

The Effects of Different Exercise Intensities and Modalities on Cortisol Production in Healthy Individuals: A Review

Short Review

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Abstract

Cortisol is a hormone that is secreted in response to physiological stress. Exercise contributes significantly to changes in circulating cortisol concentrations. With exercise, there is increased activation of the sympathetic system to stimulate the release of adrenocorticotrophic hormone, which releases cortisol into the blood. Current research has predominately studied the effects that aerobic exercise and resistance training have on cortisol production. Prolonged aerobic exercise, especially at higher intensities, significantly elevates cortisol concentrations when compared to similar duration and intensities of resistance exercise. Age, gender, physical fitness level, exercise intensity, training status, and modality are all variables that influence the production of cortisol. Elevated cortisol concentrations are highly indicative of muscle catabolism, increasing the loss of lean muscle tissue. This is a significant health concern for the growing elderly population. The rate of cortisol production changes as an individual ages and has been observed to have differing responses to exercise intensities in males and females. Cortisol production is correlated with exercise intensity and duration but does not increase the same across all exercise intensities. Higher exercise intensities and duration appear to be the main contributing factors that influence the production of cortisol, increasing the potential for muscle catabolism and muscle loss.

Key Words: Aerobic Exercise, Resistance Training,

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Introduction

Circulating cortisol concentrations are always present in the blood and undergo fluctuations in concentrations due to physiologic and psychologic stressors ¹. The release of epinephrine and norepinephrine by the activation of the sympathetic nervous system stimulates the hypothalamus to release corticotropin-releasing hormone (CRH) from the anterior pituitary gland ². CRH stimulates the pituitary synthesis of adrenocorticotrophic hormone (ACTH) via the hypothalamic-pituitary-adrenal (HPA) axis. ACTH acts on the adrenal cortex to release cortisol ³. Cortisol levels are

regulated through negative feedback of reduced ACTH ¹. Increases in ACTH signal the hypothalamus to lower the production of the CRH. Changes in exercise intensity, duration, training status, and mode of exercise elicits changes in circulating blood cortisol concentrations. Cortisol is taken up by the liver, skeletal muscle, and adipose tissue to activate multiple energy pathways. In the adipose tissue, cortisol promotes the hydrolysis of triglycerides to produce glycerol and free fatty acids ⁴. In the skeletal muscle tissue, cortisol facilitates the initiation of protein degradation, converting proteins to amino acids. Elevated cortisol concentrations promote the degradation of skeletal muscle by increasing muscle catabolism, along with gluconeogenesis. This produces a greater rate of muscle catabolism compared to anabolism, which decreases lean muscle mass ⁵. In the liver, elevated cortisol concentrations may cause the liver to begin gluconeogenesis, generating a surplus in energy production from carbohydrates. Though higher cortisol concentrations stimulate adverse physiological effects, cortisol is also important in maintaining normal physiological processes (e.g., immune and stress response, and glucose and protein homeostasis) ⁶. Exercise intensities influence essential hormonal responses during exercise, specifically in cortisol ⁷. A common comparison is between high-intensity and low-intensity exercise. Training modalities are increasingly migrating to encompass more high-intensity interval exercises (HIIE), which include aerobic training (AT) and resistance training (RT) ⁸⁻¹⁰. These training modalities and intensities affect cortisol production both positively and negatively ¹⁰⁻¹². There are additional variables to consider, such as age, gender, time of day, and physical activity levels that influence cortisol responses to exercise intensities ¹³⁻¹⁵. Higher exercise intensities are positively correlated to elevated cortisol concentrations; however, there are exceptions to this general claim ¹. Cortisol was shown to be significantly lower in 90% 1-RM when compared to 75% 1-RM in resistance-trained individuals ¹⁰. The same was observed in eight trained men participating in high and low volume rowing protocol where cortisol was not significantly changed in resting values ¹⁶. This potentially could be attributed to participants' level of training and conditioning. However, numerous studies have shown increased cortisol concentrations when correlated with intensity levels in both trained and untrained individuals. Low versus moderate-intensity exercises decreased resting cortisol concentrations after untrained men completed an eight-week RT program ¹³. When evaluating intensity levels, time has been shown to contribute to increases and decreases in cortisol production significantly ^{17,18}. In addition, the hormonal effect that cortisol has on muscle function is dynamic to maintaining health and performance for young and older individuals. Age has been shown to significantly impact the production of cortisol and exacerbates the rate of muscle atrophy and sarcopenia ^{14,15}. Aside from these variables that affect the hormonal responses of cortisol production, gender has a significant impact on cortisol and is a contributing factor to health and performance ¹⁹. Therefore, the purpose of this review was to examine the impact that different exercise intensities and modalities have on cortisol production in healthy men and women.

