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Neuromuscular and Endocrine Responses of Elite Players During an Australian Rules Football Season

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Purpose: To examine variations in neuromuscular and hormonal status and their relationship to performance throughout a season of elite Australian Rules Football (ARF). ***Methods:*** Fifteen elite ARF players performed a single jump (CMJ1) and 5 repeated countermovement jumps (CMJ5), and provided saliva samples for the analysis of cortisol (C) and testosterone (T) before the season commenced (Pre) and during the 22-match season. Magnitudes of effects were reported with the effect size (ES) statistic. Correlations were performed to analyze relationships between assessment variables and match time, training load, and performance. ***Results:*** CMJ1Flight time:Contraction time was substantially reduced on 60% of measurement occasions. Magnitudes of change compared with Pre ranged from 1.0 ± 7.4% (ES 0.04 ± 0.29) to −17.1 ± 21.8% (ES −0.77 ± 0.81). Cortisol was substantially lower (up to −40 ± 14.1%, ES of −2.17 ± 0.56) than Pre in all but one comparison. Testosterone response was varied, whereas T:C increased substantially on 70% of occasions, with increases to 92.7 ± 27.8% (ES 2.03 ± 0.76). CMJ1Flight time:Contraction time (r = .24 ± 0.13) and C displayed (r = −0.16 ± 0.1) small correlations with performance. ***Conclusion:*** The response of CMJ1Flight time:Contraction time suggests periods of neuromuscular fatigue. Change in T:C indicates subjects were unlikely to have been in a catabolic state during the season. Increase in C compared with Pre had a small negative correlation with performance. Both CMJ1Flight time:Contraction time and C may be useful variables for monitoring responses to training and competition in elite ARF athletes.

Keywords: neuromuscular fatigue, testosterone, cortisol, team sport, monitoring

Whereas previous work[1–11] has detailed various neuromuscular and endocrine responses to athletic competition and training, a limited amount has investigated season-long responses in elite team sport athletes. There is uncertainty regarding the expected pattern of response in these variables and their usefulness in deter-

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mining the appropriateness of training loads, the impact of training and competition volumes on change in these measures, and the relationships between change in measurement variables and performance.

There is a suggestion that low-frequency neuromuscular fatigue is an important capacity to quantify in elite athletes, and functional stretch shortening cycle (SSC) activities may be capable of this.[12] Recently, the ratio of flight time to contraction time (measured from the commencement of the countermovement phase until the subject leaves the ground) from a single countermovement jump (CMJ) proved the most useful variable for assessing low-frequency fatigue in Australian Rules Football (ARF) owing to the capacity to detect delayed neuromuscular recovery.[2] Another potentially useful variable identified in this study was the average flight time from 5 consecutive CMJs.[2] Examination of short-term responses using a squat jump and CMJ have also been conducted in collegiate soccer[9] and American Football.[8] Although measures of force and power have been shown to decrease following collegiate soccer play,[9] both measures demonstrated a return to baseline after the American Football match.[8] Despite providing insight into short-term neuromuscular responses, these results may not transfer to long competition phases. Furthermore, neuromuscular responses may be sport specific and the ability of SSC tasks to detect neuromuscular fatigue may depend on the sport and assessment variable.

Although limited, some work has examined responses in team sport athletes over longer periods.[13–15] A reduction in CMJ height was found after 3 days of international handball competition,[13] and various neuromuscular changes up to 120 hours after an elite ARF match have also been reported.[2] Research in rugby league players has produced varied results[14,15] and it may be that measures such as jump height lack the resolution to detect neuromuscular fatigue in high-level team sport athletes.[2,14] Monitoring neuromuscular fatigue in longer term studies may be enhanced by assessing the response of alternative variables, and scope exists for examinations over entire competitive seasons.

