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Beyond Training Load: Integrated Assessment of Physiological Adaptations, Physical Fitness, and Training Stress in Adolescent Soccer Players

Heart Rate Variability in Training Load Monitoring

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ABSTRACT: **Background**: Intense conditioning protocols are essential to achieve performance gains in soccer. However, inter-individual variability and insufficient recovery period can induce performance decline and overtraining in players. It is important to assess training load (TL) alongside the heart rate variability (HRV) of soccer players to monitor training adaptation status. The primary objective of this investigation was to assess the influence of TL on HRV, cardiorespiratory variables, and physical capabilities in adolescent soccer players.

Methods: Eighty male volunteers (age:12-14 years) were recruited in this study and allocated into two distinct cohorts: Sedentary Control Group (SCG, n= 40) and Soccer Players Group (SPG, n =40). The SPG underwent a training program (12 weeks); SCG volunteers were engaged in recreational pursuits. Body morphology, physical abilities, cardiorespiratory variables and HRV were assessed at the beginning (0 week), mid intervention (8 week) and post intervention (12 week) of the study. Training load was measured at mid and post intervention. Repeated-measures ANOVA, with subsequent Bonferroni post hoc test and Pearson's correlation were applied.

Results: A notable elevation ($p<0.05$) in HRV (SDNN, RMSSD, Total power), VO2max, muscle strength, speed, lung function; alongside marked reduction ($p<0.05$) in LF/HF ratio, heart rate, SBP, body fat content were observed in SPG. HRV showed negative and positive association with TL and VO2max respectively.

Conclusion: An improvement in HRV, strength and cardiorespiratory variables indicate success of training program. It is important to assess training load which helps to reduce overtraining and design modified training regimens.

1. INTRODUCTION

Soccer (football) players require enhanced endurance, anaerobic fitness strength, speed, technical and tactical skills [1]. Moreover, their mental balance and decision making during the match can alter the performance [2]. To achieve these skills, soccer players undergo high intensity training. However, adaptations to training vary in different individuals. Training load beyond body's coping ability may cause detrimental health and performance effect. Adolescent soccer players are susceptible

to overtraining due to improper periodization of training and recovery [3]. Therefore, monitoring of players for training adaptations and load is essential to identify the signs of overtraining and fatigue in players [4].

Cardiorespiratory endurance helps player to perform better and sustain longer time in field. It is also important for highly intensive efforts and quick recovery between intermittent bouts [5]. Assessments of cardiorespiratory variables along with training load can ensure that current training plan is capable of enhancing aerobic capacity without increasing the risk of physiological stress [6]. Moreover, strength and speed is essential for dribbling, running, ball manoeuvres, directional change in field. Body morphological characteristics such as body fat content, muscle mass impacts strength and speed performance [7]. Adolescent players may experience fluctuation in body morphology and strength due to growth spurts [8]. Therefore, it should be ensured that accumulated training stress are causing positive adaptations without increasing fatigue [9]. HRV can indicate training stress in players. It is a non-invasive way to check sympathovagal balance [10]. Previous investigations suggest parasympathetic dominance after the intervention, is associated with enhanced training adaptation and recovery [11]. Moreover, diminution in LF/HF spectral ratio indicates a shift towards parasympathetic domain [12].

Previous studies have demonstrated autonomic and physical responses to training-associated load. However, there is a need for this type of assessment among Indian soccer players of adolescent age group throughout different regions. It is essential to understand the interaction of training load with physical motor abilities, HRV, body morphology, and cardiopulmonary determinants in adolescents. This may explain how training plan should be formed to perfectly distribute load. Therefore, this investigation was conceptualized to check the efficacy of training-associated stress on body morphology, HRV, physical motor abilities, and cardiorespiratory determinants in adolescent male soccer players.

2. MATERIALS AND METHODS

2.1 Participant Characteristics and Sample Estimation

The current research was carried out at the Department of Physiology within the Midnapore College Research Centre (Science) at Midnapore College (Autonomous), affiliated to Vidyasagar University in West Bengal, India. To determine the appropriate number of subjects, G*Power software (V.3.1.9.7) was applied [13]. Following inpust were incorporated: the type I error probability was capped at 0.05; it was coupled with statistical power of 0.95. The effect size selected as 0.40 due to findings of earlier studies. The experimental framework of this study was incorporated in the software as two distinct cohort evaluated across three intervals.This generated a minimum total sample of 52 participants. To avoid statistical concerns due to withdrawal, total ninety male adolescents (aged 12-14 years) from West Midnapore district were randomly recruited. Four subjects were dismissed due to health problems and six because of absence from training and testing. Rest of them were divided into two distinct cohorts: Sedentary Control group (SCG, n=40) and Soccer Players Group (SPG, n=40).

2.2 Experimental Design

To familiarize participants with the training and testing protocols, their recruitment was done 15 days prior to the beginning of the intervention. Both cohorts were instructed to abstain from any other supplementary exercise or physical activity. Assessments of body morphology, physical capacities, cardiorespiratory fitness and HRV was done at baseline (0 week), mid-intervention (8 week) and post intervention (12 week). Training load of SPG were measured for all individual weeks (Figure 1).

2.3 Training: The SPG group received structure soccer specific training programme (Table 1 and 2) for five days per week, two hours each day, for three months duration. Training was provided by trained coaches. However, the SCG cohort did not participate in the conditioning but they were engaged in recreational pursuits.

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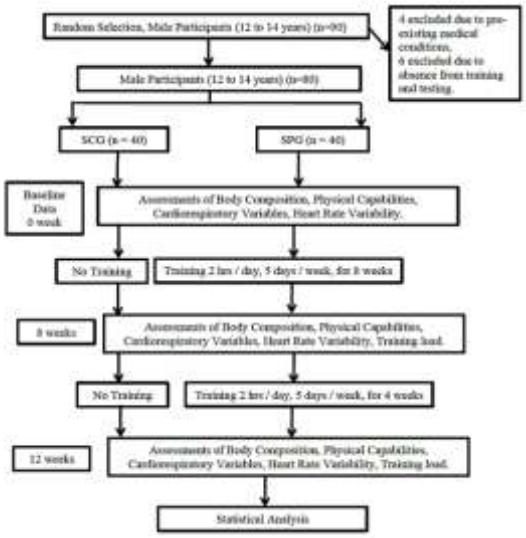

Figure 1: Experimental Design

Table 1: Phases of Training.

