Effect of 3-week progressive overloading and 1-week tapering on performance, internal training load, stress tolerance and heart rate variability in under-19 Brazilian badminton players

Gabriel H.O. de Araujo[1], Diego H. Figueiredo[1], Diogo H. Figueiredo[1], Alessandra P. Kauffman[1], Cecília S. Peserico[2], Fabiana A. Machado[1,2,3]

[1]Associate Post-graduate Program in Physical Education UEM/UEL, Department of Physical Education, State University of Maringá, Maringá - PR, Brazil. [2]Department of Physical Education, State University of Maringá, Maringá - PR, Brazil. [3]Post-graduate Program of Physiological Sciences, Department of Physiological Sciences, State University of Maringá, Maringá - PR, Brazil.

doi: 10.18176/archmeddeporte.00090

Received: 20/01/2022
Accepted: 12/05/2022

Summary

Objective: This study aimed to determine the effect of 3-week progressive overloading and 1-week tapering during a pre-season on performance, internal training load, stress tolerance, and heart rate variability in under-19 Brazilian badminton players.
Material and method: Eight male under-19 badminton players (age 16.1 ± 0.6 years; height 1.68 ± 7.7 m; body mass 57.2 ± 5.8 kg; body mass index 20.3 ± 2.5 kg·m^{-2}; body fat 8.0 ± 2.7 %), competing at the state level had physical and physiological monitored over four weeks during pre-season. Players underwent a badminton-specific movement agility test, 5-m multiple shuttle test, Yo-Yo Intermittent Recovery test level 1, and performed vertical jumps before and after the pre-season. During the training, the heart rate variability and internal training load were monitored daily, and weekly were stress tolerance was recorded by psychometric responses.
Results: The players showed significant improvements in all performance variables assessed after the training period. The internal training load during overloading was higher (1635 ± 109.9; 2490 ± 124; 2850 ± 210 AU) compared to tapering (1335 ± 100 AU). The stress tolerance decreased during overloading (4.0 ± 0.7; 8.2 ± 1.3; 10.1 ± 1.4) and increased during tapering (5.5 ± 1.5). In addition, higher internal training load during overloading resulted in a greater reduction in root-mean-square difference of successive R-R intervals (lnRMSSDmean) (4.2 ± 0.2; 4.1 ± 0.1; 4.0 ± 0.1 ms) and a smaller coefficient of variation (lnRMSSDcv) (4.5 ± 2.6; 2.1 ± 1.2; 1.4 ± 0.9 %), and the significant reduction in the internal training load during tapering led to a decrease in lnRMSSDmean (1.3 ± 0.5 ms).
Conclusions: Our results suggest that using badminton training programs during the pre-season, including intermittent high-intensity actions with progressive overloading followed by a tapering is sufficient to result in positive adaptations in performance and led to adaptative changes in internal training load, stress tolerance, and heart rate variability.

Key words:
Performance. Autonomic nervous system. Periodization. Monitoring.

Efecto de la sobrecarga progresiva de 3 semanas y la reducción gradual de 1 semana sobre el rendimiento, la carga de entrenamiento interno, la tolerancia al estrés y la variabilidad de la frecuencia cardíaca en jugadores brasileños de Bádminton menores de 19 años

Resumen

Objetivo: Este estudio tuvo como objetivo determinar el efecto de la sobrecarga progresiva de 3 semanas y la reducción gradual de 1 semana durante una pretemporada sobre el rendimiento, la carga de entrenamiento interno, la tolerancia al estrés y la variabilidad de la frecuencia cardíaca en jugadores de bádminton brasileños menores de 19 años.
Material y método: Ocho jugadores masculinos de bádminton sub-19 (edad 16,1 ± 0,6 años; altura 1,68 ± 7,7 m; masa corporal 57,2 ± 5,8 kg; índice de masa corporal 20,3 ± 2,5 kg·m^{-2}; grasa corporal 8,0 ± 2,7 %), que competían a nivel estatal fueron monitoreados en sus aspectos físicos y fisiológicos durante cuatro semanas en la pretemporada. Los jugadores realizaron un test de agilidad específico de bádminton, el test 5-m multiple shuttle test, el test Yo-Yo y realizaron saltos verticales antes y después de la pretemporada. Durante el entrenamiento, se monitoreó diariamente la variabilidad de la frecuencia cardíaca y la carga interna de entrenamiento. Además, semanalmente se registró la tolerancia al estrés mediante respuestas psicométricas.
Resultados: Los jugadores mostraron mejoras significativas en todas las variables de rendimiento evaluadas después del período de entrenamiento. La carga de entrenamiento interna durante la sobrecarga fue más grande (1.635 ± 109,9; 2.490

Correspondence: Cecília Segabinazi Peserico
E-mail: ceciliapeserico@gmail.com

± 124; 2.850 ± 210 AU) en comparación con la última semana de cargas reducidas (1.335 ± 100 AU). La tolerancia al estrés disminuyó durante la sobrecarga (4,0 ± 0,7; 8,2 ± 1,3; 10,1 ± 1,4) y aumentó durante la última semana (5,5 ± 1,5). Además, las altas cargas del entrenamiento interno durante la sobrecarga resultaron en una gran reducción en la diferencia de la raíz cuadrada media de intervalos R-R sucesivos (lnRMSSDmean) (4,2 ± 0,2; 4,1 ± 0,1; 4,0 ± 0,1 ms) y un coeficiente de variación más pequeño (lnRMSSDcv) (4,5 ± 2,6; 2,1 ± 1,2; 1,4 ± 0,9 %), y la reducción significativa en la carga de entrenamiento interno durante la última semana condujo a una disminución en lnRMSSDmean (1,3 ± 0,5 ms).