There is relatively more research investigating long-term hormonal response to elite team sport competition than exists in the study of neuromuscular fatigue. Rugby league[14,15] and soccer[1,5,6,10,16] have been studied repeatedly, in addition to American Football.[11] Cortisol (C) has a role as a stress hormone and its presence is suggested as an indicator of the endocrine systems response to exercise.[17] Testosterone (T) is important in muscle hypertrophy and muscle glycogen synthesis[18] and it is possible that T, C, or their ratio value, T:C,[4] could be useful in assessing the impact of training and competition as a reflection of the balance between anabolic and catabolic processes.[17] However, results of longer term studies[1,6,10,11] have been equivocal and included a rise in C during a soccer season and return to baseline 2 months postseason with no change evident in T or T:C,[6] while a reduction in T was the only change noted during 15 weeks of American Football training.[11] The expected hormonal response and therefore usefulness of these measures for early detection of overreaching or overtraining in team sport athletes over extended periods is unclear. Responses may be sport specific and cyclic across longer periods, necessitating profiling of individual sports.

Despite previous examinations of neuromuscular and endocrine responses in team sports, weekly variations in elite-level contact team sport are poorly understood. There is likely to be some modification to endocrine and neuromuscular status during a season of elite ARF. These responses may include various magnitudes of suppression or elevation that occur independently or in parallel. It is possible that change in these variables is related to workload or performance and, in the case of hormonal measures, may reflect modifications to total body anabolic:catabolic balance. Therefore, the purpose of this research was to examine weekly variations of low-frequency neuromuscular fatigue and hormonal status in elite ARF players over a competitive season with a view to determining the response to training and playing loads, and to examine the relationship between these variables and performance.

Methods

Subjects

This study involved 15 elite ARF players (age 24.9 ± 2.4 years, height 1.87 ± 0.07 m, and mass 88.0 ± 7.9 kg) representing an Australian Football League (AFL) team during a 22-match regular season. Subjects had played an average of 124 ± 53 AFL regular season matches before the study commenced. The research was approved by the University Human Research Ethics Committee, and all subjects signed an informed consent document.

Design

The typical weekly training and match schedule is displayed in Figure 1. Countermovement jump data and saliva samples were collected on the morning of Day 3 (approximately 72 to 144 hours postmatch). Subjects were familiar with the CMJ1, CMJ5, and saliva sample techniques after participating in multiple practice sessions before the commencement of the season. Baseline data were collected in a rested state approximately 36 hours before the first match of the season (Pre) and on 20 occasions throughout the 22-match season (Mid 1 to 2 to Mid 21 to 22). A bye occurred following the Round-12 match and no data were collected Mid

Time/Day	1	2	3	4	5	6	7
AM	Training or Recovery if match on Day 7	Off	Data collection & Flexibility	Individual skill training	Training	Recovery if no match PM	Recovery
PM	Weights	Off	Training	*Match* or Weights	*Match* or Off	*Match* or Off	*Match*

Figure 1 — Typical weekly training and match schedule. *Italics* indicate when matches were played. Data collection occurred in the morning on Day 3. The day following each match included a water-based recovery session. Training consisted of various skill and tactical drills.

bye-12 or Mid 13 to 14. Subjects unable to produce maximum effort during the CMJ1 and CMJ5 did not perform these tests, resulting in a varied number of data sets across the study period and a mean of 10.1 ± 1.6 subjects per data collection point.

Methodology

Subjects performed a 2-minute dynamic warm up consisting of various running patterns including high knees, heel flicks, and lateral movements followed by 3 practice CMJs before the CMJ1 measurement trial. The CMJ1 trial was followed by collection of a 60-s unstimulated saliva sample for analysis of T, C, and T:C. Saliva samples were collected by passively drooling directly into a plastic tube. A strong relationship exists between salivary and serum unbound C at rest ($r = 0.93$) and during exercise ($r = 0.90$)[19] with concentrations independent of saliva flow rate.[20]

Subjects were requested to maintain their normal training diet throughout the study period and ingest only water in the 60 min before data collection. Samples were provided in a rested state following approximately 36 hours inactivity and subjects participated in only the prescribed weekly training sessions. Saliva samples were placed in a refrigerator and then frozen at −80°C for subsequent analysis. Cortisol (μg/dL) and T (pg/mL) were determined in duplicate by enzyme-linked immunosorbent assay (Salimetrics, PA, USA) using a microplate reader (SpectraMax 190, Molecular Devices, CA, USA). Typical Error and coefficient of variation as a percentage of the T and C assays was 9.1/8.1% and 0.07/3.9% respectively. The CMJ5 trial was performed after provision of the saliva sample.

