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ORIGINAL

EFFECT OF HIGH-INTENSITY STRENGTH EXERCISE ON COGNITIVE PERFORMANCE

EFECTO DE UN EJERCICIO DE FUERZA DE ALTA INTENSIDAD SOBRE EL RENDIMIENTO COGNIVITO

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ABSTRACT

OBJECTIVES The first aim of this study was to elucidate the effects of a single high-intensity strength exercise until failure on behavioral (i.e., attention) and physiological (i.e., salivary cortisol) responses. The second goal was to evaluate the effect of the performance of the cognitive tasks on cortisol levels. **METHODS** Fourteen physically active subjects completed a physical stress exercise consisting of six sets of squat repetitions to failure. Salivary cortisol and cognitive functions were evaluated in counterbalanced order prior to and following exercise-induced stress. **RESULTS** The results showed lower cortisol levels before the exercise and higher cortisol values before the cognitive task ($p < 0.05$). **CONCLUSION** Exercise-induced stress had a detrimental effect on attention. Furthermore, the effects of stress on cognitive performance seemed to depend on the time elapsed between the cessation of the exercise and the evaluation of these but not the type of high-intensity exercise performed.

KEYWORDS: Strength, stress, cortisol, cognitive performance, squat

RESUMEN

OBJETIVO. El objetivo principal de este estudio fue dilucidar los efectos de un ejercicio de fuerza de alta intensidad hasta el fallo en las respuestas conductuales y fisiológicas. El segundo objetivo fue evaluar el efecto del desempeño de las tareas cognitivas sobre los niveles de cortisol. MÉTODOS: Catorce sujetos activos completaron un ejercicio de estrés físico compuesto de 6 series de sentadillas hasta el fallo. El cortisol salival y las funciones cognitivas se evaluaron de forma contrabalanceada antes y después del ejercicio. RESULTADOS: Se mostraron niveles de cortisol más bajos antes del ejercicio y más altos antes de la tarea cognitiva ($p<0.05$). CONCLUSIONES: El estrés inducido por el ejercicio tuvo un efecto perjudicial en la atención. Además, los efectos del estrés en el rendimiento cognitivo parecen depender del tiempo transcurrido entre el cese del ejercicio y la evaluación de estos, pero no del tipo de ejercicio de alta intensidad realizado.

PALABRAS CLAVE: Fuerza, estrés, cortisol, rendimiento cognitivo, sentadilla.

1. INTRODUCTION

The effects produced by physical exercise on different psychological and/or physiological variables can be analyzed acutely (following the performance immediately after carrying out physical activity) or analyzing the changes over time (chronic effects) (1, 2). In the case of high-intensity physical exercise, we must consider that catecholamines, the growth hormone, the adrenocorticotropic hormone, prolactin, and cortisol all increase and that hypophyseal gonadotropins descend, acting as a stressor (3).

Some hormones have been greatly studied in relation to high-intensity physical exercise. Specifically, changes in testosterone and cortisol and their ratio (T/C) have been considered as indicators of adaptation to both acute and chronic physical effort (4). In general, the intensity of exercise loads affects the production of cortisol; in the case of values close to the anaerobic threshold (approximately 80% of VO2max) or intensities that cause exhaustion, an increase in stress hormones (adrenaline and cortisol) is observed, which quickly leads to a state of psychophysical overload (5). This stress increases blood and salivary cortisol concentrations (6, 7), and both parameters are closely correlated (8). Therefore, catabolic processes are favored over anabolic ones, which benefits the adjustment of the organism in the short but not the long term (9).

Accordingly, with regard to the conceptual links between cortisol and exercise, cortisol may be related to the effects of exercise on cognition (10). In fact, the previous study of Heaney et al. (11) found that the beneficial effects of a single episode of high-intensity exercise on cognitive performance could be attributed to acute declines in cortisol levels. However, although previous work has shown that cortisol can modulate cognitive performance (e.g., control, attention, memory), because of contradictory findings, this issue remains unclear (10, 12, 13). Indeed, the pattern of the effects of cortisol on cognition seems to follow a U-shaped curve (14). Thus, while moderate levels are associated with an improvement in cognitive performance (15, 16), higher cortisol levels interfere with cognitive functions that rely heavily on prefrontal networks (e.g., inhibitory control, attention regulation, memory recovery) (15, 17, 18).

