

Temporal associations between individual changes in hormones, training motivation and physical performance in elite and non-elite trained men

AUTHORS: Crewther BT^{1,2}, Carruthers J³, Kilduff LP^{4,7}, Sanctuary CE⁵, Cook CJ^{2,6,7}

¹ Institute of Sport – National Research Institute, Warsaw, Poland

² Hamlyn Centre, Imperial College, London, UK

³ Al-Attar Physical Medicine, Rehabilitation and Sports Medicine Center, Doha, Qatar

⁴ Applied Sports, Technology, Exercise and Medicine, College of Engineering, Swansea University, Swansea, UK

⁵ Newcastle Knights Rugby League, Newcastle, Australia

⁶ School of Sport, Health and Exercise Science, Bangor University, Bangor, UK

⁷ Welsh Institute of Performance Science, Swansea University, Swansea, UK

ABSTRACT: To advance our understanding of the hormonal contribution to athletic performance, we examined the temporal associations between individual changes in testosterone (T) and/or cortisol (C) concentrations, training motivation and physical performance in elite and non-elite trained men. Two male cohorts classified as elites (n = 12) and non-elites (n = 12) completed five testing sessions over a six-week period. The athletes were tested for salivary T, C, T/C ratio, self-perceived training motivation, countermovement jump (CMJ) height and isometric mid-thigh pull peak force (IMTP PF), after which an actual training workout was performed. The elite men reported higher motivation to train and they produced greater CMJ height overall, whereas the non-elites had higher pooled T levels (p < 0.05). No significant group differences in C concentrations, T/C ratio or IMTP PF were found. The individual changes in T levels were positively associated with training motivation in the elite men only (p = 0.033), but the hormonal and motivation measures did not predict CMJ height or IMTP PF in either group. The monitoring of elite and non-elite men across a short training block revealed differences in T levels, motivation and lower-body power, which may reflect training and competitive factors in each group. Despite having lower T levels, the elite athletes showed better linkage between pre-training T fluctuations and subsequent motivation to train. The nature of the performance tests (i.e. single repetition trials) could partly explain the lack of an association with the hormonal and motivational measures.

CITATION: 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):215–221.

Received: 2015-09-22; Reviewed: 2015-12-23; Re-submitted: 2016-01-08; Accepted: 2016-01-09; Published: 2016-05-01.

Corresponding author:

Blair Crewther

Department of Endocrinology

Institute of Sport – National

Research Institute

01-982 Warsaw

Poland

E-mail: blair.crewther@gmail.com

Key words:

Endocrine

Behaviour

Rugby league

Adaptation

INTRODUCTION

In sport, the testosterone (T) contribution to athletic performance and training adaptation has largely been attributed to a morphological mechanism involving protein metabolism and changes in muscle size [1]. Some studies [2, 3, 4] have however questioned the importance of acute physiological T changes as a signal for muscle growth. Testosterone is also an important social hormone and thus, may help to regulate athlete emotions and behaviours (e.g. motivation, mood, aggression) in different sporting situations [5, 6]. This positions T as more of a mediator in psychological functioning on a day-to-day basis. It also provides a novel framework for understanding both sporting performance and the equivocal results concerning T and muscle hypertrophy.

There is growing evidence linking T to motivational drive. For example, T administration can enhance motivation for action [7] and general motivation by reducing unconscious fear [8]. Testosterone

can also promote increases in voluntary exercise [9, 10], as a physical indicator of motivation. Similarly, in a sporting context, athlete T levels before training were positively correlated to self-selected training loads [11] and workloads [12], whilst greater T responses to competition were associated with higher motivation to win [13, 14]. Thus, fluctuations in T availability during training sessions and competition could be a major factor in determining the outcomes of these activities. To our knowledge, no research has examined the T effect on perceived motivation to train and physical performance under normal training conditions.

Cortisol (C) is another training biomarker with a recognised role in mobilising energy resources [6]. As with T, there is evidence linking C to motivational behaviours (e.g. risk taking and tolerance) in men [15, 16], as well as being a correlate of related psychological features (e.g. negative mood, self-efficacy) in sport [13, 17]. These

outcomes could partly explain the observed relationships between C and athlete performance (including ranking) during exercise testing [18, 19] and competition [20, 21, 22]. Once again, few studies have assessed C from the novel perspective of a training motivational hormone with a permissive performance effect. With this in mind, monitoring the T and/or C concentrations of athletes before a training session and their association with the aforementioned outcomes would provide further insight regarding the hormonal contribution to athletic performance.

