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R.V. Gomes

A. Moreira

L. Lodo

Kazunori Nosaka

Edith Cowan University, k.nosaka@ecu.edu.au

A.J. Coutts

See next page for additional authors

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Authors

R.V. Gomes, A. Moreira, L. Lodo, Kazunori Nosaka, A.J. Coutts, and M.S. Aoki

MONITORING TRAINING LOADS, STRESS, IMMUNE-ENDOCRINE RESPONSES AND PERFORMANCE IN TENNIS PLAYERS

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AUTHORS: Gomes R.V.¹, Moreira A.¹, Lodo L.¹, Nosaka K.², Coutts A.J.³, Aoki M.S.⁴

¹ School of Physical Education and Sport, University of São Paulo, São Paulo, Brazil

² School of Exercise, Biomedical and Health Sciences, Edith Cowan University, Western Australia, Australia

³ Sport and Exercise Discipline Group, Health, University of Technology, Sydney, Lindfield, NSW, Australia

⁴ School of Arts, Sciences and Humanities, University of São Paulo, São Paulo, Brazil

Reprint request to:
Rodrigo Vitasovic Gomes
Rua Sardinha da Silveira, 79
02339060 São Paulo
Brazil
E-mail: gomesrv@usp.br

ABSTRACT: The study aim was to investigate the effect of a periodised pre-season training plan on internal training load and subsequent stress tolerance, immune-endocrine responses and physical performance in tennis players. Well-trained young tennis players ($n = 10$) were monitored across the pre-season period, which was divided into 4 weeks of progressive overloading training and a 1-week tapering period. Weekly measures of internal training load, training monotony and stress tolerance (sources and symptoms of stress) were taken, along with salivary testosterone, cortisol and immunoglobulin A. One repetition maximum strength, running endurance, jump height and agility were assessed before and after training. The periodised training plan led to significant weekly changes in training loads (i.e. increasing in weeks 3 and 4, decreasing in week 5) and post-training improvements in strength, endurance and agility ($P < 0.05$). Cortisol concentration and the symptoms of stress also increased in weeks 3 and/or 4, before returning to baseline in week 5 ($P < 0.05$). Conversely, the testosterone to cortisol ratio decreased in weeks 3 and 4, before returning to baseline in week 5 ($P < 0.05$). In conclusion, the training plan evoked adaptive changes in stress tolerance and hormonal responses, which may have mediated the improvements in physical performance.

KEY WORDS: testosterone, cortisol, immunoglobulin A, competition, periodisation, adolescents

INTRODUCTION

Tennis is a popular competitive sport attracting millions of players and fans worldwide. It can be played on several different surfaces, including grass, clay and artificial turf. The match itself is characterised by relatively short, high-intensity bouts of intermittent exercise with players moving in all directions [13]. High performance tennis players are subjected to an intensive yearly competitive schedule comprising multiple tournaments as well as invitational and qualifying events. Thus, the pre-season period is crucial for developing those fitness components (e.g. maximum strength and power, speed, agility) required for the competitive season.

To achieve the fitness requirements for tennis, a periodised approach is typically employed that alternates a progressive training load, followed by reduced loading leading into a competitive phase. Modifying training loads in this manner allows the adaptive systems to recover sufficiently to better express physical performance during a real competition [5]. Thus, it would be beneficial to profile the training loads (external and internal) of tennis players leading into a competition to assess the effectiveness of a periodised training programme for improving physical performance. Such information could also be used to

make necessary training adjustments to ensure that the balance between adaptive physiology and recovery is optimised before a competition.