Most research on high-intensity physical exercise has focused on the study of these effects with protocols based on short and/or long aerobic exercises (19, 20). Nonetheless, research examining the effects of acute strength exercise on cognitive performance is more limited (21), and more research is needed to facilitate our understanding of whether strength exercise benefits different types of cognitive performance equally.

Taking all this into account, the study of the concurrent effect of a high-intensity exercise on cognitive performance and the endocrinological system has yielded inconsistent results. Therefore, the authors hypothesize that cognitive performance decreases after stress-induced exercise when it coincides with the peak of cortisol. To confirm or disprove this hypothesis, the objectives of this study were to elucidate the effects of high-intensity physical exercise up to failure on behavioral (attention) and physiological (salivary cortisol) responses and to assess the effect of cognitive task performance on cortisol levels.

1. MATERIALS AND METHODS

1.1Sample

To determine the appropriate sample size for this study, a priori power analysis was conducted using freely available software G*Power 3.1.9 (University of Düsseldorf, Düsseldorf, Germany). The effect size calculation was based on recent reviews on the acute stressors and cortisol responses (12) and the effect of high-intensity exercise on cognitive performances (22). The optimum sample size of 14 participants was calculated by fixing the probability of a type 1 error at an alpha of 0.05 to yield 0.80 power for an effect size of 0.28. Fourteen healthy males [mean (standard error (SE); age: 32.5 (0.96) years; weight: 78.02 (1.63) kg; height: 175.35 (2.5) cm] were recruited to participate in this study. All subjects were physically active (at least 5 days/week of physical activity practice), with an ability to lift their body weight at least 1.5 times during the half-squat exercise and without any history of neurological or psychiatric diseases, drug abuse, or medication intake that might influence results.

The subjects provided informed consent to participate in the study. The protocols used in this research received ethical clearance by the University of Valencia's Ethical Committee. These protocols also met the requirements set out in the Declaration of Helsinki, 1975, which was subsequently reviewed in 2008.

2.2 Procedure

The participants were tested in a within-subject design on 2 experimental days with an interval of 48 h: day 1, learning and incremental load protocol to reach 1 RM (1 repetition maximum) and force-speed curve in half-squat position (1 RMHS); day 2, squat-induced stress and cognitive task session. To exclude the confounding effects of circadian cortisol variations, all testing took place in the afternoon between 13:30 and 18:00 h (23).

Prior to data acquisition, the researchers informed the participants of the protocol to be performed. The subjects then provided consent to participate in the study. In this session, the researchers instructed the subjects not to take stimulants 24 hours before the study (e.g., coffee, energy drinks).

Day 1: Preliminary Testing

Following arrival at the laboratory, the participants were fitted with Polar RS800CX HR monitors (Polar Electro Ltd., Kempele, Finland). Subsequently, the participants spent a relaxation phase on a stretcher and, as a breathing exercise, followed a metronome marking of 40 beats/min for 10 min. The participants then completed and became familiar with the cognitive task, the Psychomotor Vigilance Task (PVT). An incremental load protocol for calculating 1 RMHS was then used according to

Brzycki's equation (24), employing a maximum of 7 reps. The cinematic parameters for each repetition were calculated using a dynamic measurement system (T-Force System; Ergotech, Murcia, Spain). The optimal load (OL) was determined, allowing us to select which three load charges to shift by each subject during session 2. The behavior of muscular power during training sets was observed using normally 3 load/velocity combinations (low, optimal, and heavy) (25).

Day 2: Protocol Testing

In session 2 (48 h after), all the participants were fitted with Polar RS800CX HR monitors and returned to repeat the relaxation phase. Prior to this, each participant performed 2 half-squat sets for each of the 3 loading conditions: optimal or OL, low (15% below OL), and heavy (15% above OL), totaling 6 sets. Each set was performed to failure or a maximum of 20 repetitions. All the participants performed the half squat using these loads in increasing order, and all the repetitions were carried out as quickly as possible. The recovery time between sets of the same load was 1 min and 3 min between sets of different loads (26).

During this session, the cognitive performance of the participants was evaluated by the PVT for measuring vigilance. Their cognitive functions were evaluated before and 15 min after physical stress, coinciding with the expected highest cortisol concentrations (23). After completing both cognitive tasks, C2 was measured.

