

Hormonal responses to striking combat sports competition: a systematic review and meta-analysis

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ABSTRACT: Striking combat sports are challenging, commonly stressing the endocrinological system based on a mixture of body-contact actions and physiological efforts. The aims of this systematic review and meta-analysis were to discuss the hormonal responses related to striking combat sports competitions and to investigate the moderator and mediator variables of the hormonal response-competition/outcome relationship. Three electronic databases (i.e., PubMed, Google Scholar and ScienceDirect) were systematically searched (up to February 2016) followed by a manual search of retrieved papers. The data showed a moderate increase in cortisol (C) (ES = 0.79; 95% CI 0.31–1.28; $p = 0.001$), an extremely large increase in adrenaline (ES = 4.22; 95% CI 2.62–5.82; $p < 0.001$), and a very large increase in noradrenaline (ES = 3.40; 95% CI 1.03–5.76; $p = 0.005$) and human growth hormone (HGH) levels (ES = 3.69; 95% CI 1.96–5.42; $p < 0.001$) immediately following the combat events, compared to the control condition i.e., "pre-combat". Furthermore, amateur athletes had a larger increase in C levels compared to highly trained athletes (ES = 2.91 [very large] vs ES = 0.56 [small]), while evening events showed greater alterations in C levels compared to morning events (ES = 1.91 [large] vs ES = 0.48 [small]), without significant differences between them ($p = 0.26$ and $p = 0.06$, respectively). The present meta-analysis also showed a small, insignificant increase in testosterone (T) (ES = 0.47 [small]; 95% CI -0.45–0.99; $p = 0.074$) and a decrease in insulin-like growth factor 1 levels (ES = -0.20 [trivial]; 95% CI -0.78–0.37; $p = 0.486$) immediately following the combat events, compared to the control condition. The type of combat sports practised, participants' gender, and the nature of competition contests (i.e., official vs simulation) did not moderate the relationship between competition and hormonal response. Additionally, sub-analysis results showed a significant difference between younger and older athletes ($Q = 4.05$, $p = 0.044$), suggesting that after combat, younger individuals (less than 17 years of age) had a small decrease in T levels (ES = -0.58), compared with the moderate increase observed in older individuals (ES = 0.76). In conclusion, irrespective of striking combat sports types, the results showed that both official and simulated bouts are a real stressor of the hormonal system of practitioners. Coaches and applied practitioners should adopt "pre-competitive cognitive/coping strategies" to improve the psychological state that mediates the hormonal changes-competition/outcome relationship of their athletes in order to mitigate athletes' stress.

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INTRODUCTION

Striking combat sports (i.e., karate, taekwondo, boxing and kickboxing) are widely practised around the world [1-7]. Competition is the most remarkable stressor situation for the physiological, hormonal and psychological aspects of the individual [8-10]. However, there are several methods used by coaches and strength and conditioning specialists to evaluate the internal and external combat loads under-

taken and to monitor athletes' stress *per se*. To date, many studies have examined physiological responses (e.g., heart rate, blood lactate) to karate [11,12], boxing [13] and kickboxing competitions [14-15] as a method to quantify the internal combat load. Furthermore, evaluation of hormonal changes is also used to quantify the internal combat load during striking combat sports competitions [16-18].

The acute endocrine/hormone response to exercise bouts, training and competition has received considerable attention in recent years [16,19-23]. Particularly, the most widely used hormones to quantify athletes' stress *per se* during competitions are testosterone (*T*) and cortisol (*C*). Testosterone is a steroid hormone secreted by the Leydig cells of the testes under hypothalamic and pituitary control defining the hypothalamo-pituitary-testicular (HPT) axis [23]. Testosterone has many physiological roles within the body, all of which can be placed into two categories: androgenic and anabolic [23]. Cortisol is also a steroid hormone, secreted by the adrenal cortex via the hypothalamus-pituitary-adrenal (HPA) axis. It is known as the regulator hormone of immune function and has a catabolic effect on tissue. It is also associated with a decrease in the activity of some anabolic hormones, such as insulin-like growth factor 1 (IGF-1) and human growth hormone (HGH) [9]. High levels of *C* could be associated with fatigue and inflammation, increasing the risk of injury and indicating overtraining [22]. In addition, the testosterone/cortisol (*T/C*) ratio has been considered as an accurate indicator of overtraining in athletes [22]. Accordingly, several studies have reported that striking combat sports competition is a very high intensity and stressful activity that results in increased *C* levels [5,16,24]. In contrast, the same consensus does not apply to karate *kata* and *kumite* due to significant increases in glucose, *T* and catecholamines levels, without significant changes in insulin and *C* concentrations [17]. This controversy may be due to differences in age, gender, and the nature of the competition. For instance, the determination of moderator variables (i.e., which type of competition is most stressful) that influence the effect of competition on hormonal responses is important to help coaches and strength and conditioning professionals adapt their training interventions to meet the needs of the athlete and to control these variables.

Performance in competitions and demanding work activities indicates that the concomitant measurement of hormonal and psychological parameters offers a unique possibility to achieve a more comprehensive evaluation of the stress responses of the practitioners [18,25]. In addition, previous studies have shown that competition events known to increase stress are associated with a higher increase of *C* concentrations and psychological stress, and reduction of *T* levels and *T/C* ratio [16,18]. For instance, an integrated psychobiological stress-related measurement during competition could be of considerable interest for studies on athlete performance and behaviour [18]. Typically, measuring psychological variables, which are also called mediator factors, could help researchers and coaches understand why and how the increase or decrease of stress in the competition was achieved. Indeed, this could be explained by the inconsistent effect of competition on the mediating variables or by the psychological state of practitioners prior to the competition.

A synthesis of the literature about hormonal responses related to striking combat sports athletes may be helpful and of great applicable importance towards understanding the level of effort, stress *per se* and the real physiological demands of such an activity. Fur-

thermore, a summary of the studies related to striking combat practitioners would offer essential knowledge with regards to effectively monitoring training load as well as the acute changes in stress-related parameters, avoiding the development of non-functional overreaching conditions or, the most importantly, overtraining syndrome [9,12]. In view of the non-consensual studies available in the scientific literature, a systematic review and meta-analysis that precisely summarize and investigate the effects of striking combat sports on hormonal responses and the possible mediator/moderator variables that may interfere could help improving training and competition programme planning. Therefore, the aims of the present systematic review and meta-analysis were to (a) discuss the hormonal responses related to striking combat sports competition from the available scientific studies and (b) determine the moderator and mediator variables (i.e., self-efficacy, mood state, anxiety and motivation) interfering in the hormone changes-competition relationship.

MATERIALS AND METHODS

1. Search strategy

This review was conducted in accordance with Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) Statement guidelines [26] (Figure 1). A computerized search was performed in PubMed, Google Scholar and ScienceDirect (up to February 2016) for English-language, peer-reviewed investigations using the terms "boxing", "taekwondo", "karate", or "kickboxing" alone and together with "hormonal response", and "stress".

2. Inclusion and exclusion criteria

To be suitable for inclusion, studies had to fulfil the following selection criteria: (a) non-randomized controlled trials (NRCTs); (b) studies focusing on striking combat sports with hormonal responses measurements (i.e., *C*, *T*, adrenaline, noradrenaline, IGF-1, and HGH); (c) studies containing healthy, amateur and elite participants practising striking competition; and (d) studies written in English. Studies of older adults (age >60 years) were excluded. Also, reviews, comments, interviews, letters, posters, book chapters, and books were also excluded.

Hormonal measurements methods using blood, urine or saliva samples were included in the present study. According to Archer [27], Book *et al.* [28] and Wang *et al.* [29], salivary and serum methods are equally valid, exhibiting strong positive correlations with one another. The potentially relevant studies were screened for eligibility by two reviewers (MS and AP) by examining the titles, abstracts and full texts.

3. Quality appraisal

Two reviewers (MS and AP) conducted a methodological quality assessment on each included article using the modified Downs and Black scale [30], which is appropriate for nonrandomized control trials (NRCTs) and case-control study designs. Twenty-seven items were used to determine the Methodological Quality Checklist of each

study. Twenty-six 'yes'-or-'no' questions are scored totalling up to 26 possible points. In this review, the questions were categorized under 4 sections: Reporting (10 items), External validity (3 items), Study bias (7 items), and Confounding and selection bias (6 items). Moderator and mediator variables whose hormonal concentrations changed were recorded when applicable.

4. Possible moderator and mediator variables

The research literature suggests many potential moderators of hormonal changes such as the combat sport practised (karate vs taekwondo vs kickboxing), age (≤ 17 vs > 17 years), gender (male vs female), and competitive levels (amateur vs highly trained) of participants, the circadian rhythm/time of day (morning vs evening) and the nature of the competition contests (simulation vs official). Therefore, it would be useful to investigate the effects of these moderator variables on competition events and hormone-changes relationship. Furthermore, possible mediator variables, such as self-confidence, anger, mood state, and anxiety, have been shown to influence the

hormonal stress to competition and were therefore included in the study. The effect sizes (ESs) were calculated as the standardized difference in means adopted for paired groups [31].

5. Statistical analysis

The meta-analyses were performed using Comprehensive Meta-analysis software (Version 2.0, Biostat Inc., Englewood, NJ, USA). The mean differences and 95% confidence intervals (CIs) were calculated for the included studies. The I^2 measure of inconsistency was used to examine between-study variability; values of 25, 50 and 75% represent low, moderate and high statistical heterogeneity, respectively [32]. The publication bias was assessed by examining the asymmetry of the funnel plots using Egger's test, and a significant publication bias was considered when $p < 0.10$. Although the heterogeneity of the effects in the present meta-analysis ranged from 0% to 72% (see Results section), it was decided to apply a random-effects model of meta-analysis in all comparisons, to determine the pooled effect of striking combat sports on hormonal responses.

