAFOROĞLU**[2]

Abstract

High-intensity interval training, which has been used for more than a century to improve athletic performance, is an exercise method consisting of short bursts of high activity followed by low-intensity activities for recovery or rest. The endocrine system plays a key role in physiological adaptations in exercise by regulating anabolic and catabolic processes. The aim of this review is to compile existing information and contribute to the literature by examining in detail the changes that occur in testosterone, growth hormone and cortisol, hormones that play an important role in body metabolism, following high-intensity interval training in athletes. Different mechanisms play a role in post-exercise hormone level changes. The literature search was conducted in Turkish and English, using the electronic databases PubMed, Web of Science, and Google Scholar, with the keywords 'high-intensity interval training', 'testosterone', 'growth hormone', 'cortisol'. The type, duration and intensity of exercise affect the performance of the athlete and the endocrine response. The level of testosterone, a metabolic-androgenic steroid hormone, increases after high-intensity interval training. The stress that arises because of exercise following high-intensity interval training plays a decisive role in cortisol levels. It is widely believed that growth hormone increases in athletes after high-intensity interval training. However, stress, fatigue, lack of sleep, and intense and prolonged exercise can also cause a decrease in growth hormone levels. All exercises result in physiological changes. These physiological changes in athletes must be considered when planning exercises correctly for maximum performance.

***Keywords**:* Cortisol, Growth Hormone, High Intensity Interval Training, Testosterone

INTRODUCTION

High-intensity interval training (HIIT) is an exercise approach that consists of brief periods of very intense activity alternated with lower-intensity movements for rest or recovery. (Cao et al., 2019). This method is generally applied to enhance athletic performance. It has formed the basis of training programmes for elite endurance athletes for over a century (Coates et., al 2023). Typically, it includes traditional exercise methods such as running, cycling, and rowing (Menz et al., 2019). Various training protocols have been developed, such as Peter Coe, Timmon, Tabata, and Gabala (Altınkök, 2015; Bilge et al., 2021).

High-intensity interval training consists of non-maximal high-intensity exercises lasting less than 45 seconds or between 2 and 4 minutes, or sprint series lasting less than 10 seconds, with intervals of 20-30 seconds between sprints. All protocols include recovery periods. These variable-length sessions, including recovery periods are combined to form training programmes lasting a total of 5 to 40 minutes (Buchheit and Laursen, 2013). High-intensity workloads corresponding to 90% of VO_2max, 75% of maximal power, or 90% of the minimum running speed required to reach VO_2max are performed at effort levels perceived as 'very hard' to 'extremely hard' on the Borg scale (Atakan et al., 2021). As with other exercise protocols, when planning HIIT, as with other exercise protocols the number of

[1] Corresponding Author: Ankara Yıldırım Beyazıt University, Ankara, Türkiye. ekay@aybu.edu.tr
[2] Ankara Yıldırım Beyazıt University, Ankara, Türkiye. baharkulunkoglu@aybu.edu.tr

repetitions, number of sets, intensity and duration of the load, recovery time, and form of exercise should be taken into account (Akgül et al., 2017).

It is known that exercises that create high physiological demand have significant effects, particularly on the endocrine system (Dote-Montero et al., 2021). The endocrine system plays a significant role in physiological adaptations to exercise by regulating anabolic and catabolic processes (Öncen and Aydın, 2023). The human body releases various hormone-like substances that exert endocrine and autocrine effects on tissues. Physiologically, hormones play a regulatory role in numerous processes, including reproduction, hydration, cardiovascular regulation, growth and development, metabolism and stress reactivity. In most cases, the effects of exercise on the endocrine system are positive. It contributes to improved health and performance by enhancing the functions of tissues and organs (Hackney and Lane, 2015).

Changes in key hormones including testosterone, growth hormone, cortisol, and insulin are also observed in athletes after HIIT (Athanasiou et al., 2023; Kilian et al., 2016; Öniz and Göçer 2021). Testosterone is primarily a metabolic-androgenic steroid hormone that interacts with androgen receptors in skeletal muscle (Kraemer et al., 2020). It has been reported that plasma testosterone levels increase in young and elderly men after acute exercise, and that trained individuals exhibit a higher androgen response to maximal exercise (Mitat et al., 2016). Growth hormone, produced by the hypothalamus and affecting on somatotropic cells in the anterior pituitary gland, shows a significant increase 15 minutes after exercise in both endurance and intermittent exercise (Athanasiou et al., 2023). Cortisol, a glucocorticoid secreted by the adrenal cortex, is the primary stress hormone. During exercise, cortisol has a key role for managing blood sugar and supporting metabolic regulation. It has been reported that cortisol levels increase after acute exercise (Mennitti et al., 2024). Insulin is one of the key hormones that regulate glucose metabolism and glucose uptake in peripheral tissues. Physical activity requires fuel mobilisation and oxidation. During physical activity, insulin's effects on fuel storage are suppressed and insulin secretion is reduced (Chen et al., 2024).