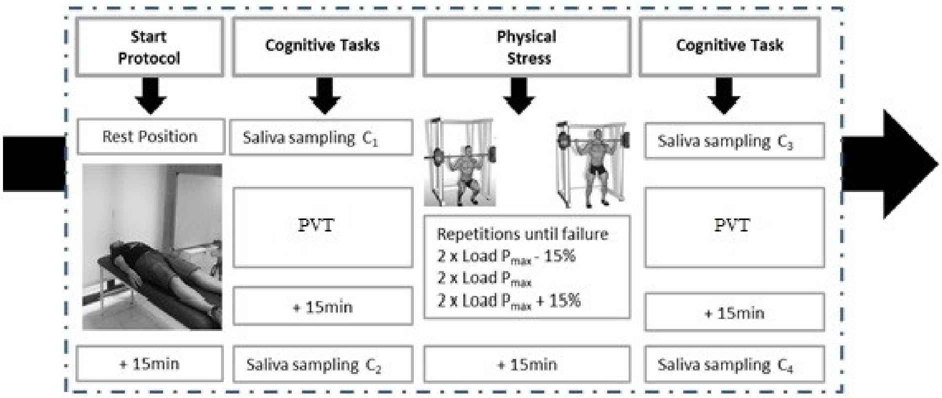

Figure 1. Experimental setup studio.

2.3 Measures and Materials

2.3.1 Saliva Sampling and Cortisol Analyses

Salivary samples were collected 4 times throughout the session and according to the criteria established by (27): C1, after the participants finished the relaxation phase; C2, 15 min following cognitive tasks and before the physical stress exercise; C3, 15 min after the muscular stress exercise finished; and C4, 15 min after the completion of the cognitive tasks.

The saliva samples were collected with a “salivette” (SARSTEDT S. A., Spain). All the participants received instructions for properly collecting saliva samples. Care was taken so that the participants had not brushed their teeth, eaten, or drunk anything 30 min prior to the saliva sample being taken.
Thus, the research procedures and saliva sample collection were set, taking into account the time interval between these procedures and awakening. The samples were stored in a freezer at −20°C and later analyzed using commercial salivary cortisol ELISA kits (DRG Instruments GmbH, Germany). All the samples were analyzed simultaneously and in duplicates.

2.3.2 Psychomotor Vigilance Task (PVT)

The PVT is based on that originally established by Wilkinson and Houghton (1982). This was designed to measure sustained attention by recording the reaction time (RT) of the participants to visual stimuli that occurred at random intervals. Using E-Prime® (Schneider, Eschman, & Zuccolotto, 2002) software and 15″ laptops, computerized stimuli to measure this function were generated. Moreover, data acquisition and data analyses were performed using this software. In each trial, black horizontal bars were shown on the screen on a gray background. The bars later changed to a vertical position at random intervals [2,000 to 10,000 milliseconds (ms)]. The participants were instructed to respond as quickly as possible to detect the change. They should respond with their dominant hand by pressing the laptop’s spacebar. The mean RT was computed as the mean of the time elapsed between the stimulus presentation and the response. The anticipation (AT) responses were considered as RT < 150 ms and lapses (LP) (RT > 500 ms). The task duration was 9 min, divided into 3 blocks of 3 min each.

2.4 Statistical Analysis

Statistical analysis was performed using SPSS 21 for Windows (IBM Corporation, Armonk, NY). We first applied descriptive statistics to calculate the mean and median as measures of central tendency and standard deviation and interquartile range as measures of dispersion. The assumption of normality was then checked by means of the K–S test. As for cortisol, we applied a parametric analysis because this variable passed the normality test once log transformation was achieved. Two factors repeated ANOVA measures [stress state (pre- and post-stress) and testing time (pre– and post–cognitive task)]. The follow-up was performed using pairwise comparison with a Bonferroni correction.

Regarding cognitive data acquired during the task, we computed the RT, LP, and AT for each participant. The RT was computed as the mean of time elapsed between the stimulus presentation and the response. Trials with an RT lower than 100 ms were computed as AT, and those with an RT higher than 500 ms were computed as LP. Moreover, the task was divided into 3 blocks of 3 min, and variables were computed for each block.

The main interaction effects of the stress state and block in RT were tested using 2 factors of repeated ANOVA measures [stress state (pre- and post-stress) and 3 blocks (blocks 1, 2, and 3)]. When significant effects were found, pairwise comparisons with a Bonferroni correction were requested. Finally, the AT and LP were analyzed using a nonparametric test (i.e., these variables did not pass the normality assumption). Concretely, the Wilcoxon signed-rank test was specifically applied to check for differences between pre– and post–physical stress. In addition, Friedman's ANOVA was applied to determine the block effects in these variables since each person has values for the 3 blocks in the 2 time points (pre– and post–physical stress). A follow-up was performed with the Wilcoxon signed-rank test. Finally, Spearman correlations were performed to establish lineal relationships between CORT and cognitive variables pre– and post–physical stress. We also performed correlations with the delta values (pre– and post–physical stress). The significance level was set at p = .05 for all of the analysis.