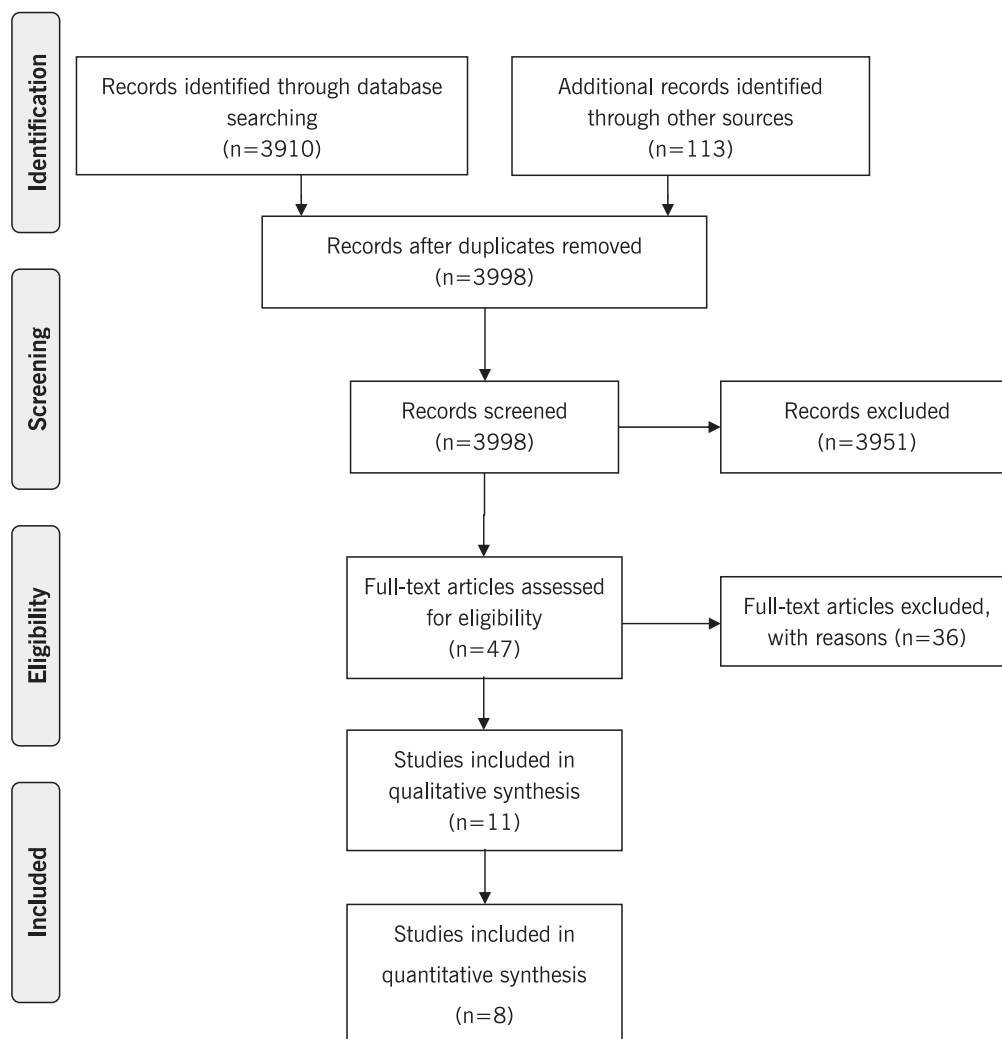


FIG. 1. Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) flow-chart.

Further, the effect size (ES) was calculated according to the following formula:

$$ES = \frac{M_{post} - M_{pre}}{SD_{pooled}}$$

In accordance with Hedges [31], this formula was adjusted for sample size:

$$J = 1 - \left(\frac{3}{4N_i - 1} \right)$$

where N_i is the total sample size of the intervention group minus one. The magnitude of the effects was interpreted as changes using the following criteria: trivial (< 0.20), small (0.21–0.60), moderate (0.61–1.20), large (1.21–2.00), very large (2.01–4.00) and ex-

tremely large (> 4.00) [31]. Additionally, a meta-regression was also performed to examine whether the age of athletes may predict alterations in C and T levels following striking combat sports events/competitions. The significance level of $p < 0.05$ was used for all analyses.

RESULTS

1. Literature search

The full texts of 47 articles were retrieved and assessed for eligibility against the inclusion criteria. After reviewing the full text of 47 articles, 36 articles were excluded and the remaining 11 qualitative studies were included (Figure 1). More specifically, 8 quantitative

TABLE 1. Hormonal responses between pre- and post-karate competition (mean \pm SD or relative effect %).

| Study | Parmigiani et al. [24] | Azarbayjani et al. [34] | Benedini et al. [17] | Chaabène et al. [16] |
|--|---|---|---|---|
| Type of competition | Simulation | Official | Simulation | Simulation |
| Athletes' characteristics (gender, n, age) | Healthy Italian karateka (Males: n=24; 26.75 \pm 7.98 years) | Iranian elite karateka (Females: n=20; 21.1 \pm 3.0 years) | Healthy Italian karateka (Males: n=6; Females: n=4; 21.9 \pm 1.1 years) | Tunisian elite karateka (Males: n=9; 20.5 \pm 2.8 years) |
| Combat duration (min) | 3 min | 3 min | 3 min | 3 min |
| Collection method (time of day) | Blood (evening) | Salivary (morning) | Blood (morning) | Salivary (evening) |
| Unit | ng/ml | ng/ml | nmol/L | μ g/dL |
| Cortisol | Pre <i>Kumite</i> 108.36 \pm 9.41 | Pre match 14.07 \pm 7.18 Imm-Post combat 26.86 \pm 19.67 | Pre <i>Kata</i> and <i>Kumite</i> 752.5 \pm 52 | Pre match 9.25 \pm 6.20 Imm-Post 13.30 \pm 3.38 |
| | Imm-Post <i>Kumite</i> 162.80 \pm 11.09 ^{ab} Pre <i>Kata</i> 103.40 \pm 11.56 Imm-Post <i>Kata</i> 115.00 \pm 12.03 (NSD) | | Imm-Post <i>Kumite</i> 759.1 \pm 46 (NSD) Imm-Post <i>Kata</i> 711.1 \pm 87 (NSD) | |
| Testosterone | Pre <i>Kumite</i> 3.95 \pm 0.41 Imm-Post <i>Kumite</i> 4.46 \pm 0.49 ^{a,b} Pre <i>Kata</i> 3.90 \pm 0.33 Imm-Post <i>Kata</i> 4.03 \pm 0.36 (NSD) | | Pre <i>Kata</i> and <i>Kumite</i> 6.7 \pm 1.4 Imm-Post <i>Kumite</i> 9.1 \pm 1.9 ^a Imm-Post <i>Kata</i> 7.9 \pm 1.7 ^a | Imm-Post combat 1 4.7% (NSD) Imm-Post combat 2 \downarrow 12.9% ^a |
| | | | Pre <i>Kata</i> and <i>Kumite</i> 702 \pm 127 Imm-Post <i>Kumite</i> 3.269 \pm 590 ^a Imm-Post <i>Kata</i> 1.871 \pm 367 ^a | |
| Adrenaline | | | Pre 1.149 \pm 75 Imm-Post <i>Kumite</i> 2.356 \pm 313 ^a Imm-Post <i>Kata</i> 2.023 \pm 229 ^a | |
| Noradrenaline | | | | |

^a: significantly different from pre-competition level at $p < 0.05$; ^b: significantly different from *kata* at $p < 0.05$; NSD: no significant different compared to pre-competition; NR: not reported; Imm: Immediately; \uparrow : increased; \downarrow : decreased.

studies were included for full review and data synthesis. From the quantitative studies, four studies examined the C responses to striking combat sports competitions; four studies investigated the T response; two studies assessed the adrenaline and noradrenaline responses; one study assessed the IGF-1 response; and finally one study measured the HGH response.