The literature search was conducted in Turkish and English, using the electronic databases PubMed, Web of Science, and Google Scholar, with the keywords ‘high-intensity interval training’, ‘testosterone’, ‘growth hormone’, ‘cortisol’; 'insulin-like growth factor'; “insulin”; “athletes”. The titles and abstracts of relevant studies conducted on athletes were screened by researchers. The full texts of studies deemed appropriate were examined in detail. This study was conducted due the need of clarifying clear results in terms of the effects of HIIT on hormonal responses in athletes, inconsistencies in findings, and differences in protocols. This review aims to provide evidence-based contributions to the field by evaluating the existing literature and examining the hormonal changes that affect performance in different training plans.

The Effect of High-Intensity Interval Training on Testosterone Hormone

Testosterone is a highly potent naturally occurring androgenic–anabolic hormone that plays a regulatory role in the growth and maintenance of skeletal muscle, bone tissue, and red blood cells. Acute testosterone levels may vary in relation tothe type of exercise (Dote-Montero et al., 2021). Along with the type of exercise, volume, duration, the intensity of exercise also plays a role in testosterone levels (Riachy, 2020; Sayyah, 2019). It has been reported that testosterone levels increase after intense training (Gençoğlu and Akkuş 2020). Plasma testosterone levels increase following prolonged aerobic exercise. This increase is linked to the intensity of the physical exercise performed (Cofre et al., 2024). When exercise intensity decreases from 70% to 40%, the hormonal response also decreases. An acute increase in testosterone levels is reported after high-intensity resistance exercises (Sholi et al., 2016). Hayes et al. (2015) reported significant differences in standardised effect sizes between aerobic strength adn resistance exercises in terms of salivary testosterone levels in their meta-analysis study. Kilian et al. (2016) compared HIIT and high-volume exercise in young cyclists and showed that testosterone levels increased immediately after exercise in the high-volume exercise group, while in HIIT, they increased both immediately after exercise and at the 30-minute mark. Previous studies have showed that this increase in testosterone has a protective effect against proteolytic pathways and glycogen stores. Sheykhlouvand et al. (2022) showed a significant increase in testosterone levels in professional canoe athletes after three weeks of HIIT at varying intensities and durations and attributed this increase to anabolic adaptations. Sylta et al. (2017) observed a decrease in testosterone levels in well-trained cyclists at the end of the first four weeks following a 12-week HIIT programme, followed by an increase thereafter. An acute increase in circulating testosterone concentration is expected as an anabolic response immediately after high-intensity endurance exercise, whereas a decrease in serum testosterone concentrations may be observed following periods of intense training. The upregulation of testosterone may be associated with an increase in the expression of androgen receptors. This situation may explain the temporary decrease in serum testosterone levels due to increased binding of testosterone to androgen receptors and, consequently, increased testosterone uptake in muscle cells. According to these results, the initial decrease in testosterone levels should not be associated with a loss of performance. Monje et al. (2020) found no change in salivary testosterone levels in either male or female athletes following a 20-minute high-intensity interval training session in long-distance runners. It is known that saliva testosterone levels correlated with plasma free testosterone. For this reason, researchers expected an increase in post-exercise saliva testosterone levels. The exercise duration and intensity may affect cortisol and testosterone responses. Insufficient exercise intensity, short rest periods, and the athletes' training history may not have affected testosterone levels. The acute increase in testosterone levels following a single HIIT session can be explained by a decrease in plasma volume, hepatic clearance and breakdown rates. Following this increase, testosterone levels return to baseline levels within 15-30 minutes. The androgenic-anabolic effect of testosterone can be explained by genomic and non-genomic pathways. With regard to genomic androgens, free testosterone diffuses from the membrane into the cell cytoplasm to bind to the intracellular androgen receptor. This induces protein synthesis by increasing the expression of target genes. This process can take hours or even days. As far as the non-genomic androgen effects are concerned, testosterone can attach to a membrane receptor that triggers intracellular signalling cascades within seconds. Although the biological functions of the acute increase in testosterone levels as a response to exercise remain somewhat unclear, the non-genomic androgen effect may explain the increase in acute testosterone levels (Dote-Montero et al., 2021).

