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Review

Are free testosterone and cortisol concentrations associated with training motivation in elite male athletes?

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ABSTRACT

Objectives: To examine correlative associations between salivary free testosterone (T) and cortisol (C) concentrations and training motivation in elite male athletes.
Design: Single group, longitudinal design with repeated measures.
Methods: Participants ($n = 15$) completed a 5-week progressive resistance training programme. Across 2 weekly workouts, pre and post measures of salivary free T and C concentrations were taken along with voluntary chosen workload, as a proxy for training motivation. Strength and body mass were assessed pre and post training.
Results: Individual changes in pre-workout free T concentrations correlated strongly to voluntary workloads (pooled $r = 0.81$, $p < 0.001$). Pre-workout free C concentrations was weakly correlated to voluntary workload (pooled $r = 0.35$). Pre-workout hormones ($r = 0.57$–0.89) and the strength gains were also related.
Conclusions: The salivary free T concentrations of male athletes presented before training were strongly associated with subsequent voluntary workloads, indicating a potential link to training motivation.

Testosterone (T) is a potent steroid hormone with important social effects, including motivation (McCall & Singer, 2012). For example, T administration can increase human motivation to engage in primed action-concepts (Aarts & van Honk, 2009) and reduce unconscious fear following exposure to a visual stimulus (van Honk, Peper, & Schutter, 2005). Individuals with higher T concentrations also take greater risks in financial (Coates, Gurnell, & Sarnyai, 2010) and physical domains (Ronay & von Hippel, 2010). Moreover, watching a motivational video can increase T levels and subsequent performance in elite athletes (Cook & Crewther, 2012). The athlete model perhaps represents an analogy to general motivation around physical performance and related competition in humans.

Athlete T concentrations before testing or training have correlated with various performance and training outcomes (Cardinale & Stone, 2006; Crewther, Cook, Gaviglio, Kilduff, & Drawer, 2012; Crewther, Lowe, Weatherby, Gill, & Keogh, 2009; Raastad, Glomsheller, Bjøro, & Hallén, 2001), and to functional effort during competition (Robazza et al., 2012), which could be attributed to pre-encounter T changes and the expression of physical actions related to motivation. A recent study on female athletes reported strong correlations between free T levels and voluntary (self-chosen) training load, as one proxy for training motivation (Cook & Beaven, 2013). Extending this work to male athletes would provide further understanding of the behavioural effects of T in a physical domain.

Evidence also suggests that cortisol (C) has potential as a predictive marker of athlete performance in training or competition (Cook, Crewther, & Smith, 2012; Crewther, Heke, & Keogh, 2011; Crewther et al., 2009; Passelergue, Robert, & Lac, 1995), but little research has specifically addressed a link between C concentrations and training motivation in an athletic population. Therefore, we examined the possibility of associations between salivary free T and C concentrations and voluntary workload selection in a group of elite male athletes under normal training conditions.

Materials and methods

Participants

Fifteen elite male rugby union players were recruited with a mean age, height and body mass of 21.3 ± 1.0 years, 1.85 ± 0.05 m

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and 98.1 ± 6.5 kg, respectively. Participants had a resistance-training history of more than 3 years and were considered physically fit and injury-free. Each participant had a full explanation of the protocols and signed informed consent before the study commenced. The study procedures were performed with University Ethics approval.

Training programme and testing

Participants completed a 5-week progressive exercise programme involving 3 resistance-training sessions per week (Monday, Wednesday and Friday). Voluntary workload was assessed during the Monday and Friday training sessions, along with salivary free T and C concentrations. The workouts were performed in the morning at the same time of day (1000 and 1130 h) to account for diurnal variation (Hayes, Bickerstaff, & Baker, 2010). Participants were also tested before and after the 5-week training block for body mass and 3 repetition maximum (3RM) lifts on a free-weight back squat and a bench press.

In the Monday and Friday workouts, squat and bench press exercises were performed as follows; week 1 = 4–5 sets (4–6 repetitions), week 2 and 3 = 4–6 sets (4–8 repetitions), week 4 = 4–7 sets (5–10 repetitions) and week 5 = 4–7 sets (6–12 repetitions). Training intensity was based on estimated 3RM loads and participants chose their own workload, being the product of the number of sets and repetitions performed (i.e. total repetitions). If any participant felt motivated to perform a greater (or lesser) workload above that prescribed for each training session, they were allowed to do so at their own discretion. Voluntary workload was calculated as the relative (%) difference between the actual and prescribed workloads. In the Wednesday workouts, a similar programme was employed using an incline barbell press, a front squat and weighted chin-up exercises. Rest periods of 2–3 min and 3–5 min were employed between all sets and exercises, respectively.

Saliva collection and analysis

Saliva samples were collected by passive drool 10 min before, and 5 min after, each workout and stored frozen before assay. After thawing and centrifugation, the samples were analysed for T and C concentrations using commercial kits (Salimetrics LLC, USA) and the manufacturers' guidelines. The T assay had a detection limit of 6 pg/ml with intra- and inter-assay coefficients of variation (CV) of 2.5–12.0%. The C assay had a detection limit of 0.12 ng/ml with intra- and inter-assay CV of 1.9–9.7%.