Literature Review Methods

A literature review was performed to examine the effects of aerobic and resistance exercise intensities on cortisol production. The search was performed on PubMed, Medline, and EBSCO Host. The search terms used were "resistance training cortisol," "aerobic exercise cortisol," "anaerobic exercise cortisol," "combined exercise cortisol," "exercise cortisol men," "exercise cortisol women," and "resistance training cortisol men/women." The search was concluded on September 1, 2021. Criteria required for research articles to be included in the review. Cortisol had to be measured during multiple time points with a minimum of pre and post-exercise intervention (aerobic, resistance, or both). Males and females, all ages, serum, plasma, and salivary measures of cortisol that were collected through a blood draw or swabs collected orally, including all exercise intensities, and healthy individuals at different stages of development. The literature review produced nineteen articles focusing on aerobic exercise, thirteen articles focusing on resistance training, and four articles focused on combined aerobic exercise and resistance training's influence on cortisol production. A single investigator performed the methodological quality of included studies.

Aerobic Exercise Intensities Impact on Cortisol Production

With aerobic exercise, cortisol has been observed to increase depending on intensity levels ²⁰⁻²³. Exercise modalities, intensity, training status, and outcomes in cortisol production in males and females are displayed in Table 1. In one study, seven endurance-trained athletes completed three exercise protocols. Exercise conditions included HIIE, steady-state exercise (SSE), and prolonged endurance exercise ²⁴. SSE displayed no significant changes in cortisol concentrations, differing from HIIE, which displayed slight increases in cortisol production. However, prolonged endurance exercise exhibited the greatest changes in cortisol, increasing circulating levels by two-fold²⁵. Time appears to be the main contributing factor that influences cortisol concentrations with aerobic exercise ²⁶⁻²⁹. In a study involving eight trained male athletes, cortisol concentrations were significantly elevated after completing a 120-minute acute bout of sub-maximal exercise. When comparing 120 to 45-minute time trials, cortisol had a greater increase with the longer exercise protocol ³⁰. However, when relating HIIE to SSE for the same amount of time, there is a greater cortisol response to HIIE than SSE. It was concluded that cortisol responded less to continuous exercise in higher

trained individuals³¹. When an acute bout of HIIE was divided up into very short bouts (4x30s sprints) and compared to high volume endurance (HVE) training (50% $\text{VO}_{2\text{max}}$ for 60 min). HIIE elicited significant increases in cortisol with no significant change in the HVE group³. During an incremental cycle ergometer test, an intensity of 60% $\text{VO}_{2\text{peak}}$ stimulated a significant change in cortisol levels compared to baseline. Cortisol concentrations were further elevated following the exercise protocol¹⁸. Additionally, Hill et al.¹ had moderately trained men participate in an acute treadmill test set at 40%, 60%, 80%, and 100% $\text{VO}_{2\text{max}}$. After comparing moderate-intensity exercise to the low-intensity (40%) exercise session, there was a significant increase in cortisol concentrations in an exercise session consisting of 60-80%. These changes in cortisol concentrations are more than likely due to greater sympathetic activation by exercise intensities greater than 50-60%. However, cortisol and ACTH levels in low-intensity exercise may also be dependent on circulating glucose concentrations during prolonged exercise³². Training status poses a significant impact on cortisol responses during aerobic exercise. There appears to be a blunting or reduced sensitivity when participating in higher-intensity exercises and SEE^{16,20,33,34}. An acute low-to-moderate-intensity exercise of 60% for 50 minutes once a week for 12 weeks in sedentary young males was shown to have no significant changes in cortisol concentrations at lower exercise intensities. Exhibiting that a sedentary lifestyle could have adverse effects on metabolic hormones¹⁶. In endurance-trained males, SEE attenuated cortisol production compared to HIIE and prolonged endurance exercise—demonstrating that training adaptations contributed heavily to attenuating cortisol production in different HIIE and SEE modalities¹⁷.

