ORIGINAL ARTICLE

TRENDS in
Sport Sciences
2024; 31(3): 179-186
ISSN 2299-9590
DOI: 10.23829/TSS.2024.31.3-6

Impact of customized training program on physical attributes of badminton players

MANIKA GHOSH[1], SUTANU CHAKRABORTY[1], PUNYASLOK MOHAPATRA[1], ABHISHEK SINGH[1], MAYANK SHARMA[1], DINESH BEHERA[1], DIGPAL RANAWAT[2]

Abstract

Introduction. Badminton is one of the most popular sports which requires agility and strength. It is also a sport that needs a good amount of physical, physiological, technical and tactical assessment and training. Aim of Study. The purpose of this study was to investigate effects of training based on an undulating periodization routine supported by scientific assessments of physical and physiological variables of badminton players. Material and Methods. Twenty players registered themselves to take part in the study, however, a group of 10 male badminton players was eligible to participate after meeting inclusion criteria. Flexibility, handgrip strength, dynamic balance, agility, and aerobic capacity tests were performed before a commencement of a training routine, which consisted of endurance activities, mobility exercises, and strength sessions based on a previous scientific assessment. The same test parameters were also assessed after the training period. The athletes continued their badminton training for 12 weeks, which was also included in the customized training routine. A statistical analysis was performed to compare obtained data before and after the training program. Normality of the obtained data was also assessed. Results. Significant improvements in handgrip strength and agility ($p < 0.05$) were noted. In addition, positive trends were observed in flexibility, dynamic balance and aerobic capacity of the athletes. Conclusions. The 12-week customized training routine consisting of undulating periodization had positive effects on strength, mobility, agility and other physiological variables of the badminton players. However, better results may be achieved by continuing this training routine in the future.

KEYWORDS: training, strength, agility, badminton, periodization.

Received: 31 March 2024
Accepted: 31 May 2024

Corresponding author: scphysiology7191@gmail.com

[1] *Sports Science Centre, Abhinav Bindra Targeting Performance (ABTP), Kalinga Stadium, Bhubaneswar, Odisha, India*
[2] *Abhinav Futuristics Private Limited (AFL), Mohali, Punjab, India*

Introduction

Badminton became an Olympic sport in 1992 at the Olympic Games in Barcelona and has remained a part of the Olympic Games to date. Currently, badminton is one of the most popular and fastest racket sports worldwide that demands quick and forceful shots, coupled with agile footwork. Also at a national level badminton is among the most widely played sports, boasting prominent role models who serve as inspiration for junior players, motivating them to aspire to high levels of competitiveness. The sport consists of five different categories: men's singles, women's singles, men's doubles, women's doubles, and mixed doubles [24]. Badminton players need to keep their center of gravity (COG) within a base of support while performing rapid and asymmetrical upper limbs movements. Consequently, excellent body balance is essential for improving badminton skills, enhancing athletic performance, and preventing injuries [28].

Previous research has showed that rally durations typically range from 1 to 45 seconds. Moreover, researchers have documented an average rally interval of 10 seconds and an average rest interval of 26 seconds. During these swift and demanding rallies, a shuttlecock can reach speeds of up to 426 km/h, with an approximate