Conclusión: Nuestros resultados sugieren que el uso de programas de entrenamiento de bádminton durante la pretemporada, que incluyen acciones intermitentes de alta intensidad con sobrecarga progresiva seguida de una semana de cargas reducidas, es suficiente para dar como resultado adaptaciones positivas en el rendimiento y condujo a cambios adaptativos en la carga de entrenamiento interno, en la tolerancia al estrés y en la variabilidad de la frecuencia cardiaca.

Palabras clave:
Rendimiento. Sistema nervioso autónomo. Periodización. Supervisión.

Introduction

Badminton has been characterized as a high-intensity sport that combines intermittent actions of very intense anaerobic exercises with changes in direction and longer lower-intensity periods of aerobic exercises[1,2]. Due to these demands, a high level of speed, coordination, agility, strength, and explosive jumps are required from badminton players[1-3].

The pre-season is considered as a period to develop positive physiological adaptations that maximize physical components (*e.g.*, maximum strength and power, speed, and agility), which are required for the competitive season[4-6]. A strategy that usually occurs during this period involves phases of deliberate overloading (OL), followed by a tapering period (TP) that consist of a gradual reduction in the training load (TL)[4,6]. However, this requires careful individual TL monitoring in an attempt to balance periods of stress and recovery, leading to an increase in performance. Thus, it is important that coaches use physiological, psychological, and performance parameters for measurement and control TL to obtain information on how athletes are responding to different training stressors[5-7].

Among the measures used to effectively estimate the internal training load (ITL), the session rating of perceived exertion (sRPE) is considered a practical and valid method that demonstrated high correlations with physiological and psychological parameters[7,8]. Furthermore, changes in ITL are associated with changes in stress levels during training programs[7,9]. In this context, previous studies have demonstrated that measures of stress tolerance (ST) evaluated using the daily analysis of life demands for athletes (DALDA) questionnaire[10] are sensitive to increases and decreases in the ITL[4,7,9], reflecting some positive adaptations[6,7]. In addition to sRPE and DALDA, another important physiological measure used to monitor ITL in different sports is heart rate variability (HRV), which is typically characterized by decreases during periods of higher TL, with increases following periods of lower TL, mirroring recovery, which leads to improvements in performance[4,11,12].

Some studies involving racquet sports sought to monitor the TL and training effects using tools, such as sRPE, DALDA, heart rate (HR), and physical tests[6,13,14]. Gomes *et al.*[6] when monitoring the ITL and ST of young tennis players during the pre-season, found an increase in stress symptoms in the weeks with higher ITL values, generating adaptive changes in the ST assessed by the DALDA questionnaire. In addition, Moreira *et al.*[14] monitored the training of 12 professional tennis players based on the sRPE and the HR methods and verified an even distribution for low and moderate intensities zones, but relatively few sessions in high intensity zone. However, specifically with badminton training, previous studies aimed to test the effectiveness of complementary training programs by assessing the performance variables of the players[15,16], or to monitor a training period using HR and blood markers (*e.g.*, lactate, creatine kinase)[16,17]. Moreover, no study involving badminton players used physical tests, sRPE, DALDA, and HRV to monitor training responses and changes in performance. Thus, we are not aware of studies that clarify adaptive physiology responses during periods of badminton training, especially during the pre-season.

Concerning badminton training, coaches should incorporate periodization models during the pre-season that effectively lead to performance improvements and keep players in an optimal condition to compete[1,15,16]. Therefore, this study aimed to determine the effect of 3-week progressive OL and 1-week TP during the pre-season on performance, ITL, ST and HRV in under-19 Brazilian badminton players. The hypothesis is that the training period improves the performance of the players and that ITL, ST and HRV are different between the training phases.