Resistance Training Intensities Impact on Cortisol Production

Cortisol production is significantly correlated to RT modalities and intensities. Specific effects of RT on cortisol concentrations are displayed in Table 2. In resistance-trained individuals, cortisol was observed to be affected differently in three acute protocols consisting of hypertrophy (75% 1-RM squats), strength (90% 1-RM squats), and power (0% 1-RM box jumps). Cortisol was assessed over 48 hours with significant changes presenting immediately post-exercise (IPE). Strength and power groups were decreased while the hypertrophy group was significantly elevated¹⁰. Similarly, Szivak et al.⁹ had nine males and nine females who were RT trained to participate in acute RT, consisting of high intervals at 75% 1-RM. Cortisol concentrations increased at IPE, 15, and 60 minutes, peaking IPE in both males and females. Strength training appears to display diminished acute changes in cortisol concentrations when heavier RT protocols are combined with lower reps and longer rest periods between sets. Higher RT intensities (>75%) produced greater cortisol responses when compared to low- and moderate-intensity levels³⁵⁻³⁷. High repetitions with short rest periods increase cortisol levels in RT primarily due to greater sympathetic activation that is correlated with increases in heart rate. When high-intensity RT (75% 1-RM for 15 reps) was compared to moderate-intensity RT (60% 15 reps), the results demonstrated that high-intensity elicits a significant (68% increase) cortisol response within the first 3 hours post-exercise, while moderate-intensity had no significant changes. Each exercise condition implemented 2 minute rest periods in-between each set, totaling 90 minutes of exercise time³⁸. Training status in RT is significantly correlated to cortisol production in varied resistance exercise intensities. When comparing untrained men to moderately or highly trained men, there are different responses to cortisol production. Arazi et al.¹³ observed significant decreases in resting cortisol levels after completing 3 x 8 weeks of moderate-intensity RT exercises of squats and bench press in untrained men¹³. Acute RT produces different cortisol responses in untrained individuals that differ from regular exercise. Physically fit, untrained individuals who participate in an acute bout of RT responded differently than trained individuals. Nine physically fit untrained males completed high-intensity normal movement (HINM) (80%), low-intensity slow movement (LISM) (40%), and low-intensity normal movement (LINM) (40%). HINM increased blood cortisol IPE and returned to baseline after 30 minutes. LISM significantly increased cortisol levels IPE and levels remained elevated for 30 minutes. LINM gradually decreased circulating cortisol from pre-exercise until 30 minutes' post-exercise, returning to baseline post 30 minutes³⁹. Further supporting exercise intensity and time having the greatest influence on sympathetic activation.

Combined Resistance Training and Aerobic Exercise Intensities Impact on Cortisol Production

While done separately, aerobic exercise and RT affect cortisol production due to the exercise intensity and duration. Multi-facet exercises that incorporate both aerobic exercise and RT produce varied responses. Shrek et al.⁴⁰ observed ten male rock climbers who performed 55' submaximal vertical climbs for thirty minutes or to exhaustion, whichever came first. After comparing the hormonal responses, pre-exercise, and IPE, cortisol did not significantly increase due to the large variability in cortisol concentrations. Three subjects showed a decrease, two subjects showed a minimal response, and five subjects showed an increase.⁴⁰ While the protocol, according to Shrek et al.⁴⁰ was more aerobic than expected, and rock climbing was a more isometric and concentric contraction, this is potentially the reason for such varied results. In studies that implemented acute bouts of HIIE aerobic exercise of 75% of $\text{VO}_{2\text{max}}$ elicited higher cortisol responses when compared to fast tempo eccentric contractions.^{34,37}

Table 1. Production of Cortisol in Response to Different Aerobic Exercise Intensities