rate of one hit per second. Previous studies have reported that matches lasting 30-60 minutes involve 68-83 rallies [8]. The Badminton World Federation (BWF) introduced a new "scoring system" in 2006, adding another layer to a game. In this updated format, a match comprises of the best of three games, and a first player to reach 21 points wins each game [20]. In order to overcome these growing challenges, players need exceptional reaction, speed, agility, and quickness to showcase peak athleticism on a court [19]. Variations in badminton match play characteristics account for significance of estimating physical and physiological attributes of badminton players' on-court performance.
Badminton is an incredibly versatile sport that imposes substantial physical, physiological, technical, and tactical requirements. However, it is a physical and physiological fitness component that directly influences extent of demands placed on player's technical and tactical abilities [17]. Previous studies have described this dynamic game as having high-intensity, intermittent characteristics that require players to perform short bursts of maximal or submaximal efforts, quick changes of directions, jumps, lunges, and explosive lower and upper body movements from various postural positions [3]. Similarly, research studies have shown that an energy profile of badminton players during games has a predominant aerobic profile ranging from 60% to 70% of total energy system utilization. Some researchers have identified the adenosine triphosphate-phosphocreatine (ATP-CP) system and the glycolysis system as primary sources of energy [11]. The majority of previous research studies focused on senior badminton athletes, whereas physical and physiological attributes that help junior badminton athletes achieve peak performance may not be the same for senior athletes. Without understanding a current physical and physiological status of athletes, we cannot properly assert training regimens that may become effective for them after proper periodization according to a players' competition calendar [12]. Therefore, the purpose of this study is to focus on physical and physiological attributes of badminton players and to evaluate effectiveness of training routines on their overall performance.

Aim of Study

Numerous studies were focused on identifying physical and physiological attributes of elite badminton players. Previous sports science studies have identified different variables that contribute to on-court performance of senior badminton players. These variables include a combination of aerobic stamina, flexibility, power, speed, agility, strength, explosiveness, coordination, reaction, and technical skills. Therefore, this study aimed to identify physiological characteristics of junior badminton players and to examine a potential impact of a specific undulating training regime based on outcomes of scientific assessments regarding physical and physiological variables of junior badminton players.

Material and Methods

Participants

Twenty badminton players participated voluntarily, of which 10 male badminton players were recruited for this study based on the inclusion criteria. The research adhered to the principles of the Declaration of Helsinki, and informed declarations and consents were obtained from coaches and the study participants. The purpose of the study and a perspective of performance improvement were discussed with each participant and the coaches before a commencement of the study. No invasive procedures were performed in studying a parameter included in this study. Each athlete had a minimum of 4 years of training, 2 years of official badminton competitions, and no recent history of any musculoskeletal injuries within last 6 months. All participants were in good health and had no chronic medical conditions. The data was collected as a part of observation of the players, when they were routinely assessed throughout a season.

Study design

The study consisted of a 12-week training period. Before starting the customized training protocol, the sports science staff conducted scientific evaluations of anthropometric variables, flexibility, handgrip strength, dynamic balance, agility, and aerobic capacity using

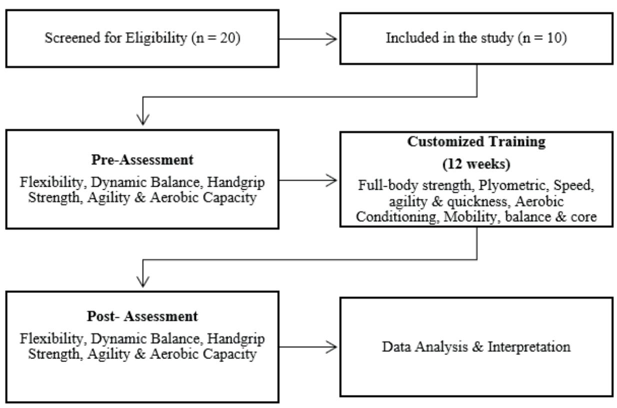


Figure 1. The study design

standard protocols. After the training period, the sports science staff evaluated the same test parameters. The badminton athletes continued their badminton training for 12 weeks, which was also included in the customized training routine. Figure 1 represents the study design of this research.

Physical and physiological variables

Before measuring the physical and physiological parameters, the anthropometric measurements were taken. A stadiometer was used to measure body height, whereas a weighing machine was used to check body weight of the participants. BMI was calculated by dividing body weight by a square of body height. The participants wore minimal clothing throughout the measurement process. They were required to maintain contact between their middle fingers and respective sides of their thighs while looking straight ahead at a fixed point during the measurement of body weight and body height. Table 1 presents the demographic statistics of the anthropometric variables of the badminton players.

