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Neuromuscular and Endocrine Responses of Elite Players to an Australian Rules Football Match

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Purpose: To examine the acute and short-term responses of variables obtained during a single countermovement jump (CMJ1); repeated countermovement jump involving 5 consecutive efforts without a pause (CMJ5); and cortisol, testosterone, and testosterone-to-cortisol ratio (T:C) to an elite Australian Rules Football (ARF) match with a view to determining which variables may be most useful for ongoing monitoring. ***Methods:*** Twenty-two elite ARF players participating in a preseason cup match performed a CMJ1 and a CMJ5 and provided saliva samples 48 h before the match (48pre), prematch (Pre), postmatch, 24 h post (24post), 72 h post (72post), 96 h post (96post), and 120 h post (120post). The magnitude of change in variables at each time point compared with Pre and 48pre was analyzed using the effect size (ES) statistic. ***Results:*** A substantial decrement in the pre- to postmatch comparison occurred in the ratio of CMJ1 Flight time:Contraction time (ES −0.65 ± 0.28). Cortisol (ES 2.34 ± 1.06) and T:C (ES −0.52 ± 0.42) displayed large pre- to postmatch changes. The response of countermovement variables at 24post and beyond compared with prematch and 48pre was varied, with only CMJ1 Flight time:Contraction time displaying a substantial decrease (ES −0.32 ± 0.26) postmatch compared with 48pre. Cortisol displayed a clear pattern of response with substantial elevations up to 24post compared with Pre and 48pre. ***Conclusion*:** CMJ1 Flight time:Contraction time appears to be the most useful variable for monitoring neuromuscular status in elite ARF players due to its substantial change compared with 48pre and prematch. Monitoring cortisol, due to its predictable pattern of response, may provide a useful measure of hormonal status.

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

Muscle fatigue has been defined as a reduction in maximal force-generating capacity[1] and is believed to involve many factors at various sites, including both central and peripheral origins.[2] It has been suggested that a practical test capable of assessing low-frequency fatigue in athletes is warranted.[3] The effective plan-

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ning of postcompetition recovery and preparation for subsequent competition necessitates accurate assessment of the impact of game play on the neuromuscular system.

Stretch shortening cycle (SSC) activities may be useful in the study of neuromuscular fatigue because metabolic, mechanical, and neural elements are taxed in conjunction with disturbances of stretch-reflex activation.[4] Recovery from SSC exercise occurs in two phases characterized by an initial large drop in performance, followed by a transient recovery, and then a further drop that generally peaks 48 to 72 hours postexercise.[4]

Various forms of vertical jump (VJ) have been used in the assessment of athletic performance[5–8] and assessing repetitive VJ power may also be important.[5] However, the use of VJ protocols to study the fatiguing effect of team game performance is limited. Hoffman et al[7] found CMJ peak power and force was maintained pre- to post-soccer match, whereas peak force was lower at 24 hours after compared with before. Hoffman et al[6] found various changes in peak force and power in American football players, while Ronglan et al[9] demonstrated a significant decrement in countermovement jump (CMJ) height over 3 days of elite handball competition. There appears to have been no investigation examining the impact of an elite ARF match on CMJ variables to assess their potential usefulness as a measure of neuromuscular status.

In addition to changes in muscular performance due to fatigue, numerous researchers have examined the influence of team game performance on endocrine response.[10–13] Cortisol (C) is considered an important stress hormone and its presence is said to indicate the neuroendocrine system's response to exercise.[14] Testosterone (T) is anabolic in nature and important in muscle hypertrophy and increasing muscle glycogen synthesis.[15] Testosterone has also been implicated in aggressive behavior.[15] As C and T vary in opposite directions in response to exercise, this may represent an imbalance between anabolic and catabolic hormones resulting in a decreased T:C ratio when loads are increased.[12] It is possible that various hormonal measures may assist in assessing the response to training[14]; however, their potential usefulness in ARF is unknown.

Previous work[12] has found T and C rest-day values to be comparable to competition-day values in rugby players, with T decreased and C and T:C increased postgame. Hoffman et al[10] found elevated C levels during a season of American Football although values were within normal ranges, and T:C was lower at the end of the season while T remained at baseline. Filaire et al[13] revealed C was not influenced by 9 months of professional soccer training, although an intensive training block resulted in decreased T. The nature of ARF provides a unique vehicle for the study of hormonal response to performance as it combines the contact nature of rugby and the running volumes of soccer.