Countermovement jumps were performed on a commercially available force plate (400 Series Performance Plate, Fitness Technology, Adelaide, Australia) connected to a computer running software (Ballistic Measurement System, Fitness Technology) that recorded vertical ground reaction forces. Subjects performed the CMJ1 and CMJ5 with hands held in place on the hips. In the CMJ1, subjects were instructed to jump as high as possible, whereas in the CMJ5 subjects were required to jump as high as possible for 5 consecutive efforts without a pause between jumps. Countermovement depth was self selected by the subject. Trials were analyzed using custom-designed software (Matlab, Mathworks, Natick, MA, USA) capable of automatically calculating values for key performance variables.

Previously, the most useful CMJ variables for monitoring neuromuscular fatigue in an elite ARF population have been identified.[2] As a result, CMJ1Flight time:Contraction time (representing the time from the initiation of the countermovement until the subject leaves the force plate) in seconds and CMJ5Flight time in seconds (representing the average flight time of the 5 repetitions) were collected at each sample point.

In addition to CMJ and hormonal data as both absolute scores and the percent difference from Pre (%Pre), training volume (min) representing total time active in all training drills performed in a week, excluding rest periods between drills; match time (min) and % match time for each round; cumulative totals after each round; and season totals were collected. Votes based on playing performance awarded by 5 coaching staff on a 0-to-5 (maximum of 25 per match per subject) basis for all subjects in each match, that determined Club Champion Awards, were also recorded. Votes represented an assessment by the coaching staff on the effectiveness of the subjects' performance compared with the role assigned to them for the match.

Statistical Analysis

Variables were log transformed to reduce bias due to nonuniformity of error and analyzed using the effect size (ES) statistic with 90% confidence intervals (CI) and percentage change to determine the magnitude of effects. Magnitudes of change were classified as a substantial increase or decrease when there was a ≥75% likelihood of the effect being equal to or greater than the smallest worthwhile change estimated as 0.2 × between-subject standard deviation (small ES). Effects with less certainty were classified as trivial and where the ±90% CI of the ES crossed the boundaries of ES −0.2 and 0.2, the effect was reported as unclear.[2,21]

Pearson correlations (*r*) were calculated using SPSS for Windows (Version 13.0) to assess relationships of absolute values and percentage difference from Pre scores (%Pre) between CMJ and hormonal measures, match time, training volume, and votes. Correlations were calculated for variables measured at the same time point (eg, Pre) and also to assess delayed relationships (eg, Pre vs Mid 1 to 2). The magnitude of *r* ± 90% CI was classified as 0.1 to 0.3 small, 0.3 to 0.5 moderate, 0.5 to 0.7 large, 0.7 to 0.9 very large, and 0.9 to 0.99 nearly perfect[22] and classified as practically important where there was a ≥75% likelihood of the correlation exceeding the smallest practically important (0.1) value, using an Excel spreadsheet.[23] Correlations of ≥0.1 with less certain practical importance have not been reported.

Results

Training and Performance Data

Values are reported as mean ± SD. Weekly training volume and match time was 58 ± 19 min per week and 102 ± 15 min per subject, respectively. Total season match time was 2071 ± 230min (78.5 ± 8.7% of possible match time). Combined weekly match time and training volume was 144 ± 43 min per subject. Season total votes were 346 ± 63 per athlete (13 ± 6 per round). The team won 17 of 22 matches during the study period.

CMJ Measures

CMJ1Flight time:Contraction time (Tables 1 and 2) was substantially lower than Pre at 60% of sample points. Magnitudes of change compared with Pre ranged from unclear (1.0 ± 7.4%, ES 0.04 ± 0.29) Mid 5 to 6 to a substantial decrease (−17.1 ± 21.8%, ES −0.77 ± 0.81) Mid 8 to 9. The response was trivial on 4 occasions and unclear 20% of the time.

In contrast, CMJ5Flight time (Figure 2A) responded unclearly at 70% of data points and displayed a substantial decrement only 3 times throughout the season. Magnitudes of change ranged from −4.3 ± 3.6% (ES −0.83 ± 0.67) to 2.0 ± 2.5% (ES 0.39 ± 0.48).