Material and method

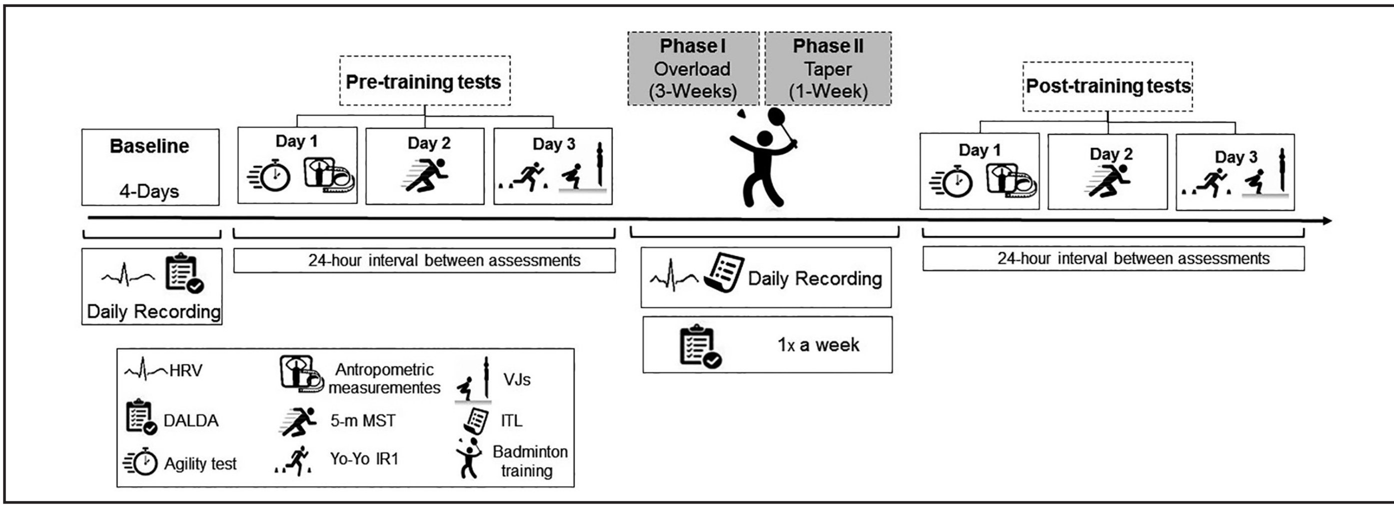
Participants

Eight male under-19 Brazilian badminton players (age 16.1 ± 0.6 years; height 168 ± 7.7 cm; body mass 57.2 ± 5.8 kg; body mass index (BMI) 20.3 ± 2.5 $kg \cdot m^{-2}$; body fat 8.0 ± 2.7%), competing at state level volunteered to participate in this study. For a participant's data to be included in the final analysis, the following criteria were adopted: (a) completion of 100% of the training sessions during the pre-season; (b) completion of the sRPE to determine the ITL and DALDA questionnaire to determine the ST; (c) completion HRV daily before each training session; and (d) have no injuries during the training period. Before the study, the participants and their parents were informed about the testing and training procedures, possible risks involved, and provided written informed consent. This study was approved by the Human Research Ethics Committee. All research was conducted ethically according to Helsinki declaration.

Design

The experimental protocol consisted of a baseline (BL) period of 4 days during which DALDA and HRV were measured daily. After the

Figure 1. Schematic representation of the experimental design.



Note: HRV: heart rate variability; DALDA: daily analysis of life demands for athletes questionnaire; 5-m MST: 5-m multiple shuttle test; Yo-Yo IR1: Yo-Yo intermittent recovery test level I; VJs: vertical jumps; ITL: internal training load.

BL, participants performed the following tests with an interval of 24 h between trials: anthropometric measurements and badminton-specific movement agility test (day 1); 5-m multiple shuttle test (5-m MST) (day 2); vertical jumps tests (VJs) and Yo-Yo Intermittent Recovery test level 1 (Yo-Yo IR1) (day 3). These tests were repeated after the end of the training program following the same procedures. The pre-season training program consisted of two phases. The phase I consisted of a 3-week progressive OL, and the phase II consisted of a 1-week TP. During both phases, HRV and ITL were monitored daily, and DALDA questionnaire evaluated at the end of each training week. The experimental protocol is illustrated in Figure 1.

Procedures

Badminton-specific movement agility test

The test to determine agility was performed with specifics badminton movements using the protocol described previous by Ooi *et al.*[3]. Each participant had 10 min to complete own specific warm-up and two submaximal efforts on the badminton-specific movement agility test. The test was performed on a single badminton court with standardized measures, and required players to perform rapid sideways and diagonal movements with abrupt changes in direction to touch the shuttlecocks with their hands. The test had two phases, in which the players should position themselves in the central base of the court to start and return with at least one foot to the center of the court to validate their execution during and at the end of the test.

The first phase was performed with sideways agility movements, in which the players had to move laterally across the width of the court for a total of 10 repetitions in order to strike each up-turned shuttlecocks placed at each corner. There were five shuttlecocks on each side of the court on the lateral line at a distance of 30 cm between them. In the second phase of the test, there were four shuttlecocks positioned diagonally in the four corners of the court within the service zones with a distance of 30 cm between them. In this phase, the players moved diagonally in a sequence of four different directions for a total of 16 repetitions. Between the phases the players had five minutes for recovery. The execution time was monitored by a manual stopwatch adjusted by the evaluator; a visual analysis of the movement was performed to verify if the participant was performing displacements with specific Badminton movement. For the data analysis, the duration times of phase 1 and phase 2 were added and it was considered as the total time performance[3].

5-m multiple shuttle test (5-m MST)

The 5-m MST was performed according to the methods described by Boddington *et al.*[18] to determine sprint performance. Each participant had 10 min to complete own specific warm-up and two submaximal efforts of the 5-m MST. For this test, six cones were placed 5 m apart from each other in a straight line to cover a total distance of 25 m. The test consisted of six sprints with a change of direction, with run time of 30 s sprint and 35 s recovery time between sprints. To start the test, players positioned themselves in the first cone and upon an auditory signal they sprinted 5 m to a second cone, touched the ground with one hand and returned to the first cone. Then, they sprinted 10 m to a third cone and back to the first cone, etc., until 30 s. The players should accumulate the greatest possible distance within the 30 s execution time. The performance was determined by the total distance (m) (the total distance covered during the 6 × 30-s sprints/shuttles)[18].

Vertical jumps (VJs)

Performances in VJs were measured using an electronic platform (Jump System Pro 1.0 Cefise®, Nova Odessa-SP, Brazil), equipment designed to determine contact time and vertical jump flight time[19]. Participants performed three different vertical jump tests: Squat Jump (SJ), Countermovement Jump (CMJ), and Countermovement Jump with arms help (CMJA). Before testing, the players performed self-administered submaximal CMJs and SJ as warm-up. In the SJ test, the participants were crouched isometric with his hands on his waist, at the signal of the evaluator performed the jump. In the CMJ tests, the participants stood on the mat, fully erect with his hands positioned at the waist; at the signal of the appraiser, he squatted quickly and then made the jump. Finally, in the CMJA participants followed the same recommendations of the CMJ test but used the aid of the arms to propel themselves. All tests were performed three times, with an interval of 10 s between repetitions and the highest value obtained of height (cm) was used as the performance for analysis[19].

Yo-Yo intermittent recovery test level I (Yo-Yo IR1)

The Yo-Yo Intermittent Recovery Test Level I (Yo-Yo IR1) protocol was conducted according to procedures of the established methods[20]. This test consisted of 20-m shuttle runs performed at increasing velocities, with 10 s of active recovery between runs until voluntary exhaustion. The test was controlled by audio beeps located immediately adjacent to the 20-m long running lanes indicated by markers. The test was considered ended when the participant twice failed to reach the front line in time (objective evaluation) or the participant felt unable to complete another shuttle at the dictated speed. The total distance covered (m) during the Yo-Yo IR1 was considered as the testing score[20].