Different tools have been used to assess how athletes cope with changes in training loads. For example, Moreira et al. [18] demonstrated that the cortisol level was augmented and the immunoglobulin A (IgA) secretion rate was reduced after 4 weeks of elevated training loads. In addition, a greater training load increased the negative perception of both the symptoms and sources of stress using the Daily Analysis of Life Demands for Athletes (DALDA) questionnaire [18]. Robson-Ansley et al. [22] also reported an elevation in plasma IL-6 and creatine kinase activity following 4 weeks of intensified training in endurance athletes. Furthermore, they detected an increase in the symptoms of stress using the DALDA, 1 week before the IL-6 and creatine kinase changes. In response to 6 weeks of intensified training, decreases in endurance capacity and jumping distance were also reported, with an increase in the stress symptoms [5]. Collectively, these findings suggest that training responses can be effectively monitored using questionnaires, hormones, and immune markers.

To date, relatively few reports have examined the training stressors imposed on young elite tennis players during pre-season and the subsequent impact on physical performance. In fact, a review of applied tennis physiology highlighted the need for more research in this area [13]. The monitoring of young athletes could provide valuable information for coaches and sports scientists regarding how an athlete is coping and adapting to different training stressors, thereby optimising the training outcomes by minimising the likelihood of injury, illness and overtraining.

Therefore, this study investigated the effect of a periodised pre-season training plan on internal training load, stress tolerance, immune-endocrine responses and physical performance in young tennis players. It was hypothesised that the temporal changes in external training loads (i.e. increasing across 4 weeks, 1-week tapering) would closely map the reporting of internal training loads and the weekly responses of the measured parameters, thereby leading to post-training improvement in physical performance.

MATERIALS AND METHODS

Subjects. Ten young tennis players were recruited for this study (mean \pm SD: age, 18.5 ± 0.4 years; height, 178 ± 4 cm; body mass, 72.4 ± 6.0 kg). Each player had at least 5 years of sport-specific training for tennis and they played at a highly competitive level (i.e. all were nationally ranked junior players). Throughout the experimental period, participants performed 8-10 sessions each week, which included resistance training, plyometrics, agility drills, sport speed and skill conditioning. All participants were considered healthy and injury-free after initial pre-screening. They each took part in this study after having the protocols explained to them and giving their written informed consent. The University's Ethics Committee approved the research protocol.

Experimental design

The study participants were monitored during the pre-season period, which was divided into 4 weeks of progressive overloading training and a 1-week tapering period. Pre- and post-training assessments were made for 1 repetition maximum (1RM) strength, endurance, jump height and agility, along with weekly measures of internal training load (session RPE), training monotony, training stress tolerance and salivary measures of immunoglobulin A (IgA), testosterone and cortisol concentrations. These are common measures of training stress and adaptive physiology [5,17,22] that could be easily implemented within the training procedures of the study population.

Periodised training plan

The training focus was on developing endurance, strength, power and agility during the experimental period (Table 1). In the first 2 weeks, the players completed additional interval-based endurance training sessions. These training sessions involved repeated running bouts (training at a low to moderate intensity) at distances of 400-1000 m. Sport-specific endurance was further developed in weeks 3 and 4 using interval-based running at shorter distances of 100-400 m, but performed at higher intensities than the previous training block. In addition, 4 weekly resistance training sessions were completed in the morning. In the first 2 weeks of the training period an endurance-hypertrophy programme was prescribed, whilst a maximal power programme was implemented in weeks 3, 4 and 5. For skill, agility and speed development, court-based training drills were completed during weeks 2, 3, 4 and 5. The intensity of these drills was greater in weeks 3, 4 and 5, as compared with week 2. In general, the training plan was characterised by high initial training volume and low intensity, and as training progressed, volume decreased and intensity gradually increased.