Phases of Training			Baseline	Preparatory (8 weeks)		Competitive (4 weeks)	
Sub-Phases			Zero level baseline	General Preparation *(Physical Preparation)*	Specific Preparation *(Technical & Tactical)*	Pre-Competition (PC)	Main Competition
Periodization	Strength		—	Anatomical adaptation	Maximal Strength	Conversion / Power	Maintenance
	Endurance		—	Aerobic	Anaerobic	Specific / Ergogenesis	Maintenance
	Speed		—	Specific high	Specific high / Alactic	Specific	Maximum / Competition
	Skills		—	Foundation	Advanced	Simulation	Competition
Macro / Mesocycles			0 weeks	2–4 weeks *(Mesocycle 1)*	5–8 weeks *(Mesocycle 2)*	9–10 weeks *(Mesocycle 3)*	11–12 weeks *(Mesocycle 4)*
Training Factors	Volume	100%	—	80–90%	70–90%	70%	60–70%
	Intensity	90%	—	70–80%	80–90%	80%	80–90%
	Peaking	80%	—	70–75%	70–75%	80%	>90%
	Physical Preparation	70%	—	50–55%	40–45%	30%	30%

	Technical Preparation	60%	—	40–45%	40–45%	35%	35%
	Tactical Preparation	50%	—	10%	10%	35%	35%
	Psychological Preparation	40%	—	10%	10%	20%	30–35%

Table 2: 12 Week Training Schedule for Soccer Players.

Day	Preparatory Phase: General	Preparatory Phase: Specific	Pre-Competition	Competitive Phase: Main
Mon	Warm-up, Skills, Endurance: 2000m, 30m hurdles 4 reps (75–85% HR), Strength: Sit/push/squat 3x12-15 (75–80% HR), Tactical, Small Sided Games, Cool Down	Warm-up, Endurance: 1000m, hurdles 3 reps, HIIT 3 reps (85–95% HR), Skills, Tactical, Match Practice(11v11), Cool Down	Warm-up, Endurance: Positional running (85–95% HR), Skills, Tactical, Match Practice(11v11), Cool Down	Warm-up, Endurance: Aerobic recovery (75–80% HR), Skills, Tactical, Match Practice(11v11), Cool Down
Tue	Warm-up, Speed: 20m x4, 100m x1, ball sprints x3 (85–90% HR), Skills, Tactical, Match Practice(11v11), Cool Down	Warm-up, Speed: 20m x5, 100m x1, ball sprints x4 (90–95%+ HR), Strength: Sit-up 3x20, push-up 3x15, squat 4x8 (85–90% HR), Skills, Tactical, Small Sided Games, Cool Down	Warm-up, Speed: 20m x4, 100m x1, ball sprints x3 (90–95% HR), Skills, Tactical, Match Practice, Cool Down	Warm-up, Speed: 20m x3, 100m x1, ball sprints x3 max speed (95%+ HR), Skills, Tactical, Small Sided Games, Cool Down
Wed	Warm-up, Skills, Endurance: 2500m, hurdles 3 reps (75–85% HR), Strength: Sit-up 3x15, push-up 4x12, squat 3x15 (75–80% HR), Tactical, Small Sided Games, Cool Down	Warm-up, Endurance: 1000m, 30m shuttle 8 reps (85–95% HR), Skills, Tactical, Match Practice(11v11), Cool Down	Warm-up, Endurance: 1000m, 150m HIIT 3 reps (85–95% HR), Strength: Sit-up 3x20, plyo push 3x12, broad jump 3x10 (85–95% HR), Skills, Tactical, Match Practice(11v11), Cool Down	Warm-up, Endurance: 1000m, 100m HIIT 5 reps (80–90% HR), Skills, Tactical, Match Practice(11v11), Cool Down
Thu	Active Rest: Light jog (<70% HR), Mobility, Tactical board, Relaxation	Active Rest: Light jog (<70% HR), Mobility, Tactical board, Relaxation	Active Rest: Light jog (<70% HR), Mobility, Tactical board, Relaxation	Active Rest: Light jog (<70% HR), Mobility, Tactical board, Relaxation
Fri	Warm-up, Skills, Endurance: 1500m, HIIT 4 reps (75–85% HR), Strength: Sit/push/squat 3x15 (75–80% HR),	Warm-up, Speed: 20m x4, 100m x1, ball sprints x3 (90–95%+ HR), Strength: Adv core 4x20, push/squat 3x15 (80–90% HR), Skills,	Warm-up, Speed: 20m x4, 100m x1, ball sprints x3 (90–95% HR), Skills, Tactical, Small Sided Games, Cool Down	Warm-up, Speed: 20m x3, 100m x1, ball sprints x3 (90–95% HR), Skills, Tactical,

	Tactical, Small Sided Games, Cool Down	Tactical, Small Sided Games, Cool Down		Small Sided Games, Cool Down
Sat	Warm-up, Speed: 20m x4, 100m x1, ball sprints x4 (85–90% HR), Skills, Tactical, Match Practice(11v11), Cool Down	Warm-up, Endurance: 30m sprints 6 reps (85–95% HR), Skills, Tactical, Match Practice (11v11), Cool Down	Warm-up, Speed: 20m x3, 100m x1 (85–90% HR), Match Practice (11v11), Cool Down	Warm-up, Match Practice (Competitive 90min) (85–95% HR), Cool Down
Sun	Complete Rest	Complete Rest	Complete Rest	Complete Rest

2.4 Ethical approval and Clinical Trial Permission

Written consents were obtained from guardians of the subjects. They were fully briefed on the potential complications of the investigation. Ethical Clearance for this study was granted by the Institutional Ethics Committee (Human Studies) at Midnapore College (Autonomous) (Ref. No.: MC/IEC (HS)/PHY/Ph.D.RF/03/2023; Date: 23.09.2023). The study protocol is recorded in the Clinical Trials Registry of India, under the accession number CTRI/2025/08/093534.