Uncertainty remains regarding the pattern of neuromuscular fatigue and hormonal responses to elite-level contact sport, and the influence of an elite ARF match is unknown. It is currently unclear whether such measures, including a functional athletic task capable of detecting low-frequency neuromuscular fatigue, are useful monitoring tools. Quantification of the impact of game play on the neuromuscular and endocrine systems is essential to planning effective training over the subsequent week. Therefore, the purpose of this study was to examine the acute and short-term impact of an elite-level ARF match on neuromuscular status and hormonal response in an attempt to determine which measures may be most useful for ongoing monitoring of elite ARF players.

Methods

Subjects

This study involved 22 elite ARF players (age 23.3 ± 2.7 y, height 1.9 ± 0.1m, and mass 89.6 ± 7.3 kg) representing an Australian Football League (AFL) team in a preseason cup match. Subjects had played an average of 64.3 ± 51.7 AFL regular season matches. The research was approved by the University Human Research Ethics Committee and all subjects signed an informed consent document.

Design

The testing and training schedule is displayed in Figure 1. Single countermovement jump (CMJ1) data, five repeated countermovement jump (CMJ5) data, and saliva samples were collected at 48pre, prematch, postmatch, 24post, 72post, 96post, and 120post match. Subjects were familiar with the CMJ1, CMJ5, and saliva sample techniques after participating in multiple practice sessions and completing pre- and postmatch testing in two intraclub matches before the preseason cup match. All data, except for postmatch, were collected between 1500 and 1530. Postmatch data were collected between 1830 to 1850 and this was within 20 minutes of match completion. For various reasons, some subjects were unable to provide data at all time points. Data were analyzed for between 16 and 21 subjects for the CMJ and 17 to 22 subjects for hormonal variables at each time point. Subjects participated in the team's regular weekly training schedule (Figure 1) throughout the data collection period.

Methodology

Before each CMJ1 trial, subjects performed a 2-minute dynamic warm-up consisting of various running patterns including jogging, high knees, and skipping. Subjects then performed three practice CMJs before the measurement trial. The CMJ1 trial was followed by collection of a 60-second unstimulated saliva sample for analysis of T, C, and T:C. Saliva samples were collected by passively drooling directly into a plastic tube. There is a strong relationship between salivary and serum unbound cortisol both at rest (r = .93) and during exercise (r = .90),[16] and saliva measures of cortisol and testosterone concentrations are independent of saliva flow rate.[17] All subjects were requested to maintain their normal training diet throughout the study period and refrain from ingesting anything other than water in the 60 minutes before provision of each saliva sample. Subjects were also required to provide samples in a rested state with a minimum of 5 hours inactivity and participate in only the prescribed weekly training sessions. Saliva samples were placed in a refrigerator and then frozen at a temperature of −80°C and stored 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

Time/Day	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
AM	Off	Off	Off	Pool based recovery	Off	Flexibility	Individual Skill Training	Off
PM	*48pre* Skill Training	Off	*Pre* Match *Post*	*24post* Strength Training	Off	*72post* Skill Training	*96post* Strength Training	*120post* Skill Training

Figure 1 — Test and training schedule 48pre to 120post (test times in *italics*).

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. Following provision of a saliva sample, subjects performed the CMJ5 trial.

CMJ trials were performed on a commercially available force plate (400 Series Performance Plate; Fitness Technology, Adelaide, Australia) connected to computer software (Ballistic Measurement System; Fitness Technology) capable of recording vertical ground reaction forces. In both the CMJ1 and CMJ5 conditions, subjects were required to perform a CMJ with hands held in place on the hips. In the CMJ1, subjects were instructed to jump as high as possible, while in the CMJ5, subjects were required to jump as high as possible for five consecutive efforts without a pause between jumps. Countermovement depth was self selected by the subject. Each trial was then analyzed using custom designed software (Mathworks, Natick, MA, USA) capable of automatically detecting values for the variables of interest.