TABLE 1. DESCRIPTION OF TRAINING COMPLETED DURING THE 5-WEEK PERIOD

	Week 1	Week 2	Week 3	Week 4	Week 5
Resistance training					
Number of sets	21	28	25	25	15
Repetitions·set ⁻¹	20-15	12	6	6	6
Goal Intensity (%1-RM)	60%	70%	50%	30%	30%
Rest period	1 min	2 min	3 min	3 min	3 min
Sessions·week ⁻¹	4	4	4	4	2
Agility Speed training					
Number of sets	-	5	6	6	6
Repetitions·set ⁻¹	-	50	60	60	30
Goal Intensity	-	Moderate	All-out	All-out	All-out
Work-to-rest ratio	-	1:2	1:3	1:3	1:3
Sessions·week ⁻¹	-	1	3	3	2
Intermittent Training					
Reps x distance	5 x 1000 m	5 x 1000 m 5 x 400 m	10 x 400 m 10 x 200 m 10 x 100 m	10 x 400 m 10 x 200 m 10 x 100 m	-
Goal Intensity	Moderate	Moderate	High	High	-
Work-to-rest ratio	1:1	1:1;1:2	1:2;1:3	1:2	-
Distance·week ⁻¹	~15 km	~21 km	~21 km	~14 km	-
Sessions·week ⁻¹	3	3	3	2	-

The tapering week was completed using a step-wise format involving an immediate decrease in training volume, being ~50% of that prescribed in the preceding week, with the frequency of most training sessions also reduced by ~50% [19]. Two 'friendly' matches were also implemented during the tapering week, with the aim to mimic the demands of actual tennis matches. These simulated matches (best of 3 sets) were played in the afternoons against individuals of similar playing abilities. The resistance training programme continued in the tapering week, but the focus was on power development and only 2 morning sessions were performed during this period, and these were alternated with speed and agility sessions.

Weekly training measures

Internal training load

Internal training load was calculated using the session RPE method [8]. This method requires each athlete to provide a rating of perceived exertion (RPE; CR-10 scale) for each session. To do this, the players were asked a simple question 30 minutes after training: "How was your workout?" A training load score was calculated by multiplying the RPE value by the duration of training (in minutes). An index of training monotony was also obtained by dividing the mean daily training load by the standard deviation [8]. Data from all tennis and conditioning sessions were combined to provide an absolute training load score for each week of training.

Stress tolerance

Athlete stress response was assessed using the DALDA questionnaire [23], which was completed on the 1st (Baseline), 7th, 14th, 21st, 28th, and 35th day of this study. The DALDA questionnaire is divided into 2 parts, Part A and Part B, which represent the sources of stress and the symptoms of stress, respectively. The participants in this study were asked to rate each item in this questionnaire as "worse than normal", "normal" or "better than normal". The responses rated "worse than normal" were retained for analysis. Although it is advised that the DALDA be used on a daily basis or every other day, a weekly assessment was chosen to minimise disruptions to the athletes' schedules and to ensure a greater compliance rate. The DALDA has been used previously on a weekly basis without having its sensitivity diminished [22].

Pre- and post-training measures

Strength, agility, endurance and power testing was completed over 2 sessions (both pre- and post-training) after 2 days of complete rest following previous exercise. The first assessment was 1 repetition maximum (1RM) testing for strength using standard equipment and procedures [24]. After a warm-up, participants were tested for their 1RM lifts on the bench press and leg press exercises. A single repetition to failure protocol was used, in which the load was steadily increased over 3-4 attempts (separated by 3-minute rest) until the participant was unable to complete a full lift using a proper technique. To prevent injury and to provide verbal support, 2 trained spotters were always present during testing.

Running agility

The 40 m agility T-test was administered after the first strength test, using published methods [20]. The test distance was adapted from the original protocol (from 36.56 m to 40 m) to maintain its nature and characteristics, but without compromising the validity and reliability of the test. Each subject began with both feet behind a starting point and, after an audio signal, sprinted 10 m forward to touch a cone, then shuffled 5 m to the left and 10 m to the right, and then 5 m back to the left, before returning to the starting point. Electronic sensors (Photo-cell system, CEFISE[®], Brazil) were set 0.75 m above the floor and positioned 3 m apart facing each other on either side of the starting line. The clock started when the players passed the electronic sensors and it stopped when the players crossed the sensors' plane. This test has excellent reliability (ICC= 0.98) [20].