Most sport studies are cross-sectional in their design and/or analysis so the reported associations are still limited to between-individual comparisons [13, 14, 17, 18, 19, 20, 21, 22]. These outcomes can differ from those modelled for an individual athlete over time [23]. Therefore, more longitudinal research is needed to profile hormone secretion (i.e. temporal changes) and usage (i.e. associations with training motivation and physical performance) on a within-subject level, which is arguably more important to athletic training and development. It has also been suggested that elite athletes may better utilise hormones than lesser trained men to enable continued adaptation in sport, particularly on an individual level [6]. This could be addressed by comparing elite and non-elite athletes [20, 24, 25, 26], as a framework to characterise hormonal variation and linkage to relevant athletic outputs as a function of training status.

This study examined the temporal associations between the individual changes in hormones (T, C, T/C ratio) before training, training motivation and subsequent physical performance (power, strength) in elite and non-elite trained men. The elite group were professional male rugby league players and the non-elites were weight-trained males, with longitudinal monitoring conducted over a short training block during the competitive rugby league season. Based on these details, we hypothesized that the elites would exhibit different hormonal (e.g. higher C, T/C ratio) and performance (e.g. greater power) profiles from the non-elites. We also hypothesized that the individual changes in T and/or C levels would be related to the training motivation and physical performance outcomes, but this association would be stronger in the elite group [6, 20, 27].

MATERIALS AND METHODS

Subjects. We recruited 12 professional male rugby league players (elites) and 12 non-professional male athletes (non-elites) for this study. The elite group were training six days a week involving multiple skill, fitness and recovery sessions (up to 12 per week, 45-90 minutes per session), and they played in one-two competitive games per week. The non-elite group were training up to four days a week, mainly resistance-type exercise workouts (3-5 sessions weekly, 45-60 minutes each), but none were professional or full-time athletes. The inclusion criteria for this study included; more than three years of specialised training experience (> 3 days weekly), with no injuries or medical problems that would influence the study outcomes. Informed consent was signed before the study commenced. This experiment was performed in accordance with the ethical standards of

the Helsinki Declaration and approval was provided by the Swansea University Research Ethics Committee, Wales.

Experimental design

A two-group, descriptive longitudinal study was undertaken to address the study hypotheses. The elite and non-elite groups were monitored across five testing sessions over a six-week period. In each session, the following measures were taken in order: salivary T, C, T/C ratio and subjective ratings of training motivation followed the assessment of countermovement jump (CMJ) height and isometric mid-thigh pull peak force (IMTP PF). Power and strength assessments of this nature are common in sport [18, 19, 23, 28, 29] and both reflect important physical attributes for the elite group, as professional rugby league players [30], with further linkage to sport-specific speed in rugby league [29]. The study participants were familiar with each assessment and all testing was performed immediately before a normal training workout to improve adherence and the ecological validity of the study findings.

Testing schedule

Athlete testing was conducted during the 2011 Super League season with seven rugby league games played over the six-week monitoring period. The elite group were assessed two-four days after each game to ensure adequate recovery of the hormonal and neuromuscular systems [31]. If two games were played within a five-day period, then no further testing was performed that week. The non-elite men were assessed within two days of testing the elite group to ensure that the timing of assessments were relatively comparable. These were also implemented two days after their own competitive endeavours to ensure appropriate rest was provided, thereby aiding the hormonal comparisons. All sessions were completed between 0730 and 1130 hours, with participants awake for more than 90 minutes to account for an early morning rise in hormones [22]. Within this four-hour window, the participants completed their own assessments within a shorter timeframe (± 1 hour) to provide some consistency for each athlete tested. There are minimal circadian hormonal changes over such a short time period [32].

Scheduling problems in the first session did result in a later assessment (1600 hours) for four men in the non-elite group. As such, time of day was included as a covariate in the statistical analyses and data were examined with and without these subjects in the first session.

The two groups were assessed at separate venues due to practical constraints, although the testing procedures and equipment employed were identical. Two exercise professionals (both males) monitored each session, collected the study data and provided verbal encouragement with respect to performance. Both groups continued training throughout this study, but all exercise was avoided in the morning of testing to eliminate any fatigue effects, or a potentiating effect of morning exercise on hormones and performance [28]. Due to the study timing within the competitive season, the elite group

were primarily training to maintain peak physical performance, with the non-elite group also employing a maintenance-type training programme for the purpose of this project. To account for dietary factors, each participant was instructed to maintain the same food and fluid intake on each testing day, along with the timing of morning meals to ensure consistency (on a within-subject level) across the monitoring period. Given that the athletes in both groups had several years of training experience, we expected that they would choose routine meals to meet their macronutrient (e.g. carbohydrates, protein, fats) needs for the following session that day.