References	Mode of Exercise	Subjects	Training Status	Intensity Level	Intervention Length	Biological Tissue	Cortisol Collection Times	Cortisol Outcomes
Rojas Vega et al (2006)	CE	n = 8 ♂ = 8	Trained Athletes	HIIE (Incremental)	Acute	Serum	Pre, 10-w-up, IPE, 3, 6, 10, & 15 min	HIIE = Sig. ↑@ 10 & 15 mins
Hew-Butler et al (2008)	A	n = 7 ♂ = 7	Trained Endurance Athletes	HIIE - Exhaustion SSE - 60 min PEE - 56 KM	Acute	Serum	Pre-and Post	HIIE - ↑ Slightly SEE - ↓ (No sig. changes) PEE - ↑ 2X
Hill et al (2008)	A	n = 12 ♂ = 12	Moderately Trained	40%, 60%, 80% VO ² _{max}	Acute	Serum	Pre & Post for each exercise condition	60% and 80% was sig. ↑ compared to 40%
Witard et al (2012)	CE	n = 8 ♂ = 8	Trained	120 min sub-max test followed by 45 min time trial.	1 week moderate and 1-week high intensity	Serum	Pre, during sub-max, during time trial, 1 hour PE	PE C levels in moderate intensity was ↑ greater than high intensity
Deuster et al (1989)	A	n = 21 ♂ = 7 untrained, 7 moderately, 7 highly	Untrained, moderately (M), and highly (H)	50%, 70% and 90%	1 x week x 3 weeks	Serum	15 pre, pre, during exercise (15 & 25), PE, 35, 45, 55, 65, 85, 105, and 125	C ↑ greater in exercise intensities of 50%-90%, and was greater in untrained men compared to M/H trained
WJ Kraemer et al (1995)	RT/A	n = 35 ♂ = 35	Health Physically Fit	HI/SE, HI/S, HI/E, Upper Body HI/SE, Control	2x12 weeks;	Serum	Pre, 4, 8, 12 weeks	HI/SE - ↑ pre-12 weeks; HI/S - initially ↑ then ↓ by week 12; HI/E - ↑ pre-12 weeks; Upper Body HI/SE - initially ↑ then ↓ by week 12

Wahl et al (2010)	CE	n = 11 ♂ = 11	Health Physically Fit	HIIE (2 x 4 (30 s)) vs High Volume Endurance Training (HVT 1 hour)	Acute	Serum	Pre, 10-, 60-, & 240-mins PE	C sig. ↑ in HIIE @ 10 mins PE; but did not have any sig. during HVT
Maresh et al (2006)	A	n = 9 ♂ = 9	Trained Endurance Athletes	70% and 85% @ Hydration (Euhydrated/Hypo hydrated 5% body mass)	Acute	Serum	Pre, IPE, & 20 mins	C was ↑ in both exercise intensities in hypo hydration vs euhydration @ pre, 20 min PE
Viru et al (2008)	CE	n = 8 ♂ = 8	Health Physically Fit	Low intensity 60% (3 min incremental WL)	Acute	Serum	Pre & each stage	Sig. ↑ after 1st stage & remained stable until last 2 stages then ↑ more.
Buono and Yeager et al (1991)	CE	n = 7 ♂ = 7	Health Physically Fit	VO _{2max} (WL was increased by 50 watts each stage)	Acute	Serum	Pre, Each stage, PE	C was only sig. ↑ at exhaustion
Tremblay et al (2005)	A	n = 8 ♂ = 8	Trained Endurance Athletes	Treadmill - 40, 80, 120 mins @ 55%	Acute	Serum	Pre, 1, 2, 3, & 4 hours from start of run	C only ↑ at 120 mins, all other protocols ↓ across time.
Näveri et al (1985)	CE	n = 8 ♂ = 8	Trained	10 min = 63%; 10 min = 83%; 5-7 min = VO _{2max}	Acute	Serum	Pre-and Post	Only sig. ↑ was in VO _{2max}
Peake et al (2004)	CE	n = 10 ♂ = 10	Trained Endurance Athletes	HIE - VO _{2max} , MIE - continuous @ 80%	Acute	Serum	Pre, IPE, 1- & 2- hour PE	C ↑ IPE in HIE; MIE no sig. changes
Buono et al (1986)	CE	n = 6 ♂ = 6	*	120% of VO _{2max} for 1 min	Acute	Serum	Pre, IPE, 5-, 15-, & 30-mins PE	C sig. ↑ @ 15 mins PE
Farrell et al (1983)	A	n = 6 ♂ = 3 ♀ = 3	Health Physically Fit	Treadmill runs @ 65% and 80% for 20 mins. Incremental run till exhaustion	Acute	Serum	Pre-and IPE	C ↑ similarly across all exercise conditions
Kuoppasalmi et al (1980)	A	n = 5 (YM) ♂ = 5	Trained Sprinters Athletes	MI - 90 min run @ 4.3 min/km; HI - 45 min run @ 3.3 min/km	Acute	Serum	Pre-and IPE	HI ↑ C 27% and MI ↑ C 43%
Meckel et al (2009)	A	n = 6 ♂ = 6	Trained	4 x 250 M x 3 min rest in between @ 80% intensity	Acute	Serum	Pre, IPE each run, 1 hour PE	C did not sig. change during the protocol