2.5 Measurements

2.5.1 Measurement of Body Morphology, Physical Capacities and Cardiorespiratory Variables

The height and body mas of participants were estimated to evaluate body mass index [14]. A (Cescorf, USA) skinfold calliper was used to acquire skin folds to determine body adiposity percentage [14], to determine total adipose tissue and lean body mass [15].

Estimation of hand grip was performed utilizing hand grip dynamometer (Baseline, USA). For this the subjects had to hold the dynamometer and the handle was adjusted according to their grip span. Their elbow was flexed at right angle, keeping the forearm in a neutral stance. The wrist was at slight extension. At this position, they were asked to squeeze the handle for five seconds with maximum strength. Hand grip strength was noted with an accuracy of ten grams [16]. Similarly, estimation of muscular strength at leg and back portions were conducted utilizing a back and leg dynamometer (Baseline, USA). For back strength, the subject stood on the dynamometer platform keeping their feet spread at the designated place. Then the chain length of the attachment bar was calibrated according to their reach. Then the subjects were instructed to pull the bar upward with a supinated grip. This pull was with maximal force, which lasted five seconds. This exertion was done avoiding sudden jerking and torso bending. Similarly, leg strength was estimated by adjusting subject's posture. For this, subjects had to stand on the platform keeping their knees flexed at one hundred and ten degrees. The as per their reach, the chain length was calibrated. They were instructed to stand upright with a forward gaze. Then they had to pull the attachment bar with maximal force, while trying to straighten the leg against the resistance. It was ensured that, the force exertion was without jerks or spinal bending. All these estimations were repeated for three times and maximum value was noted with an accuracy of ten grams [16]. To quantify sprinting speed a thirty-meter acceleration test was conducted on a ground with slip-resistant surface. Following ten seconds warm up, the participants stood at starting line with a stationary stance. The participants started running after receiving auditory signal. They had to sprint towards a designated distance with maximal exertion. Any form of jumping and rolling was not allowed in this assessment [17]. For determining lower back and hamstring flexibility of the participants, a Sit and Reach Test box (Baseline, USA) was utilized. Following an initial warm-up, the participants sat on the floor barefoot, with their lower leg completely extended. Both feet were positioned flat against the wall of the box. The box had a slider calibrated to zero. The subjects placed one hand over another and kept the fingertips on the slider. Then they flexed their trunk to slide the indicator. The flexion was without jerks and knee bending. The final position of the slider provided the estimate of the flexibility with a precise measurement of fifty millimetres [18].

Following fifteen minutes of inactivity in supine position, an (Omron, Japan) electronic sphygmomanometer was used to measure blood pressure [19], and baseline heart rate was recorded via Polar H10 chest strap (Polar, Finland) [20]. The Level 1 variant of the Intermittent Recovery Yo-Yo assessment was deployed to determine maximum aerobic capacity [21]. For this

assessment, a twenty-five meter non slip ground surface was marked with cones. It had two zones, a twenty-meter running zone and a five-meter recovery zone. The participants had to run forty-meter shuttles repeatedly with ten seconds of recovery. They had to follow auditory cue for the run and the recovery. Until, a participant felt exhaustion or missed designated marker twice, the assessment was continued. The total distance sprinted was logged to estimate maximum aerobic capacity using predefined formulations [21]. The maximum and recovery heart rates were recorded during this field test using the heart rate monitor [22]. When the subjects were exhausted during this test, their maximum heart rate was recorded. Then recovery heart rates were noted in next three consecutive minutes. A digital portable spirometer (Care Fusion, Japan) was employed to estimate the lung function capabilities of the subjects [23].

2.5.2 Evaluation of HRV

First the subjected rested for 15 minutes in supine condition. Then 5 minutes of supine HRV recording was obtained through a Polar H10 chest strap (Polar, Finland). This evaluation was conducted during 7:00-8:00 AM in a dark room to avoid circadian disruptions. The room temperature was also regulated (24-27 degree Celsius). The SPG participants were directed to abstain from physical exertion at least 2 days before the assessments. The data from chest trap were wirelessly transferred to the Elite HRV software (Elite HRV, USA). The RR intervals were exported to the Kubios HRV software (V-3.5.0, Finland) [24, 25]. Ectopic beats and artifacts were filtered using the software's automatic correction feature. The baseline trends in the recoding were also excluded by this software. Then the temporal and spectral indices of the HRV session was incorporated for analysis.

2.5.3 Assessment of Training Load

Training load was also assessed by the conventionally established rate of perceived exertion (RPE) questionnaire along with modified Category Ratio-10 scale. Here, the RPE score and training time (two hours) denote internal training intensity and volume respectively. All 12 weeks training load, monotony and strain were assessed applying standardized calculations [26, 27]:

Training load = Session RPE × Duration.

Monotony = Average weekly training load ÷ Standard deviation of the weekly training load.

Training Strain = Monotony × Average weekly training load.

2.6 Data Analysis Strategy

IBM SPSS software (V.27) was utilized for all assessments. Data distribution and normality were assessed through the Shapiro-Wilk test. To examine the interaction and primary effects of both group and time, a repeated-measures ANOVA was executed alongside Mauchly's test to check sphericity. Whenever sphericity assumptions were not met, the degrees of freedom were adjusted through the Greenhouse-Geisser and Huynh-Feldt corrections. Then, post hoc analyses including Bonferroni adjustments were done to identify within-group variations. However, cross-cohort comparisons were assessed by independent sample t-test. Partial Eta Squared (η^2p) was computed which indicates main effect size. It is the magnitude of observed changes among parameters. Directional correlations between parameters were computed utilizing Pearson's correlation. The variations in training load metrics were evaluated through a one-way ANOVA along with Bonferroni adjustments. The significant threshold was determined at $\alpha = 0.05$ [28].

3. RESULTS AND DISCUSSION

3.1 Assessment of Body Morphology and Motor Physical Ability

There were no statistically distinct differences between SCG and SPG body morphology variables. The body adiposity percentage and fat mass of the SPG diminished at both the midpoint and upon completion of the study ($p<0.05$). But after the intervention in weight, BMI, and lean body mass elevated among the SPG ($p<0.05$). In case of physical capabilities, the grip, leg and back muscle strength elevated successfully ($p<0.05$) at mid and post intervention in SPG. Similarly, the flexibility also improved after training. Sprint time subsequently diminished ($p<0.05$) among SPG in mid and post intervention indicating increase in speed. However, no such alterations were exhibited by SCG (Table 3).