Salivary hormone assessment

Salivary steroids provide a surrogate marker for the biologically active free hormone [33]. Saliva samples (~1 ml) were collected by passive drool at the start of each session and stored using recommended guidelines [34]. To prevent sample contamination, the participants were instructed to refrain from taking any food or hot drinks before sampling [11]. After thawing and centrifugation (2000 rpm × 10 minutes), the samples were analysed using immunoassay kits (Salimetrics LLC, USA) and the manufacturers' guidelines. The minimum detection limit for the T assay was 6.1 pg/ml with inter-assay coefficients of variation (CV) of < 12%. The C assay had a detection limit of 0.12 ng/ml with inter-assay CV of < 7%. Samples for each participant were assayed in the same plate to eliminate inter-assay variability.

Training motivation assessment

Training motivation was assessed immediately after saliva collection. Given that motivation to exercise is both task and environment specific [35], we asked each athlete, "How would you rate your motivation to train right now?". Physical testing and training are both characterised by the need to exert maximum effort and often across the same exercises, so we anticipated that this measure would be applicable to both activities. The motivational ratings used previously by elite athletes [13, 14] were modified to derive a 20-point range for better discriminative ability, anchored against 1 (extremely low) up to 20 (extremely high). The exercise professionals collected these data after showing the athletes a visual scale with each outcome and rating. This type of information is routinely collected within the sporting environment and enabled rapid assessment with little intrusion to the athletes.

Physical performance assessment

The CMJ's were performed on a jump mat (Probotics Inc., Huntsville, USA). With the hands akimbo, participants squatted down to a self-selected depth before explosively jumping to achieve maximal height. The jump mat provides valid height estimates compared to a criterion system ($r = 0.97$) [36] and pilot testing indicated reliable data (CV's < 2.0%). Next, IMTP PF was assessed using a digital dynamometer (T.K.K.5402, Takei Co., Japan). Standing on a purpose-built platform, the participants assumed a semi-squat position and grabbed

the handle of a chain connected to the dynamometer. They extended at the hips and back in an attempt to stand in an upright position. Strength testing with this device is very reliable ($r = 0.99$) [37]. For both exercises, three warm-up trials were performed followed by three maximal trials with full recovery (i.e. 1 minute for each CMJ, 3 minutes for each IMTP) between each attempt. The best lifts for each test were used for analysis.

Statistical analyses

The hormonal and motivation variables were log-transformed before analysis to normalise data distribution, but the raw values are depicted to allow study comparisons. The hormonal, motivation and performance data were assessed using a generalized estimation equation (GEE) model [38]. Main effects (session, group) and interactions (session × group) were determined by significance testing of the Wald chi-square statistic (χ^2). The Bonferroni sequential procedure was used for post hoc testing. Within-subject modelling was employed to assess the temporal associations between the predictor (hormones) and outcome (motivation, performance) variables, based on individual slope patterns and paired T-test analysis between the group mean and zero [39]. Group demographics (i.e. age, height, body mass) were compared using unpaired T-tests. The significance level was set at $p \leq 0.05$.

RESULTS

The elite men were significantly ($p \leq 0.05$) younger (23.4 ± 3.6 years) and taller (183.4 ± 5.5 cm) than the non-elite men (29.6 ± 9.7 years, 176.3 ± 5.3 cm), respectively, but both groups had a similar ($p = 0.099$) body mass (elite 95.4 ± 11.0 kg; non-elite 88.0 ± 10.0 kg). Body mass did not change significantly in either group over time (data not shown). To account for baseline differences that may influence the study results, the variables age, time of day and testing date were entered as covariates in the GEE modelling of hormones and motivation, with athlete height also included when modelling the physical performance data.

The analysis of T (Figure 1A) revealed a significant group effect ($\chi^2(1) = 9.43$, $p = 0.002$), with the non-elite men exhibiting higher pooled T concentrations than the elite men, but no session effect ($\chi^2(4) = 6.80$, $p = 0.147$) or interaction occurred ($\chi^2(4) = 4.26$, $p = 0.372$). Cortisol testing (Figure 1B) revealed no significant effects by session ($\chi^2(4) = 3.36$, $p = 0.499$), group ($\chi^2(1) = 0.18$, $p = 0.674$) or any interaction ($\chi^2(4) = 6.20$, $p = 0.185$). Likewise, no session ($\chi^2(4) = 2.90$, $p = 0.575$), group ($\chi^2(1) = 2.54$, $p = 0.111$) or interaction ($\chi^2(4) = 3.67$, $p = 0.453$) effect on the T/C ratio was noted (Figure 1C),