Abbreviations: A = Aerobic; B = Baseline; BF = Blood Flow; CE = Cycle Ergometer; C = Cortisol; E = Endurance; EM = Elderly Men; EW = Elderly Women; HIIE = High Intensity Interval Exercise; MM = Middle-age Men; MW = Middle-age Women; PEE = Prolonged Endurance Exercise; H = Hypertrophy; IPE = Immediately Post-Exercise; P = Power; PE = Post Exercise; R = Running; RT = Resistance Training; S = Strength; SSE = Steady State Exercise; WL = Workload; YM = Young Men; YW = Young Women; ↓ = Decreased; ↑ = Increased; ♂ = Male; ♀ = Female; * = Unknown

Table 2. Production of Cortisol in Response to Different Resistance Training Intensities

References	Mode of Exercise	Subjects	Training Status	Intensity Level	Intervention Length	Biological Tissue	Cortisol Collection Times	Cortisol Outcomes
Smilios et al (2007)	RT	n = 17 ♂ = (9 YM), (8 EM)	Health Physically Fit	3 x 15 reps @ 60 % of 1-RM (90 s rest); 6 exercises	Acute	Serum	Pre, IPE, & 15 min PE	C sig. ↑ IPE in both YM/EM;
Raastad et al (2000)	RT	n = 9 ♂ = 9	Trained - strength Athletes	High - 100% of 3 reps max for squats and 100% of 6 reps max for leg extension; Moderate - 70% of High (rest 4-6 mins)	Acute	Serum	Pre, 30 mins into exercise, 15-, 30-, 45-, & 60-mins PE, & 3, 7, 11, 22, 33 hrs. PE.	C ↑ greater during High vs. Moderate; But ↓ in both protocols throughout exercise and PE.
Goto et al (2008)	RT	n = 9 ♂ = 9 (YM)	Health Physically Fit	5 sets knee extension, HI normal movement (NM) 80%, LI Slow Movement 40%, LI normal NM 40%	Acute	Serum	Pre, 5-, 15-, & 30-mins PE.	C ↓ low normal across all time points; high normal ↑ 5 min IPE returned to B @ 30 mins; low slow movement Sig. ↑ the most 5 min PE & returning to B in 30 mins
Fujita et al (2007)	RT	n = 6 ♂ = 6 (YM)	Health Physically Fit	1-RM (BF restriction @ 20%); 1-RM no BF restriction	Acute	Serum	Pre, IPE, 20, 40, 60, 120, & 180 mins	No sig. changes with 1-RM no BF restriction until 150 min; Sig. ↑ @ 10 min PE in (BF restriction group) returned to B @ 180 min.
Szivak et al (2013)	RT	n = 18 ♂ = 9 ♀ = 9	Trained	HI - 75% 1-RM	Acute	Serum	Pre, IPE, 15 & 60 mins	C ↑ in both groups @ IPE, 15, 60 mins. Peaked @ 15 mins