2. Characteristics of included studies

The total number of participants included in this review was 123 (89 males and 34 females). Furthermore, the number of participants per study ranged between 9 and 24. The range of the subject's age within the selected studies was 14.4 to 26.7 years. All studies were cross-sectional with pre- and post-combat hormonal analysis

TABLE 2. Hormonal responses between pre- and post- taekwondo competition (mean ± SD or relative effect %).

| Study | Pilz-Burstein et al. [35] | Chiodo et al. [18] | Capranica et al. [33] | Bridge et al. [25] |
|--|--|--|--|--|
| Type of competition | Simulation | Official | Official | Simulation |
| Athletes' characteristics (gender, n, age) | Cadets and junior Israeli National Team (males: n=10; females: n=10; 14.4±1.0 years) | Italian youth black belt level (males: n=10; females: n=6; 14±0 years) | Italian young "Cadetti/ Cadets B" blue belt level (males : n=12; 10.4±0.2 years) | Elite British national team and British technical centres of excellence (males : n=10; 18±2 years) |
| Combat time duration (min) | Three fights/ 8 min each (3 rounds, 2 min each, separated by 1-min recovery in-between) The rest in-between the fights was 30 min | 3x2 min rounds with a 1 min break in-between | 3x2 min rounds with a 1 min break in-between | 3x2-min rounds with 1-min recovery in between |
| Collection method (time of day) | Blood (morning) | Salivary (morning) | Salivary (12:00 to 13:00 p.m.) | Blood (NR) |
| Unit | nmol/L for T and C; ng/ml for IGF-I | nmol/L | nmol/L | nmol/L |
| Cortisol | Pre 482±107 (male) Imm-Post 626±138 ^a (male) Pre 568±116 (female) Imm-Post 629±146 ^a (female) | Imm-Post ↑24% (NSD) (male) Imm-Post ↑58% (NSD) (female) | Imm-Post ↑58% (NSD) After 30-min ↑214% ^a | |
| Testosterone | Pre 8.7±6.5 (male) Imm-Post 2.1±1.0 ^c (male) Pre 1.74±0.7 [§] (female) Imm-Post 1.74±0.7 (female) | | | |
| IGF-I | Pre 338.2±120.0 (male) Imm-Post 315.5±114.2 ^a (male) Pre 401.7±88.8 (female) Imm-Post 380.5±81.9 ^a (female) | | | |
| Adrenaline | | | | Pre 0.5±0.3 Imm-Post 2.7±1.7 ^a |
| Noradrenaline | | | | Pre 2.0±0.4 Imm-Post 14.3±9.4 ^a |

^a: significantly different from pre-competition level at p < 0.05; ^c: significantly different between-group change, pre versus post levels, at p < 0.05; [§]: significant difference in baseline level males versus females at p < 0.05; ; IGF-I: insulin-like growth factor 1; Imm: immediately; NR: not reported↑: increased.

(Table 1, 2, 3). Participants' characteristics, such as gender, age, competitive level, and time of day at which hormonal measurements were measured, are presented in Tables 1, 2, and 3.

3. Methodological quality

The methodological quality scores of the included studies ranged from 8 to 16, with the average score being around 12. Two of the included studies [17,34] were of high quality, three investigations [16,24,25] were of moderate quality, and the remaining three studies were of low quality [15,35,36] (Table 1, Table 2, Table 3). Future research needs to control nutrition status, sleep quality, health and psychological states of each participant. Furthermore, studies should also state participants' specific characteristics, such as age and gender. In summary, this evaluation highlighted a number of areas in need of improvement to reduce the risk of bias and provide evidence for the generalization of findings, which would increase the quality of research in this field.

4. Publication bias

Egger's test was performed to provide statistical evidence of funnel plot asymmetry (Figure 2) and the results indicated publication bias for all analyses ($p < 0.10$).

5. Effects of striking combat sports on hormonal changes

5.1. Effects of striking combat sports competition on cortisol level changes

The pooled effect of seven studies (ten ESSs) included in the meta-analysis showed a moderate increase of C level (ES = 0.79; 95% CI 0.31–1.28; $p = 0.001$) immediately following the combat events,

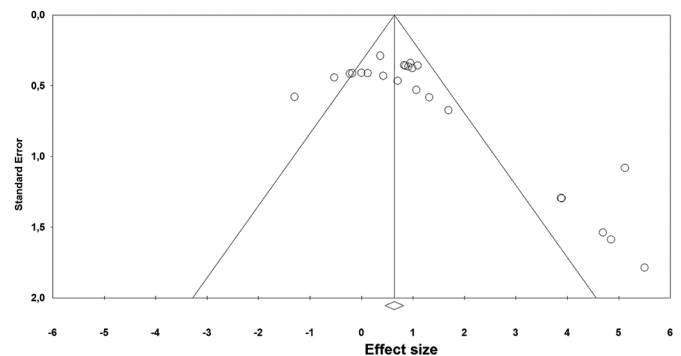


FIG. 2. Funnel plot showing evidence of publication bias for the meta-analysis for all analyses.

TABLE 3. Hormonal responses between pre- and post-kickboxing competition (mean ± SD or relative effect %).

| Study | Moreira et al. [36] | Ouergui et al. [15] | Ouergui et al. [5]* |
|--|---|---|--|
| Type of competition | Simulation | Official | Simulation |
| Athletes' characteristics (gender, n, age) | São Paulo regional or national kickboxers (males: n=20; 23±4 years) | Tunisian regional and national kickboxers (males: n=20; 21.3±2.7 years) | Tunisian regional and national kickboxers (NR: n=20; 21.3±2.7 years) |
| Combat duration (min) | 3x4 min with 1 min rest in-between | 3x2 min with 1 min rest in-between | 3x2 min with 1 min rest in-between |
| Collection method (time of day) | Salivary (morning) | Blood (evening) | Blood (NR) |
| Unit | ng/ml | ng/ml | ng/ml |
| Cortisol | Pre 38.5±19.0 Imm-Post 57.5±21.0 ^a | Pre 97.7±49.2 Imm-Post 143.7±39.4 ^a | Pre 97.7±37.1 Imm-Post 143.7±29.4 ^a |
| Testosterone | | Pre 3.2±1.3 Imm-Post 4.5±1.6 ^a | Pre 3.2±1.3 Imm-Post 4.5±1.6 ^a |
| T/C ratio | | Pre 0.03±0.01 Imm-Post 0.03±0.01(NSD) | Pre 0.03±0.01 Imm-Post 0.03±0.01 (NSD) |
| GH | | Pre 0.6±0.6 Imm-Post 11.4±4.1 ^a | Pre 0.6±0.6 Imm-Post 11.4±4.1 ^a |

^a: significantly different from pre-competition level at $p < 0.05$; GH: growth hormone; NSD: not significantly different compared to pre-competition; NR: not reported; Imm: immediately; *: we did not use this study in the quantitative synthesis because the authors presented the same data in the study of Ouergui et al. [15].

compared to the control condition i.e., pre-combat (Figure 3). The effects of striking combat sports competitions on C responses relative to different moderator variables are presented in Table 4. Thus, when comparing pre- to post-C level changes among different sports, there was no difference in ES magnitude ($Q = 0.41$; $p = 0.815$). However, a slightly greater effect on C levels was observed following both karate ($ES = 0.86$) and kickboxing ($ES = 0.95$) competitions, compared to taekwondo ($ES = 0.68$). Regardless of the practised sport, age proved to be a insignificant predictor of C level changes ($B = 0.07457$, $Z = 1.048$, $p = 0.294$). Sub-group analysis showed that athletes older than 17 years had slightly higher C levels than younger ones ($ES = 0.83$ vs $ES = 0.68$) immediately following the combat event, although insignificant differences were observed ($Q = 0.12$, $p = 0.731$). Males had a greater C response than females ($ES = 1.21$ [large] vs $ES = 0.66$ [small]); however, due to high variance of ESs among the included studies, significance of those results was not achieved ($Q = 1.67$, $p = 0.196$). Further, amateur athletes had larger increases in C levels compared to highly trained athletes ($ES = 2.91$ [very large] vs $ES = 0.58$ [small]), without a significant difference between them ($p = 0.26$). Regarding the time of day, evening events showed greater alterations in C levels compared to morning events ($ES = 1.50$ [large] vs $ES = 0.48$ [small]), without

a significant difference between them ($p = 0.08$). Finally, both the simulated and official events showed significant moderate C level modulations ($ES = 0.80$ and $ES = 0.91$, respectively).

Based on two studies' results (four ESs), alterations in C levels following the two different forms of karate (i.e., *kumite* and *kata*) were analysed. Both *kumite* and *kata* increase C levels ($ES = 2.61$ [very large] and $ES = 0.24$ [small], respectively); however, due to high variance of ESs and heterogeneity among the included studies, significance of those results was not achieved. In addition, following both simulated and official kickboxing competitions, a moderate effect on C response was observed ($ES = 0.94$ and $ES = 0.83$, respectively).

5.2. Effects of striking combat sports on testosterone level changes

The pooled effect of four studies (seven ESs) included in this meta-analysis showed a small, insignificant increase in T levels ($ES = 0.47$; 95% CI -0.45–0.99; $p = 0.074$) immediately following the combat events, compared to the control condition i.e., pre-combat (Figure 4). Effects of striking combat sports competitions on T responses relative to different moderator variables are presented in Table 5. Thus, when comparing pre- to post-T level changes among

TABLE 4. Cortisol responses to striking combat sports competitions relative to different moderator variables.

| Independent variables | ES | Variance | 95% CI | p | I ² (%) | df | Q value and (p) between groups |
|--------------------------------|------|----------|---------------|---------|--------------------|----|--------------------------------|
| Type of sport | | | | | | | |
| karate | 0.86 | 0.18 | 0.02 to 1.70 | 0.045 | 81.39 | 5 | |
| taekwondo | 0.68 | 0.11 | 0.02 to 1.33 | 0.042 | 0.00 | 1 | |
| kickboxing | 0.95 | 0.07 | 0.44 to 1.46 | < 0.001 | 0.00 | 1 | 0.41 (0.815) |
| Age of athletes | | | | | | | |
| ≤17 | 0.68 | 0.11 | 0.02 to 1.33 | 0.042 | 0.00 | 1 | |
| >17 | 0.83 | 0.05 | 0.24 to 1.43 | 0.006 | 74.99 | 7 | 0.12 (0.731) |
| Gender | | | | | | | |
| male | 1.21 | 0.11 | 0.58 to 1.85 | < 0.001 | 66.28 | 5 | |
| female | 0.66 | 0.08 | 0.13 to 1.20 | 0.015 | 0.00 | 1 | 1.67 (0.196) |
| Competitive level | | | | | | | |
| amateur | 2.91 | 4.33 | -1.17 to 6.99 | 0.162 | 92.60 | 1 | |
| trained | 0.58 | 0.03 | 0.21 to 0.94 | 0.002 | 36.96 | 7 | 1.25 (0.264) |
| Circadian rhythm | | | | | | | |
| morning | 0.48 | 0.06 | 0.02 to 0.94 | 0.043 | 47.66 | 5 | |
| evening | 1.50 | 0.29 | 0.45 to 2.55 | 0.005 | 85.69 | 3 | 3.06 (0.080) |
| Nature of competition contests | | | | | | | |
| simulation | 0.80 | 0.11 | 0.16 to 1.44 | 0.014 | 78.58 | 7 | |
| official | 0.91 | 0.07 | 0.40 to 1.41 | < 0.001 | 0 | 1 | 0.07 (0.798) |