Running endurance

The Yo-Yo intermittent endurance test was performed after the second strength test, according to a previous method [4]. The test consists of repeated 20-m shuttle runs at progressively increasing speeds dictated by an audio bleep emitted from a CD player. Between each shuttle the players had a 5-s period of jogging around a marker placed 2.5 m behind the finishing line. Failure to achieve the shuttle run in time on 2 occasions resulted in termination of the test and the distance covered in the last complete successful shuttle was recorded and represented the test result. In this study, the player ran outdoors on a flat surface. The total distance covered was recorded in metres.

Jumping power

Squat jumps (SJ) and counter movement jumps (CMJ) were performed using previously described methods [15]. Following a standardised warm-up, 3 SJ and 3 CMJ trials were performed in a randomised order on a jump mat (Jump System Pro[®] – Cefise[®], Brazil). The SJ was performed as a concentric only movement, whereas the CMJ was performed as a coupled eccentric-concentric movement. The arms were kept akimbo to remove the effects of arm swing and a 2-min rest period was provided between efforts. Maximal vertical jump height (in cm) was determined and the best trial used for analysis. The jump mat provides valid measures of jump height compared to a criterion system ($r = 0.967$) [16]. Pilot testing indicated that the jump mat system also provides reliable measures (CVs < 2.0%).

Salivary hormone and immune markers

Saliva samples were collected at rest on the 1st (Baseline), 7th, 14th, 21st, 28th and 35th day of this study. To account for diurnal variation, the samples were collected at the same time on each day (8.00 am). Subjects abstained from food and caffeine products for at least 2 hours prior to saliva collection, and were required to rinse out their mouths with distilled water immediately prior. The participants were in a seated position, with eyes open, head tilted slightly forward, and making minimal orofacial movement. Unstimulated saliva was then collected into sterile 15-ml centrifuge tubes over a 5-minute period.

The saliva samples were frozen and stored at -80°C until assay. Testosterone and cortisol were each determined in duplicate using an enzyme-linked immunosorbent assay (Salimetrics[®], USA) according to the manufacturer's instructions. The testosterone to cortisol ratio was calculated from these data. Salivary IgA concentration was also measured by an enzyme-linked immunosorbent assay (Salivary Secretory IgA EIA, Salimetrics[®], USA), as per the manufacturer's instructions.

Statistical analyses

The distribution of the collected data was analysed by the Shapiro-Wilk test and Mauchly's test of sphericity. A one-way analysis of variance with repeated measures was used to compare the temporal

changes in the weekly measured variables and the pre- and post-training variables. When a significant main effect was identified, the Tukey HSD test was used as the post hoc procedure to determine the location of the significant result. Pearson's correlation coefficients were used to examine the relationships between the subjective (training load and symptoms of stress) and objective (hormones) markers across the training period, being 5 time points of observation and 10 subjects. The level of significance was set at $P < 0.05$.

RESULTS

Figure 1 shows that internal training load increased significantly during weeks 3 and 4 (vs. week 1), before returning to the baseline value at week 5 ($P < 0.05$). Training monotony remained relatively stable from weeks 1 to 3, from the baseline value, but decreased significantly in week 5 ($P < 0.05$).

Significant improvements (Table 2, $P < 0.05$) in bench press and leg press 1RM strength were identified post-training (vs. pre-training). Yo-Yo IE and agility performance also improved significantly from pre- to post-training ($P < 0.05$). There were no significant changes in SJ and CMJ height after training ($P > 0.05$).