Arazi et al (2013)	RT	n = 18 ♂ = (10 YM), (8 MM)	Untrained	Bench, squat (moderate)	3x8 weeks	Serum	Pre & Post (8 weeks)	Both groups saw sig. ↓ from Pre-to Post
McCaulley et al (2008)	RT	n = 10 ♂ = 10	Trained (Strength/ Power)	H - 75% 1-RM S - 90% 1-RM P - 0% 1-RM	Acute	Serum	Pre, IPE, 60 min, 24, & 48 Hr.	H - ↑ Sig. (12.4%) @ IPE S - ↓ Sig. (18.2%) @ IPE P - ↓ Sig. (23%) @ IPE
Häkkinen and Pakarinen (1995)	RT	n = 47 ♂ = 24 (YM, MM, EM) ♀ = 23 (YW, MW, EW)	Untrained	5 sets x 10 reps 1-RM	Acute	Serum	Pre, 4, 6, 7, & 8 hours PE	No sig. C changes occurred in any of the women's group; all men groups ↑ during exercise, with MM having the only sig. ↑.
Kim et al (2014)	RT	n = 13 (YW) ♀ = 13	Health Physically Fit	Low intensity 1-RM @ 20% with 2 sets of 15 reps; 80% 1-RM 3 x 10; BF was restricted	Acute	Serum	Pre-and IPE	C sig. ↑ IPE for both protocols. No sig. differences between protocols.
Villanueva et al (2012)	RT	n = 6 ♂ = 6	Health Physically Fit	S- 8 x 3 @ 85% H - 3 x 10 @ 70%	Acute	Serum	Pre, IPE, 15 & 30 mins	C did not sig. change during any of the exercise sessions
Fatouros et al (2009)	RT	n = 40 (inactive) ♂ = 40	Sedentary	B, low, moderate, high intensity	Acute	Serum	Pre, IPE, 12, 24, 48, & 72 hours PE	C peaked IPE in all conditions and remained elevated 12 hours except B which decreased
Häkkinen et al (1998)	RT	n = 20 ♂ = (10 YM), (10 EM)	Health Physically Fit	4 x 1 x 10 = 40 maximal isometric contractions	Acute	Serum	Pre - lower and upper extremity; Post – lower, and upper extremity	No Sig. Changes were observed in YM or EM
Kruger et al (2011)	RT	n = 15 ♂ = 15	Health Physically Fit	HI - 75% of the 1RM (2 min breaks); MI - 60% 1-RM (total 90 mins' protocol)	Acute	Serum	Pre, IPE, 3 & 24 hours PE	C sig. ↑ 3 hrs. PE in HI, but no sig. changes in MI.

Abbreviations: A = Aerobic; B = Baseline; BF = Blood Flow; CE = Cycle Ergometer; C = Cortisol; E = Endurance; EM = Elderly Men; EW = Elderly Women; HIIE = High Intensity Interval Exercise; MM = Middle-age Men; MW = Middle-age Women; PEE = Prolonged Endurance Exercise; H = Hypertrophy; IPE = immediately Post-Exercise; P = Power; PE = Post Exercise; R = Running; RT = Resistance Training; S = Strength; SSE = Steady State Exercise; WL = Workload; YM = Young Men; YW = Young Women; ↓ = Decreased; ↑ = Increased; ♂ = Male; ♀ = Female.

Thus, indicating that exercise intensity is still one of the main factors influencing greater cortisol production. Magalhaes et al.⁴¹ compared the differences between moderate continuous training to RT and high-intensity interval training (HIIT) and found no significant difference in cortisol levels between both groups from the start of the intervention to the end. The lack of changes could be due to the exercise adaptations the patients may have gained over the course of the exercise intervention. As seen in previous studies, training adaptations seem to reduce the sensitivity of cortisol in individuals.^{25,29} Similar results were observed by Ambrozy et al.⁴² who examined a decrease in the cortisol levels of men between the ages of 35-40 years old. The men performed eight weeks of HIIT and RT and demonstrated a more balanced testosterone/cortisol ratio. An increase in testosterone indicated which training adaptation occurred and resulted in a blunting or loss in cortisol sensitivity.^{25,42}

Conclusion

Exercise intensities significantly affect cortisol production differently in aerobic and RT. Cortisol has a higher level of expression in aerobic exercises with extended time periods of increased sympathetic activation or RT that utilizes high intervals for prolonged periods. Overall aerobic exercise stimulates greater production of cortisol when compared to RT. Table 2 shows that exercise time periods of 60 minutes or greater at 65% to 90% (moderate-to-high) intensity will elicit the greatest increases in cortisol. Also, multiple repeated days of high-intensity endurance exercise will elevate cortisol concentrations 2.2 to 2.6-fold greater post-exercise in cross country skiers¹⁸. Cortisol concentrations were studied in short sprint protocols (4 x 250 M) with three-minute rest in-between, with no significant increase in cortisol production⁴⁷. RT with longer rest periods appears to attenuate cortisol production, but increased cortisol activation is elevated with shorter rest periods, as shown in Table 2. There exist marginal differences in cortisol production with aerobic exercise between men and women²⁸. However, the research is limited to only a single study when compared with 12 studies focused on men. Farrell et al.²⁸ introduced an acute bout of incremental (65% and 80%) aerobic exercise in three men and three women who were healthy and fit. Regardless of gender, cortisol increased the same in both males and females post-exercise.