The session effect on training motivation (Figure 2) approached significance ($\chi^2(4) = 8.90$, $p = 0.064$), whereas the group ($\chi^2(1) = 43.2$, $p < 0.001$) and interaction results ($\chi^2(4) = 12.3$, $p = 0.015$) were statistically significant. Post hoc testing revealed higher motivation scores in the elite group during sessions 2-5, compared to the non-elite results in all sessions ($p < 0.05$), with the elites also

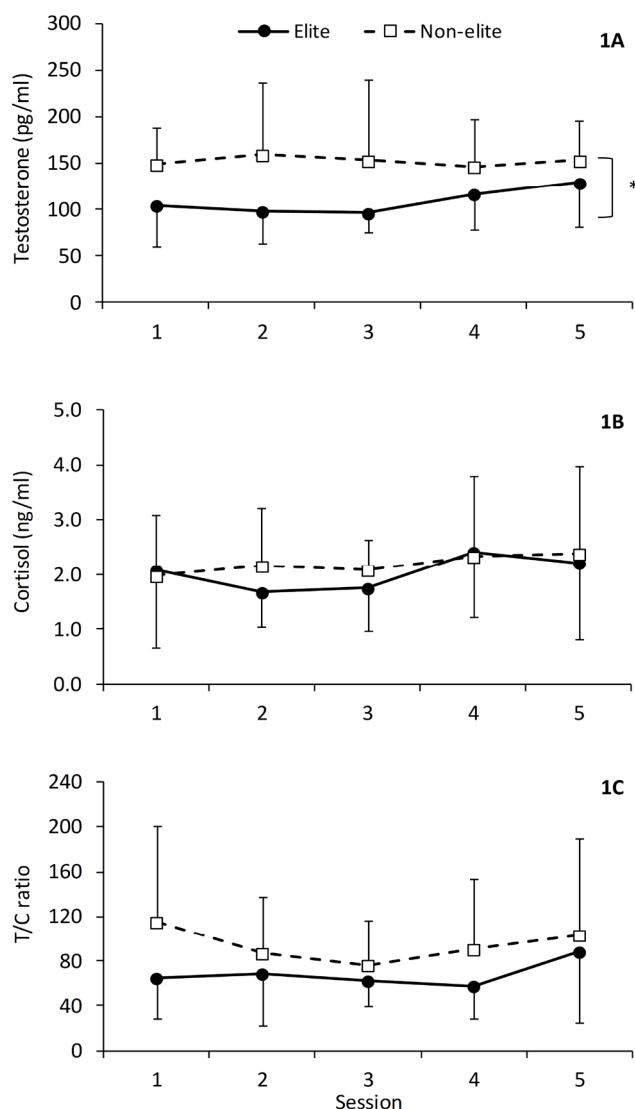


FIG. 1. Estimated marginal means (\pm SD) for the salivary concentrations of testosterone (1A), cortisol (1B) and the testosterone to cortisol ratio (T/C ratio - 1C) in the elite and non-elite athlete groups. *Significant group difference $p < 0.05$

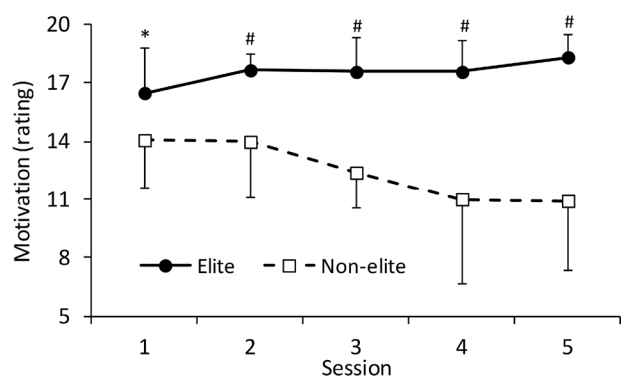


FIG. 2. Estimated marginal means (\pm SD) for self-perceived training motivation in the elite and non-elite athlete groups. *Significantly different from the non-elite sessions 3, 4 and 5 $p < 0.05$, #Significantly different from the non-elite sessions 1-5 $p < 0.05$.

reporting higher ratings in session 1 than the non-elites during sessions 3-4 ($p < 0.05$).

As seen in Figure 3A, the session effect on CMJ height was significant ($\chi^2(4) = 27.3, p < 0.001$), with session 3 performance superior to session 1 ($p = 0.040$). The group effect was also significant ($\chi^2(1) = 5.1, p = 0.023$), with the elites producing greater CMJ height than the non-elites. No interaction effect on CMJ height emerged ($\chi^2(4) = 5.8, p = 0.212$). We also observed a session effect on IMTP PF ($\chi^2(4) = 14.1, p = 0.007$), being higher overall in session 2 than session 1 (Figure 3B), but no group effect ($\chi^2(1) = 0.57, p = 0.452$) or interaction was found ($\chi^2(4) = 0.70, p = 0.951$). The removal of four subjects in session 1 did not influence any study outcome, so we have presented the data with all available subjects.