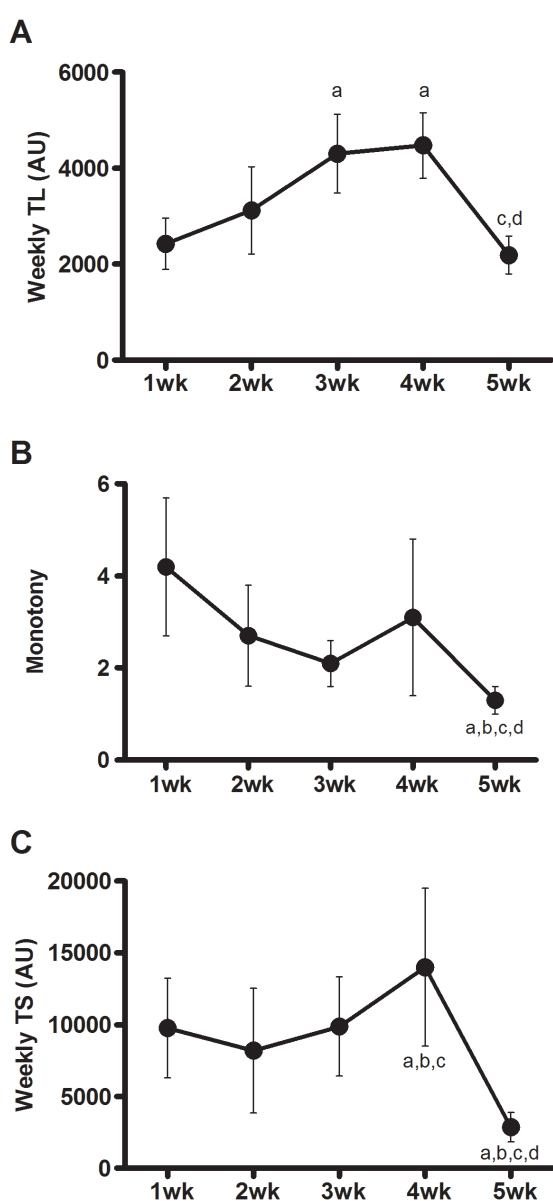


FIG. 1. WEEKLY TRAINING LOAD (1A), TRAINING MONOTONY (1B) AND TRAINING STRAIN (1C) OF TENNIS PLAYERS DURING THE 5-WEEK PRE-SEASON PERIOD

Note: a – different from week 1; b – different from week 2; c – different from week 3; d – different from week 4

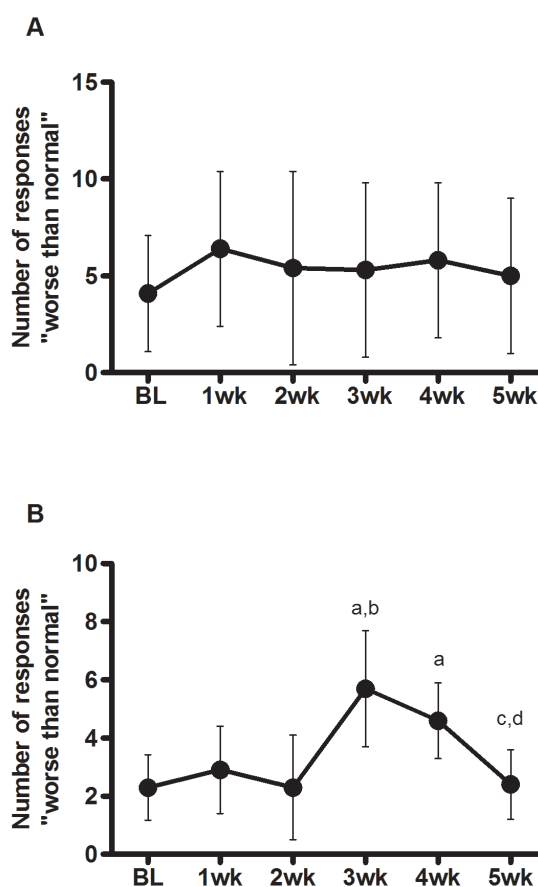


FIG. 2. DALDA SCORE INDICATING THE NUMBER OF RESPONSES "WORSE THAN NORMAL" TO SOURCE OF STRESS (2A) AND SYMPTOMS OF STRESS (2B) IN TENNIS PLAYERS DURING THE 5-WEEK PRE-SEASON PERIOD

Note: a – different from baseline (BL); b – different from weeks 1 and 2; c – different from week 3; d – different from week 4

TABLE 2. BENCH PRESS 1RM TEST (BP 1RM), LEG PRESS 1RM TEST (LP 1RM), CMJ TEST, SJ TEST, YO-YO TEST, T-TEST OF TENNIS PLAYERS DURING 5-WEEK PRE-SEASON