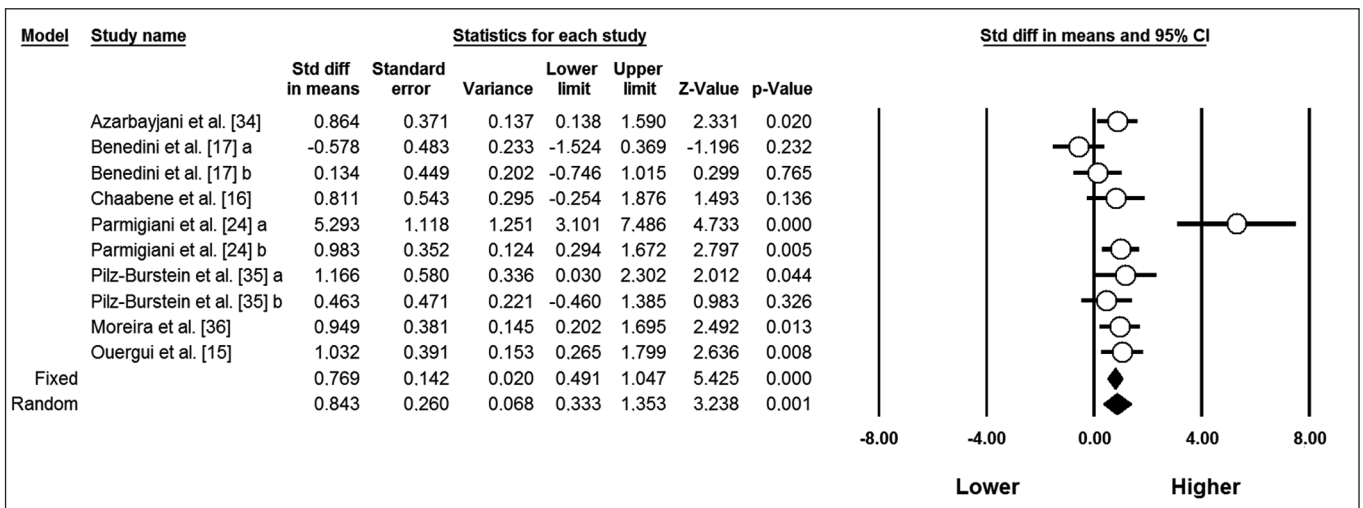


FIG. 3. Forest plot of cortisol changes induced by striking combat sports competitions.

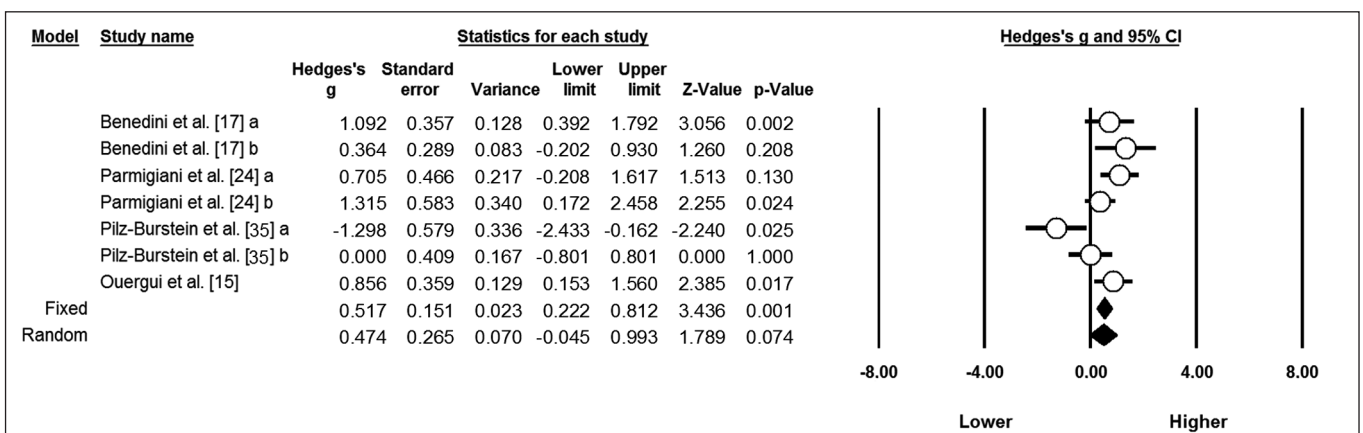


FIG. 4. Forest plot of testosterone changes induced by striking combat sports competitions.

different sports, no significant difference in ES ($Q = 4.20$; $p = 0.122$) was observed. However, when comparing individual sports, a borderline significant difference was observed ($Q = 3.801$, $p = 0.051$) between kickboxing (moderate increase in T levels, $ES = 0.86$) and taekwondo (small decrease in T levels, $ES = -0.58$). Also, a significant difference was observed ($Q = 3.881$, $p = 0.049$) following karate events (moderate increase in T levels, $ES = 0.76$) compared to taekwondo (small decrease in T levels, $ES = -0.58$). Meta regression analysis showed that athletes' age is a significant predictor of the observed T level alterations following striking combat sports events ($B = 0.101$, $Z = 1.995$, $p = 0.046$, Figure 5). Additionally, sub-group analysis confirmed meta-regression results where a significant difference was observed between younger and older athletes ($Q = 4.05$, $p = 0.044$), suggesting that younger individuals (less than 17 years of age) had a small decrease in T levels ($ES = -0.58$), compared to the moderate increase observed in older individuals

($ES = 0.76$) following combat events. Males had a greater T response than females ($ES = 0.36$ [small] vs $ES = 0.00$ [trivial]); however, due to high variance of ESs among the included studies, significance of those results was not achieved ($Q = 0.30$; $p = 0.533$). Furthermore, amateur athletes had a larger T level increase compared to highly trained athletes ($ES = 0.70$ [moderate] vs $ES = 0.34$ [small]), without a significant difference between them ($p = 0.50$). Regarding the time of day, evening events showed greater alterations in T levels compared to morning events ($ES = 0.73$ [moderate] vs $ES = 0.19$ [trivial]), without a significant difference between them ($p = 0.32$, respectively). Alterations in T levels were slightly higher in official events ($ES = 0.86$ [moderate]) compared to simulation events ($ES = 0.40$ [small]), while only those observed after official events were significant ($p = 0.017$).

Based on two studies' results (four ESs), alterations in T levels following the two different forms of karate (i.e., *kumite* and *kata*)

were analysed. The results showed that both *kumite* and *kata* increase *T* levels (ES = 1.15 [moderate] and ES = 0.46 [small], respectively); however, only those alterations following *kumite* were significant ($p < 0.001$), without a significant difference between the two karate forms ($Q = 3.15$; $p = 0.076$).

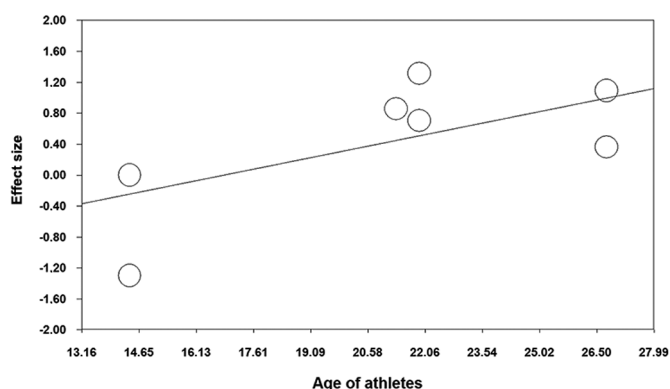


FIG. 5. Meta-regression performed with age as moderator.

5.3. Effects of striking combat sports on adrenaline, noradrenaline, insulin-like growth factor 1 and human growth hormone level changes

The summarized effect of two studies (three ESs) showed an extremely large increase in adrenaline level (ES = 4.22; 95% CI 2.62–5.82; $p < 0.001$) immediately following karate and taekwondo events, compared to the control condition i.e., pre-combat (Figure 6). Only two studies (three ESs) aimed at investigating the effect of noradrenaline levels immediately following combat events. Accordingly, summarized effects of karate and taekwondo showed a very large increase (ES = 3.40; 95% CI 1.03–5.76; $p = 0.005$) of noradrenaline levels immediately following the karate and taekwondo events, compared to the control condition (Figure 7). IGF-1 alterations were investigated in only one study (two ESs), where a trivial and insignificant decrease was observed (ES = -0.20; 95% CI -0.78–0.37; $p = 0.486$) (Figure 8). Finally, based on one study's results, a very large increase was observed in HGH levels (ES = 3.69; 95% CI 1.96–5.42; $p < 0.001$) immediately following kickboxing competitions, compared to the control condition.