In the elite group (Table 1), the individual changes in T concentrations was a significant predictor of training motivation ($p = 0.033$) with C also showing some ability to predict this variable ($p = 0.078$), although the latter result did not reach the threshold for statistical significance. No hormonal variables predicted training motivation in the non-elite group ($p > 0.09$). In both athlete groups, the individual changes in T, C and the T/C ratio did not significantly predict either CMJ height or IMTP PF. In addition, the motivation ratings did not significantly predict any performance outcome (data not shown).

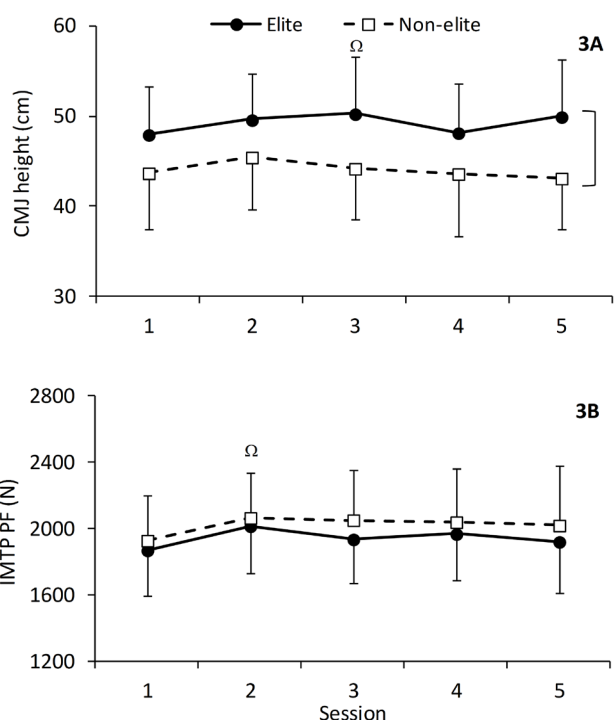


FIG. 3. Estimated marginal means (\pm SD) for countermovement jump (CMJ) height (3A) and isometric mid-thigh pull peak force (IMTP PF) (3B) in the elite and non-elite athlete groups. *Significant group difference $p < 0.05$, ΩSignificantly different from session 1 $p < 0.05$.

TABLE I. Mean slopes (\pm SD) between the hormonal predictors and the training motivation and physical performance outcomes in the elite and non-elite athlete groups.

	Elite			Non-elite		
	Motivation	CMJ height	IMTP PF	Motivation	CMJ height	IMTP PF
Testosterone	0.86* \pm 1.41	-0.41 \pm 2.02	59.8 \pm 197	-2.22 \pm 4.17	0.02 \pm 2.40	-62.0 \pm 227
Cortisol	0.97 \pm 2.55	-0.53 \pm 2.43	91.8 \pm 222	-0.53 \pm 4.68	-0.90 \pm 5.04	28.6 \pm 207
T/C ratio	-0.33 \pm 1.35	1.04 \pm 4.41	-43.1 \pm 359	1.89 \pm 4.56	-0.30 \pm 3.06	22.6 \pm 260

Note: T/C = testosterone to cortisol, CMJ = countermovement jump, IMTP PF = isometric mid-thigh pull peak force. *Significant slope value $p < 0.05$

DISCUSSION

The longitudinal monitoring of two athlete cohorts across a short training block revealed lower T concentrations overall in the elite group (vs. non-elites), but the elites reported being more motivated to train and they exhibited more physical power in the lower body. Within-subject modelling identified a positive association between the individual changes in T concentrations and training motivation in the elite men only. In both groups, the hormonal measures were unrelated to the individual changes in power and strength over time.

Salivary hormone concentrations in both groups were stable over time, but the pooled T values were higher in the non-elites (vs. elites), which is consistent with prior research [25]. This difference could reflect the greater training volume of the elite group and/or the residual effects of the rugby league games played [31], as a loss in sports competition can potentially depress T secretion for several days [40]. This is an important consideration for this study, as the team of elite athletes suffered four losses during the monitoring period and three of these were substantial (i.e. by 24 or more points), plus a further loss only four days before the study began. One's self-appraisal of performance might also influence post-competition T changes [17], particularly during a post-match reviewing process [41]. In professional rugby players, the type of coach feedback received when reviewing match footage was found to promote different T profiles and reactive changes for up to a week later [41].