Internal training load (ITL)

The sRPE method was adopted to measure ITL[21]. Thirty minutes after the end of each training session, players were asked to report RPE for the intensity of the session using the CR-10 scale[22]. To determine ITL, expressed in arbitrary units (AU), the product of session duration (minutes) and sRPE score (CR-10) rated by the player was used. The duration of the training sessions was recorded from the start (warm-up) to the end of the session (cool-down). The weekly-accumulated ITL was calculated intra-individually for the analysis. From the ITL data, strain and monotony were calculated weekly. Monotony was calculated by dividing the average load of the week by the standard deviation, while the strain was calculated by multiplying the monotony by the weekly sum of training loads[21].

Stress tolerance (ST)

To evaluate ST, the Portuguese version[23] of the DALDA questionnaire[10] was filled out daily during BL and at the end of each training week. Although it has been suggested that DALDA be used on a daily basis, it was previously used on a weekly basis without having its sensitivity diminished. The DALDA is divided into parts A (9 questions) and B (25 questions), which represents the sources and symptoms of stress respectively. The possible answers for each item are "better than normal", "normal" and "worse than normal". For each training session, the sum of the scores marked as "worse than normal" of the questionnaire was recorded for analysis.

Heart rate variability (HRV)

All HRV measures were performed daily during BL and before each training session. The same conditions were maintained during each HRV measurement. HRV was recorded with a portable heart rate monitor (RS800cx Polar®, Kempele, Finland), previously validated for this purpose[24]. After allowing 1 min for stabilization, HRV were measured for 1 min[25] in a quiet environment, with the participants in a standing position. These data were then downloaded to Polar Pro-trainer 5 software (Polar Electro Oy®, Kempele, Finland). Occasional artefacts and non-sinus beats were replaced with the interpolated adjacent normal cycle. Subsequently, the data were analysed using specialized HRV analysis software (Kubios HRV Analysis®, version 3.0 Biomedical Signals Analysis Group, University of Kuopio, Finland). The vagally mediated HRV parameter used for analysis was the logarithm of the root-mean square difference of successive R-R interval (lnRMSSD). Since lnRMSSD is considered consistent under paced and spontaneous breathing[26], all HRV recordings were completed under spontaneous-breathing conditions. The intra-individual weekly mean (lnRMSSDmean) and its coefficient of variation (lnRMSSDcv) were calculated for the analysis. The lnRMSSDcv was calculated as follows: $CV = ([SD/mean] \times 100)$.

Training program

The training program consisted of four weeks of traditional badminton training during the pre-season (*i.e.*, general preparatory) divided into two phases (3-week OL, and 1-week TP). Each training week included three training sessions lasting 117.8 ± 7.6 min. The training focus was on developing resistance, strength, power, mobility, repeat sprints, speed, agility, coordination and pattern movements. Table 1 displays the weekly training microcycles from the training program. Badminton practice sessions (BP) involved the development of technical and tactical skills in conjunction with pattern movement's exercises and anticipation skills during all weeks. Additionally, the agility, coordination, flexibility and lower and upper limb power development, court-based drills were completed during the BP.

Specific resistance training (RT) was performed, involving the multi-shuttle feeding (*i.e.*, shuttlecock control) and continuous displacements in game situations[27]. During RT the players hit eight shuttles which were fed by the trainer. The shuttle feeding was standardized with the trainer serving the shuttles with a badminton racket a frequency of 8 shuttlecocks every 15 s was standardized as described by Wee *et al.*[27]. Sprint-agility training (SAT) was performed daily over all training weeks, requiring participants to complete sprints with specific movement on the court (four points). The number of sprints was gradually increased

Table 1. Microcycle structure during the badminton pre-season training.

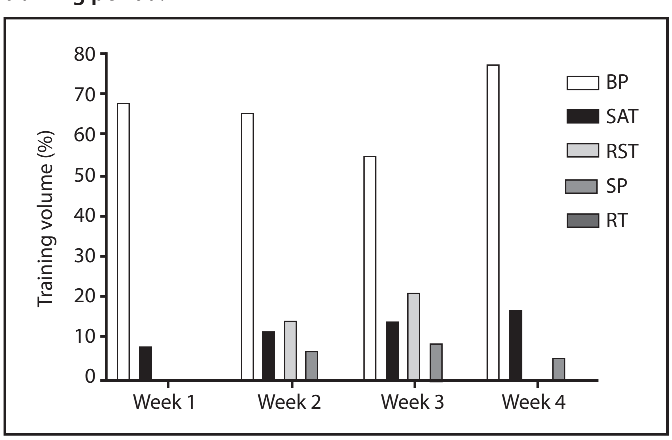
	Week 1	Week 2	Week 3	Week 4
Monday	BP, RT, SAT	BP, SAT, RST	BP, SAT, RST	BP, BP, SAT
Tuesday	—	—	—	—
Wednesday	BP, SAT	BP, SAT, SP	BP, SAT, SP	BP, SAT, SP
Thursday	—	—	—	—
Friday	BP, RT, SAT	BP, SAT, RST	BP, SAT, RST	BP, SAT

Note: RT: Specific resistance training; BP: Badminton practice session; SAT: Sprint agility training in court; RST: Repeat sprint training; SP: Speed training; —: rest.

Table 2. Description of the specific badminton training program during the 4-week pre-season.