The Effect of High-Intensity Interval Training on Cortisol

Cortisol, whose secretion begins at birth, is a hormone that affects carbohydrate, protein and fat metabolism and protects the body against changes in physiological balance (Monje et al., 2020). It is a catabolic hormone that regulates metabolic and physiological stress responses and immune functions (Kilian et al., 2016). When cortisol is secreted in the body, it is distributed to various tissues in the body, such as skeletal muscle, liver and adipose tissue. Its presence in different tissues helps regulate critical physiological processes such as protein and fat metabolism and exercise capacity (Şahin et al., 2018). Exercise activates the hypothalamic-pituitary-adrenal axis as a stressor, leading to cortisol synthesis. As with testosterone, acute increases in cortisol levels may be associated with a decrease in plasma volume, hepatic clearance, and degradation rates (Dote-Montero et al., 2021). It is reported that exercise intensity must be at 60% VO_2max or above for an increase in saliva cortisol levels. The post-exercise increase in cortisol is important due to its catabolic effect on exercise-induced damaged proteins. This creates a pool for the synthesis of new amino acids (Kilian et al., 2016). Since there is a high correlation between exercise intensity and cortisol levels, hormone release is greater in athletes than in sedentary individuals (Öniz et al., 2021). Regarding cortisol, while studies show that long-term strength training (10-24 weeks) reduces cortisol levels, other studies indicate that shorter training periods, such as 6 weeks, increase cortisol levels (Keleş et al., 2024). Following high-intensity interval training administered three times a week for three weeks to professional male canoe polo athletes, an increase in total cortisol levels was observed, while no change in serum cortisol levels was detected. Total cortisol is widely utilized to evaluate training-induced physiological strain and is considered a marker of the anabolic–catabolic balance. The increase in total cortisol levels may also be associated with an increase in total testosterone levels (Sheykhlouvand et al., 2016). Monje et al. (2020) found an increase in post-exercise saliva cortisol levels in both female and male athletes at the 20-minute mark following a 4-minute run with 10 repetitions that produced 90% VO_2max. It has been reported that salivary cortisol levels increase in men in relation to the intensity and duration of continuous endurance exercise, and in women in relation to high-intensity short-term endurance exercise. Given that cortisol is a well-known physiological stress marker, it has been stated that the exercise protocol applied in this study was sufficiently stressful. In young athletes, saliva cortisol levels at 30 and 60 minutes after HIIT were reported to be significantly higher in the HIIT group. In both groups, cortisol levels decreased below baseline after 180 minutes of cycling training (Kilian et al., 2016). Sheykhlouvand et al. (2022) found no changes in athletes' serum cortisol levels following rowing-based HIIT and resistance-type HIIT protocols. However, it found an increase in total testosterone and the testosterone/cortisol (T/C) ratio. The T/K ratio is widely used to assess the physiological load of training and the catabolic-anabolic balance. In some studies, total testosterone levels are reduced in the blood due to the supressing caused by cortisol. Cortisol can also affect insulin hormone levels in a similar way to total testosterone (Koca et al., 2023). In another study conducted on university student runners, no change was observed in the athletes' cortisol levels after high-intensity interval training at 90-95 per cent heart rate. The training programme consists of 12-15 minutes of exercise per set, comprising 1 minute of steady running at 70-75% heart rate reserve (HRR), followed by a 30-second sprint to reach 85-90% HRR, and then 1 minute of running without rest. The authors claim that athletes' cortisol levels do not change due to insufficiently intense training (Purnomo et al., 2023). Factors such as athletes' training duration, type, intensity, and training status affect serum cortisol concentration. In women, serum cortisol levels may be higher after competitions, and pre- and post-match serum cortisol changes may vary less (Bonato et al., 2017).

The Effect of High-Intensity Interval Training on Growth Hormone, Insulin-Like Growth Factor-1 and Insulin