Cortisol is often raised and the T/C ratio lowered in elite athletes (vs. lesser trained) during testing, training and competition [20, 26, 27], thereby indicating a higher state of metabolic stress during sporting activities. Conversely, the elite and non-elite men presented similar C and T/C ratio profiles in this work. This seems to be counterintuitive given the greater training volume of the elite group, who also played at least one weekly game in a sport that produces noticeable muscle damage and fatigue [30, 31]. An alternative explanation is that C reflects both physical demands and coping resources, such that well-trained athletes may better tolerate physical and psychological stress [25, 42] and thus, could exhibit similar stress profiles to athletes with lower demands and coping abilities. We did observe large variability in C and the T/C ratio, which is another common feature in sport [20, 26, 27, 31], and one that could influence our ability to detect a hormonal difference between the two study cohorts.

The elite men reported being more motivated to train (and consistently so) than the non-elites and this possibly reflects their full-

time status as professional athletes. Although both cohorts displayed similar IMTP PF across this study, the elite men produced greater CMJ height overall. This is not surprising as force (strength) generation at speed (power) is a better indicator of functional performance in most sports and an important attribute in rugby league [30]. We generally found no changes in the power and strength abilities of the elite and non-elite men, thereby reflecting the maintenance-type training programmes employed by each cohort. For the elites, some variation in the prescribed intensity of training did occur depending on the outcome of each rugby league game (i.e. a loss would result in 1-2 harder training sessions earlier in the week), but this represented only a small number of the total weekly sessions and was unlikely to influence the study outcomes.

On an individual level, the T fluctuations that occurred prior to each session were positively associated with training motivation in the elite men only, despite having lower T levels overall. This is consistent with reports of positive correlations between athlete T levels and physical [11, 12] and perceptual indicators of motivation [13, 14]. These data support suggestions that some elite male athletes may better utilize T as a training resource than lesser trained men [6]. This idea is supported by stronger hormonal linkage to performance and physiological outcomes in elite-trained groups than non-elites or recreational athletes [20, 24, 25, 27]. This usage, as our results suggest, could involve better linkage between T availability and one's volitional drive to exert maximal physical effort when exercising. Given that the T effects on motivational behaviours can occur outside of conscious awareness [7, 8], it could also be argued that elite athletes possess stronger self-evaluative abilities that reflect subtle changes in T physiology.

Unexpectedly, none of the hormonal or motivation measures predicted CMJ height or IMTP PF in either cohort. It is possible that the nature of these tests (i.e. maximal single repetition trials with long recovery periods) indicate neuromuscular rather than motivational drive, which arguably has components of persistence, adherence and effort over time [35]. Indeed, previous tests of physical motivation were based on the amount of load lifted (i.e. volume or intensity) across entire training sessions [11, 12], with an additional element of self choice. The CMJ and IMTP tests were employed to position the results against other literature using power and strength assessments [18, 19, 23, 28, 29]. The statistical approach taken is another consideration. Most studies have reported the hormonal

associations when variables are analyzed between subjects [13, 14, 17, 18, 19, 20, 21, 22], but these outcomes can differ when the same data are modelled within subjects [23]. Consistent with this finding, between-subject testing in this study (data not shown) revealed only three significant hormonal relationships with either CMJ height or IMTP PF out of 80 bivariate comparisons in both groups.

We do acknowledge some of the study limitations. As an example, the between-group differences in weekly training volume and frequency, along with the different testing locations and schedules, but these are inherent problems when performing research on separate groups of athletes, especially those that differ in training status. Furthermore, we recognise that a change in the motivational state of the athlete might be driving the T responses [43] and subsequent associations. This could arise from anticipation of achievement in a challenge situation in sport (e.g. training, competition) [5], which we did not assess. Adding to these complexities, other social factors relating to the testing environment, the use of verbal encouragement and the presence of other athletes might also influence the study outcomes.