	Pre-training	Post training
BP 1RM (kg)	74.3 ± 16.3	81.0 ± 17.7*
LP 1RM (kg)	454.4 ± 78.9	507.8 ± 88.9*
Yo-Yo test (m)	894.4 ± 241.4	1104.4 ± 363.0*
T test (s)	9.99 ± 0.49	9.45 ± 0.47*
SJ (cm)	30.3 ± 5.5	30.8 ± 6.1
CMJ (cm)	33.4 ± 6.2	34.1 ± 6.2

Note: * Significantly different from pre-training; RM - repetition maximum; Yo-Yo test - Yo-Yo intermittent endurance test; T test - the 40 m running agility test; CMJ - counter movement jumps; SJ - Squat jumps

A significant increase in the symptoms of stress was noted in week 3 from baseline and week 1, with this measure then decreasing in week 5 from the preceding weeks ($P < 0.05$, Figure 2B). There was no significant change in the sources of stress over time ($P > 0.05$, Figure 2A).

A significant increase in salivary cortisol concentration was seen in week 4 (vs. baseline, $P < 0.05$, Figure 3A), returning to baseline in week 5. Conversely, the testosterone to cortisol ratio was lowered in weeks 3 and 4 (vs. baseline, $P < 0.05$, Figure 3C), before returning to baseline in week 5. Testosterone (Figure 3B) and IgA concentrations (Figure 3D) did not change across the study period ($P > 0.05$).

Significant correlations were detected between the internal training load and the endocrine responses (cortisol concentration; $r = 0.64$; $p < 0.05$ and testosterone to cortisol ratio; $r = -0.77$; $p < 0.05$) during the pre-season period. There were also significant correlations between the symptoms of stress and the cortisol level ($r = 0.71$; $p < 0.05$), as well for the symptoms of stress and the testosterone to cortisol ratio ($r = -0.68$; $p < 0.05$).

DISCUSSION

This study on young tennis players was undertaken to examine the effect of a periodised pre-season training plan on internal training load, stress tolerance, immune-endocrine responses and physical performance. The main findings were: 1) the periodised planning of external training load was mirrored by the internal training load in weeks 3, 4 (both increasing) and 5 (decreasing); 2) the changes in external training load were also accompanied by the symptoms of stress (increasing week 3, decreasing week 5), the salivary cortisol (increasing week 4, decreasing week 5) and the testosterone to cortisol ratio (increasing weeks 3 and 4, decreasing week 5); 3) the subjective markers of stress (internal training load and symptoms of stress) showed moderate correlations with the objective markers (cortisol and testosterone to cortisol ratio); and 4) the periodised training plan was effective in developing strength, endurance and agility of young tennis players.