Growth hormone, composed of 191 amino acids, is a typical secretory protein that supports longitudinal bone growth. Growth hormone secretion is regulated by the circadian rhythm and is primarily released at night (Han et al., 2025). Growth hormone, which promotes cell production and renewal and is secreted by the anterior pituitary gland, increases during exercise, stress and deep sleep (Civan et al., 2018). The intensity of exercise, the amount of work exerted during exercise, the amount of muscle mass used during exercise, physical fitness, and the state of training affect growth hormone levels after acute exercise. Plasma growth hormone increases 10-20 minutes after aerobic exercise, reaches its peak level at the end of exercise, and remains above baseline levels for 2 hours after exercise (Kanaley et al., 1997). Similar to acute aerobic exercise, growth hormone levels increase after acute resistance exercise, reaching their peak at the end of the exercise. They return to baseline levels 90 minutes after the end of the exercise (Wideman et al., 2002). The acute effects of high-intensity interval training on growth hormone following acute exercise are unclear. High-intensity interval training increases growth hormone; however, age, stress, fatigue levels, sleep deprivation and intense, prolonged exercise can reduce growth hormone levels. Öniz (2024) found that in professional athletes competing in swimming, football and basketball, growth hormone levels decreased from baseline levels following two weeks of HIIT. They reported that growth hormone levels peaked 15 minutes after exercise and then began to decline. Although there is limited data showing that high-intensity interval training increases growth hormone, it has been reported that growth hormone may also increase after a single session of HIIT. In particular, an increase in growth hormone can be observed following high-intensity interval training combined with sprint exercises at short intervals (Athanasiou et al., 2023; Bonato et al., 2017). Jonathan et al. (2014) reported that after HIIT and continuous moderate-intensity exercise performed by cyclists and triathletes, serum growth hormone concentration levels increased in both groups. Following HIIT, serum concentration levels were higher in the initial measurements compared to the continuous moderate-intensity exercise group, and serum concentration levels remained higher for 2 hours during the recovery period after exercise. Growth hormone, together with cortisol, plays a role in regulating blood glucose concentration during exercise, albeit to a very small extent, and stimulates lipolysis during exercise. The increase in growth hormone following HIIT can be linked to these mechanisms. Yıldırak and Erdoğan (2024) found a positive increase in growth hormones following HIIT applied to judokas. Interval training has been reported to have a greater effect on the increase in growth hormone in judokas. Changes occurring in biochemical parameters have an effect on this situation.

Insulin-like growth factor (IGF-1) is an important anabolic hormone that plays a role in growth, regulation of cell metabolism, basic biological functions, cell proliferation and apoptosis Exercise creates a mechanical load that increases the release of IGF-1. IGF-1 is secreted by the liver and its metabolic structure is very similar to insulin (El and Karakaya, 2022). It is known that IGF-1 levels in muscle increase after exercise, especially after eccentric resistance exercises (Bamman et al., 2001).

Various studies report no change in circulating IGF-1 during exercise; however, reviews have also reported cases of increases or decreases in IGF-1 (Nurten et al., 2012). Since the effect of IGF-1 is largely dependent on various IGF-binding proteins, free active IGF-1 often does not fully correlate with changes in total IGF-1 (Frystyk, 2010). It has been reported that IGF-1 levels decrease after intense exercise. The decrease in IGF-1 hormone levels during intense exercise reduces negative feedback, thereby increasing the release of growth hormone It is suggested that this decrease may further increase circulating growth hormone, thereby supporting the use of fatty acids as fuel for exercising muscles (Birzniece, 2019). IGF-1 stimulates muscle anabolism and may also increase the availability of fuel for exercising muscles (Russell-Jones et al., 1994). Although IGF-1 levels following HIIT have been studied in different populations such as obese individuals, young women, and the elderly, studies conducted in specific athletes following HIIT are quite limited (Avazpour et al., 2020; Herbert et al., 2017; Jimenez-Roldán et al., 2025). IGF-1 levels were found to be higher in female athletes at the Olympic level compared to the control group (Eklund et al., 2021). GH and IGF-1 levels were examined in young ice hockey players after maximum physical exercise. Although there was a marked increase in GH after exercise, no significant change was observed in IGF-1 levels. This is an example showing that IGF-1 may not change in the short term after intense exercise in athletes. (Kochańska-Dziurowicz et al., 2015). Herpert et al. (2017) found an increase in IGF-1 levels after HIIT in their study conducted on master athletes and sedentary individuals. This increase has been greater in sedentary individuals than in elite athletes. However, upon examination, master athletes have higher IGF-1 levels than sedentary individuals before starting exercise. This situation clearly demonstrates that exercise history and exercise intensity determine the IGF-I response. It was found that IGF-1 levels increased in female athletes following continuous exercise and HIIT, but no significant difference was detected between the exercises (Ghasemi and Nayebifa, 2024).