As a result of previous work[18] that has determined the CMJ1 and CMJ5 variables with the highest reliability (CV 0.8% to 8.0%), the following variables were collected for analysis. In the CMJ1, we recorded height in centimeters, flight time in seconds, peak power in watts, relative peak power in watts per kilogram, mean power in watts, relative mean power in watts per kilogram, peak force in newtons, relative peak force in newtons per kilogram, mean force in newtons, relative mean force in newtons per kilogram, and flight time:contraction time (representing the time from the initiation of the countermovement until the subject leaves the force plate) in seconds. In the CMJ5, flight time, peak power, relative peak power, peak force, relative peak force, mean force, and relative mean force were collected, with the score representing the average of the values for each of the five jump repetitions.

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 change at each time point compared with 48pre and prematch values. Calculations were performed using an Excel spreadsheet.[19] The ES was calculated using the following formula: ES = $(M_1 - M_2)/s$, where M_1 = mean of one group, M_2 = mean of second group, s = standard deviation. The magnitude of change was classified as a substantial increase, substantial decrease, trivial, or unclear. The description of a substantial increase or decrease was applied when there was a 75% or greater likelihood of the effect being equal to or greater than the ES ±0.2 (small) reference value. Less certain effects were classified as trivial and where the ±90% CI of the ES crossed the boundaries of ES −0.2 and 0.2 the magnitude of change was reported as unclear. This methodology has been described in detail elsewhere.[20] It has been suggested that an important step in increasing the applicability of research to practice is to calculate and report statistics that show the magnitude of a treatment effect,[20] and a similar approach has been used previously.[21]

In this study, CMJ variables displaying an ES decrease of ≥0.40 from prematch to postmatch were considered for analysis beyond the prematch versus postmatch comparison to highlight CMJ variables that are depressed by ARF