Self-confidence, anger, motivation and competitive anxiety were the mediator variables of hormonal change-competition/outcomes relationship in striking combat sports athletes.

TABLE 5. Testosterone responses to striking combat sports competitions relative to different moderator variables.

| Independent variables | ES | Variance | 95% CI | p | I ² (%) | df | Q value and (p) between groups |
|--------------------------------|-------|----------|---------------|---------|--------------------|----|--------------------------------|
| Type of sport | | | | | | | |
| karate | 0.76 | 0.05 | 0.33 to 1.18 | < 0.001 | 17.55 | 3 | |
| taekwondo | -0.58 | 0.42 | -1.85 to 0.68 | 0.366 | 70.14 | 1 | |
| kickboxing | 0.86 | 0.13 | 0.15 to 1.56 | 0.017 | 0.00 | 0 | 4.20 (0.122) |
| Age of athletes | | | | | | | |
| ≤17 | -0.58 | 0.42 | -1.85 to 0.68 | 0.366 | 70.14 | 1 | |
| >17 | 0.76 | 0.03 | 0.43 to 1.09 | < 0.001 | 0.00 | 4 | 4.05 (0.044) |
| Gender | | | | | | | |
| male | 0.36 | 0.16 | -0.43 to 1.15 | 0.373 | 77.90 | 3 | |
| female | 0.00 | 0.17 | -0.80 to 0.80 | 1.000 | 0.00 | 0 | 0.30 (0.533) |
| Competitive level | | | | | | | |
| amateur | 0.70 | 0.13 | -0.01 to 1.41 | 0.054 | 60.14 | 1 | |
| trained | 0.34 | 0.15 | -0.42 to 1.11 | 0.382 | 71.53 | 4 | 0.45 (0.505) |
| Circadian rhythm | | | | | | | |
| morning | 0.19 | 0.25 | -0.79 to 1.16 | 0.707 | 74.47 | 3 | |
| evening | 0.73 | 0.05 | 0.29 to 1.17 | 0.001 | 27.05 | 2 | 0.98 (0.322) |
| Nature of competition contests | | | | | | | |
| simulation | 0.40 | 0.10 | -0.22 to 1.01 | 0.205 | 68.99 | 5 | |
| official | 0.86 | 0.13 | 0.15 to 1.56 | 0.017 | 0.00 | 0 | 0.94 (0.333) |

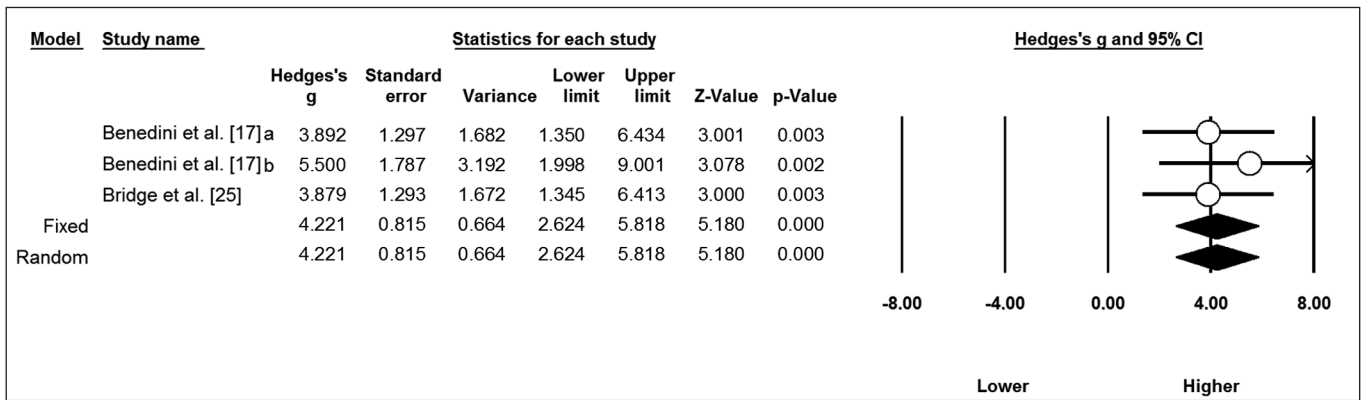


FIG. 6. Forest plot of adrenaline changes induced by striking combat sports competitions.

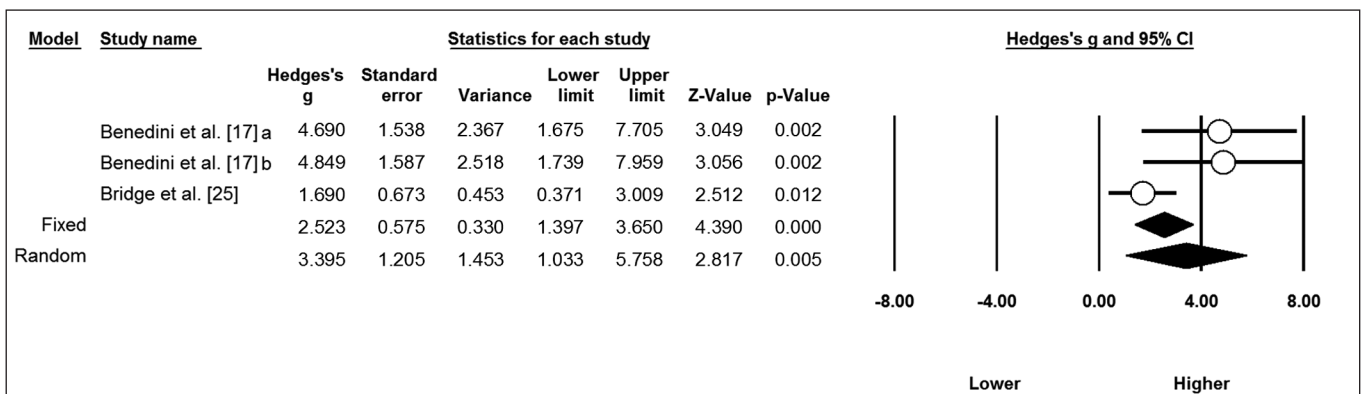


FIG. 7. Forest plot of noradrenaline changes induced by striking combat sports competitions.

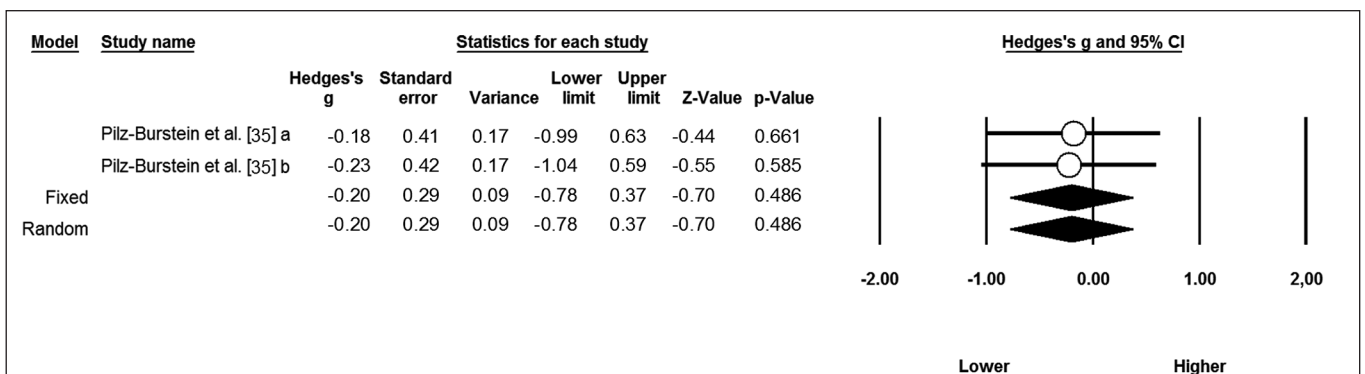


FIG. 8. Forest plot of insulin-like growth factor 1 changes induced by striking combat sports competitions.

DISCUSSION

1. Hormonal responses

1.1. Karate

Karate is a striking combat sport including two main forms (i.e., *kata* and *kumite*) (for more details see Chaabène et al., [12]). During simulated karate, Benedini et al. [17] compared the pre- and post-3 min hormonal response to *kata* and *kumite* forms. The authors re-

ported that both forms produced significant increases in glucose, *T* and catecholamine levels, without appreciable changes in insulin and *C* concentrations [17]. However, glucose and epinephrine concentrations increased more after *kumite* than *kata*. Furthermore, *T* was increased after both exercises. With regards to *C* concentrations, no significant differences were observed between pre- (752.5 ± 52 nmol/l) and post-exercise in either the *kumite* or *kata*

form (759.1 ± 46 and 711.1 ± 87 nmol/l, respectively) [17]. Other researchers studied hormonal responses during *kumite* and *kata* contests and revealed that *T* increased only during *kumite* (pre = 3.95 ± 0.41 vs post = 4.46 ± 0.49 ng/ml). Similarly, *C* increased significantly between pre and post *kumite* activity (pre = 108.36 ± 9.41 vs post = 162.80 ± 11.09 ng/ml) but not pre and post *kata* activity (pre = 103.40 ± 11.56 vs post = 115.00 ± 12.03 ng/ml) [24]. The present review showed that both *kumite* and *kata* resulted in an increase in *C* levels (ES = 2.61 [very large] and ES = 0.24 [small], respectively); however, due to high variance of ESs and heterogeneity among the included studies [17,24], significance of those results was not achieved. Recently, Chaabène et al. [16] showed that simulated karate competition could be considered as a challenging situation and a very-high intensity and stressful activity in male elite level karateka. Particularly, during two consecutive bouts, salivary cortisol (sC) increased progressively and significantly from pre-combat 1 to post-combat 1 and from pre-combat 1 to post-combat 2. The sC values recorded at post-combat 2 would be considered the highest compared to those recorded at post-combat 1. In regards to salivary testosterone (sT), it decreased significantly in post-combat 2. These findings highlight the catabolic hormonal responses that occurred, particularly during the second karate bout. This observation was reinforced by the significant decrease of *T/C* ratio just after the second combat ($\Delta\% = -43.5$) compared to the first combat ($\Delta\% = -31.1$).