2. RESULTS

2.1 Cortisol Measures

Our results showed a significant effect of strength on physical stress [$F(1, 13) = 5.89$, $p = .03$, partial $\eta 2 = .31$], showing that cortisol increased post–physical stress with respect to pre–physical stress (Figure 2). Moreover, a significant effect of cognitive task was observed [$F(1, 13) = 17.28$, $p = .001$, partial $\eta 2 = .57$], observing lower cortisol values post–cognitive task compared to pre–cognitive task values. A non-significant interaction was observed between strength and exercise-induced stress × cognitive task–induced stress ($p = .347$).

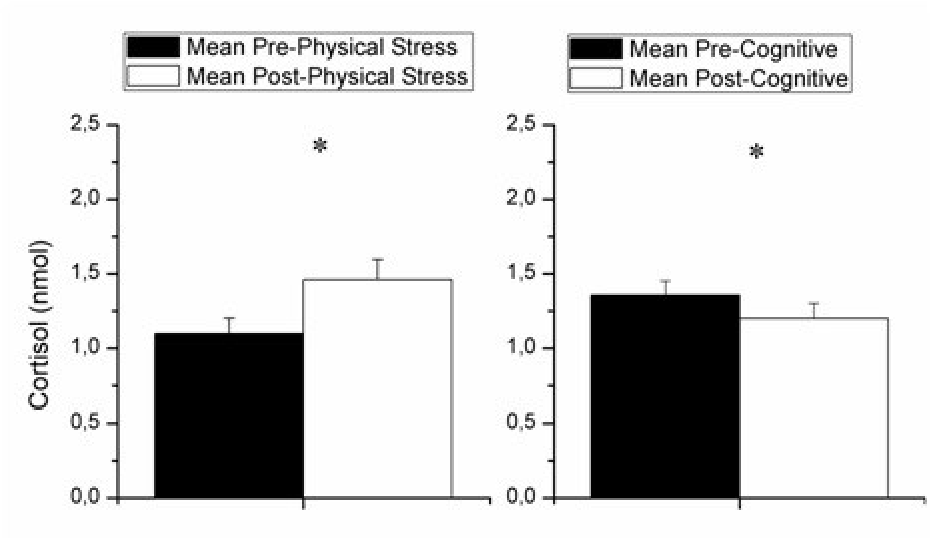

Figure 2. CORT data study.

3.2 Psychomotor Vigilance Task (PVT)

The RT data showed a significant effect of physical stress [$F(1, 13) = 5.66$, $p = .03$, partial $\eta 2 = .30$], observing that in the pre–physical stress condition, the participants responded more quickly (mean = 275.43, SE = 5.25) than in the post–physical stress condition (mean = 291.86, SE = 8.07). Nevertheless, a non-significant effect of the block [$F(2, 26) = 3.29$, $p = .053$, partial $\eta 2 = 0.20$] and a non-significant physical stress × block interaction effect [$F(2, 26) = 1.56$, $p = .23$, partial $\eta 2 = .11$] were found.

Moreover, in total LP, a physical stress effect ($z = -2.07$; $p = .044$; $r = -.55$) was observed. In particular, the total LP pre–physical stress was lower (mean = 1.21, SE = .24) than in the post–physical stress condition (mean = 2.29, SE = .51). We found no significant effects of physical stress on the AT of PVT. Moreover, no effect of the block on the total LP and AT of PVT was found.

Table 1. *RT, LP, and AT for Blocks*

	PVT Pre-Fatigue			PVT Post-Fatigue		
	Block 1	Block 2	Block 3	Block 1	Block 2	Block 3
RT (ms)	267 (5.71)	273 (6.38)	284 (6.93)	282 (8.58)	300 (10.80)	292 (9.46)
LP	.00 (.00)	.00 (1.0)	0.50 (1.0)	.00 (1.0)	1.0 (1.0)	.00 (1.0)
AT	.00 (1.0)	1.0 (1.25)	.00 (1.25)	.00 (0.25)	.50 (2.0)	.00 (1.25)

*The data for RT is expressed as mean (standard error). The data for LP and AT is expressed as median (interquartile range).