Table 1 Effect Size ± 90% CI Change, Qualitative Descriptor, and Percentage Change Mid 1–2 to Mid 11–12 Compared with Pre for CMJ1Flight time:Contraction Time (s) and Cortisol (μg/dL)

Sample (Hours from previous match)	Flight time:Contraction time (s)	Cortisol (μg/dL)
Mid 1–2(+144)	−0.39 ± 0.33 substantial↓ −9.2%	−0.27 ± 0.39 trivial −6.1%
Mid 2–3(+72)	−0.20 ± 0.22 trivial −4.9%	−1.23 ± 0.67 substantial↓ −25.9%
Mid 3–4(+96)	−0.39 ± 0.31 substantial↓ −9.1%	−1.10 ± 0.6 substantial↓ −22.8%
Mid 4–5(+72)	−0.57 ± 0.58 substantial↓ −13.1%	−1.06 ± 0.62 substantial↓ −22.1%
Mid 5–6(+96)	0.04 ± 0.29 unclear 1.0%	−1.35 ± 0.73 substantial↓ −27.2%
Mid 6–7(+96)	0.21 ± 0.18 trivial 5.4%	−2.17 ± 0.56 substantial↓ −40.0%
Mid 7–8(+96)	−0.35 ± 0.32 substantial↓ −8.1%	−0.88 ± 0.47 substantial↓ −18.8%
Mid 8–9(+72)	−0.77 ± 0.81 substantial↓ −17.1%	−1.29 ± 0.42 substantial↓ −26.2%
Mid 9–10(+72)	−0.31 ± 0.51 unclear −7.4%	−1.15 ± 0.51 substantial↓ −23.7%
Mid 10–11(+96)	−0.57 ± 0.59 substantial↓ −13.0%	−1.15 ± 0.54 substantial↓ −23.7%
Mid 11–12(+72)	−0.59 ± 0.58 substantial↓ −13.4%	−0.75 ± 0.53 substantial↓ −16.1%

Note. A substantial increase or decrease was classified as a ≥75% likelihood of the effect being greater than or equal to the ES 0.2 (small) reference value. Effects were classified as unclear where the ±90% CI of the ES crossed the boundaries of ES −0.2 and +0.2.

Table 2 Effect Size ± 90% CI Change, Qualitative Descriptor, and Percentage Change Mid Bye–13 to Mid 21–22 Compared with Pre for CMJ1Flight time:Contraction time (s) and Cortisol (μg/dL)

Sample (Hours from previous match)	Flight time:Contraction time (s)	Cortisol (μg/dL)
Mid Bye–13(+360)	–0.48 ± 0.41 substantial↓ –11.2%	–0.58 ± 0.57 substantial↓ –12.7%
Mid 14–15(+96)	–0.49 ± 0.53 substantial↓ –11.4%	–0.46 ± 0.39 substantial↓ –10.2%
Mid 15–16(+96)	–0.71 ± 0.49 substantial↓ –15.9%	–0.74 ± 0.72 substantial↓ –15.9%
Mid 16–17(+96)	–0.47 ± 0.99 unclear –10.9%	–0.85 ± 0.55 substantial↓ –18.1%
Mid 17–18(+96)	–0.06 ± 0.47 unclear –1.4%	–0.67 ± 0.45 substantial↓ –14.6%
Mid 18–19(+120)	–0.34 ± 0.47 trivial –8.0%	–0.62 ± 0.52 substantial↓ –13.6%
Mid 19–20(+96)	–0.41 ± 0.28 substantial↓ –9.6%	–0.50 ± 0.50 substantial↓ –11.2%
Mid 20–21(+72)	–0.56 ± 0.42 substantial↓ –12.7%	–0.63 ± 0.66 substantial↓ –13.9%
Mid 21-22(+72)	–0.15 ± 0.27 trivial –3.5%	–0.52 ± 0.47 substantial↓ –11.5%

Note. A substantial increase or decrease was classified as a ≥75% likelihood of the effect being greater than or equal to the ES 0.2 (small) reference value. Effects were classified as unclear where the ±90%CI of the ES crossed the boundaries of ES –0.2 and +0.2.