Statistical analyses

The hormone, body mass and strength outcomes were assessed using analysis of variance (ANOVA). Within each workout, the relative (%) changes in voluntary workload were assessed using *t*-tests and then compared over time with ANOVA. The Bonferroni post hoc procedure was used where appropriate. Pearson correlations were used to assess the hormonal relationships (pooled *r*) with voluntary workload across all training sessions, as described (Cook & Crewther, 2012). Briefly, the correlational result for each participant's data was converted to a *z* score using Fisher's *r* to *z* transformation and the group score was back-transformed to derive a pooled *r* value. A combined *P* value was obtained using the Stouffer-weighted *Z* method. The relationships between the hormonal outcomes (averaged across all sessions) and the strength outcomes were also examined using Pearson correlations. Significance was set at an alpha level of $p \leq 0.05$.

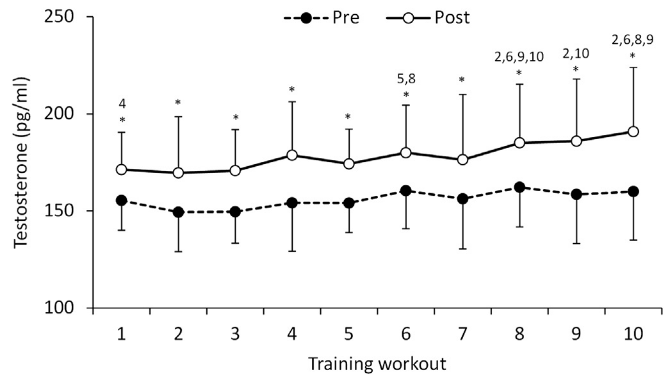

Fig. 1. Free testosterone concentrations pre and post each workout (mean ± SD). *Significant from corresponding pre-workout sample $p < 0.001$; [2]Significant from pre-workout 2, [4]Significant from pre-workout 4, [5]Significant from pre-workout 5, [6]Significant from pre-workout 6, [8]Significant from pre-workout 8, [9]Significant from pre-workout 9, [10]Significant from pre-workout 10, all at $p < 0.001$.

Results

Testosterone analysis revealed a significant workout effect ($p < 0.001$, Fig. 1) with higher free T concentrations in the post-workout samples. There was no significant time effect, but the interaction was significant ($p < 0.001$). Within each workout, T was elevated from pre to post and post-workout T levels across workouts 1, 6, 8, 9 and 10 were significantly higher than many other pre-workout samples ($p < 0.001$). Cortisol analysis revealed no significant workout or time effect, and no interactions ($p > 0.075$, Fig. 2).

Voluntary workload was elevated within workouts 3 to 10 ($p < 0.05$, Fig. 3). A significant time effect was identified for this training variable ($p = 0.017$) with a greater workload completed in workout 6 than workout 1.

Voluntary workloads correlated strongly and positively to pre-workout free T concentrations (pooled $r = 0.81$, $p < 0.001$, Fig. 4), but was weakly correlated to pre-workout free C levels (pooled $r = 0.35$) and the workout changes (%) in free T ($r = 0.25$) and C ($r = -0.08$) concentrations.

The training programme also promoted increases in body mass (pre 98.1 ± 6.5 kg to post 101.8 ± 6.2 kg), 3RM squat (pre 165.8 ± 11.1 kg to post 177.5 ± 8.7 kg) and bench press (pre 139.7 ± 7.7 kg to post 147.8 ± 7.4 kg) strength ($p < 0.001$). Pre-workout T and C levels, once averaged over time, correlated to the strength gains ($r = 0.57$–0.89, $p < 0.05$).

Discussion

A number of studies have linked T to human motivation and related actions (e.g. risk taking, risk aversion, unconscious fear,

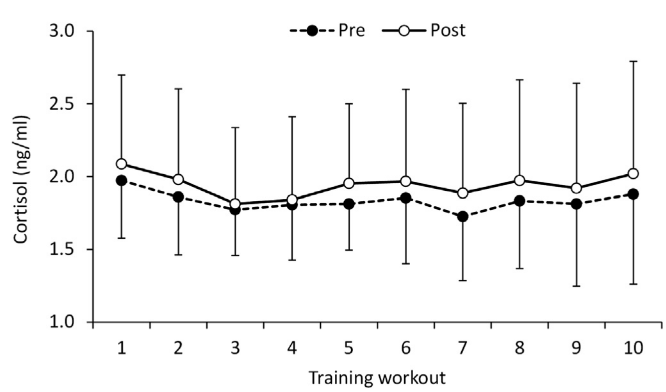

Fig. 2. Free cortisol concentrations pre and post each workout (mean ± SD).