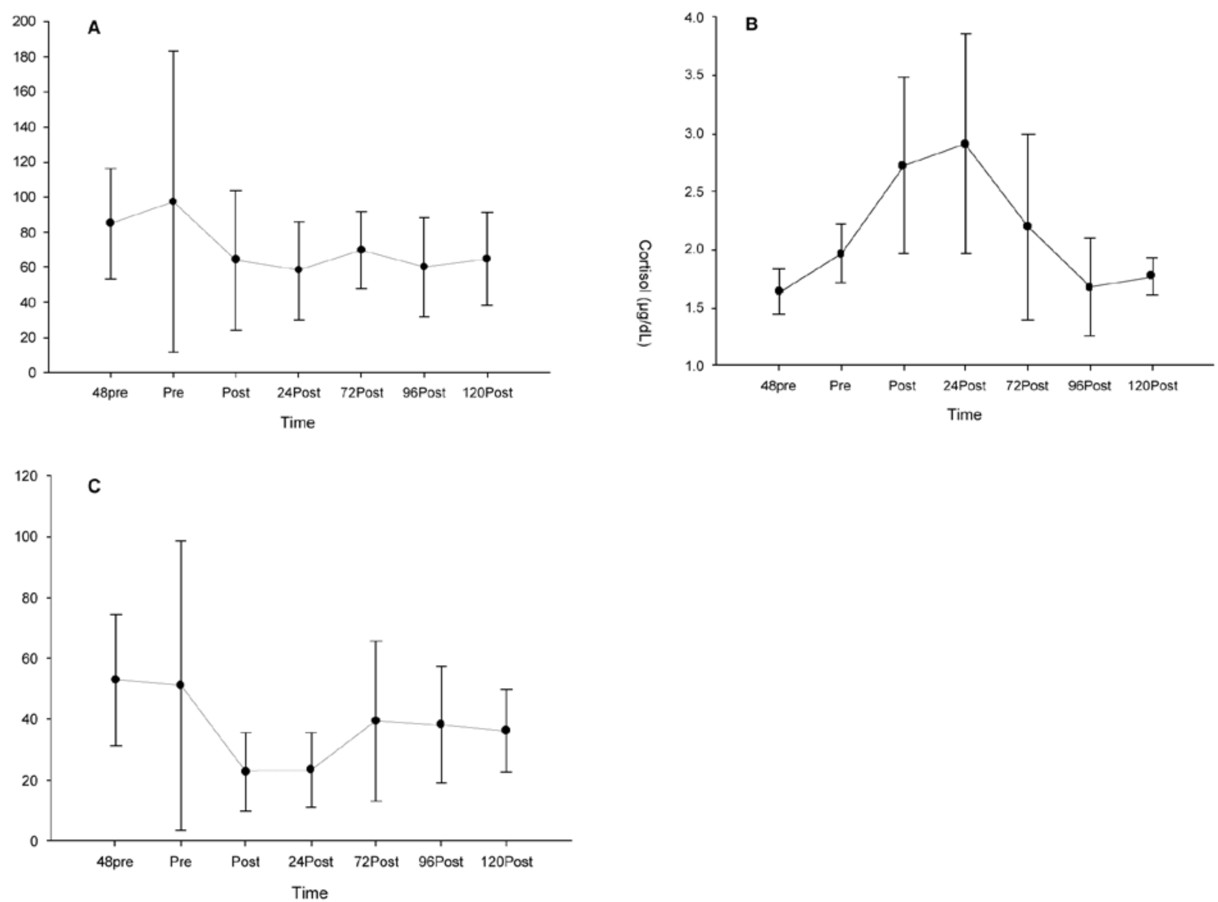

Figure 2 — Endocrine responses 48pre game to 120post game. (A)Testosterone, (B) Cortisol, and (C) Testosterone:Cortisol (T:C). Values are represented as mean ± SD.

Table 1 CMJ ES ±90% Confidence Interval Change, Qualitative Descriptor, and Percentage Change Compared with Prematch

Variable/Time	48pre	Post	24post	72post	96post	120post
CMJ1 Flight Time (s)	−0.53 ± 0.41 substantially↓ −2.2%	−0.89 ± 0.56 substantially↓ −3.6%	−0.84 ± 0.56 substantially↓ −3.5%	−0.10 ± 0.36 unclear −0.4%	−0.02 ± 0.51 unclear −0.1	−0.07 ± 0.47 unclear −0.3
CMJ1 Mean power (W)	−0.17 ± 0.31 trivial −2.9%	−0.57 ± 0.39 substantially↓ −9.4%	−0.81 ± 0.39 substantially↓ −13.0%	−0.37 ± 0.32 substantially↓ −6.1%	−0.08 ± 0.40 unclear −1.5%	−0.27 ± 0.29 trivial −4.5%
CMJ1 Relative mean power (W/kg)	−0.19 ± 0.36 trivial −2.8%	−0.53 ± 0.44 substantially↓ −7.7%	−0.87 ± 0.43 substantially↓ −12.4%	−0.40 ± 0.36 substantially↓ −5.9%	−0.06 ± 0.45 unclear −0.9%	−0.28 ± 0.33 trivial −4.2%
CMJ1 Relative mean force (N/kg)	−0.22 ± 0.22 trivial −0.8%	−0.42 ± 0.32 substantially↓ −1.5%	−0.69 ± 0.33 substantially↓ −2.5%	−0.24 ± 0.21 trivial −0.9%	−0.11 ± 0.3 trivial −0.4%	−0.17 ± 0.27 trivial −0.6%
CMJ1 Flight time:Contraction time (s)	−0.28 ± 0.26 trivial −7.6%	−0.65 ± 0.28 substantially↓ −16.7%	−0.67 ± 0.28 substantially↓ −17.1%	−0.14 ± 0.22 trivial −3.7%	−0.13 ± 0.35 unclear −3.5%	−0.20 ± 0.22 trivial −5.4%
CMJ5 Flight time (s)	−0.80 ± 0.29 substantially↓ −3.8%	−0.50 ± 0.22 substantially ↓ −2.4%	−0.76 ± 0.31 substantially↓ −3.6%	−0.45 ± 0.26 substantially↓ −2.1%	−0.20 ± 0.23 trivial −1.0%	−0.31 ± 0.20 substantially↓ −1.5%

Note. A substantial increase or decrease was classified as ≥75% likelihood of the effect being greater than or equal to the ES ±0.2 (small) reference value. Less certain effects were classified as trivial, and where the ±90%CI of the ES crossed the boundaries of ES −0.2 and +0.2 the magnitude of change is described as unclear.

match play. An ES of this magnitude lies halfway between ES that have been classified as small (0.2) and moderate (0.6).[22] The ES 0.4 threshold was chosen as a change of this magnitude allowed an initial reduction of CMJ variables for analysis, by highlighting those variables impacted by more than a small magnitude in the prematch to postmatch comparison, without unnecessarily removing variables by using a stricter ES 0.6 threshold.

Results

Subjects played an average of 80.0 ± 12.0 minutes (74.3 ± 11.1% of total match time).

Excluded CMJ Variables

The following variables have been excluded from further analysis on the basis of ES decrements of <0.40 in the pre- versus postmatch comparison.