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Table 3: Effects of Training on Body Morphology and Physical Ability Variables of Adolescent Soccer Players

Parameter	SCG (n=40)			SPG (n=40)			F Value (p value) [η^2p]		
	0 Week	8 Week	12 Week	0 Week	8 Week	12 Week	Group	Training	Interaction
Height (cm)	151.04 ± 5.36	151.04 ± 5.34	150.97 ± 5.46	151.30 ± 5.95	151.26 ± 5.90	151.13 ± 5.97	0.03 (0.87) [0.00]	3.35 (0.06) [0.04]	0.43 (0.57) [0.01]
Weight (Kg)	45.10 ± 4.70	45.09 ± 4.63	45.19 ± 4.51	44.74 ± 4.89	45.31* ± 4.17	45.30 ± 3.99	0.00 (0.99) [0.00]	5.29 (0.01) [0.06]	.4.14 (0.03) [0.05]
BMI (kg/m^2)	19.70 ± 0.72	19.70 ± 0.69	19.77 ± 0.65	19.47 ± 0.68	19.76* ± 0.56	19.80* ± 0.60	0.12 (0.73) [0.00]	7.96 (0.002) [0.93]	5.01 (0.02) [0.06]
Body Fat (%)	14.86 ± 2.39	14.89 ± 2.21	14.95 ± 2.22	13.21 ± 2.76	11.53*$ ± 2.11	11.17*$ ± 1.72	35.50 (<0.001) [0.32]	38.23 (<0.001) [0.33]	44.02 (<0.001) [0.36]
Fat Mass (kg)	6.78 ± 1.63	6.78 ± 1.55	6.82 ±1.52	6.01 ± 1.78	5.28*$ ± 1.29	5.09*$ ± 1.08	16.92 (<0.001) [0.18]	23.98 (<0.001) [0.24]	27.35 (<0.001) [0.26]
Lean Body Mass (kg)	38.32 ± 3.33	38.30 ± 3.32	38.36 ± 3.26	38.73 ± 3.39	40.03*$ ± 3.18	40.21*$ ± 3.20	3.31 (0.07) [0.04]	78.34 (<0.001) [0.50]	73.73(<0.001) [0.49]
GSTR (kg)	22.92 ± 4.52	22.89 ± 3.98	23.05 ± 3.96	28.80$ ± 4.09	30.56*$ ± 3.92	32.16*#$ ± 3.89	70.99 (<0.001) [0.48]	86.30 (<0.001) [0.53]	74.83(<0.001) [0.50]
GSTL (kg)	22.23 ± 4.57	22.16 ± 3.97	21.70 ± 3.58	27.34$ ± 4.15	29.08*$ ± 3.86	30.33*#$ ± 3.84	61.42 (<0.001) [0.44]	33.46 (<0.001) [0.30]	65.98(<0.001) [0.46]
BST (kg)	46.78 ± 8.62	46.50 ± 8.66	46.65 ± 8.2	61.05$ ± 9.12	71.6*$ ± 8.31	76.63*#$ ± 7.76	158.17 <0.001) [0.67]	213.05 <0.001) [0.73]	222.49(<0.001) [0.74]
LST (Kg)	62.25 ± 8.69	61.72 ± 8.52	61.88 ± 8.80	85.68$ ±16.66	97.95*$ ±17.04	102.6*#$ ±16.28	131.03 <0.001) [0.63]	173.90 (0.001) [0.70]	193.24(<0.001) [0.71]
Flexibility (cm)	20.78 ± 4.23	20.94 ± 4.09	20.91 ± 3.89	27.21$ ± 5.46	32.77*$ ± 5.33	34.48*#$ ± 4.98	105.40 <0.001) [0.58]	261.88 (0.001) [0.77]	240.32(<0.001) [0.75]
30 m sprint (s)	6.01 ± 0.51	6.04 ± 0.62	6.05 ±0.63	5.23$ ± 0.44	4.90*$ ± 0.34	4.84*#$ ± 0.37	103.76 <0.001) [0.57]	38.00(<0.001) [0.33]	52.11(<0.001) [0.40]

Data are (mean ± SD) analyzed via two-way mixed ANOVA. Post hoc tests included Bonferroni (within-group) and independent t-tests (between-group). η^2p = Partial Eta Squared (indicate effect size); $p < 0.05$: * vs. week 0; # week 8 vs. week 12; $ SCG vs. SPG. BMI = Body Mass Index; LBM = Lean Body Mass; GSTR = Grip Strength of Right Hand; GSTL = Grip Strength of Left Hand; BST = Back Strength; LST= Leg Strength; 30 M Sprint = 30-Metre Sprint Time.

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3.2 Assessment of Physiological Determinants

The cardiorespiratory determinants of SPG were already improved at baseline compared to SCG. SPG had significantly lower resting and recovery heart rates, blood pressures along with elevated maximum aerobic capacity, maximum heart rate, lung function variables relative to SCG ($p<0.05$). Moreover, in subsequent weeks resting and recovery heart rates were diminished ($p<0.05$) and VO_{2max}, FVC, PEFR, FEV_1 improved ($p<0.05$) in SPG. No alterations in maximum heart rate in SPG were observed after the interventions. The cardiorespiratory determinants remained unchanged in SCG throughout the intervention (Table 4).