	Week 1	Week 2	Week 3	Week 4
Sprint-Agility training (SAT)				
Repetitions	7 to 9 × 20 s	9 to 11 × 20 s	11 to 13 × 20 s	13 to 15 × 20 s
Goal intensity	All-out	All-out	All-out	All-out
Rest period between repetitions	10 s	10 s	10 s	10 s
Repeated sprint training (RST)				
Number of sets	-	2	3	-
Repetitions	-	4 × 30 s	4 × 30 s	-
Goal intensity	-	High	All-out	-
Rest period between repetitions	-	35 s	35 s	-
Rest period between sets	-	3 min	2.30 min	-
Speed training (SP)				
Number of sets	-	3	3	2
Repetitions	-			
	-	5 × 10 m	8 × 10 m	4 × 10 m
		4 × 20 m	6 × 20 m	3 × 20 m
Goal intensity	-	High	All-out	High
Rest period between repetitions	-	20 s	40 s	20 s
Rest period between sets	-	2 min	3 min	2 min
Specific Resistance training (RT)				
Number of sets	3	-	-	-
Repetitions	10 x 15 s			
Goal intensity	High	-	-	-
Rest period between repetitions	30 s	-	-	-
Rest period between sets	1 min	-	-	-

Figure 2. Description of the training volume (%) during the 4-week training period.



RT: Specific resistance training; BP: Badminton practice session; SAT: Sprint agility training in court; RST: Repeat sprint training; SP: Speed training; —: rest.

from seven to 15 during the 4-week training period as described by Waklate *et al.*[15]. A maximal power program was implemented in weeks two and three, which included a repeated sprint training (RST), and speed training (SP), prescribed based on the 5-m MST protocol[18]. During week four, the volume of SP was decreased by decreasing the number of sets while training intensity was maintained. Conditioning program details (i.e. RT, SAT, RST and SP) are displayed in Table 2, the volume of the training program is detailed in Figure 2.

Statistical analysis

Statistical procedures were performed using the software Statistical Package for the Social Sciences (SPSS® v 23.0 for Windows, Inc, Chicago, IL, USA). Data normality was verified by the Shapiro-Wilk test and the data are showed as mean ± standard deviation (SD). The sphericity was tested with Mauchly`s test and Greenhouse-Geisser corrections were made when assumptions of sphericity were violated. One-way analysis of variance for repeated measures (ANOVA) followed by the Bonferroni *post-hoc* test was used to evaluate differences in ITL, monotony, strain, ST values and HRV parameters across the training weeks. To evaluate differences in performance variables from pre to post training intervention a paired-sample t test was used. Additionally, the percentage change value (%) was calculated for each variable. The level of significance was set at $P < 0.05$ for all statistical analysis.

Results

Table 3 shows the results of SJ, CMJ, CMJA, badminton-specific movement agility test, 5-m MST and Yo-Yo IR1 pre- and post-training. There were significant improvements in all variables pre- to post-training.

Figure 3 demonstrates the ITL, monotony, and strain during the 4-weeks. The ITL increase in week two and three (2490 ± 124 and 2850 ± 210 AU, respectively) compared to week one (1635 ± 109.9 AU). These variables decreased significantly during week four (1335 ± 100 AU) when compared to all training weeks. Regarding monotony, there was no changes during week two and four (1.85 ± 0.1 and 1.63 ± 0.2

Table 3. Mean ± standard deviation (SD) and change (%) for performance variables at pre- and post-training (N = 8).

Variables	Pre-training	Post-training	% Change	*P*
SJ (cm)	33.2 ± 6.2	34.7 ± 5.4*	5.2 ± 6.3	0.048
CMJ (cm)	35.0 ± 6.5	37.1 ± 5.6*	6.6 ± 7.1	0.028
CMJA (cm)	41.1 ± 8.2	43.5 ± 7.8*	6.4 ± 5.7	0.012
Agility test (s)	57.5 ± 5.1	54.4 ± 3.9*	-5.3 ± 3.2	0.003
5-m MST (m)	556.5 ± 75.8	685.6 ± 72.8*	21.9 ± 12.1	<0.001
Yo-Yo IR1 (m)	737.5 ± 239.4	1065 ± 337.3*	49.5 ± 47.3	0.011

SJ: Squat Jump; CMJ: Counter Movement Jump; CMJA: Counter Movement Jump with arms help; 5-m MST: 5-m Multiple Shuttle Test; Yo-Yo IR1: Yo-Yo Intermittent Recovery test level 1. *: Significantly different from pre-training.

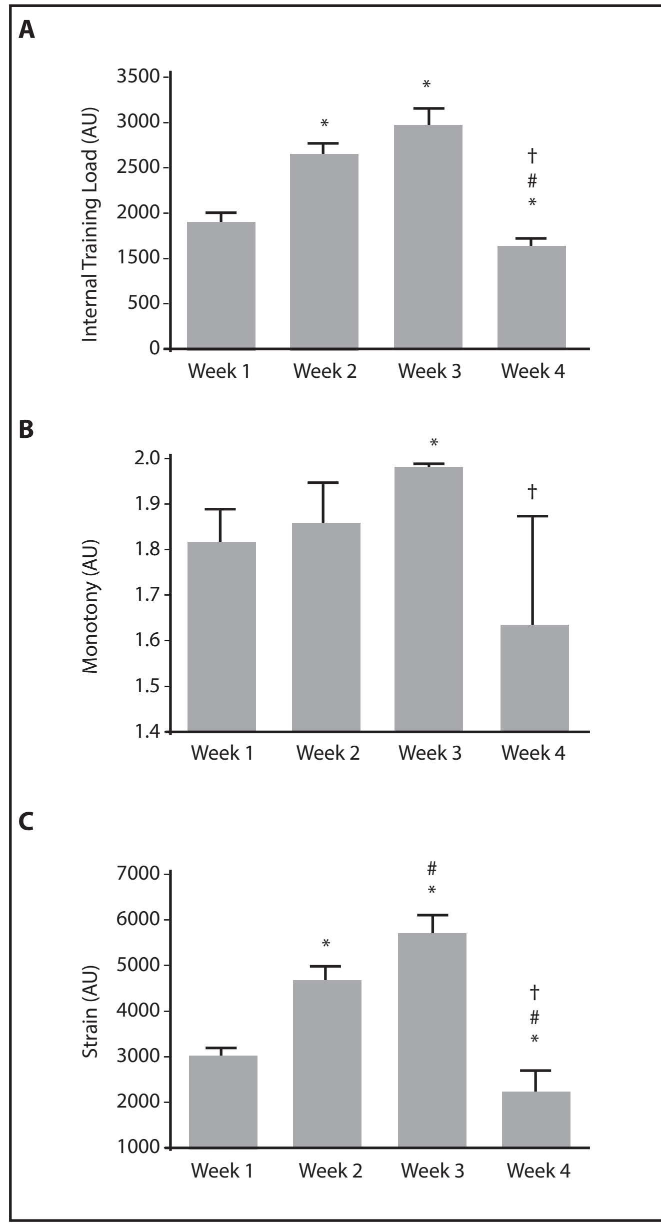
AU, respectively) compared to week one (1.81 ± 0.1 AU), with higher values during week three (2.0 ± 0.0 AU) compared to week one and two. In addition, training monotony was lower during week four (1.63 ± 0.2 AU) when compared to week three (2.0 ± 0.0 AU). Significant increases in training strain were found during week two and three (4615 ± 333 and 5621 ± 419 AU) compared to week one (2962 ± 216 AU), with a significant decrease during week four (2192 ± 447 AU) compared to all training weeks (Figure 3).