REFERENCES

- Kraemer WJ, Mazzetti SA. Hormonal mechanisms related to the expression of muscular strength and power. In: Komi PV, editor. *Strength and Power in Sport*. Boston: Blackwell Scientific Publishing; 2003. p. 73-95.
- West DW, Burd NA, Tang JE, Moore DR, Staples AW, Holwerda AM, et al. Elevations in ostensibly anabolic hormones with resistance exercise enhance neither training-induced muscle hypertrophy nor strength of the elbow flexors. *J Appl Physiol*. 2010;108(1):60-7.
- West DW, Kujbida GW, Moore DR, Atherton P, Burd NA, Padzik JP, et al. Resistance exercise-induced increases in putative anabolic hormones do not enhance muscle protein synthesis or intracellular signalling in young men. *J Physiol*. 2009;587(Pt 21):5239-47.
- Wilkinson SB, Tarnopolsky MA, Grant EJ, Correia CE, Phillips SM. Hypertrophy with unilateral resistance exercise occurs without increases in endogenous anabolic hormone concentration. *Eur J Appl Physiol*. 2006;98(6):546-55.
- Chichinadze K, Lazarashvili A, Chichinadze N, Gachechiladze L. Testosterone dynamics during encounter: role of emotional factors. *J Comp Physiol A*. 2012;198(7):485-94.
- 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.
- Aarts H, van Honk J. Testosterone and unconscious positive priming increase human motivation separately. *NeuroReport*. 2009;20(14):1300-3.
- van Honk J, Peper JS, Schutter DJ. Testosterone reduces unconscious fear but not consciously experienced anxiety: Implications for the disorders of fear and anxiety. *Biol Psychiat*. 2005;58(3):218-25.
- Wood RI. Oral testosterone self-administration in male hamsters: dose-response, voluntary exercise, and individual differences. *Horm Behav*. 2002;41(3):247-58.
- Ibejunjo C, Eash JK, Li C, Ma Q, Glass DJ. Voluntary running, skeletal muscle gene expression, and signaling inversely regulated by orchidectomy and testosterone replacement. *Am J Physiol Endoc M*. 2011;300(2):E327-40.
- Cook CJ, Beaven MC. Salivary testosterone is related to self-selected training load in elite female athletes. *Physiol Behav*. 2013;116-117:8-12.
- Cook CJ, Crewther BT, Kilduff LP. Are free testosterone and cortisol concentrations associated with training motivation in elite male athletes? *Psychol Sport Exerc*. 2013;14(6):882-5.
- Suay F, Salvador A, González-Bono E, Sanchis C, Martínez M, Martínez-Sanchis S, et al. Effects of competition and its outcome on serum testosterone, cortisol and prolactin. *Psychoneuroendocrino*. 1999;24(5):551-66.
- Salvador A, Suay F, González-Bono E, Serrano MA. Anticipatory cortisol, testosterone and psychological responses to judo competition in young men. *Psychoneuroendocrino*. 2003;28(3):364-75.
- Putman P, Antypa N, Crysovergi P, van der Does WAJ. Exogenous cortisol acutely influences motivated decision making in healthy young men. *Psychopharmacology*. 2010;208(2):257-63.
- Carney DR, Cuddy AJ, Yap AJ. Power posing: brief nonverbal displays affect neuroendocrine levels and risk tolerance. *Psychol Sci*. 2010;21(10):1363-8.
- Serrano MA, Salvador A, González-Bono E, Sanchis C, Suay F. Hormonal responses to competition. *Psicothema*. 2000;12(3):440-4.
- Crewther BT, Lowe T, Weatherby RP, Gill N, Keogh J. Neuromuscular performance of elite rugby union players and relationships with salivary hormones. *J Strength Cond Res*. 2009;23(7):2046-53.
- Kraemer WJ, French DN, Paxton N, Häkkinen K, Volek JS, Sebastianelli WJ, et al. Changes in exercise performance and hormonal concentrations over a big ten soccer season in starters and nonstarters. *J Strength Cond Res*. 2004;18(1):121-8.
- Passelergue P, Robert A, Lac G. Salivary cortisol and testosterone variations during an official and a simulated weight-lifting competition. *Int J Sports Med*. 1995;16(5):298-303.
- Crewther BT, Heke T, Keogh JWL. The effects of training volume and competition on the salivary cortisol concentrations of Olympic weightlifters. *J Strength Cond Res*. 2011;25(1):10-5.

CONCLUSIONS

We identified group differences in T levels, motivation and lower-body power between the elite and non-elite men across a short training block, which may reflect the training environment, athlete status and competitive factors. Although the elites had lower T levels overall, they did show better linkage (positive association) between the individual changes in T and motivation to train. The hormonal and motivation measures were not associated with any performance outcome and this is partly explainable by the nature of the tests undertaken.

Acknowledgements

We acknowledge with gratitude the athletes and coaching staff that contributed to this study. This project was supported by a grant from the Engineering and Physical Sciences Research Council UK and the UK Sport Council, as part of the Elite Sport Performance Research in Training (ESPRIT) with Pervasive Sensing Programme [EP/H009744/1].

Conflict of interests: The authors declared no conflict of interests regarding the publication of this manuscript.