Table 4: Effects of Training on Physiological Determinants of Adolescent Soccer Players

Parameter	SCG (n=40)			SPG (n=40)			F Value (p value) [η^2p]		
	0 Week	8 Week	12 Week	0 Week	8 Week	12 Week	Group	Training	Interaction
RHR (bpm)	81.10 ± 7.43	80.65 ± 6.55	80.08 ± 6.62	71.93$ ± 9.63	61.58*$ ± 4.26	58.80*#$ ± 3.03	150.28 (<0.001) [0.66]	98.51 (<0.001) [0.56]	74.85 (<0.001) [0.50]
RSBP (mm Hg)	116.03 ± 3.45	116.75 ± 3.83	116.78 ± 3.34	115.18 ± 4.02	110.10*$ ± 2.87	107.85*#$ ± 2.38	66.74 (<0.001) [0.46]	63.92 (<0.001) [0.45]	99.09 (<0.001) [0.56]
RDBP (mm Hg)	77.30 ± 3.16	77.93 ± 3.27	77.60 ± 2.77	77.90 ± 3.23	75.63 ± 2.44	73.18*$ ± 2.85	14.79 (<0.001) [0.16]	20.97 (<0.001) [0.21]	26.68 (<0.001) [0.26]
HR_{Max} (bpm)	197.03 ± 2.17	197.28 ± 2.06	197.10 ± 1.75	204.21$ ± 3.08	204.38$ ± 2.32	204.33$ ± 1.85	262.19 (<0.001) [0.77]	0.53 (0.58) [0.00]	0.04 (0.94) [0.00]
HR_{REC1} (bpm)	177.25 ± 3.44	176.88 ± 3.91	176.78 ± 4.11	170.35$ ± 4.84	163.10*$ ± 2.92	158.73*#$ ± 3.34	352.96 (<0.001) [0.82]	39.77 (<0.001) [0.34]	39.59 (<0.001) [0.29]
HR_{REC2} (bpm)	157.68 ± 3.73	158.43 ± 4.13	158.10 ± 3.40	141.83$ ± 4.27	133.63*$ ± 4.22	128.40*#$ ± 4.59	1063.31 (<0.001) [0.93]	34.68 (<0.001) [0.31]	45.86 (<0.001) [0.37]
HR_{REC3} (bpm)	137.50 ± 3.15	138.55 ± 3.59	138.40 ± 3.52	129.28$ ± 4.79	117.73*$ ± 4.67	112.48*#$ ± 4.87	584.13 (<0.001) [0.88]	65.42 (<0.001) [0.46]	91.34 (<0.001) [0.54]
VO_{2max} (ml/min/kg)	40.67 ± 2.31	41.01 ± 2.32	41.09 ± 2.07	43.30 $ ± 1.96	44.93 *$ ± 1.58	46.29 *#$ ± 1.59	93.90 (<0.001) [0.55]	73.51 (<0.001) [0.49]	41.78 (<0.001) [0.35]
FEV_1 (L)	2.31 ± 0.29	2.32 ± 0.25	2.32 ± 0.24	2.78$ ± 0.32	3.33*$ ± 0.24	3.38*#$ ± 0.22	261.68 (<0.001) [0.77]	119.88 (<0.001) [0.61]	108.39 (<0.001) [0.58]

FVC (L)	2.33 ± 0.29	2.34 ± 0.25	2.36 ± 0.23	2.80$ ± 0.34	3.36*$ ± 0.24	3.42*#$ ± 0.22	263.69 (<0.001) [0.77]	115.79 (<0.001) [0.60]	101.89 (<0.001) [0.57]
PEFR (L/min)	287.68 ±55.65	288.68 ±53.30	287.93 ±52.18	350.93$ ± 55.16	436.60*$ ± 47.32	455.13*#$ ± 38.99	141.24 (<0.001) [0.64]	128.31 (<0.001) [0.62]	125.63 (<0.001) [0.62]

Data are (mean ± SD) analyzed via two-way mixed ANOVA. Post hoc tests included Bonferroni (within-group) and independent t-tests (between-group). η^2p = Partial Eta Squared (indicate effect size); $p < 0.05$: * vs. week 0; # week 8 vs. week 12; $ SCG vs. SPG. RHR = Resting Heart Rate; RSBP = Resting Systolic Blood Pressure; RDBP = Resting Diastolic Blood Pressure; RHR = Resting Heart Rate; HR_{Max} = Maximum Heart Rate; HR_{REC1} = Heart Rate Recovery after 1 minute; HR_{REC2} = Heart Rate Recovery after 2 minutes; HR_{REC3} = Heart Rate Recovery after 3 minutes; VO_{2max} = Maximal aerobic capacity; FEV_1 = Forced Expiratory Volume in 1 Second; FVC = Forced Vital Capacity; PEFR = Peak Expiratory Flow Rate.

3.3 Evaluation of HRV metrics

Pre-intervention HRV variables were notably distinct in both groups. SPG had higher SDNN, PNN50%, RMSSD, Mean RR interval, RR Triangular Index, PNS index, Triangular Interpolation of NN Interval Histogram, LF, TP, HF and VLF spectral power than SCG ($p<0.05$). Additionally, SCG also showed elevated SNS index, maximum and minimum heart rate during 5-minute supine resting HRV recording, stress index compared to SPG ($p<0.05$). At mid and post intervention SDNN, PNN50%, RMSSD, Mean RR interval, RR Triangular Index, PNS index, Triangular Interpolation of NN Interval Histogram, LF, TP, HF and VLF spectral power showed statistically discernible elevation among SPG. Simultaneously, their SNS index, stress index and LF/HF spectral ratio diminished notably ($p<0.05$). No such alterations were observed among SCG (Table 5).

Table 5: Effects of Training on Heart Rate Variability (HRV) of Adolescent Soccer Players

Parameter	SCG (n=40)			SPG (n=40)			F Value (p value) [η^2p]		
	0 Week	8 Week	12 Week	0 Week	8 Week	12 Week	Group	Training	Interaction
SDNN (ms)	32.52 ± 9.23	31.74 ±7.90	31.14 ±7.26	54.39$ ± 11.41	77.26*$ ±26.70	84.21*$# ± 27.57	136.08 (<0.001) [0.64]	46.71 (<0.001) [0.38]	55.50 (<0.001) [0.42]
RMSSD (ms)	29.36 ± 8.83	28.02 ± 6.83	27.90 ± 6.97	58.99 $ ± 16.73	97.89*$ ±36.68	105.33*$# ± 30.14	189.38 (<0.001) [0.71]	92.09 (<0.001) [0.54]	104.88 (<0.001) [0.57]
LNRMSSD (ms)	3.34 ± 0.29	3.31 ±0.22	3.30 ±0.22	4.04 ±0.29	4.52* ± 0.35	4.62$# ± 0.27	359.44 (<0.001) [0.82]	94.93 (<0.001) [0.55]	120.67 (<0.001)[0.61]
PNN50 (%)	15.42 ± 4.59	15.26 ±4.29	15.36 ±4.31	30.69$ ± 15.33	50.99*$ ±12.88	56.27*$# ±10.17	258.23 (<0.001) [0.77]	114.63 (<0.001) [0.60]	116.39 (<0.001) [0.60]
RR triangular index	7.64 ± 1.97	7.46 ±1.90	7.49 ± 1.97	11.63$ ± 1.94	13.83*$ ± 1.56	16.03*$# ± 1.35	341.20 (<0.001) [0.81]	66.80 (<0.001) [0.46]	76.19 (<0.001) [0.49]
TINN (ms)	172.45 ±59.25	168.80 ±54.09	168.43 ±53.07	319.10$ ± 72.30	379.43*$ ± 62.58	416.98*$# ± 51.75	267.65 (<0.001) [0.77]	64.07 (<0.001) [0.45]	76.08 (<0.001) [0.49]