Hormonal Measures

Cortisol (Tables 1 and 2) was substantially lower than Pre (mean ± SD, 2.34 ± 0.62 μg/dL) in all comparisons except for Mid 1 to 2, where the response was trivial (–6.1 ± 9.7% , ES –0.27 ± 0.39). The largest decrease occurred Mid 6 to 7 (–40 ± 14.1%, ES –2.17 ± 0.56) and the smallest substantial decrease (Mid 14 to 15) was –10.2 ± 9.6% (ES –0.46 ± 0.39).

Testosterone (Figure 2B) response was the most varied of the hormonal measures; with substantial increases, decreases and unclear responses in 45%, 10%, and 45% of comparisons respectively versus the Pre value (mean ± *SD* 90.90 ±

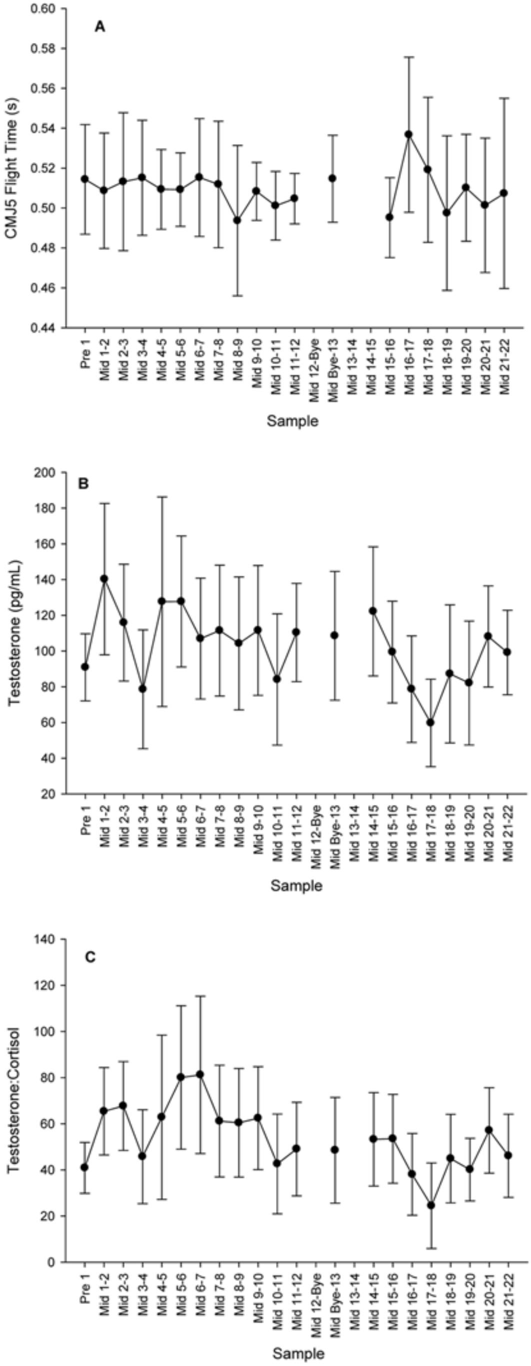

Figure 2 — (A) CMJ5Flight time (s), (B) testosterone (pg/mL), and (C) Testosterone: Cortisol Pre to Mid 21 to 22. Values are displayed as mean ± SD.

18.78 pg/mL). The largest reduction occurred Mid 17 to 18 (−38.7 ± 35.7%, ES −2.29 ± 1.43), and the largest increase occurred Mid 1 to 2 (50.7 ± 14.4%, ES 1.92 ± 0.63). Testosterone responded unclearly on more occasions (9) than any other variable.

Testosterone:Cortisol (Figure 2C) increased substantially on 14 (70%) occasions and responded unclearly in all other comparisons to Pre (mean ± *SD* 40.88 ± 11.02). Increases ranged from 28.1 ± 25.8% (ES 0.77 ± 0.71) at Mid 15 to 16 to 92.7 ± 27.8% (ES 2.03 ± 0.76) at Mid 6 to 7.