Table 4 presents the results of lnRMSSDmean, lnRMSSDcv and DALDA "worse than normal" scores during BL and throughout the training weeks. When compared to BL, reduction in lnRMSSDmean was significant only during week four. In addition, lnRMSSDmean was significantly lower during week three compared with week two. During week four, lnRMSSDmean was significantly lower compared to all weeks of training. Regarding to lnRMSSDcv, there was a significantly reduction during week three compared to week one, while reduction in week four were found when compared to BL and week one. DALDA "worse than normal" scores progressively increased until week three compared to BL, with a decreased during week four compared to week two and three.

Discussion

The aim of this study was to determine the effect of 3-week progressive overloading and 1-week tapering during a pre-season on performance, internal training load (ITL), stress tolerance (ST), and heart rate variability (HRV) among under-19 badminton players. The main findings were as follows: an improvement in all performance variables

Figure 3. Overall internal training load (A), monotony (B) and strain (C) in arbitrary units (AU) during the 4-week training period (N = 8).



* P < 0.05 compared to week 1; # P < 0.05 compared to week 2; † P < 0.05 compared to week 3.

Table 4. Mean ± standard deviation (SD) for lnRMSSDmean, lnRMSSDcv and DALDA "worse than normal" score during baseline (BL) and throughout training weeks (N = 8).

Variable	BL	Week 1	Week 2	Week 3	Week 4
$lnRMSSD_{mean}$ (ms)	4.2 ± 0.2	4.2 ± 0.2	4.1 ± 0.1	4.0 ± 0.1 †	3.9 ± 0.1*, #, †, ‡
lnRMSSDcv (%)	2.7 ± 1.2	4.5 ± 2.6	2.1 ± 1.2	1.4 ± 0.9 #	1.3 ± 0.5 *, #
DALDA "worse-than-normal"	2.5 ± 0.5	4.0 ± 0.7 *	8.2 ± 1.3 *, #	10.1 ± 1.4 *, #, †	5.5 ± 1.5 *, †, ‡

Note: lnRMSSDmean, weekly mean log-transformed root-mean square difference of successive R-R intervals; lnRMSSDcv, coefficient of variation of weekly log-transformed root-mean square difference of successive R-R intervals; DALDA, daily analysis of life demands for athlete's questionnaire.

*: P < 0.05 compared to BL; #: P < 0.05 compared to week 1; †: P < 0.05 compared to week 2; ‡: P < 0.05 compared to week 3.

after the pre-season, the ITL during OL was higher compared to that during the TP, and the ST decreased during OL and increased during TP. In addition, a higher ITL during OL resulted in a greater reduction in lnRMSSDmean and a smaller lnRMSSDcv, and the significant decrease in ITL during the tapering period led to a decrease in lnRMSSDmean. These results confirm the initial hypothesis of the study.

According to previous research, it is suggested that a badminton training program should address intensities and actions that resemble the competitive reality[2,15]. Thus, it is essential that the physical preparation of badminton players consist of repetitive high-intensity actions of short duration combined with actions of agility, speed, and VJs[2,3,28]. The training program of the present study not only addressed the development of anaerobic power and aerobic endurance, but also sought to promote improvements in the agility, speed, and VJs, which are variables associated to the technical complexity and tactic of badminton players[3,15,28].

In the present study, the pre-season training led to significant improvements in VJs, badminton-specific movement agility test, Yo-Yo IR1 and 5-m MST performances. Similar to our findings, Gomes *et al*.[6] investigated the effect of four weeks of progressive OL training and a 1-week TP during the pre-season on ITL, ST, immune-endocrine responses, and physical performance in 10 young tennis players was investigated. In addition, similarly to the present study, agility-speed exercises and high-intensity intermittent actions were prescribed. The authors identified significant improvements in the Yo-Yo IR1 and agility T-test as found in our results; however, Gomes *et al*.[6] did not identify a significant increase in VJs (*e.g*., SJ and CMJ), which was different from our findings.

Regarding the badminton investigations Waklate *et al*.[15] investigated whether supplementing regular group training with short sessions of badminton-specific agility-sprint training conferred any greater changes in performance than regular training alone during a 4-week pre-season in 12 elite badminton players. The supplementary training group reported improvements in the 300-m shuttle run (2.4 ± 2.7%) and in the badminton sprint protocol (3.6 ± 2.6%); however, the control group did not show significant improvements in any performance variable, which was different our findings. It is important to mention that Waklate *et al*.[15] did not evaluate the aerobic power and VJs of the players. Wee *et al*.[16] investigated the effects of four weeks of high-intensity intermittent badminton multi-shuttle complementary training on the performance variables of 18 university badminton players, the authors reported significant improvements in $\dot{V}O_{2max}$, mean power, leg reactive strength, and agility in the experimental group. However, the control group with regular badminton training showed no improvement in all performance variables.