SNS Index	1.65 ± 0.72	1.64 ± 0.69	1.68 ± 0.69	0.50$ ± 1.16	-0.47*$ ± 0.97	-0.56*#$ ± 0.93	97.58 (<0.001) [0.56]	57.50 (<0.001) [0.42]	59.16 (<0.001) [0.43]
PNS Index	-1.31 ± 0.64	-1.25 ± 0.74	-1.29 ± 0.62	0.45$ ± 1.11	1.60*$ ± 0.60	1.81*#$ ± 0.47	349.98 (<0.001) [0.82]	51.74 (<0.001) [0.40]	46.99 (<0.001) [0.38]
Stress Index (SI)	13.17 ± 3.48	12.95 ± 2.80	12.30 ± 2.56	8.02# ± 1.84	5.03*$ ± 0.97	4.67*$# ± 0.68	283.31 (<0.001) [0.75]	52.91 (<0.001) [0.40]	25.25 (<0.001) [0.25]
HRmax (bpm)	100.13 ±14.07	99.95 ±10.31	99.45 ± 11.40	87.03$ ± 12.63	72.75*$ ± 6.75	68.95*$# ± 5.28	121.37 (<0.001) [0.61]	66.38 (<0.001) [0.46]	58.76 (<0.001) [0.43]
HRmin (bpm)	72.78 ± 8.79	73.05 ± 7.57	72.70 ± 7.06	61.50$ ± 8.03	54.18*$ ± 4.34	49.88*$# ± 3.05	170.65 (<0.001) [0.69]	45.45 (<0.001) [0.37]	45.12 (<0.001) [0.37]
Mean RR Interval (ms)	746.28 ±74.69	749.30 ± 67.08	750.13 ± 66.63	850.00$ ±120.87	978.73*$ ± 66.41	1022.58*$ # ± 50.32	161.64 (<0.001) [0.68]	115.71 (<0.001) [0.60]	105.78 (<0.001) [0.58]
Total Power (ms^2)	957.68 ±556.74	948.30 ±544.11	953.63 ±545.98	2068.15 $ ± 759.54	3696.08*$ ±1010.85	4250.40*$ # ± 943.93	265.35(<0.001) [0.77]	124.62 (<0.001) [0.62]	125.99 (<0.001) [0.62]
VLF Power (ms^2)	70.83 ±28.82	70.58 ± 24.01	70.68 ± 24.49	174.18$ ± 92.07	181.60$ ± 95.58	187.95$ ± 79.26	102.64 (<0.001) [0.57]	0.32(0.59) [0.004]	0.34(0.58) [0.004]
LF Power (ms^2)	579.03 ±377.01	575.05 ±370.45	577.10 ±369.09	1126.15 $ ± 535.86	1548.60*$ ± 544.08	1657.98*$ # ± 505.44	89.61 (<0.001) [0.54]	25.26 (<0.001) [0.25]	25.79 (<0.001) [0.25]
HF Power (ms^2)	307.83 ±84.28	302.68 ±178.72	305.85 ±180.93	767.83$ ± 393.83	1965.88*$ ± 657.82	2404.48*$ # ± 605.71	191.34 (<0.001) [0.71]	132.80 (<0.001) [0.63]	133.79 (<0.001) [0.63]
LF/ HF Ratio	1.93 ±0.59	1.94 ± 0.57	1.93 ± 0.57	1.73 ±0.93	0.85*$ ±0.38	0.72*$# ± 0.26	62.77 (<0.001) [0.45]	33.06 (<0.001) [0.30]	32.84 (<0.001) [0.30]

Data are (mean ± SD) analyzed via two-way mixed ANOVA. Post hoc tests included Bonferroni (within-group) and independent t-tests (between-group). η^2p = Partial Eta Squared (indicate effect size); $p < 0.05$: * vs. week 0; # week 8 vs. week 12; $ SCG vs. SPG. RMSSD = Root Mean Square of Successive Differences; SDNN = Standard Deviation of Normal-to-Normal Intervals; LNRMSSD = Natural Logarithm of Root Mean Square of Successive Differences; pNN5 = Percentage of Successive Normal-to-Normal Interval Differences Greater Than 50 ms; RR Triangular Index = RR Interval Triangular Index; TINN = Triangular Interpolation of NN Interval Histogram; SNS = Sympathetic Nervous System Index; PNS = Parasympathetic Nervous System Index; HRmax = Maximum Heart Rate recorded during 5-minute supine resting HRV recording; HRmin = Minimum Heart Rate recorded during 5-minute supine resting HRV recording; Mean RR Interval = Mean Normal-to-Normal RR Interval; VLF Power = Very-Low-Frequency Power; LF Power = Low-Frequency Power; HF Power = High-Frequency Power; LF/HF Ratio = Low-Frequency to High-Frequency Power Ratio.

3.4 Evaluation of Perceived Exertion, Training Monotony, Strain and Load

Training load assessed through the RPE method showed a significantly higher value in Week 3 and a significantly lower value in Week 12 ($p < 0.05$), with an overall 12-week average of 533.54 ± 83.30 AU. Training strain peaked in week 3 and was lowest

in week 12 ($p < 0.05$), with a 12-week average of 742.76 ± 116.15 AU. Monotony also followed a similar trend, being highest in week 3 and lowest in week 12 ($p < 0.05$), averaging at 1.36 ± 0.21 AU (Table 6).