Correlations

CMJ1Flight time:Contraction time %Pre displayed a small correlation with T:C %Pre (r = .20 ± 0.13). A similar magnitude relationship was evident between CMJ1Flight time:Contraction time %Pre from one data point and T:C %Pre from the following data point (r = 0.25 ± 0.13). CMJ1Flight time:Contraction time had a small correlation (r = −0.16 ± 0.13) with votes received 1 match later than the match immediately following the CMJ sample. CMJ1Flight time:Contraction time %Pre also correlated with votes obtained 2 matches after the match immediately following the CMJ sample (r = .24 ± 0.13). CMJ5Flight time correlated with votes (r = −0.16 ± 0.14) awarded 2 matches later than the one immediately after CMJ sample. CMJ5Flight time was also correlated with C (r = −0.17 ± 0.14) 1 data point after the CMJ sample. Cortisol %Pre displayed a small correlation with votes (r = −0.16 ± 0.1) in the match immediately following the C sample. Cortisol had a similar magnitude relationship (r = 0.16 ± 0.1) with votes awarded 1 match later than the match immediately following provision of the C sample.

Match time displayed a small (r = .2 ± 0.13) correlation with CMJ1Flight time:Contraction time % Pre measured after the match. Total cumulative match time had small correlations with T (r = −0.19 ± 0.1), T %Pre (r = −0.15 ± 0.1), C (r = .18 ± 0.1) and T:C (r = −0.15 ± 0.1). Total cumulative match time as a percentage of possible match time displayed small correlations with CMJ1Flight time:Contraction time (r = −0.3 ± 0.11), T (r = .16 ± 0.1), T %Pre (r = .17 ± 0.1) and T:C %Pre (r = .2 ± 0.1). No practically important correlation was revealed between any hormonal or neuromuscular measure and number of hours from the previous match.

Discussion

CMJ Measures

In the current study, CMJ1Flight time:Contraction time showed a substantial reduction in numerous comparisons whereas CMJ5Flight time responded less clearly. Most previous studies have addressed neuromuscular responses over relatively short training periods, rather than extended competition seasons. A study of collegiate soccer players discovered reduced sprint speed and CMJ performance late into an 11-week season.[10] A study of semiprofessional rugby league players[14] found no change in CMJ after 6 weeks of overload training, while a similar group of athletes[15] displayed a clinically important reduction in the same measure after a period of overload training. The relatively short-term nature of previous research limits the capacity to compare results with those of the current study as acute responses may be unrepresentative of long-term changes. However, because CMJ1Flight time:Contraction time has demonstrated a clear pattern of depression and recovery following an ARF match,[2] it is reasonable to assume that substantial decrements seen in this study are indicative of acute low-frequency neuromuscular fatigue.[12] Periods of nonfunctional overreaching or overtraining would likely have resulted in extended periods of substantial reductions and less frequent return to baseline owing to the longer time required for recovery.[11] Critically, previous research suggests that the strength-training stimulus applied on Day 1 (PM) is of little consequence to the pattern of neuromuscular fatigue and recovery measured on Day 3 (AM).[2] Whether the neuromuscular fatigue evident is of central or of peripheral origin[24] cannot be determined from our results, although changes in hip and knee angles[25] and a decrease in muscle-tendon stiffness resulting from prior SSC exercise[26] may be responsible for the decrements observed.

Interestingly, the longest period of neuromuscular fatigue was 5 consecutive measurements (Mid 10 to 11 to Mid 15 to 16), although this is possibly an exaggeration of the extent of neuromuscular fatigue, as no measurements were taken Mid 12–bye or Mid 13 to 14. If the trend for a substantial reduction was maintained in the weeks without data, it may indicate that athletes involved in high-level weekly team sport competitions have a threshold capacity to cope with repeated loading, after which time they enter a period of neuromuscular overreaching[11] but rebound, given effective periodization.[15] Inappropriate periodization may result in an extended period of nonfunctional overreaching and potentially overtraining.[11] This may have implications for the design of training programs for elite-level contact team sport athletes who compete on a weekly basis over long seasons.