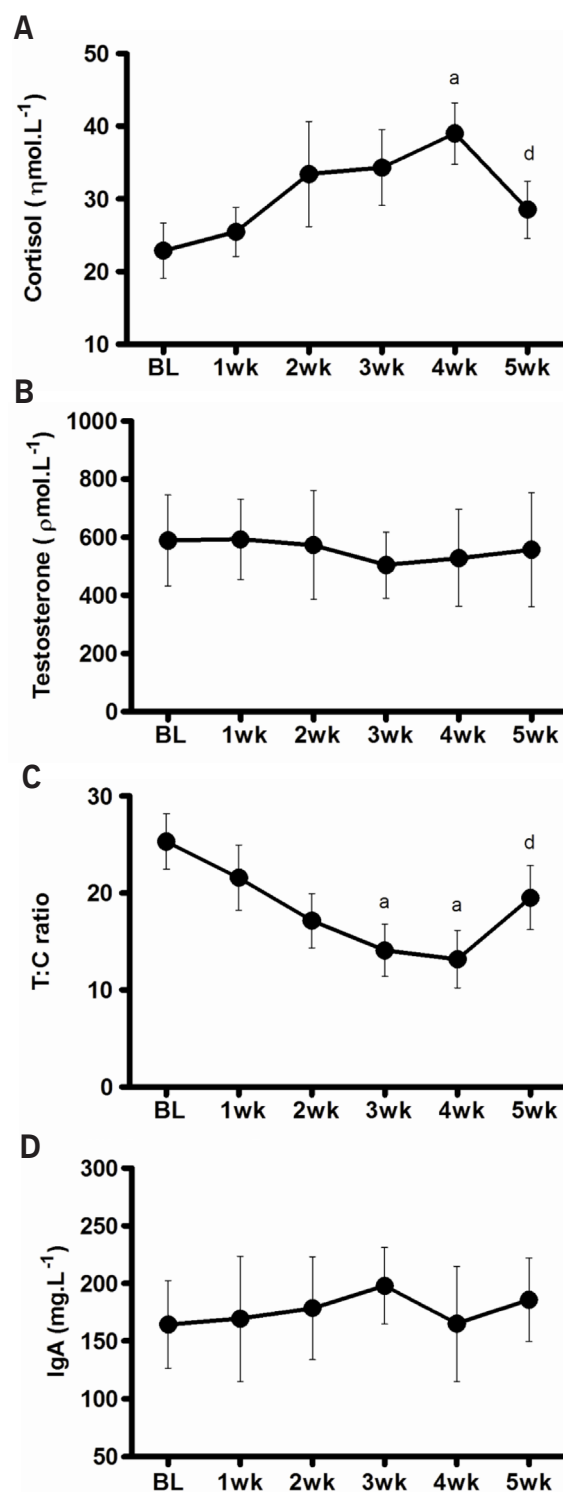


FIG. 3. CORTISOL (3A), TESTOSTERONE (3B), TESTOSTERONE:CORTISOL RATIO (3C), AND IGA (3D) OF TENNIS PLAYERS DURING THE 5-WEEK PRE-SEASON PERIOD

Note: a – different from baseline (BL); d – different from week 4

Consistent with the initial hypothesis, the overloading training phase (weeks 3 and 4) and subsequent 7-day tapering period (week 5) were mirrored by participant reporting of internal training loads from week 3 to 5. A number of investigations have highlighted the effective use of session RPE as a simple tool for monitoring

training loads in other sports such as soccer [2,10] and rugby league [12]. However, no other studies have attempted to quantify the training stressors imposed on young tennis players during a short pre-competition phase and the subsequent impact on different physical measures of performance capacity.

During the 4-week overloading period, the players demonstrated a worsening in symptoms of stress, indicated by the greater number of responses “worse than normal” in Part B of the DALDA. This part of the questionnaire is associated with “symptoms”, which reflect an athlete’s ability to cope with training stress. However, despite this increase in negative perception of stress, there was no significant change in the sources of stress across the study period. This is consistent with other studies that have reported an increase in the “symptoms of stress” following an intensified period of running training [1], which then returned to the previous value when the training load was reduced. Moreover, Robson-Ansley et al. [22] showed that the DALDA could detect an increase in stress level before any immunological change during an acute period of intensified running training in highly trained endurance athletes. More recently, Moreira et al. [18] noted that the number of responses “worse than normal” to symptoms of stress was increased during an intensified training period, which coincided with greater incidence of episodes of upper respiratory tract infections, in basketball players. Collectively, these findings support the use of the DALDA as a practical tool for monitoring training loads.

Salivary cortisol concentration and testosterone to cortisol ratio both mirrored the changes in training loads (from week 3 to 5). In fact, significant relationships were detected between the endocrine responses and the internal training load. As a common stress marker, it is not surprising that cortisol tended to increase with greater training load and decrease when loading was reduced, thereby driving the opposite trend in the testosterone to cortisol ratio. These findings have support from other studies [5,8,27], which suggest that such measures may be useful biological markers of training responses. When used as part of a multi-factorial monitoring programme, these measures may assist coaches making decisions regarding how a group or individual is responding to training.