The training strategy used in the present study sought to integrate specific and general physical exercises[15,16], within a strategy that is characterized by an OL in weeks one to three, followed by a TP during the week four. Concerning the analysis of the training intensity distribution based on the sRPE method, the data showed that ITL at weeks two and three and were higher compared to week one, followed by a significant reduction in week four. Similar to our findings, Gomes *et al*.[6] using a similar training intervention during the pre-season led to a progressive increase in the ITL in 4-weeks (≈ 2000 - 4500 AU), followed by a significant reduction in week five (≈ 2000 AU) that promoted improvements in performance of tennis players.

It is known that despite the risk of nonfunctional overreaching or even an overtraining syndrome, high ITL during the pre-season are necessary to generate positive adaptations and increases in performance[13], which was proven in the present study. Moreover, our results demonstrated that the ITL and strain were aligned with the planned OL and TP training weeks. This finding is in agreement with previous studies that identified a relationship between strain and changes in ITL in racket sports[6,13]. The decrease in ITL and strain identified in the week four is related to the programmed TP strategy.

It is important to mention that the balance between strain and recovery can determine the benefits of the training; thus, monitoring measures related to fatigue (*i.e*., physiological and psychometric variables) can predict symptoms of overtraining and stress during a training period[7,13]. In our study, we identified a decrease in ST during the OL period compared to the BL, indicated by the greater number of "worse than normal" responses from DALDA questionnaire; changes in the DALDA score of "worse than normal" responses are related to adaptive changes in the ST[4,6,7,13]. Similar ST responses were reported by Gomes *et al*.[6] identified decreases in ST, during OL, indicated by the greater number of "worse than normal" responses from DALDA; followed by an improvement during TP in tennis players during the pre-season. These results confirm that DALDA is a sensitive tool that detects changes in ITL as previously reported[4,7]. However, no previous study sought to monitor ST responses to ITL changes in badminton players.

Concerning the HRV results, we found no changes in lnRMSSDmean during the first 2-weeks of OL, but found increases in lnRMSSDcv during the first week OL and a decrease during the second week of OL. In addition, during the TP, lnRMSSDmean and lnRMSSDcv decreased. It is important to emphasize that no study with racquet sports investigated HRV responses during the pre-season, especially during badminton training. These findings during OL are similar to a previous study with female soccer players, which demonstrated that lnRMSSDcv increases with no changes in lnRMSSDmean during a period of increased ITL[29]. Thus, it seems that the badminton players from the present investigation were not able to cope well with the initial TL. The decrease in lnRMSSDcv during the week two of OL was similar to a previous study with rugby sevens athletes during a second exposure to higher ITL, which the authors interpreted as a reflection of an improved ability to maintain cardiac autonomic homeostasis even when ITL is intensified[30].

Furthermore, during the week three of OL and during TP a decrease in lnRMSSDcv and lnRMSSDmean was found. These results could be related to the increases in anaerobic workload imposed during weeks two and three. It has been shown that parasympathetic reactivation is highly impaired after repeated sprint training, which is associated with an increase in plasma metabolites and a higher sympathetic activity[31]. The results found during TP are in contrast with previous studies, which demonstrated increases in lnRMSSDmean coupled with decreases in lnRMSSDcv values after reductions in the ITL[29,25]. However, despite the increase in ST found during TP, we suggest that the reduction in ITL in the last week of training was not sufficient to reestablish the ST and lnRMSSD values of the players in relation to the baseline value[4,29,32], or was due to some of the persisting effects of fatigue or the inadequate recovery from the higher TLs weeks.

The small sample size in the present study could be considered as a limitation. However, it can be explained by the fact that in Brazil badminton is an incipient modality making it difficult to carry out studies with a large number of players with a higher competitive level. In addition, there are few studies in the literature related to the training and performance of badminton players; therefore, the comparisons in the present study are limited to other modalities. The lack of performance tests at the end of the OL phase could be considered another limitation, which in turn would provide more data related to the effects of increased ITL on performance, ST, and HRV responses.

Conclusions

Four-week pre-season improved performance in under-19 badminton Brazilian players and the periodized training program evoked a progressive increase in ITL during OL, followed by a significant reduction during TP. Furthermore, modifications in ITL resulted in adaptive changes in ST, indicated by the DALDA questionnaire, and in HRV, demonstrated by the fluctuations in the values of lnRMSSDmean e lnRMSSDcv. Monitoring individual ITL in conjunction with ST and lnRMSSD responses can provide valuable information that leads coaches to strategically manipulate ITLs individually. The results of the present study provide new information on the performance testing and monitoring of ITL, ST, and HRV in under-19 badminton players during a pre-season, which can help coaches to prescribe badminton training programs more successfully.

Acknowledgements

The authors would like to acknowledge to the participants of the present study and Ph.D. Alessandro Moura Zagatto for supplied the equipment. This research was kindly logistic supported by Maringaense Association of Badminton and Parabadminton, (Maringá, PR - Brazil). The results of the current study do not constitute endorsement of the products by the authors or the journal.

Conflict of interest

The authors do not declare a conflict of interest.