Insulin is one of the fundamental regulatory hormones of metabolism. Insulin is expressed in pancreatic beta islet cells, and its release begins with an increase in blood glucose levels (Gültekin, 2017). Insulin is secreted after food intake. It is the primary hormone responsible for the storage of glucose as glycogen and fatty acids as triglycerides. Exercise, on the other hand, requires the activation and oxidation of fuel stores. Therefore, insulin's fuel storage effects of insulin must be suppressed during exercise. In contrast, after exercise, the fuel stores that were utilised during exercise, particularly the glycogen stores in the muscles, need to be refilled. This process is facilitated by an increase in insulin sensitivity in the muscles involved in the exercise. As a result, glycogen synthesis is carried out. In physically trained subjects, insulin sensitivity is higher than in non-trained subjects due to adaptations in vascular structure, skeletal muscle and adipose tissue (Richter et al., 2021). Insulin levels and blood glucose levels vary depending on the intensity and duration of exercise (Aydın et al., 2000). It has been reported that insulin levels decrease during exercise in athletes who perform 45-minute endurance training and in non-athletes, and that basal insulin levels in athletes are lower than in non-athletes (Wirtfh et al., 1981). Soslu et al. (2023) reported that glucose and insulin levels were significantly lower in basketball players after a 7-week HIIT program. In this case, it has been suggested that thyroid hormones, which increase the sensitivity of pancreatic cells to stimuli that cause insulin release, may play an active role in insulin secretion. In contrast, Çalışkan (2025) conducted a study in which two different HIIT groups were given different rest periods. While statistically insignificant decreases in insulin levels were observed among participants, no difference in insulin levels was found between the groups. In general, it is widely believed that acute, rapid and intense exercise can cause changes in insulin levels.

DISCUSSION and CONCLUSION

Recently, HIIT is preferred among athletes more due to the athletes' short preparation periods that requires rapid and effective adaptation, and repetitive exercise types that reduce athletes' performance and affect them psychologically (Akgül et al., 2017). While the degree of hormonal response depends on the pre-exercise state, hormonal adaptations become increasingly important as exercise duration increases. Testosterone levels increase with high-intensity and high-volume exercise. This increase presents itself acutely. The timing and persistence of the increase may vary depending on the structure of the protocol. It has been reported that the increase in testosterone hormone is particularly related to the intensity of exercise (Mitat et al., 2016). The increase in testosterone levels after HIIT supports this thesis. A decline may be observed after prolonged and intense training, but this should not be interpreted as a negative occurrence. It is thought that an adaptation process associated with increased receptor expression and greater uptake of testosterone into cells is responsible for this. Methodological differences in existing studies and contradictions in the results of some studies indicate a need for more controlled and standardised research in this field. It has been observed that cortisol levels are examined alongside testosterone following HIIT, particularly in athletes (Kilian et al., 2016). Cortisol levels may vary depending on different exercise protocols. Cortisol levels increase in acute measurements due to the stress caused by exercise, but decrease below baseline levels in subsequent measurements (Kilian et al., 2016). This response varies depending on the type of exercise, duration, protocol applied, and the athletes' training history. This response varies depending on the type of exercise, duration, protocol applied, and the athletes' training history. The level of exertion and different measurement times may play an active role in the possible differences in changes in salivary cortisol and serum cortisol after HIIT. Cortisol is particularly important in conjunction with testosterone for interpreting the physiological load of training and the anabolic-catabolic balance. Although it is generally believed that growth hormone increases after HIIT in athletes, the number of studies is limited. Although an acute increase in growth hormone is observed after HIIT, this effect is not consistent for every workout. In this situation, differences in methodology, as w It appears that the effect of HIIT on growth hormone is not certain. ell as participants' physiological, physical and psychological differences, also play a role. The current literature indicates that the response of IGF-1 to exercise is highly variable. Some studies report an increase in IGF-1 levels after HIIT and intense exercise, while others report no significant change or a decrease. In this case, the intensity and type of exercise, as well as individuals' training levels, physiological characteristics, and the regulatory role of IGF-binding proteins may be influential. Therefore, there is a need for studies in different sports groups using standardised protocols in athletes after HIIT. The suppression of insulin release during exercise is a physiologically necessary and expected response for energy metabolism. Insulin levels may decrease significantly after HIIT. The absence of statistically significant changes in similar protocols highlights the importance of methodological and individual differences and limits the generalisability of the results. Therefore, the current findings indicate that HIIT may play a regulatory role in the insulin response. Consequently, HIIT causes temporary increases in testosterone and cortisol hormones in athletes, and can also produce certain responses in the growth hormone, IGF-1 and insulin axis. However, there is currently no widely accepted, high-level evidence in the literature indicating that growth hormone significantly increases IGF-1 hormone levels or significantly reduces insulin levels. All exercises cause physiological changes in the human body, and these changes are among the factors that affect athletic performance, such as strength and endurance (Gençoğlu and Akkuş, 2020). The studies conducted show that no specific HIIT programme has been applied and that no studies have been carried out to examine hormone levels in the same branches. It has also been noted that the number of studies examining hormone levels in athletes following HIIT training is quite limited. In future studies and applications; the type, intensity and duration of exercise should be planned correctly, physiological changes that may affect maximum performance in athletes should be taken into account, and stress management should be monitored.

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