The lower cortisol concentration after the tapering period and the absence of change in the immune mucosal function, in addition to the better stress tolerance state (fewer responses “worse than normal” as compared with week 3 and 4), indicated that the tennis players were in general good health before the competitive season. The significant correlation between the cortisol level and the symptoms of stress confirms the potential use of this hormone as a stress-related training marker. The lack of change in testosterone suggests that this measure is less sensitive for monitoring the training stressors faced by the young tennis players leading into a competition period. However, it is important to acknowledge some of the methodological limitations in the present study (i.e. 1 sample per testing day, lack of control data), which do not allow the analysis of circadian variation.

Varying the training loads and recovery in the pre-season period is conducive to achieving optimal physical performance [19]. In this study, the tennis players showed improvements in endurance, strength and agility, confirming that their overall physical fitness benefited from the periodised training plan. Other investigators have affirmed that elite athletes need to increase training loads during a certain phase of periodisation followed by a tapering period (characterised by a reduction in training load) to achieve desirable adaptations [5]. The absence of change in the jump test was unexpected and could be attributed, in part, to the ‘interference phenomenon’ [9]. That is, the concurrent training of power, strength and endurance (along with other physical qualities) might compromise the development of one or more of these areas. Whilst the research is equivocal on this topic [3,9,14], the mechanisms associated with power production seem to be the most affected by concurrent strength and endurance training [14].

Tennis match play is characterised by intermittent activities, alternating short bouts (4–10 s) of high-intensity exercise and short (10–20 s) recovery periods, with longer rest periods of 60 to 90 s [7,13]. These activity profiles include brief sprints, accelerations and frequent changes in direction, indicating that physical qualities such as strength and endurance, but in particular agility and speed, are relevant to successful performance in tennis competition. The observed improvements in T-test agility, 1RM strength and Yo-Yo endurance confirmed that the young tennis players entered the competitive season in a better physical condition when compared to the beginning of the training plan. It is also possible that the post-training improvement in performance was, in part, mediated by concomitant changes in psychological and hormonal states, as indicated by the adaptive changes in stress tolerance, cortisol and testosterone to cortisol ratio. The appropriate management of training loads during successive competitions and at different periods of the playing season is another area for future research.

Salivary IgA concentration did not change with training, which is consistent with previous studies [21,25,26]. Tiollier et al. [26] reported that despite an increase in upper respiratory tract infection incidence after a 3-week period of military training, followed by an intensive 5-day combat course, salivary IgA was unchanged. No change in IgA was also seen after 21 days of intensified training in trained male cyclists [25] and after 3 months of swimming training [21]. A significant decrease in mucosal immunity may only be observed during periods of intense unaccustomed training and when accompanied by extreme psychological stress. For instance, Jemmott et al. [11] reported a reduction in IgA with chronic psychological stress and Deiner et al. [6] showed that sustained periods of psychological stress can also reduce IgA. Along these lines, Moreira et al. [17] demonstrated a reduction in IgA level in both athletes and staff members during a 17-day preparation period for an international basketball championship. However, since multiple factors other than training and psychological stress can affect sIgA (sleep, food, climate, etc), it is likely that these factors may not have been sufficiently perturbed to affect the immune status of the young tennis players in this study.

CONCLUSIONS

The periodised training plan evoked similar weekly changes in external and internal training loads in young tennis players. The observed modifications in training loads resulted in adaptive changes in stress tolerance, cortisol concentration and testosterone to cortisol ratio, which may have mediated the post-training improvement in physical performance. These findings confirm the effectiveness of a simple periodised training plan (initial overloading and then tapering with a step-wise format) for improving the performance capacity of young tennis players. Moreover, these data support the use of the session RPE and DALDA as practical and accessible tools for monitoring training. Hormonal profile could also provide a useful measure of training responses. When used as part of a multi-factorial

monitoring programme, these psychometric and physiological measures may assist coaches making decisions regarding how a group or individual is responding to training.

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Conflict of interest: None declared

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