Bibliography

1. Phomsoupha M, Laffaye G. The science of badminton: game characteristics, anthropometry, physiology, visual fitness and biomechanics. *Sports Med.* 2015;45:473-95.
2. Madsen CM, Badault B, Nybo L. Cross-sectional and longitudinal examination of exercise capacity in elite youth badminton players. *J Strength Cond Res.* 2018;32:1754-61.
3. Ooi CH, Tan A, Ahmad A, *et al.* Physiological characteristics of elite and sub-elite badminton players. *J Sports Sci.* 2009;27:1591-9.
4. Figueiredo DH, Figueiredo DH, Moreira A, Gonçalves HR, Stanganelli LC. Effect of overload and tapering on individual heart rate variability, stress tolerance, and intermittent running performance in soccer players during a preseason. *J Strength Cond Res*. 2019; 33:1222-31.
5. Figueiredo DH, Moreira A, Gonçalves HR, Dourado AC. Dose-response relationship between internal training load and changes in performance during the preseason in youth soccer players. *J Strength Cond Res.* 2021;00:1–8.
6. Gomes RV, Moreira A, Lodo L, Nosaka K, Coutts AJ, Aoki MS. Monitoring training loads, stress, immune-endocrine responses and performance in tennis players. *Biol Sport.* 2013;30:173.
7. Halson SL. Monitoring training load to understand fatigue in athletes. *Sports Med.* 2014;44:139-47.
8. Haddad M, Stylianides G, Djaoui L, Dellal A, Chamari K. Session-RPE method for training load monitoring: validity, ecological usefulness, and influencing factors. *Front Neurosci.* 2017;11:612.
9. Heidari J, Beckmann J, Bertollo M, *et al.* Multidimensional monitoring of recovery status and implications for performance. *Int J Sports Physiol Perform.* 2019;14:2-8.
10. Rushall BS. A tool for measuring stress tolerance in elite athletes. *J Appl Sport Psychology.* 1990;2:51-66.
11. Flatt AA, Esco MR, Nakamura FY, Plews DJ. Interpreting daily heart rate variability changes in collegiate female soccer players. *J Sports Med Phys Fitness.* 2017;57:907-15.
12. Flatt AA, Hornikel B, Esco MR. Heart rate variability and psychometric responses to overload and tapering in collegiate sprint-swimmers. *J Sci Med Sport.* 2017;20:606-10.
13. Fernandez-Fernandez J, Sanz D, Sarabia JM, Moya, M. The effects of sport-specific drills training or high-intensity interval training in young tennis players. *Int J Sports Physiol Perform*. 2016;12:90-8.
14. Moreira A, Gomes RV, Capitani CD, Lopes CR, Santos AR, Aoki MS. Training intensity distribution in young tennis players. *Int J Sports Sci Coach*. 2016;11:880–6.
15. Waklate BM, O'Brien BJ, Paton CD, Young W. Supplementing regular training with short-duration sprint-agility training leads to a substantial increase in repeated sprint-agility performance with national level badminton players. *J Strength Cond Res*. 2009; 23:1477-81.
16. Wee EH, Low JY, Chan KQ, Ler HY. Effects of specific badminton training on aerobic and anaerobic capacity, leg strength qualities and agility among college players. *Sport Sci Res Tec Support*. 2016;192-203.
17. Yang Y. Application of serum CK and BUN determination in monitoring pre-competition training of badminton athletes. *J Huazhong Univ Sci Technology Med Sci.* 2007;27:114-6.
18. Boddington MK, Lambert MI, Gibson ASC, Noakes TD. Reliability of a 5-m multiple shuttle test. *J Sports Sci*. 2001;19:223-8.
19. Loturco I, Pereira LA, Kobal R, et al. Validity and usability of a new system for measuring and monitoring variations in vertical jump performance. *J Strength Cond Res.* 2017;31: 2579-85.
20. Bangsbo J, Laia FM, Krustrup P. The Yo-Yo intermittent recovery test. *Sports Med*. 2008; 38:37-51.
21. Foster C, Florhaug JA, Franklin J, *et al.* A new approach to monitoring exercise training. *J Strength Cond Res.* 2001;15:109-15.
22. Borg GA. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc.* 1982;14: 377-81.
23. Moreira A, Cavazzoni PB. Monitoring training due portuguese versions of wisconsin upper respiratory symptom survey-21 and daily analysis of life demands in athletes. In Portuguese. *J Phys Educ/UEM*. 2009;20:109-19.
24. Williams DP, Jarczok MN, Ellis RJ, Hillecke TK, Thayer JF, Koenig J. Two-week test–retest reliability of the Polar® RS 800 CX™ to record heart rate variability. *Clin Physiol and Funct Imaging.* 2017;37:776-81.
25. Nakamura FY, Flatt AA, Pereira LA, Ramirez-Campillo R, Loturco I, Esco, MR. Ultra-short-term heart rate variability is sensitive to training effects in team sports players. *J Sports Sci Med.* 2015;14:602-5.
26. Saboul D, Pialoux V, Hautier, C. The impact of breathing on HRV measurements: Implications for the longitudinal follow-up of athletes. *Eur J Sport Sci.* 2013; 13:534-42.
27. Wee EH, Low JY, Chan KQ, *et al.* Effects of specific badminton training on aerobic and anaerobic capacity, leg strength qualities and agility among college players. *icSPORTS.* 2017;975:192-203.
28. Phomsoupha M, Laffaye, G. Multiple repeated-sprint ability test with four changes of direction for badminton players (part 2): Predicting skill level with anthropometry, strength, shuttlecock, and displacement velocity. *J Strength Cond Res.* 2020;34:203-11.
29. Flatt AA, Esco, MR. Smartphone-derived heart-rate variability and training load in a women's soccer team. *Int J Sports Physiol Perform*. 2015;10:994-1000.
30. Flatt AA, Howells D. Effects of varying training load on heart rate variability and running performance among an Olympic rugby sevens team. *J Sci Med Sport.* 2018;22:222-6.
31. Buchheit M, Laursen PB, Ahmaidi, S. Parasympathetic reactivation after repeated sprint exercise. *Am J Physiol Heart Circ Physiol.* 2007;293:H133-H141.
32. Flatt AA, Hornikel B, Esco MR. Heart rate variability and psychometric responses to overload and tapering in collegiate sprint-swimmers. *J Sci Med Sport.* 2017;20:606-10.