3.3 Correlation Analysis

The Spearman correlations analysis found no relationship between cortisol and any of the cognitive variables. Further, the correlation between delta values (pre– and post–physical stress) also showed up as negative.

3. DISCUSSION

The main aim of the study was to describe the effect of stress induced by a strength exercise (six series of squats) on cortisol levels and cognitive function (vigilance, learning, and visuospatial memory). The main results showed that physical stress (squats) causes an increase in cortisol levels and degrades the performance of vigilance tasks (higher RTs) and learning processes (higher number of learning attempts), although it had no influence on visuospatial memory. On the other hand, it should be noted that the performance of cognitive tasks reduces cortisol levels. First, the completion of the fatiguing squats protocol could lead to significant changes concerning both physiological and attentional demands. Indeed, the physiological responses to exercise strength (i.e., cortisol) increased after the until-failure squat protocol. Hormonal response to strength training has shown increases, with no changes or decreases in circulating levels of serum total testosterone or free testosterone and an increase in cortisol (28, 29).

Endurance training and strength produce two divergent types of physiological stimuli. The former primarily involves submaximal intensity exercise at low to moderate resistance for a prolonged period. Conversely, as with our case, strength training involves brief intermittent high-intensity exercise against a heavy resistance (9).

Changes in testosterone and cortisol and their ratio (T/C) have been considered as indicators of adaptation to both acute and chronic physical effort (4), thus confirming that such strength-intermittent fatigue protocols largely disturb the hypothalamus-pituitary-adrenal (HPA) axis (7, 30).

Regarding the cognitive task effect, a decrease in cortisol was found during post-performance cognitive tests. It can be noted that the cortisol decreased significantly in both conditions (pre- and post-fatigue) following the cognitive tasks. Normally, the maximum peak of the time course for post-stressor cortisol is at 0–20 min after exercise and returns to pre-stressor levels by 41–60 min after the end of the stressor (12). These results suggest that the cognitive task employed (PVT) did not yield a sufficient mental strain to maintain or increase cortisol levels (31). Moreover, with respect to PVT, RT was significantly higher in post-fatigue conditions than in pre-fatigue conditions. This fact contradicts the results of other studies (21, 32, 33) that suggest that the transient physiological responses to exercise (e.g., endorphins, serotine) are likely to increase cognitive performance (22). Nevertheless, cognitive performance decreases after this transient period given a quick cessation of these physiological responses to exercise (22). In our case, the participant showed higher RT (i.e., lower performance) from the first block compared with the pre-exercise performance. In addition, the response accuracy of LP differs significantly between pre- and post-fatigue conditions, showing a decrease in accuracy in the post-fatigue condition. In general, impairment was characterized by significantly slower RTs and fewer correct responses, which were particularly pronounced in the first blocks following the stress exercise.

According to the theories of excitement, the relationship between stress and performance follows a U-form function in terms of investment (34). Therefore, the time elapsed between exercise and the evaluation of cognitive functions is a crucial variable in the psychophysiological effects of stress induced by exercise (35). That is to say, while an instantaneous assessment with moderate levels of stress provokes a moderate reactivity of cortisol and an activation of the adrenergic system and often leads to positive effects in cognitive performance (i.e., lower RT) (21, 32, 33), a cognitive evaluation after a period where acute stress produces large increases in cortisol (15–20 min) causes a significant reduction in cognitive performance (i.e., higher RT and low accuracy) (36–38).

In our study, this is due to the fact that during the 15 min waiting period (post-exercise) prior to the collection of salivary cortisol, a decrease in the activation of the sympathetic nervous system (predominantly in situations of stress and emergency) and an increase in the parasympathetic nervous system (predominant at rest) are observed, which explain the worse PVT performance after high-intensity strength exercise.

Considering that attentional function is vital for sport performance (39, 40), the authors believe that the results of this study could contribute innovative and fundamental information about the need to control and cope with stress and the impact on the performance of this crucial function for the processes of perception and decision making. The results will be of great interest for many sport modalities where uncertainty and adaptability to the environment are key.