CMJ1 Variables Pre- Versus Postmatch

CMJ1Height showed a small (ES –0.32 ± 0.46) decrease from pre- to postmatch. The response of CMJ1Peak power was trivial (ES 0.11 ± 0.27) while CMJ1Relative peak power increased (ES 0.49 ± 0.48) from pre- to postmatch. CMJ1Peak force displayed a trivial change (ES –0.16 ± 0.26) from pre- to postmatch while the magnitude of change in CMJ1Relative peak force was unclear (ES 0.00 ± 0.39). CMJ1Mean force decreased by a small (ES –0.35 ± 0.11) magnitude from pre- to postmatch.

CMJ5 Variables Pre- Versus Postmatch

The response of CMJ5Peak power from pre- to postmatch was trivial (ES 0.02 ± 0.10), while CMJ5Relative peak power increased by a large magnitude (ES 1.21 ± 0.64). CMJ5Peak force and Relative peak force were lower postmatch by a small margin (ES –0.33 ± 0.24 and –0.22 ± 0.34 respectively). Postmatch CMJ5Mean force displayed a small decrease (ES –0.25 ± 0.07), while the response of CMJ5Relative mean force was trivial (–0.02 ± 0.15).

CMJ and Hormonal Variables 48pre to 120post

CMJ Variables Table 1 displays CMJ ES ± 90% CI change and percentage change compared with prematch for those variables meeting the previous criteria of an ES decrease of ≥0.40 in the pre- versus postmatch comparison. Changes in CMJ variables compared with 48pre are shown in Table 3.

CMJ1Mean power, CMJ1Relative mean power, and CMJ1Relative mean force displayed substantial decreases from pre- to postmatch with decrements ranging from –1.5% to –9.4%. CMJ1Flight time:Contraction time decreased by the largest amount (–16.7%). CMJ1Flight time was substantially lower at 48pre than prematch. The pattern of response in CMJ1 parameters varied from 24post to

Table 2 Cortisol (C), Testosterone (T), and Testosterone:Cortisol (T:C) ES ±90% Confidence Interval Change, Qualitative Descriptor, and Percentage Change Compared with Prematch

Variable/Time	48pre	Post	24post	72post	96post	120post
C (μg/dL)	−1.43 ± 0.42 substantially↓ −16.5%	2.34 ± 1.06 substantially ↑ 34.2%	2.78 ± 1.16 substantially↑ 41.8%	0.34 ± 1.30 unclear 4.4%	−1.44 ± 0.91 substantially↓ −16.6%	−0.78 ± 0.43 substantially↓ −9.3%
T (pg/mL)	−0.09 ± 0.69 unclear −3.9%	−0.29 ± 0.40 unclear −21.8%	−0.37 ± 0.53 unclear −26.5%	−0.08 ± 0.36 unclear −6.5%	−0.27 ± 0.44 trivial −20.1%	−0.22 ± 0.48 unclear −16.9%
T:C	0.25 ± 0.36 trivial 24.0%	−0.52 ± 0.42 substantially↓ −36.0%	−0.67 ± 0.52 substantially↓ −43.7%	−0.06 ± 0.40 unclear −5.0%	−0.02 ± 0.50 unclear −1.9%	−0.10 ± 0.46 unclear −8.3%

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

Table 3 CMJ ES ±90% Confidence Interval Change, Qualitative Descriptor, and Percentage Change Compared with 48pre

Variable/Time	Post	24post	72post	96post	120post
CMJ1 Flight time (s)	−0.31 ± 0.57 unclear −1.5%	−0.17 ± 0.57 unclear −0.8%	0.33 ± 0.43 trivial −1.6%	0.43 ± 0.31 trivial 2.0%	0.47 ± 0.29 trivial 2.2%
CMJ1 Mean power (W)	−0.31 ± 0.73 unclear −4.8%	−0.47 ± 0.41 substantially↓ −7.1%	−0.19 ± 0.34 trivial −3.0%	0.12 ± 0.36 unclear 1.8%	0.02 ± 0.23 unclear 0.3%
CMJ1 Relative Mean power (W/kg)	−0.26 ± 0.99 unclear −3.1%	−0.57 ± 0.56 substantially↓ −6.6%	−0.26 ± 0.46 unclear −3.0%	0.19 ± 0.50 unclear 2.2%	0.03 ± 0.33 unclear 0.4%
CMJ1 Relative Mean force (N/kg)	−0.17 ± 0.45 unclear −1.5%	−0.44 ± 0.15 substantially↓ −1.3%	−0.03 ± 0.18 trivial −0.1%	0.15 ± 0.26 trivial 0.4%	0.18 ± 0.22 trivial 0.5%
CMJ1 Flight time:Contraction time (s)	−0.32 ± 0.26 substantially↓ −7.5%	−0.33 ± 0.17 substantially↓ −7.8%	0.20 ± 0.30 trivial 5.0%	0.06 ± 0.25 trivial 1.6%	0.21 ± 0.34 trivial 5.2%
CMJ5 Flight time (s)	0.19 ± 0.36 trivial 1.1%	−0.10 ± 0.28 trivial −0.5%	0.26 ± 0.34 trivial 1.4%	0.45 ± 0.27 substantially↑ 2.5%	0.50 ± 0.26 substantially↑ 2.8%