Overall, it can be concluded that karate events represent a stressful activity in both genders [16,34]. The present review shows that *C* level increased in both *kumite* and *kata* karate contests, highlighting the high-intensity nature of both karate forms. The data also showed increasing *T* levels following *kumite* and *kata* (ES = 1.15 [moderate] and ES = 0.46 [small], respectively); however, only those alterations following *kumite* were significant, with no significant difference between the two karate forms. Training programmes have to be tailored to the particular requirements of each form of karate. Future research detailing hormonal responses related to combat outcome and gender in both simulated and official karate competitions is needed.

1.2 Taekwondo

A typical taekwondo competition contains three 2 min rounds with a 1 min recovery in-between [37]. Pilz-Burstein et al. [35] studied the stress-related psychobiological responses of male and female youth (i.e., 14-years old) taekwondo practitioners during simulated competition. The results showed a significant decrease in *T* and free androgen index in male athletes with no effect on sex-hormone-binding proteins, as well as a decrease in the IGF-I levels in both genders. They also reported that *C* levels increased in both genders. However, when dealing with an official taekwondo contest, two studies were included [18,33]. Chiodo et al. [18] showed that a taekwondo bout is highly stressful for young athletes and that it induces significant increases of both salivary α -amylase (sA-A) and sC.

In the same contest, Capranica et al. [33] showed that sA-A and sC increased post-bout, with lower pre- and post-bout values than those of Chiodo et al. [18]. This difference could be due to (a) the duration of the competitions, with a lower duration during the official competitions of Capranica et al. [33] (three 1-min rounds) compared with Chiodo et al. [18] (three 2-min rounds), (b) the skill level of athletes (blue belt vs black belt, respectively), and (c) the age difference (10 vs 14 years, respectively). Regardless, these results confirm that a taekwondo bout is a highly stressful activity for young athletes. In addition, it could be possible to speculate that the high hormonal responses in the 10-year-old taekwondo athletes mirror the highest exercise intensities recorded in this group with respect to their older counterparts. During the day of the competition, taekwondo athletes can be engaged in several bouts with variable amounts of time ~30–120 min between competitions; thus cumulative effects may be expected in sC responses [18]. For instance, the development of strategies to facilitate the recovery of *C* levels and assist athletes to cope with the demands of taekwondo championships where several bouts per day are common may be an important consideration for future research. Furthermore, when comparing the stress response between genders after an official taekwondo competition, male athletes show higher absolute values, but a smaller increase (73%) between pre-bout and peak sC values than their female counterparts (199%) [18]. Indeed, further studies into the dissociation between gender and the mechanisms determining gender differences in competitive settings are strongly recommended. The relationship between high *C* responses and performance outcome and the differences in both psychological and hormones variables between different ages and levels of athlete are still unclear and future research in this context will be of practical relevance.

1.3 Kickboxing

Kickboxing is a high-intensity intermittent striking combat sport that requires complex skills and tactical excellence for success where athletes are classified by gender, weight, and age [6,7]. Kickboxing bouts consist of 3 rounds of 2 min with 1 min of recovery between [6]. During an official kickboxing contest, Ouergui et al. [15] reported a significant increase in *C*, *T* and HGH after full-contact kickboxing bouts. Furthermore, in simulated combat Moreira et al. [36] revealed that kickboxing bouts may significantly increase sC concentrations. Typically, it could be stated that sC is useful for the physiological monitoring of kickboxing during competitive bouts. Indeed, performing kickboxing bouts does not influence saliva flow rate, salivary immunoglobulin A (IgA) absolute concentration, or salivary IgA secretion rate [36]. Consequently, the results of the latter studies support the findings that kickboxing bouts could generate considerable acute stress and amplify the hormonal response by the activation of the central nervous system, typically with greater sympathetic nerve activity. Another study by Ouergui et al. [5] showed that simulated combat is not different to official combat in terms of stress response, with similar values pre- to post-combat to the results of Ouergui et

al. [15]. In addition, plasma growth hormone (GH), *C*, glucose, and lactate concentrations were significantly elevated following non-combat kickboxing (NCKB) sessions, which consisted of 10 min of very light warm-up followed by seven sets of six techniques, 20 s per technique as fast as possible, with 1 min of rest between sets [38]. Future research related to hormonal changes in official kickboxing competition, female athletes, participant levels, and for different kickboxing styles (full-contact, low-kick, light contact) are needed to support the knowledge in the field.

2. Hormonal response and combat outcome

The *T* response appeared to depend on the nature of the competition contest (particularly whether a real bout is involved), individual character and the participant's evaluation of the likelihood of winning or losing the bout. In contrast, the *C* increase appeared to follow general physical activity. Furthermore, increases in both hormones appear to be important in preparing for mental and physical demands, and may affect performance, and thus have the potential to indirectly influence the competition outcome [9]. A previous study on animal fighting reported that winners exhibit high levels of free *T* and a low level of *C*, whereas the reverse is true for losers [39]. Previous studies on sports activities have confirmed the differences in *T* and *C* responses according to the outcome of the contest (i.e., victory or defeat) [9,39]. An analysis of available data in judo athletes showed great variability in hormonal response, with *T* and *C* concentrations increasing or decreasing in winners or losers, respectively [9]. In contrast, other studies showed no significant difference in hormonal response between winners and losers after simulated kickboxing and both official and simulated karate bouts [5,16,34].

As mentioned, the human literature shows contradictory findings regarding the link between competitions, their outcome and hormonal variations (especially in relation to *T*) while also showing a high degree of methodological heterogeneity [9,40-42]. This contradiction could be due to (a) the importance of the competition for the subject, (b) blood compared with salivary hormonal sample collection, (c) the body mass index (BMI) and technical ability, and (d) the type of martial art (i.e., judo being characterized by more intense body contact compared with karate).

3. Moderator variables of hormonal changes-competition relationship

3.1 Age

Hormonal levels vary over the lifespan [43]. Therefore, the difference in age could affect the *T* response to combat sports. For instance, age significantly affected the relationship between *T* levels and the competition situation. In this view, growth and maturation processes in humans are associated with profound modifications of numerous physical and psychological characteristics and hormonal patterns. However, compared to adults, fewer data are available in young individuals on the subject of the role of endocrine system status in influencing both athletic performances and the hormonal response

to exercise-related stress [43], while in competition events, no studies in the literature have addressed this topic. Typically, the steroid hormone responses to physical stress are influenced by numerous variables, e.g. (a) individual characteristics (i.e., genes, age, gender), (b) physiological (i.e., nutrition, body composition) or pathological (i.e., obesity factors), (c) psychological conditions, and (d) the nature of physical activity performed [44]. A previous review by Kraemer and Ratamess [45] showed that age and/or maturity are mediator variables of the resistance training-endocrine response relationship. This difference could be due to the lower muscle glycogen levels at rest, higher proportions of slow twitch (type I) fibres in the vastus lateralis part of the quadriceps in children, higher plasma glucose levels, lower activity of phosphofructokinase-1 and lactate dehydrogenase enzymes, which could also explain the lower glycolytic capacity, and the limited production of muscle lactate in children compared to adults [43]. Specifically, it has been shown that after the early twenties, resting *T* levels begin to decline slowly [39].

3.2 Gender

Males had greater *T* (ES = 0.36 [small] vs ES = 0.00 [trivial], respectively) and *C* (ES = 1.21 [large] vs ES = 0.66 [small], respectively) responses than females, but without any significant differences between them. However, it has been shown that the endocrine responses to the competitive setting varied significantly by gender [35]. Furthermore, the nature of the gender difference was complex. The difference in stress response between males and females may be due to (a) the higher hormone concentrations for men at rest (particularly *T* levels), (b) higher psychological stress in men immediately before the test which represents a challenge and (c) the differences in body composition (e.g., higher fat mass in women) and/or in sexual hormonal status [46]. Accordingly, Mazur and Booth [39] found that while men showed a rise in testosterone levels prior to a contest, there was no corresponding rise for women. They concluded that the effect of competition for increasing testosterone levels appears to be specific to men. For instance, the present review showed a higher increase in stress response in female fighters than males in an official combat contest, whereas in a simulation combat contest, male fighters presented a higher increase of *C* levels than female athletes.

3.3 Time of day

The time of day at which the *C* and *T* were measured was found to be an insignificant moderator in the relationship between hormone change and competition. For instance, the current review found that evening events showed greater alterations in *C* levels compared to morning events (ES = 1.50 [large] vs ES = 0.48 [small]), without any significant difference between them. In contrast, higher physiological and psychological stress in the evening compared to the morning was reported in the literature [47]. In addition, the effect of the time at which the *T* was measured was non-significant, with a slightly greater ES level in the evening (ES = 0.73 [moderate])

compared to the morning ($ES = 0.19$ [trivial]). Coaches should consider holding the friendly competitions in the morning (between 10 a.m. and 12 noon) whenever they seek to decrease the stress response and to have specific training purposes. However, if the coaches seek to train their athletes in stressful conditions, they should delay the friendly competitions to late afternoon or early evening.