4. CONCLUSION

In conclusion, performing a physical strength fatigue protocol is a suitable method to induce sufficient stress affecting the HPA axis and segregating cortisol. Moreover, the RT and accuracy performance in a cognitive task (i.e., PVT) decreases after strength exercise–induced stress when it coincides with the maximum peak of cortisol (15 min after the strength exercise). Finally, and referring to the second objective of this study, the effects of stress on cognitive performance seem to depend on the time elapsed between the cessation of the exercise and the evaluation of these but not the type of high-intensity exercise performed.

These results could be of great interest for coaches and physical trainers of different sports and can help better organize training planning to optimize performance, taking advantage of the different moments of adrenergic excitation to perform motor tasks where RT is always decisive for decision making (41).

REFERENCES

1. Lambourne K, Tomporowski P. The effect of exercise-induced arousal on cognitive task performance: A meta-regression analysis. Brain Res. 2010;1341(Supplement C):12–24.
2. Bonet J, Parrado E, Capdevila L. Efectos agudos del ejercicio físico sobre el estado de ánimo y la HRV. Rev Int Med Cienc Act Física Deporte. 2017;17(65):85–100.
3. Tsai C-L, Wang C-H, Pan C-Y, Chen F-C, Huang T-H, Chou F-Y. Executive function and endocrinological responses to acute resistance exercise. Front Behav Neurosci. 2014;8.
4. Pedersen BK, Hoffman-Goetz L. Exercise and the Immune System: Regulation, Integration, and Adaptation. Physiol Rev. 2000;80(3):1055–81.
5. Lehmann M, Keul J. Age-associated changes of exercise-induced plasma catecholamine responses. Eur J Appl Physiol. 1986;55(3):302–6.
6. Duclos, Corcuff, Arsac, Moreau-Gaudry, Rashedi, Roger, et al. Corticotroph axis sensitivity after exercise in endurance-trained athletes. Clin Endocrinol (Oxf). 1998;48(4):493–501.
7. Labsy Z, Prieur F, Panse BL, Do M-C, Gagey O, Lasne F, et al. The diurnal patterns of cortisol and dehydroepiandrosterone in relation to intense aerobic exercise in recreationally trained soccer players. Stress. 2013;16(2):261–5.
8. Vining RF, McGinley RA. The measurement of hormones in saliva: Possibilities and pitfalls. J Steroid Biochem. 1987;27(1):81–94.
9. Bell G, Syrotuik D, Socha T, Maclean I, Quinney HA. Effect of Strength Training and Concurrent Strength and Endurance Training on Strength, Testosterone, and Cortisol. J Strength Cond Res. 1997;11(1):57.
10. Henckens MJAG, Wingen V, A G, Joëls M, Fernández G. Time-dependent effects of cortisol on selective attention and emotional interference: a functional MRI study. Front Integr Neurosci. 2012;6.
11. Heaney JLJ, Carroll D, Phillips AC. DHEA, DHEA-S and cortisol responses to acute exercise in older adults in relation to exercise training status and sex. Age. 2013;35(2):395–405.
12. Dickerson SS, Kemeny ME. Acute Stressors and Cortisol Responses: A Theoretical Integration and Synthesis of Laboratory Research. Psychol Bull. 2004;130(3):355–91.
13. van Ast VA, Cornelisse S, Marin M-F, Ackermann S, Garfinkel SN, Abercrombie HC. Modulatory mechanisms of cortisol effects on emotional learning and memory: Novel perspectives. Psychoneuroendocrinology. 2013;38(9):1874–82.
14. Lupien SJ, Maheu F, Tu M, Fiocco A, Schramek TE. The effects of stress and stress hormones on human cognition: Implications for the field of brain and cognition. Brain Cogn. 2007;65(3):209–37.
15. Butler K, Klaus K, Edwards L, Pennington K. Elevated cortisol awakening response associated with early life stress and impaired executive function in healthy adult males. Horm Behav. 2017;95(Supplement C):13–21.
16. Guenzel FM, Wolf OT, Schwabe L. Glucocorticoids boost stimulus-response memory formation in humans. Psychoneuroendocrinology. 2014;45(Supplement C):21–30.