Regarding RT, there appear to be varying results depending on the training status of both males and females^{9,14}. Age is also a significant factor; as individuals age, the rate of cortisol production in response to different exercise intensities and modalities varies. When comparing studies with both older women and men, the cortisol responses to exercise in men are increased but are unchanged in women¹⁴. The reason for this could be that the men exercised at higher intensities when compared to the women. In addition, the amount of time that was spent exercising was significantly less when compared with previous studies that observed increases in cortisol production⁹. Also, cortisol production is significantly higher with aerobic exercise when compared to RT. Studies with younger men and women presented more uniform responses with significant increases in cortisol production being similar in both genders³. The importance that elevated cortisol concentrations have in conjunction with decreases in lean muscle mass is more significant to elderly health and functional abilities than when compared to normal healthy younger individuals. Currently, the vast majority of studies involving the effect of exercise intensities on cortisol production are primarily in young to middle-aged men^{3,9,13,30}. Currently, limited studies exist that compare older men to younger men. Research involving cortisol production in women is substantially understudied when compared to men^{14,19,44}. Research in women is significantly needed, especially when comparing pre-menopausal to post-menopausal, sedentary to active, and trained too untrained. In conclusion, a literature review established that varying exercise intensity levels undeniably affect cortisol production during exercise. Nonetheless, the length of time spent exercising at higher-intensity levels appears to be the main contributing factor in increasing cortisol production. This may be attributed to greater sympathetic activation stimulated by the release of ACTH or by altered circulating glucose levels during exercise.

Table 3. Production of Cortisol in Response to Combined RT and Aerobic Exercise Intensities

References	Mode of Exercise	Subjects	Training Status	Intensity Level	Intervention Length	Biological Tissue	Cortisol Collection Times	Cortisol Outcomes
WJ Kraemer (1995)	RT/A	n = 35 ♂ = 35	Health Physically Fit	HI/SE, HI/S, HI/E, Upper Body HI/SE, Control	2 x 12 weeks;	Serum	Pre, 4, 8, 12 weeks	HI/SE - ↑ pre-12 weeks; HI/S - initially ↑ then ↓ by week 12; HI/E - ↑ pre-12 weeks; Upper Body HI/SE - initially ↑ then ↓ by week 12
Vale (2009)	RT/A	n = 35 (EW) ♀ = 12 RT, 13 E, 10 controls	Healthy	RT - 1-RM (75-85%), E - Aquatic, Control - nothing	3x12 weeks, 2 sets, 8-10 reps	Serum	Pre and Post	No sig. changes in C levels from Pre to Post
Sherk (2010)	RT/A	n = 10 ♂ = 10	Trained	Rock climbers climbed for 30 mins or until exhaustion	Acute	Serum	Pre, IPE, 15 min PE	C did not sig. change during the protocol
Magalhães (2020)	RT/A	n=80 ♂=42 ♀=38	Healthy	3 phases: Phase1 identical for both groups, 40-60% of HRR. Phase 2 for MCT exercised at 40- 60% of HRR & HIIE exercised at 70-80%. Phase 3 for HIIE only, exercised at 90% of HRR.	12 months, 3x a week	Serum	Pre and Post	No sig. changes in C levels from Pre to Post

Abbreviations: A = Aerobic; B = Baseline; BF = Blood Flow; HRR= Heart Rate Reserve; CE = Cycle Ergometer; C = Cortisol; E = Endurance; EM = Elderly Men; EW = Elderly Women; HIIE = High Intensity Interval Exercise; MM = Middle-age Men; MW = Middle-age Women; PEE = Prolonged Endurance Exercise; H = Hypertrophy; IPE = immediately Post-Exercise; P = Power; PE = Post Exercise; R = Running; RT = Resistance Training; S = Strength; SSE = Steady State Exercise; MCT= Moderate Continuous Exercise; WL = Workload; YM = Young Men; YW = Young Women; ↓ = Decreased; ↑ = Increased; ♂ = Male; ♀ = Female.

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