4. Mechanisms affecting the changes of steroid hormones

Underlying mechanisms of observed hormonal changes might be explained by changes in psychological state and alteration at both central and peripheral levels, which will be discussed in the following paragraphs.

4.1. Psychological mediators/mechanisms

A combination of “biological” and “psychological” measures can be used to characterize the athlete in terms of attitude and performance. Furthermore, psychobiological studies of martial arts can increase our understanding of the “power of mind” to modulate neurochemical responses. They could consequently be used in such combat sports activities as a form of personality training to enhance individual coping strategies in challenging situations (e.g., competition). However, some psychological variables (e.g., mental toughness, mood state) have been strongly linked with optimal performance and outcome in combat sports [10,48,49]. In addition, previous studies suggest the possibility of an intriguing correlation between psychological and biological (i.e., hormonal responses) factors in response to competitive contests [9,24,40]. Some attempts to link hormonal changes to psychological variables are reported in a few studies of sport dyadic encounters such as in judo, taekwondo and karate [24,40,50]. In this context, a clinical study of stress response, in healthy individuals, reported that harm avoidance (a behaviour modulated by anxiety) was positively related to plasma *C* concentrations, thus showing a clear association of temperamental traits and hypothalamic–pituitary–adrenal (HPA) function [51]. For instance, even though the study of Chiodo et al. [18] showed no relationship using the profile of mood states (POMS) tool, this does not exclude existing relationships that could be demonstrated with other more specific tools. Furthermore, in the perspective of the game theory applied to conflict [52] a neglected factor in many of the above studies is the possible asymmetry between contestants as regards fighting motivation, fighting ability and personality traits influencing the individual perception of the value and possible outcome of the competition [9,40]. For instance, Parmigiani et al. [24] suggest that in a symmetric type of contest the karatekas with more anxious and defensive personality traits have higher probability of losing the competition. In other words, personality traits might be an important asymmetry factor between athletes influencing both the probability of winning or losing an agonistic interaction and the different anticipatory endocrine response to the incipient fight. In addition, in a previous study on judo athletes, Suay et al. [41] observed the relationships between *T* changes in competition and motivation to win,

as well as between *C* response and self-efficacy. This suggests that humans’ hormonal response to competition is not a direct consequence of winning and losing but rather is mediated by complex psychological processes that could even contribute to the competition outcome. A previous study also reported that *C* is not strictly linked to an agonistic activity but is affected by the cognitive and emotional perception of the event [8]. In conclusion, these findings may help to explain the already evident connection between psychological state and the activation of the endocrine systems, in which the psychological skills are the mediator variable of win-loss in competition.

The lack of correlation between psychological variables, measured with psychometric tests, and hormonal response in winners and losers (especially *C*) found in some studies [9,40] may be due to the fact that personality traits measuring the temperament and personality dimension were used (i.e., Sixteen Personality Factor Questionnaire (16PF), Temperament and Character Inventory (TCI), State-Trait Anxiety Inventory (STAI)) that better evaluate the individual behavioural coping strategy than those generally used in previous studies (i.e., POMS and Buss-Durkee Hostility Inventory (BDHI)) measuring the individual hostility and mood profile (i.e., either as personality state and/or trait) in a specific competitive situation. Finally, these data are important for sports psychology and sports science in general to suggest a new area of research in psychobiology. Whereas, to date, limited studies on this topic were reported, researchers are encouraged to examine the psychological mechanisms of the hormonal response-competitive situation/outcome relationship. In the likelihood intrinsic motivation, individual self-confidence, anger, mental toughness, and competitive anxiety are the psychological variables related to a competitive event.

4.2. Central and peripheral mechanisms

Both central and peripheral factors are used to explain underlying mechanisms of steroid hormone changes. First, the central mechanism relies on the fact that free *C* concentrations of subjects negatively correlated with the motor cortex response [53]. Similarly, total *T* concentrations also negatively correlated to the cortical motor threshold in humans [53]. Second, in the supposed peripheral mechanism, *T* and *C* play important roles in mediating training adaptation, with one or more mechanisms involved, such as muscle and motor unit development, behavioural changes, and mobilization of metabolic resources [54]. However, it is difficult to draw clear conclusions about which mechanism underlying the competition-hormonal response relationship, due to the unavailable data in this context. Perhaps both central and peripheral mechanisms are involved. However, further studies in this context are needed.

Strengths and limitations of the review

The limitations and challenges associated with the analysis and interpretation of hormonal research in competition (e.g. procedural issues, analytical methods, and research design) were another discus-

sion point. For instance, hormone analytical method (e.g., Elecsys assays, enzyme-linked immunosorbent assay [ELISA], radioimmunoassay [RIA] or multiplex) and intra/inter-assay coefficient of variation were different in all studies. Thus, a relatively small sample size was reported in some of the selected studies. Limited numbers of studies on *T* response in striking combat sports were also recorded.

One of the strengths of this review is the fact that the majority of the studies included presented high to moderate methodological quality, with only three studies presenting poor quality (average of Downs and Black scale=8). Hence, their results must be interpreted with caution. In addition, the different variables studied, such as nature of the competition, age, gender, and time of day, in all the studies reviewed allowed this review to provide some basic data that will allow future studies to build on and improve the knowledge in this specific field.

CONCLUSIONS

The measurement of psychological and hormonal parameters offers a unique possibility to achieve a more comprehensive evaluation of the stress responses of the individual in competitive situations. Furthermore, this area of research can represent a useful model for monitoring the impacts of various stressors (e.g., simulation and official competitions) in athletes of different age and gender. The present systematic review and meta-analysis showed that the hormonal response during official combat competition was greater than that in simulated conditions. Thus, except the age of participants, gender, nature of the competition and time of day would not be considered as moderator variables of the hormonal change-competition relationship. Also, the studies regarding the link between the outcome of the competition and hormonal variables are contradictory. This difference may be due to (a) the importance of the competition for the athlete, (b) blood compared with salivary hormonal sample collection, and (c) the type of martial art concerned. Thus, some psychological variables, such as fighting motivation, mental toughness, competition anxiety, self-efficacy and self-confidence, represented a cause-and-effect (mediator variables) relationship between hormonal response

and outcome of the competition and the predictor variables of performance in the competition. Future studies including psychological variables in conjunction with the assessment of hormonal responses in simulated and official combat sports competition are important to understand the mechanisms of a positive or negative relationship. Also, future investigations on hormonal responses in other striking combat sports such as boxing, relevant to specific situations (simulation or official competition), gender, and participant levels are needed to support the findings presented in the current review. Furthermore, the link between psychological variables and hormonal response seems to be a very important area of future research.

The present review gathered studies about the hormonal response during official and simulation striking competitions, which are relevant for coaches to monitor training load and to facilitate the planning of specific training modalities. The schematic results of hormonal responses for striking fighters can be used to obtain references of the sport-specific demands.

Asking questions about how these hormones (*T*, *C*, adrenaline, noradrenaline, insulin-like growth factor 1 and human growth hormone) interact in a variety of settings in striking activities is likely to be an important step towards a better understanding of the physiological, psychological, and behavioural effects of these hormones. This could be used to prevent the development of non-functional overreaching conditions or overtraining syndrome and optimize training management. The current review of the acute effects of striking combat on hormonal responses could also be used to organize the precompetitive cognitive training programme to reduce the psychological and physiological stress of combat sports athletes.

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Conflict of interests

The authors declared no conflict of interests regarding the content of this manuscript.

REFERENCES

1. Bridge CA, Ferreira da Silva Santos J, Chaabène H, Pieter W, Franchini E. Physical and physiological profiles of taekwondo athletes. *Sports Med.* 2014;44(6):713-33.
2. Chaabène H, Hachana Y, Franchini E, Mkaouer B, Chamari K. Physical and physiological profile of elite karate athletes. *Sports Med.* 2012; 42:829-43.
3. Davis P, Benson P, Waldock R, Connorton A. Performance analysis of elite female amateur boxers and comparison to their male counterparts. *Int J Sports Physiol Perform.* 2016;11:55-60.
4. Davis P, Benson PR, Pitty JD, Connorton AJ, Waldock R. The activity profile of elite male amateur boxing. *Int J Sports Physiol Perform.* 2015; 10:53-57.
5. Ouergui I, Davis P, Houcine N, Marzouki H, Zaouali M, Franchini E, Gmada N, Bouhlef E. Hormonal, physiological and physical performance during simulated kickboxing combat: Differences between winners and losers. *Int J Sports Physiol Perform.* 2015. [Epub ahead of print]
6. Slimani M, Chaabene H, Miarka B, Franchini E, Chamari K, Cheour F. Kickboxing review: anthropometric, psychophysiological and activity profiles and injury epidemiology. *Biol Sport.* 2017;34(2):185-196.
7. Slimani M, Chaabene H, Miarka B, Chamari K. The activity profile of elite low-kick kickboxing competition. *Int J Sports Physiol Perform.* 2017; 12(2):182-189.
8. Pesce M, Fratta IL, Ialenti V, Patruno A, Ferrone A, Franceschelli S, Rizzuto A, Tatangelo R, Campagna G, Speranza L, Felaco M, Grilli A. Emotions, immunity and sport: Winner and loser athlete's profile of fighting sport. *Brain Behav Immun.* 2015; 46:261-9.