Table 6: Assessment of RPE, Training Load, Monotony and Strain of Adolescent Soccer Players

Week	Average RPE Score	Acute Training Load (AU)	Monotony (AU)	Training Strain (AU)
1	4.61 ± 0.38	554.14 ± 46.16	1.39 ± 0.05	769.19 ± 74.79
2	5.0 a ± 0.46	600.85a ± 55.84	1.38 ± 0.05	832.55 a ± 96.66
3	5.83 ab ± 0.32	699.43 ab ± 38.67	1.42 b ± 0.02	996.64 ab ± 61.44
4	4.75 ce ± 0.36	570.85 ce ± 42.91	1.40 ± 0.02	804.80 ce ± 70.40
5	5.36 abcd ± 0.34	642.86 abcd ± 41.08	1.41 b ± 0.03	908.42 abcd ± 67.62
6	4.92 ace ± 0.41	590.57 ace ± 49.56	1.41b ± 0.03	834.51ace ± 73.35
7	4.87ce ± 0.43	584.14 ce ± 51.11	1.41 b ± 0.03	826.32 ce ± 76.86
8	4.63 bcef ± 0.36	556.28 bcef ± 43.74	1.36 cdefg ± 0.05	755.51bcefg ± 65.19
9	4.19 abcdefgh ± 0.70	502.26 abcdefgh ± 84.28	1.34 cdefg ± 0.21	690.58 abcdefg ± 117.54
10	3.81 abcdefghi ± 0.63	456.91 abcdefghi ± 75.68	1.35 cfg ± 0.21	630.61 abcdefghi ± 106.13
11	3.29 abcdefghij ± 0.53	394.31 abcdefghij ± 63.58	1.32 abcdefgk ± 0.21	531.27 abcdefghij ± 86.92
12	3.02 abcdefghijk ± 0.49	362.52 abcdefghijk ± 59.08	1.32 acdefg ± 0.21	490.06 abcdefghijk ± 81.80
(F), {p}, [η^2]	(195.35), {<0.001}, [0.82]	(195.35), {<0.001}, [0.82]	(15.76), {<0.001}, [0.27]	(180.39), {<0.001}, [0.81]
12 Week Average	4.45 ± 0.69	533.54 ± 83.30	1.36 ± 0.21	742.76 ± 116.15

All the data were expressed as mean ± SD; n=40, One way ANOVA followed by Bonferroni post hoc test was performed; significant level $p<0.05$; RPE method when compared to 1st week –a, 2nd week- b, 3rd week- c, 4th week- d, 5th week- e, 6th week- f, 7th week- g, 8th week- h, 9th week-I, 10th week -j, 11th Week-k.

3.5 Correlation among Variables

Within the SPG, multiple correlations emerged at the midpoint of the intervention. LBM demonstrated a positive correlation with hand grip strength right (r = +0.65), leg (r = +0.73) and back (r = +0.76) muscular strength. Moreover, VO_2max exhibited positive linear relationship with SDNN (r = +0.35) and LnRMSSD (r = +0.37). 8-week Average Training load showed negative correlation with LnRMSSD (r = -0.68) (Figure 2). LBM also exhibited positive association with hand grip strength right (r = +0.63), leg (r = +0.65) and back strength (r = +0.63) at post-intervention. Similarly, LnRMSSD (r = +0.56) and SDNN (r = +0.50) were positively associated with maximum aerobic capacity after the completion of the conditioning (Figure 2).

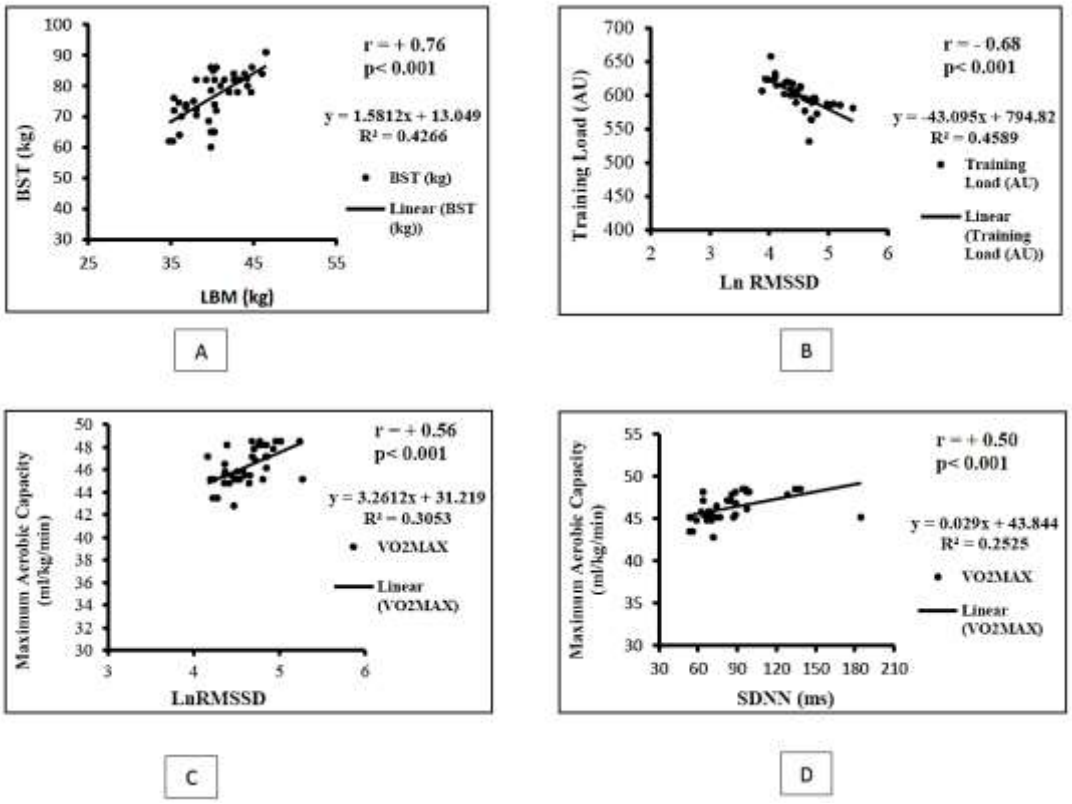

Figure 3: Correlation between Variables.