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. Less certain effects were classified as trivial and where the ±90% CI of the ES crossed the boundaries of ES −0.2 and +0.2 the magnitude of change is described as unclear.

120post. CMJ5Flight time was substantially lower at all time points compared with Pre except for 96post, where the response was trivial.

Hormonal Variables Hormonal variable responses compared with prematch are shown in Table 2. Testosterone response compared with prematch was unclear or trivial at all comparison points. Cortisol increased substantially postmatch (+34.2%) and 24post (+41.8%) with an unclear response at 72post followed by substantial decreases at 96post and 120post. Cortisol was substantially lower (−16.5%) at 48pre than prematch. Testosterone:Cortisol decreased substantially postmatch and 24post compared with prematch with unclear or trivial responses at other time points.

In comparison with 48pre (Figure 2), C displayed a substantial increase postmatch (ES 4.05 ± 1.09, 60.8%), 24post (ES 4.59 ± 1.28, 71.4%), 72 post (ES 1.72 ± 1.34, 22.3%), and 120post (ES 0.70 ± 0.48, 8.6%), with and unclear response at 96post (ES 0.18 ± 0.87, 2.14%). The magnitude of change in T postmatch compared with 48pre was trivial (ES −0.74 ± 0.80, −27.5%) with substantial decreases ranging from ES −0.41 ± 0.41 (−16.3%) at 72post to ES −0.96 ± 0.53 (−34.0%) at 96post. Testosterone:Cortisol was substantially lower at all time points compared with 48pre, with the greatest decrements occurring postmatch (ES −1.93 ± 0.98, −58.8%) and 24post (ES −1.69 ± 0.79, −54.0%) with the smallest change seen at 72post (ES −0.78 ± 0.61, −30.2%).

Discussion

Responses Compared with Pre

The initial finding of this research is the lack of change in numerous CMJ variables in response to an ARF match. Surprisingly, given the instruction to jump as high as possible, CMJ1Height was in this category. This may be in part due to the inherent limitations associated with estimating height based on the impulse momentum relationship. The substantial decrease in CMJ1Flight time, which is measured directly, provides support for this notion. Previous research has demonstrated a decrease in CMJ1Height using the same methods as the current study in international handball players over the course of three matches, although pre- and postmatch scores were not reported.[9] It could be that CMJ1Height lacks the sensitivity to detect changes from a single ARF match. Flight time is an attractive measure, however, due to the ease and relatively cheap technology required for assessment of this variable.

The response of CMJ1 and CMJ5Relative peak power suggests the potential for an increase in relative peak power from pre- to postmatch. Running and CMJ skill rehearsal, as occurs in ARF, has been show to potentiate jumping performance via increased readiness of the neuromuscular system.[23] However, it is unclear why potentiation would affect relative peak power variables and not others. Previous work examining peak power in American Football[6] and women soccer players[7] has shown no difference between pre- and postmatch Peak power levels. This suggests team sport athletes may be able to maintain relative peak power following a match, particularly as the rate of decrease has been shown to be no different between starters and nonstarters.[6]

The reduction in CMJ1Mean power and relative mean power suggests that these variables are depressed by an ARF match until at least 72post. This timeline may reflect the influence of low-frequency fatigue,[24] manifested in an altered technique whereby knee flexion angle during the countermovement is modified in an attempt to achieve maximum height,[25] resulting in decreased mean power scores. The continued depression of these measures until 72post and lack of clarity in values at 96post is a limitation to the usefulness of these variables for monitoring purposes.