9. Slimani M, Davis P, Franchini E, Moalla W. Rating of perceived exertion for quantification of training and combat loads during combat sport specific activities: a short review. *J Strength Cond Res.* 2017 [Epub ahead of print]
10. Slimani M, Miarka M, Briki W, Chéour F. Comparison of mental toughness and power tests performances in high-level kickboxers by competitive success. *Asian J Sports Med.* 2016; 9:7(2):e30840.
11. Chaabène H, Franchini E, Sterkowicz S, Tabben M, Hachana Y, et al. Physiological responses to karate specific activities. *Sci Sports.* 2015; 30:179-187.
12. Tabben M, Sioud R, Haddad M, Franchini E, Chaouachi A, Coquart J, et al. Physiological and perceived exertion responses during international karate kumite competition. *Asian J Sports Med.* 2013; 4(4):263-71.
13. Slimani M, Chaabene H, Davis P, Franchini E, Cheour F, Chamari K. Performance aspects and physiological responses in male amateur boxing competitions: A brief review. *J Strength Cond Res.* 2017;31(4):1132-1141.
14. Ouergui I, Hammouda O, Chtourou H, Gmada N, Franchini E. Effects of recovery type after a kickboxing match on blood lactate and performance in anaerobic tests. *Asian J Sports Med.* 2014;5(2):99-107.
15. Ouergui I, Houcine N, Marzouki H, Davis P, Zaouali M, Franchini E, Gmada N, Bouhleb E. Development of a noncontact kickboxing circuit training protocol that simulates elite male kickboxing competition. *J Strength Cond Res.* 2015;29(12):3405-11.
16. Chaabene H, Hellara I, Ben Ghali F, Franchini E, Neffati F, Tabben M, Najjar MF, Hachana Y. Physiological stress and performance analysis to karate combat. *J Sports Med Phys Fitness.* 2016;56(10):1125-1131.
17. Benedini S, Longo S, Caumo A, Luzi L, Invernizzi PL. Metabolic and hormonal responses to a single session of kumite (free non-contact fight) and kata (highly ritualized fight) in karate athletes. *Sport Sci Health.* 2012;8(2-3):81-85.
18. Chiodo S, Tessitore A, Cortis C, Cibelli G, Lupo C, Ammendolia A, De Rosas M, Capranica L. Stress-related hormonal and psychological changes to official youth Taekwondo competitions. *Scand J Med Sci Sports.* 2011;21:111-119.
19. Papacosta E, Nassis GP, Gleeson M. Salivary hormones and anxiety in winners and losers of an international judo competition. *J Sports Sci.* 2015;19:1-7.
20. Bouaziz T, Makni E, Passelegue P, Tabka Z, Lac G, Moalla W, Chamari K, Elloumi M. Multifactorial monitoring of training load in elite rugby sevens players: cortisol/cortisone ratio as a valid tool of training load monitoring. *Biol Sport.* 2016;33(3):231-9.
21. Crewther BT, Carruthers J, Kilduff LP, Sanctuary CE, Cook CJ. Temporal associations between individual changes in hormones, training motivation and physical performance in elite and non-elite trained men. *Biol Sport.* 2016;33(3):215-21
22. Hug M, Mullis PE, Vogt M, Ventura N, Hoppeler H. Training modalities: over-reaching and over-training in athletes, including a study of the role of hormones. *Best Pract Res Clin Endocrinol Metab.* 2003; 17(2):191-209.
23. Slimani M, Cheour F, Moalla W, Baker JS. Hormonal responses to a rugby match: a brief review. *J Sports Med Phys Fitness.* 2017 [Epub ahead of print]
24. Parmigiani S, Dado H, Bartolomucci A, Brain PF, Carbuicchio A, Costantino C, Ferrari PF, Palanza P, Volpi R. Personality traits and endocrine response as possible asymmetry factors of agonistic outcome in karate athletes. *Aggress Behav.* 2009;35(4):324-33.
25. Bridge CA, McNaughton LR, Close GL, Drust B. Taekwondo exercise protocols do not recreate the physiological responses of championship combat. *Int J Sports Med.* 2013;34(7):573-81.
26. Moher D, Tetzlaff J, et al. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Br Med J.* 2009; 339:332-6.
27. Archer J. The influence of testosterone on human aggression. *Br J Psychol.* 1991;82:1-28.
28. Book AS, Starzyk KB, Quinsey VL. The relationship between testosterone and aggression: a meta-analysis. *Aggress Violent Behav.* 2001;6:579-599.
29. Wang C, Plymate S, Nieschlag E, Paulsen C. Salivary testosterone in men: further evidence of a direct correlation with free serum testosterone. *J Clin Endocrinol Metab.* 1981; 53:1021-1024.
30. Downs SH, Black N. The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. *J Epidemiol Community Health.* 1998; 52(6):377-84.
31. Hedges L. Distribution theory for Glass's estimator of effect size and related estimators. *J Educ Stat.* 1981; 6:107-128.
32. Higgins JPT, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. *BMJ Br Med J.* 2003; 327(7414):557-60.
33. Capranica L, Lupo C, Cortis C, Chiodo S, Cibelli G, Tessitore A. Salivary cortisol and alpha-amylase reactivity to taekwondo competition in children. *Eur J Appl Physiol.* 2012; 112(2):647-52.
34. Azarbayjani MA, Rahmani M, Rasaei MJ, Tojari F, Pournemati P, Ostojic SM, Stannard SR. The effect of sport competition on salivary steroids in amateur female karate athletes. *J Phys Educ Sport.* 2010; 27:44-48.
35. Pilz-Burstein R, Ashkenazi Y, Yaakobovitz Y, Cohen Y, Zigel L, Nemet D, Shamash N, Eliakim A. Hormonal response to Taekwondo fighting simulation in elite adolescent athletes. *Eur J Appl Physiol.* 2010; 110(6):1283-90.
36. Moreira A, Arsati F, Lima-Arsati YB, Franchini E, De Araújo VC. Effect of a kickboxing match on salivary cortisol and immunoglobulin A. *Percept Mot Skills.* 2010;111(1):158-66.
37. World Taekwondo Federation. The book of teaching and learning Taekwondo. Seoul, Korea: World Taekwondo Federation Publ. 2007.
38. Ghanbari-Niaki A, Kraemer RR, Soltani R. Plasma nesfatin-1 and glucoregulatory hormone responses to two different anaerobic exercise sessions. *Eur J Appl Physiol.* 2010; 110(4):863-8.
39. Mazur A, Booth A. Testosterone and dominance in men. *Behav Brain Sci.* 1998;21:353-363.
40. Filaire E, Maso F, Sagnol M, Lac G, Ferrand C. Anxiety, hormonal responses and coping during a judo competition. *Aggress Behav.* 2001;27 (1):55-63.
41. Suay F, Salvador A, González-Bono E, Sanchis C, Martínez M, Martínéz-Sanchis S, et al. Effects of competition and its outcome on serum testosterone, cortisol and prolactin. *Psychoneuroendocrinol.* 1999; 24 (5):551-566.
42. van der Meij L, Buunk AP, Almela M, Salvador A. Testosterone responses to competition: The opponent's psychological state makes it challenging. *Biol Psychol.* 2010; 84(2):330-5.
43. Boisseau N, Delamarche P. Metabolic and hormonal responses to exercise in children and adolescents. *Sports Med.* 2000;30:405-422.
44. Cumming DC, Brunsting LA, Strich G, Ries AL, Rebar RW. Reproductive hormone increases in response to acute exercise in men. *Med Sci Sports Exerc.* 1986;18(4):369-73.

45. Kraemer WJ, Ratamess NA. Hormonal responses and adaptations to resistance exercise and training. *Sports Med.* 2005;35(4):339-61.
46. Zouhal H, Jacob C, Delamarche P, Gratas-Delamarche, A. Catecholamines and the effects of exercise, training and gender. *Sports Med.* 2008; 38:401-423.
47. Chtourou H, Souissi N. The effect of training at a specific time of day: a review. *J Strength Cond Res.* 2012; 26(7):1984-2005.
48. Beedie CJ, Terry PC, Andrew M. The profile of mood states and athletic performance: two meta-analyses. *J Appl Sport Psychol.* 2000;12:49-68.
49. Raglin JS. Psychological factors in sport performance: the mental health model revisited. *Sports Med.* 2001; 31:875-890.
50. Toskovic NN. Alterations in selected measures of mood with a single bout of dynamic Taekwondo exercise in college-age students. *Percept Mot Skills.* 2001;92:1031-8.
51. Abelson JL, Khan S, Liberzon I, Young EA. HPA axis activity in patients with panic disorder: review and synthesis of four studies. *Depress Anxiety.* 2007;24(1):66-76.
52. Maynard-Smith J. The century since Darwin. *Nature.* 1982; 15:296(5858):599-601.
53. Sale MV, Ridding MC, Nordstorm MA. Cortisol inhibits neuroplasticity induction in human motor cortex. *J Neurosci.* 2008; 28 (33): 8285-93.
54. Crewther BT, Cook C, Cardinale M, Weatherby RP, Lowe T. Two emerging concepts for elite athletes: The short-term effects of testosterone and cortisol on the neuromuscular system and the dose-response training role of these endogenous hormones. *Sports Med.* 2011; 41(2):103-23.