22. Balthazar CH, Garcia MC, Spadari-Bratfisch RC. Salivary concentrations of cortisol and testosterone and prediction of performance in a professional triathlon competition. *Stress*. 2012;15(5):495-502.
23. Crewther BT, Cook CJ, Gaviglio CM, Kilduff LP, Drawer S. Baseline strength can influence the ability of salivary free testosterone to predict squat and sprinting performance. *J Strength Cond Res*. 2012;26(1):261-8.
24. Słowińska-Lisowska M, Majda J. Hormone plasma levels from pituitary-gonadal axis in performance athletes after the 400m run. *J Sports Med Phys Fit*. 2002;42(2):243-9.
25. Moya-Albiol L, Salvador A, Costa R, Martinez-Sanchis S, Gonzalez-Bono E, Ricarte J, et al. Psychophysiological responses to the Stroop Task after a maximal cycle ergometry in elite sportsmen and physically active subjects. *Int J Psychophysiol*. 2001;40:47-59.
26. Cook CJ, Crewther BT, Smith A. Comparison of baseline free testosterone and cortisol concentrations between elite and non-elite female athletes. *Am J Hum Biol*. 2012;24(6):856-8.
27. Snegovskaya V, Viru A. Elevation of cortisol and growth hormone levels in the course of further improvement of performance capacity in trained rowers. *Int J Sports Med*. 1993;14(4):202-6.
28. Cook CJ, Kilduff LP, Crewther BT, Beaven M, West DJ. Morning based strength training improves afternoon physical performance in rugby union players. *J Sci Med Sport*. 2014;17(3):317-21.
29. West DJ, Owen NJ, Jones MR, Bracken RM, Cook CJ, Cunningham DJ, et al. Relationships between force-time characteristics of the isometric midthigh pull and dynamic performance in professional rugby league players. *J Strength Cond Res*. 2011;25(11):3070-5.
30. Gabbett T, King T, Jenkins D. Applied physiology of rugby league. *Sports Med*. 2008;38(2):119-38.
31. McLellan CP, Lovell DI, Gass GC. Creatine kinase and endocrine responses of elite players pre, during, and post rugby league match play. *J Strength Cond Res*. 2010;24(11):2908-19.
32. Kraemer WJ, Loebel CC, Volek JS, Ratamess NA, Newton RU, Wickman RB, et al. The effect of heavy resistance exercise on the circadian rhythm of salivary testosterone in men. *Eur J Appl Physiol*. 2001;84:13-8.
33. Gröschl M. Current status of salivary hormone analysis. *Clin Chem*. 2008;54(11):1759-69.
34. Toone RJ, Peacock OJ, Smith AA, Thompson D, Drawer S, Cook C, et al. Measurement of steroid hormones in saliva: Effects of sample storage condition. *Scand J Clin Lab Invest*. 2013;73(8):615-21.
35. Vallerand RJ. Intrinsic and extrinsic motivation in sport. In: Spielberger C, editor. *Encyclopedia of Applied Psychology*. 2. Florida: Elsevier; 2004. p. 427-35.
36. Leard JS, Cirillo MA, Katsnelson E, Kimiatek DA, Miller TW, Trebinovic K, et al. Validity of two alternative systems for measuring vertical jump height. *J Strength Cond Res*. 2007;21(4):1296-9.
37. Imagama S, Matsuyama Y, Hasegawa Y, Sakai Y, Ito Z, Ishiguro N, et al. Back muscle strength and spinal mobility are predictors of quality of life in middle-aged and elderly males. *Eur Spine J*. 2011;20(6):954-61.
38. Liang K-Y, Zeger SL. Longitudinal data analysis using generalized linear models. *Biometrika*. 1986;73(1):13-22.
39. Hopkins WG. A spreadsheet for analysis of straightfoward controlled trials 2003 [cited 2012 4th May]. Available from: <http://www.sportsci.org/jour/03/wghtrials.htm>.
40. Booth A, Shelley G, Mazur A, Tharp G, Kittok R. Testosterone, and winning and losing in human competition. *Horm Behav*. 1989;23(4):556-71.
41. Crewther BT, Cook CJ. Effects of different post-match recovery interventions on subsequent athlete hormonal state and game performance. *Physiol Behav*. 2012;106(4):471-5.
42. Rimmele U, Zellweger BC, Marti B, Seiler R, Mohiyeddini C, Ehlert U, et al. Trained men show lower cortisol, heart rate and psychological responses to psychosocial stress compared with untrained men. *Psychoneuroendocrino*. 2007;32:627-35.
43. Cook CJ, Crewther BT. Changes in salivary testosterone concentrations and subsequent voluntary squat performance following the presentation of short video clips. *Horm Behav*. 2012;61(1):17-22.