Reductions in CMJ Peak force following maximal run performance have been demonstrated previously[26]; however, in the current study only CMJ1Relative mean force displayed this postmatch decrement. This result is similar to that of previous research in American Football[6] and collegiate soccer[7] showing postmatch CMJ1Peak force to be unchanged from prematch. Decreased mean force production may be due to a combination of reduced central drive and failure of the excitation-contraction coupling mechanism.[2] It is likely that similar technique alterations[25] affecting mean power scores have impacted mean force results. It appears that CMJ1Relative Mean force decrements are largely recovered by 3 days postmatch. As a result, this variable may be useful for monitoring neuromuscular fatigue because substantial decrements in relative mean force beyond 72post may be indicative of delayed recovery.

While CMJ1 and CMJ5Flight time are substantially depressed until 24post, different patterns of response from 72post onward may be evidence of greater sensitivity in the CMJ5 variable. The substantial decrease demonstrated by CMJ5-Flight time at 72post compared with prematch may reflect low-frequency fatigue[24] generated by the ARF match. A similar decrease at 120post may reflect the secondary drop in performance approximately 48 hours following intense eccentric exercise (72post training session) as suggested by others.[4] Alternatively, the decrease could be a more acute response to the strength training session conducted at 96post. The lack of clarity in the response of CMJ1Flight time variable is a limitation to its usefulness in monitoring neuromuscular fatigue in elite ARF players. In contrast, CMJ5Flight time may reflect fatigue associated with the match until 96post, where a substantial decrement may be a reflection of compromised neuromuscular status. However, 96post may be too close to the next performance in week-to-week competitions to allow for adequate modifications of the training stimulus.

In a similar manner to flight time, CMJ1Flight time:Contraction time displayed a substantial decrease postmatch and 24post. This variable provides an indication of the relationship between the countermovement phase and resulting flight time. Research using hopping has shown changes in hip and knee angles after a fatigue intervention.[25] Other research has shown a decrease in muscle-tendon stiffness from prior SSC exercise resulting in increased ground contact time in drop jump performance.[8] Similar mechanisms may be responsible for the changes in Flight time:Contraction time. This variable is depressed by an ARF match for at least 24 hours postgame and, although the response is trivial at 72post, it is likely to be a small decrease at most. Therefore, a substantial decrease in CMJ1Flight time:Contraction time 72 hours after an ARF match may reflect delayed recovery. The timeline of response in this variable appears to allow an opportunity for interventions aimed at recovering neuromuscular status to be implemented in time for the next weekly competition. Based on comparisons with prematch values, this variable may be the most useful CMJ variable for assessing neuromuscular fatigue.

Cortisol and T:C showed the greatest change among endocrine variables in the pre- to postmatch comparison. The increase in C is similar to that of Haneishi et al,[11] who found that post-soccer-match C to be significantly increased above pregame values. Other research has shown C to be unchanged from pre- to post-game in American Football players, although differences postgame existed between starters and nonstarters.[6] In a similar fashion to the current study, C values have been shown to rise postcompetition in elite swimmers.[27] Postcompetition T:C in rugby players has been shown to be 2.5 times lower than rest-day values,[12] and the substantial reduction in this ratio seen in the current study may reflect a catabolic state in response to an ARF match that extends for at least 24 hours.[28] The unclear nature of the T:C response at 72post and beyond makes inferences regarding the expected pattern of response in this variable difficult. In comparison, C is substantially decreased at 96post and 120post, providing more certainty in the expected response.

The generally unclear response seen in T from postmatch to 120post makes determinations about anabolic processes due to an ARF match difficult. The expected pattern of response is unknown, given that previous research has found T to be unchanged from pre- to postmatch in American football players[6] but higher in the days following an elite-level rugby match than on a rest day,[12] although this comparison does not consider change from prematch values. The unclear change at the majority of time points suggests that T responds in a varied manner to an ARF match, therefore limiting its usefulness for regular monitoring of elite ARF players.