The response of CMJ5Flight time variable in comparison with CMJ1Flight time:Contraction time suggests it is less able to discriminate between degrees of neuromuscular status. Of the 3 occasions where CMJ5Flight time displayed a substantial reduction compared with Pre, CMJ1Flight time:Contraction time was also depressed on 2 of these occasions. On the other occasion (Mid 18 to 19), CMJ1Flight time:Contraction responded trivially but with a larger decrement (−8.0%) than CMJ5Flight time (−3.9%). Other research[3] has demonstrated an 8% reduction in 5 bound hop for distance following 4 weeks of overload training in triathletes. It appears that CMJ5Flight time, or a similar measure, may show decrements only in the presence of nonfunctional overreaching or overtraining,[11] such as that brought about by deliberate overloading or periods of extreme training and competition stress.[3,11] As the Pre time point in the current study is analogous to 48 hours prematch in previous research,[2] CMJ5Flight time is less likely than CMJ1Flight time:Contraction time to have displayed substantial decrements. Despite this, it could represent a variable capable of detecting nonfunctional neuromuscular overreaching as opposed to acute cyclical low-frequency fatigue. The usefulness of this variable throughout a season may be enhanced by obtaining a prematch sample as a baseline to compare with weekly values, as it has been shown to be more sensitive in this comparison.[2]

Hormonal Measures

The substantial reduction in C evident at 95% of comparison points is in contrast to previous work in soccer where C increased at the end of a 7-week high-intensity training phase[5] and throughout a season.[1,6] Research using American Football skill position players[11] during a 15-week off-season training program and 6 weeks of overload training in Rugby League resulted in no change to C levels.[14]

There may be a number of explanations for the results seen in the current study. First, the Pre sample may represent an elevated level in response to approximately 20 weeks of training before commencement of the competitive season. Previous work[10] that discovered C to be elevated in male collegiate soccer players at the end of a preseason phase supports this contention. Second, the training and playing load undertaken by the players throughout the competitive season may have allowed C to decrease in relation to (potentially elevated) Pre values, whereas excessive loading may have resulted in maintenance or increases compared with Pre.[10] The underlying mechanism responsible for the endocrine variation in this research is unclear. It may be related to modifications in the action of the hypothalamo-pituitary axis (HPA) on testicles or adrenals in response to the balance between exercise and recovery.[5,6] Inappropriate physiological loading would likely have resulted in increased C owing to an oversecretion of adrenocorticotrophic hormone as a response to the increased sensitivity of the HPA to stress.[27] From a hormonal perspective, the potential for inappropriate periodization resulting in overreaching appears to have been avoided[15] via a stabilization of the action of the HPA.[28] This likelihood is supported by previous work where C was substantially elevated 72 hours after an elite ARF match compared with baseline,[2] therefore emphasizing the practical importance of the reductions seen in the current study.

The response of T, and particularly T:C, may indicate the presence of a predominantly anabolic environment throughout the season, suggesting that subjects were able to recover from the stresses of training and competition.[10,11] Any regular reductions in T would probably have been the result of inhibited testicular secretion.[28] It has been proposed that T:C may be a particularly useful tool in monitoring the adaptive response to physical loading[4,15] as decreases in this ratio of >30% may indicate overtraining.[29] However, other researchers have proposed caution in the use of this ratio as a decrease does not necessarily translate to decreased performance or a state of overtraining.[5]

Research examining change in T and T:C has produced varied results. Testosterone has displayed an elevation during soccer training and competition,[1,10] in conjunction with unchanged T:C.[10] In contrast, T and T:C have shown decreases in soccer and rugby league players[5,30] whereas T remained unchanged at the end of a professional soccer season.[6] Confounding the comparison with previous research are the relatively few data points analyzed in other season-long studies. Regular analysis allows interpretation of week-to-week responses and trends over the longer term, whereas less-frequent samples may provide only a snapshot of endocrine variation that is unrepresentative of the overriding response. In the current study, T responded with substantial increases and unclearly at the same rate

(45% of data points each), whereas T:C was more predictable with predominantly large increases. In conjunction with other research,[2] increases in this ratio in the current study suggest an anabolic environment,[11] with athletes tolerating the training and competition loads.[14] Repeated high training loads during periods of hormonal imbalance may have resulted in further endocrine system disruption and ultimately compromised recovery.[28] However, the precise physiological impact of this anabolic environment is uncertain as even large reductions in T:C may be unrepresentative of performance decrements or confirmation of overreaching or overtraining.[3,14]

Correlations

Even though a number of correlations with practical importance are evident, the effects are generally small and variable. The use of a ≥75% likelihood threshold and $r \geq .1$ to signify practical importance suggests further work is needed to clarify the strength and practical importance of these relationships.