17. de Veld DMJ, Riksen-Walraven JM, de Weerth C. Acute psychosocial stress and children's memory. Stress Amst Neth. 2014;17(4):305–13.
18. Quesada AA, Wiemers US, Schoofs D, Wolf OT. Psychosocial stress exposure impairs memory retrieval in children. Psychoneuroendocrinology. 2012;37(1):125–36.
19. Chang Y-K, Etnier JL. Exploring the Dose-Response Relationship between Resistance Exercise Intensity and Cognitive Function. J Sport Exerc Psychol. 2009;31(5):640–56.
20. Pontifex MB, Hillman CH, Fernhall B, Thompson KM, Valentini TA. The Effect of Acute Aerobic and Resistance Exercise on Working Memory: Med Sci Sports Exerc. 2009;41(4):927–34.
21. Chang Y-K, Tsai C-L, Huang C-C, Wang C-C, Chu I-H. Effects of acute resistance exercise on cognition in late middle-aged adults: General or specific cognitive improvement? J Sci Med Sport. 2014;17(1):51–5.
22. Chang YK, Labban JD, Gapin JI, Etnier JL. The effects of acute exercise on cognitive performance: A meta-analysis. Brain Res. 2012 May 9;1453(Supplement C):87–101.
23. Nicolson N. Measurement of Cortisol. 2008. 37 p.
24. Brzycki M. Strength Testing—Predicting a One-Rep Max from Reps-to-Fatigue. J Phys Educ Recreat Dance. 1993;64(1):88–90.
25. Haff GG, Nimphius S. Training Principles for Power. Strength Cond J. 2012;34(6):2.
26. Mayhew DL, Thyfault JP, Koch AJ. Rest-Interval Length Affects Leukocyte Levels During Heavy Resistance Exercise. J Strength Cond Res Champaign. 2005;19(1):16–22.
27. Chatterton RT, Vogelsong KM, Lu Y, Hudgens GA. Hormonal Responses to Psychological Stress in Men Preparing for Skydiving. J Clin Endocrinol Metab. 1997;82(8):2503–9.
28. Ahtiainen JP, Pakarinen A, Alen M, Kraemer WJ, Häkkinen K. Muscle hypertrophy, hormonal adaptations and strength development during strength training in strength-trained and untrained men. Eur J Appl Physiol. 2003;89(6):555–63.
29. Busso T, Häkkinen K, Pakarinen A, Carasso C, Lacour JR, Komi PV, et al. A systems model of training responses and its relationship to hormonal responses in elite weight-lifters. Eur J Appl Physiol. 1990;61(1):48–54.
30. Heijnen S, Hommel B, Kibele A, Colzato LS. Neuromodulation of Aerobic Exercise—A Review. Front Psychol. 2016;6.
31. McEwen BS, Sapolsky RM. Stress and cognitive function. Curr Opin Neurobiol. 1995;5(2):205–16.
32. Bermejo JL, García-Massó X, Paillard T, Noé F. Fatigue does not conjointly alter postural and cognitive performance when standing in a shooting position under dual-task conditions. J Sports Sci. 2018;36(4):429–35.
33. Hillman CH, Pontifex MB, Raine LB, Castelli DM, Hall EE, Kramer AF. The effect of acute treadmill walking on cognitive control and academic achievement in preadolescent children. Neuroscience. 2009;159(3):1044–54.
34. Joëls M, Pu Z, Wiegert O, Oitzl MS, Krugers HJ. Learning under stress: how does it work? Trends Cogn Sci. 2006;10(4):152–8.

35. Crabbe JB, Dishman RK. Brain electrocortical activity during and after exercise: a quantitative synthesis. Psychophysiology. 2004;41(4):563–74.
36. Bermejo JL, Ribeiro do Couto B, Marco-Ahulló A, Villarrasa-Sapiña I, Garcia-Masso X. Effects of an incremental maximal endurance exercise stress-induced cortisol on cognitive performance. J Hum Sport Exerc. 2019;14(3):632–44.
37. Kleider HM, Parrott DJ. Aggressive shooting behavior: How working memory and threat influence shoot decisions. J Res Personal. 2009;43(3):494–7.
38. Soga K, Shishido T, Nagatomi R. Executive function during and after acute moderate aerobic exercise in adolescents. Psychol Sport Exerc. 2015;16(Part 3):7–17.
39. Brisswalter J, Collardeau M, René A. Effects of Acute Physical Exercise Characteristics on Cognitive Performance. Sports Med. 2002;32(9):555–66.
40. Furley PA, Memmert D. The role of working memory in sport. Int Rev Sport Exerc Psychol. 2010;3(2):171–94.
41. Gallego NMS, Maldonado SV, Abellán J, Contreras OR. El entrenamiento perceptivo de bloqueadoras juveniles de voleibol. Rev Int Med Cienc Act Física Deporte. 2019;18(69):135–50.

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