Responses Compared with 48pre

The response of CMJ variables postmatch compared with 48pre may provide an insight into the sensitivity of individual variables. In a similar fashion to the sensitivity shown by CMJ1Flight time:Contraction time in comparisons to the prematch value, this variable was the only CMJ measure capable of detecting a substantial change from 48pre to postmatch. The decrement shown in this comparison was maintained in the 24post versus 48pre comparison. CMJ1Mean power, relative mean power, and relative mean force were also substantially lower at 24post than 48pre; however, their ability to detect a change between 48pre and postmatch is unclear. The response at 24post versus 48pre in these variables may be attributable to similar mechanisms that are responsible for change in comparisons with Pre, such as reduced central drive and failure of the excitation-contraction coupling mechanism,[2] in conjunction with potentially altered technique.[25] The unclear nature of the response postmatch compared with 48pre suggests these variables lack the sensitivity to detect match induced changes in neuromuscular status from a rested baseline. CMJ1Flight time:Contraction time responds trivially at 72post versus 48pre and thereafter following substantial reductions postmatch and 24post, adding weight to the concept that this measure reflects the return of neuromuscular status to 48pre baseline levels following the match and further highlighting its usefulness.

Cortisol was the only hormonal variable to display a substantial change from 48pre to prematch, suggesting an anticipatory rise similar to that demonstrated previously.[27,29] The unclear nature of the change in T from 48pre to Pre is further evidence of the limitations for the use of this hormone for the regular monitoring of elite ARF players. A correlation (r = .40, P < .04) between T and number of attacks in judo players has been shown previously,[15] suggesting a link with aggressive behavior. Interestingly, the subjects in the current study were on the losing team. It is possible that subjects were not sufficiently aroused prematch, as higher arousal may have resulted in a greater difference between 48pre and prematch T. The trivial change in T:C is likely to be a function of the diversity in T and C response and is similar to results of research utilizing elite rugby players that demonstrated T:C to be similar on rest and competition days.[12]

Elevated C until 72post compared with 48pre provides further support for the large impact of ARF match play on this variable and is a similar result to previous work.[12] The secondary increase at 120post may be due to training conducted after 72post as the impact of the match is likely to have diminished.[30] The substantial decrease in T:C in all comparisons with 48pre may be evidence that in elite contact team sports where a match is followed by multiple training sessions, these measures are continually depressed, representing a catabolic environment with implications for the design of training programs. These results are in contrast to a study using elite rugby players in which T:C remained elevated above baseline values until 5 days postmatch.[12] The use of T:C to monitor the anabolic-to-catabolic balance in elite ARF players may be worthy of further investigation; however, the performance of two salivary assays may be problematic.

Practical Applications

An easy-to-administer functional test of neuromuscular status may be of great benefit to scientists and coaches working with high-level team sport athletes.[3] In elite ARF football players, CMJ1Flight time:Contraction time appears to be the most useful variable for assessing the neuromuscular response to a match. CMJ5-Flight time may be the most appropriate monitoring variable for programs that only have access to devices such as a timing mat.

Cortisol and T:C display the most predictable pattern of response of the hormonal variables studied. While T:C may be useful, the performance of two independent assays could be a limitation. Therefore, regular monitoring of C is likely to provide the most practically useful hormonal measure, as levels may be expected to be substantially lower than prematch by 96post. While the increase in C observed from pre- to postmatch suggests the impact of the match has overridden the normal diurnal decrease in C, it is possible that the increase in C postmatch was blunted by this diurnal effect. Therefore, it may also be useful in further research to assess the diurnal pattern of C in elite ARF players without the influence of a match or intense training to further clarify the impact of competition or training. Obtaining fatigue-free baseline values is likely to be important for measures of neuromuscular and endocrine status.

Conclusions

Although numerous CMJ variables were substantially lower at postmatch than prematch, CMJ1Flight time:Contraction time was the only CMJ variable to also show a substantial decline (−7.4%) from 48pre to postmatch. This magnitude of change, in conjunction with trivial responses prematch to 72post (−3.7%) and 48pre to 72post (+5%) suggest that CMJ1Flight time:Contraction time is the most sensitive and useful variable for the assessment of neuromuscular status in elite ARF players. A decrement in this variable of a substantial magnitude compared with Pre or 48pre at 72post may indicate incomplete recovery of the neuromuscular system.

Cortisol showed a clear pattern of response in the pre- to postmatch comparison, with a substantial 34.2% increase. Testosterone:Cortisol ratio was substantially lower (−36.0%) postmatch compared with prematch. Given a training schedule similar to the one undertaken by athletes in this study, it is reasonable to expect C at 96post to be substantially lower than prematch.

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