Despite this, it is interesting that some comparisons suggest a lag between change in the measurement variable and performance. For example, CMJ1Flight time:Contraction time %Pre had a small positive correlation ($r = .24 \pm 0.13$) with votes obtained 2 data points later than the CMJ variable. It is possible that changes in neuromuscular status may have a delayed influence on performance. This has potentially important practical applications, as the opportunity may exist to influence performance with interventions aimed at recovering neuromuscular status. Although speculative, the delayed relationship between neuromuscular fatigue and performance may be the result of an alteration in the time course of low-frequency neuromuscular fatigue and recovery,[2] brought about by repeated loading such as that undertaken by subjects in the current study.

The relationship between C and performance in the current study is varied. The small negative correlation between C %Pre and votes ($r = -0.16 \pm 0.1$) indicates the potential for higher levels of performance with low levels of catabolic hormone, although this relationship has a high degree of uncertainty and is in contrast to the relationship between absolute C and votes one round later. Further analysis is required to define the link between change in endocrine parameters and performance in elite ARF.

Uncertainty exists regarding the practical importance of the correlations between competition load and the majority of measurement variables in this study. However, total cumulative match time as a percentage of possible match time appears linked to the response of CMJ1Flight time:Contraction time. The relationship between competition load and hormonal measures is varied, although C shows a small increase in relation to match time, which may be important for the potential use of this variable as a marker of training and competition load.

Evidence of a relationship between neuromuscular and hormonal measures in the current study is displayed in correlations between CMJ1Flight time:Contraction time %Pre and T:C %Pre; and T:C %Pre 1 data point after the CMJ sample. Although small and variable, these relationships may indicate that change in neuromuscular status is immediately and prospectively related to endocrine response. Previous work has identified significant negative correlations between C and CMJ performance in a group of soccer players considered nonstarters and significant positive correlations between T:C and CMJ performance in starters at the end of the season.[10] A study in rugby league players found no significant correlation between endocrine measures and performance, although the authors suggested a catabolic state before an endurance test influenced the reduced performance.[15] The concept of a decrease in neuromuscular status preceding an increase in C is a variation on the notion of a catabolic state leading to reduced force production.[10] While the correlation between CMJ1Flight time:Contraction time %Pre and T:C %Pre in the current study supports the traditional concept, the relationship between the CMJ variable and T:C %Pre 1 sample point later may have been revealed because of the frequency of monitoring. Monitoring with high regularity could reveal more subtle variations in measurement variables than less frequent data collection and, consequently, important relationships may be discovered. It may be that this relationship existed in other team sport research; however, limited sampling data may have masked underlying changes.

Practical Applications

A reduction in CMJ1Flight time:Contraction time and/or increase in C compared with baseline suggests incomplete recovery of neuromuscular and hormonal status respectively. Regular monitoring of these variables throughout the season may allow instigation of appropriate interventions such as reduced training loads or periods of rest aimed at recovering neuromuscular and hormonal status. Responses should be examined in comparison with individual baseline measures on a weekly basis to specifically target manipulations of the training and competition stimulus in an effort to maximize performance.

Further research should look to confirm these results and investigate methods of moderating neuromuscular and endocrine response. The impact of changes in neuromuscular and hormonal measures should also be investigated in relation to more precise workload and performance measures such as distance run or average speed. Exploring relationships between hormonal response and anabolic:catabolic balance via imaging technology or monitoring of protein signaling pathways is an attractive area of research.

Conclusions

A competitive season of elite ARF competition elicits fluctuations in neuromuscular and endocrine responses. The response of CMJ1Flight time:contraction time indicates subjects were in a compromised neuromuscular state at 60% of data points and this reduction had a delayed relationship with votes. The pattern of response seen in C and T:C suggests subjects were unlikely to have been in a catabolic state as a result of the training and competition load. Cortisol had a small relationship to performance and in addition to CMJ1Flight time:Contraction may be a useful variable for monitoring the response to elite ARF competition and training.

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