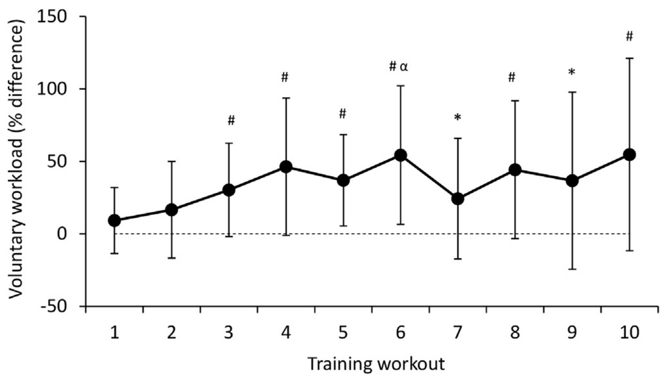

Fig. 3. Voluntary workload during each workout (mean ± SD). *Significant from baseline $p < 0.05$, #Significant from baseline $p < 0.01$, αSignificant from workout 1 $p < 0.001$.

impulsivity) in different settings (Aarts & van Honk, 2009; Coates et al., 2010; Cook & Crewther, 2012; Flegr et al., 2012; van Honk et al., 2005; Ronay & von Hippel, 2010; Sapienza, Zingales, & Maestripieri, 2009; Stanton et al., 2011). Here we displayed its association to athlete motivation in a self-controlled physical domain. Specifically, pre-workout free T concentrations correlated strongly (pooled $r = 0.81$) to voluntary workloads, with workload choice acting as a proxy marker of training motivation, once allowing for the progressive nature of the training block itself. This finding is supported by a recent study on female athletes using self-selected training loads as an indicator of motivation (Cook & Beaven, 2013).

Our results suggest that transient changes in free T levels may regulate athlete motivation to perform, possibly as a pre-encounter effect to prime certain behaviours before a stress challenge (Chichinadze, Lazarashvili, Chichinadze, & Gachechiladze, 2012). The anticipation of victory or achievement in a challenge, which implies the presence of strong motivation to win, is another variable moderating pre-encounter T levels (Chichinadze et al., 2012). This approach to understanding the biology of behaviour both compliments and differs from other models (e.g. winner-loser effect, challenge hypothesis, biosocial theory of status) that tend to focus on T responsiveness across a competitive challenge (Chichinadze et al., 2012; McCall & Singer, 2012). However, acute changes in T can predict competitive motivation (Carré & McCormick, 2008; Mehta & Josephs, 2006).

Workload selection and completion could also explain the observed improvements in strength, given that training volume is one important stimulus for neuromuscular adaptation (Crewther, Cronin, & Keogh, 2005). Perhaps not surprisingly, averaged

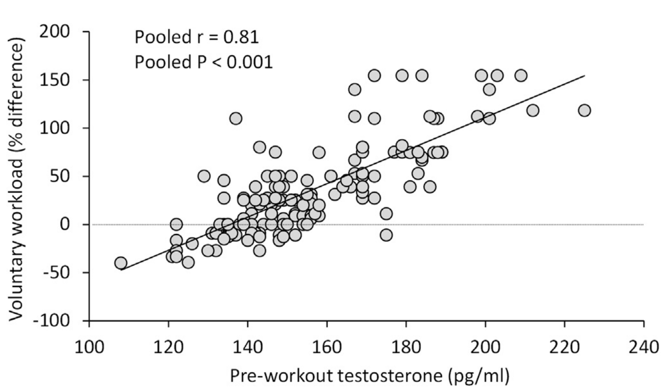

Fig. 4. Scatterplot showing the pooled correlation between pre-workout testosterone concentrations and voluntary workloads for all subjects.

pre-workout T levels correlated ($r = 0.62–0.89$) to the muscle strength gains, which is consistent with previous training studies (Ahtiainen, Pakarinen, Alén, Kraemer, & Häkkinen, 2003; Crewther et al., 2012, 2009; Raastad et al., 2001). Baseline strength can influence these associations. In a previous study (Crewther et al., 2012), a strong correlation seen between free T levels and squatting strength in male athletes with very high strength levels, whereas a weak relationship was seen in those athletes with relatively lower strength levels. Potentially, very strong athletes may exhibit greater sensitivity to changes in free T with behaviour acting as one mechanism to enable continued adaptation (Crewther, Cook, Cardinale, Weatherby, & Lowe, 2011).

Although pre-workout free C was weakly correlated to voluntary workloads (pooled $r = 0.35$), this measure (once averaged) was moderately related ($r = 0.57–0.63$) to the strength gains. Other work has reported associations between free C and different performance outcomes in weightlifters (Crewther, Heke, et al., 2011; Passelergue et al., 1995), basketball players (Robazza et al., 2012), and rugby union players (Crewther et al., 2009). Further studies have revealed higher free C levels in elite athletes compared to non-elites (Cook et al., 2012; Passelergue et al., 1995; Snegovskaya & Viru, 1993). Thus, it seems that elevations in free C levels might be conducive to elite level performance and adaptations, possibly by stimulating gluconeogenesis and glycogenolysis and through its permissive actions on other hormones (e.g. catecholamines and glucagon) (Stewart, 2002).

Conclusions

The salivary free T concentrations of elite male athletes presented before normal training sessions were strongly associated with subsequent voluntary workload selection, thereby indicating a possible link to training motivation.

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