Pearson's Correlation is performed for SPG group variables, significant level $p<0.05$. A= Correlation Between Back Strength and Lean Body Mass; B= Correlation Between Average 8-week Training Load and LnRMSSD; C= Correlation Between maximum aerobic capacity and LnRMSSD, D= Correlation Between Maximum Aerobic Capacity and SDNN.

3.6 Discussion

This study investigated the influence of a structured conditioning protocol on body morphology, physical abilities, cardiorespiratory determinants and autonomic regulation (HRV) among adolescent male soccer players. The main findings reflect improvements in overall performance and health among the players due to the conditioning intervention.

The findings indicate that body adiposity percentage and fat mass in the SPG decreased due to training [29]. In this cohort, weight, BMI, and lean body mass increased from pre intervention to mid and post intervention. However, no notable alteration was observed from mid to post intervention. These observations suggest that players experienced a localized alteration in body adiposity distribution. Additionally, improvements in isometric strength variables such as grip, leg, and back muscular strength were exhibited by the SPG. These enhancements may be due to training induced neuromuscular adaptations [30]. Generally,

these adaptations include enhanced motor unit recruitment and neuromuscular synchronization. These help to generate greater biomechanical force [30]. The SPG demonstrated positive association between LBM and strength variables at mid and post intervention. It indicates that LBM elevates isometric strength [31]. Moreover, the SPG exhibited notable gains in flexibility and speed after the conditioning intervention. Diminished musculotendinous stiffness and elevated neural tolerance to muscle stretch may result in these adaptations [32]. The improvements in sprinting speed may be caused by enhanced leg strength and neural adaptations. These ultimately enhances propulsive power and stride efficiency among the SPG [33]. The improvements in resting/recovery heart rates, VO_{2max}, FEV1, FVC, and PEFR were noted after the completion of conditioning program. This enhanced cardiopulmonary efficiency was similar to earlier research [29]. Several central and peripheral adaptations, such as elevated stroke volume and myocardial efficiency, enhanced aerobic fitness among the SPG [34]. Elevated stroke volume lowers resting heart rate and accelerates recovery. The training stimulus in the SPG enhanced muscle capillarization, mitochondrial biogenesis, which in turn improved oxygen extraction. These adaptations improved VO_{2max} [35]. Moreover, enhanced pulmonary muscle strength and compliance elevate lung capacities. These adaptations help player to sustain longer in high ventilatory demands [36].

The SPG cohort was previously engaged in soccer activities. Therefore, they exhibited elevated vagal tone pre-intervention. Following the intervention, the SPG showed alterations in temporal and spectral HRV metrics. An elevation in RMSSD, pNN50%, PNS Index, and total power alongside a diminution in SNS index and the LF/HF spectral ratio were observed among them. The improvement in SDNN denotes enhanced global autonomic variability. Additionally, enhanced RMSSD and pNN50% reflect parasympathetic modulation. Post-intervention rise in PNS index along with a fall in stress and SNS index indicates shifting of the autonomic modulation towards parasympathetic control among the SPG [12]. Importantly the reduction in LF/HF spectral ratio further confirms highly favourable sympathovagal balance. This means the conditioning intervention was well designed, which yielded positive physiological adaptations rather than inducing overtraining [37]. Aerobic training component stimulated parasympathetic dominance in SPG. It enhances resting autonomic balance [38]. The participants in the SPG cohort exhibited quick heart rate recovery. It is a sign of enhanced cardiac efficiency, which is linked to elevated HRV. Training enhances HRV and thereby improves cardiovascular health. This also helps to reduce mortality risk among players [39]. Training-associated load given to SPG were well distributed. The 12-week conditioning program reflects an average RPE, load and strain 4.45 ± 0.69 AU, 533.54 ± 83.30 AU, and 742.76 ± 116.15 AU respectively. A strategic tapering was initiated from 9th Week to keep the players in optimal condition during final phase [40]. This deliberate reduction was evidenced by 12th week training strain (490.06 ± 81.80) and load (362.52 ± 59.08 AU). Additionally, throughout the conditioning period monotony (average- 1.36 ± 0.21 AU) was below the critical threshold of 2.0. This means there was enough variation in training stress to reduce overtraining [41]. Correlation studies exhibited negative association between load and HRV. This relationship indicates that, accumulated training-associated load can cause autonomic imbalance [42]. Additionally, a positive linear association between HRV parameters and maximum aerobic capacity was observed among the SPG. It confirms that, players with better autonomic modulation can show enhanced endurance [43].

Overall, the prescribed training load successfully yielded positive adaptations in adolescent soccer cohort. The combination of monitoring training load and HRV is highly effective to ensure adaptations were obtained without exceeding players' allostatic capacity.

Practical implications: These findings offer several strategies for sports practitioners. This study exhibited a dual monitoring strategy. It integrated the monitoring of RPE-derived training strain, load and monotony alongside HRV. This is a low-cost scientific strategy to monitor players' training status and allostatic capacity. Moreover, the conditioning strategy demonstrated proper training load distribution to lower monotony and overreaching among players. This study also showed the importance of a structured tapering to gain peak performance after the completion of the intervention. This will help sports practitioners to properly plan a conditioning module according to match schedule. This study exhibits a framework of scientific training optimization and monitoring for sports persons and researchers.

Limitation: This study included a sample from a specific geographical region with age and gender restriction. This narrow sampling cannot explain the dynamics of the selected parameters in samples from other regions, age groups and genders. Future investigations should incorporate longer period, broad sampling including different age groups and gender to properly understand age and gender appropriate training periodization and monitoring strategies.

4. CONCLUSION

The implementation of properly periodized training plan can enhance body morphology, physical motor capacity, cardiorespiratory determinants and performance of players. However, assessment of training-associated load along with HRV metrics is an effective strategy to monitor training adaptations and detect signs of overtraining. Present study showed proper implementation of training load with tapering adjustment and lower monotony perfectly induces several cardiopulmonary, physical and autonomic adaptations. The relationship between HRV indicated autonomic status and training adaptations enables coaches and sports scientists to optimize training plan. This may help to develop individualized training plans for enhancement of performance and the health of players. The sampling of this study was limited to adolescent boys of a specific region. Therefore, future investigations should consider longer study duration, inclusion of female subjects and direct measures of overtraining in terms of serum biomarkers to understand proper condition of players.

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