Table 1. Demographic data related to the body composition of the badminton players

Variables	Badminton players (n = 10)
Age (year)	15 ± 1.69
Body height (cm)	170.95 ± 6.46
Body weight (kg)	55.53 ± 8.08
Body mass index (kg/m^2)	18.94 ± 2.05

Values are expressed as Mean ± SD.

Flexibility assessment

The researchers evaluated lower body and hamstring flexibility using the Sit and Reach Test according to the standard protocol [1] .

Handgrip strength assessment

The athletes underwent an assessment of handgrip strength using a digital handgrip dynamometer (Kinvent, USA). An examiner conducted the test for each hand in a standing position, while keeping a straighten elbow. When ready, the subjects applied maximum isometric effort by squeezing the dynamometer and maintained it for approximately 5 seconds [1]. The subjects were required to refrain from making any other body movements during this assessment. The test was performed twice by each athlete, and the highest score was recorded.

Dynamic balance assessment

The Y Balance Test (YBT) is an assessment of dynamic balance conducted in a single-legged position. The athletes performed the test barefoot. They positioned themselves in the center of an YBT apparatus. Subsequently, the athletes were instructed to maintain a single-legged position while reaching as far as possible with the other leg, and then return to the starting position in the center of the platform without losing balance, with their hands on an anterior superior iliac spine. The test involved reaching in three directions – anterior, posteromedial, and posterolateral – with two trials for each leg. The maximum reach distance was recorded for each trial. YBT reach distances were standardized as a percentage of leg length, which was determined by measuring a distance from a right anterior superior iliac spine of the players to a right medial malleolus in a supine position. A composite score for each leg was calculated using a formula mentioned in previous studies [13, 28].

Agility assessment

The SEMO agility test was conducted to assess the athletes' ability to change directions, execute forward sprints, diagonal back pedaling, and side shuffling movements that are commonly encountered during badminton matches. The assessments were performed on an outdoor track measuring 19 ft in length and 12 ft in width. Four cones were positioned at each corner of the track to check points of directional changes. In each trial, the athletes initiated a movement from the 1st to the 2nd cone performing side stepping as per instructions. Subsequently, the athletes turned around to the 2nd cone, back-pedaled to the 3rd cone, sprinted forward to the 1st cone, circled the cone, engaged in backward running to the 4th cone, sprinted forward to the 2nd cone, side-stepped back to the starting cone, completing the circuit. Stopwatches were used to record the test duration of each athlete. Two consecutive trials were conducted with a 4-minute interval of passive rest, and the lowest recorded time was used for further analysis [13].

Aerobic capacity assessment

Endurance ($\dot{V}O_2$ max) was evaluated using the 20-m multistage fitness test, conducted on an outdoor track. Following the established protocol for the endurance assessment [16], the athletes ran continuously between two lines, 20 meters apart and marked by cones. Recorded beeps served as cues to start running, and the athletes were required to reach the line in sync with each beep. Additionally, the participants received verbal motivation, encouragement, and information about speed changes during the assessment. An initial speed of 8.5 km/h was selected according to a protocol established by previous researchers [4] and increased by 0.5 km/h every minute. A test score was determined by a number of 20-meter laps completed until the participants either voluntarily withdrew from the test or failed to complete the test within two consecutive beeps. A total number of completed shuttles was documented and converted into equivalent $\dot{V}O_2$ max values using a formula presented in previous studies [16].

Weekly training program

The training routine incorporated endurance, speed, agility, and quickness [SAQ) training, plyometric training along with mobility exercises, and full-body strength sessions based on the results of a previous scientific evaluation.

The athletes performed the exercises, accompanied by warm-up activities that involved active full-body dynamic stretching, activation, and cool-down sessions. Each session lasted 60-90 minutes. Strength and conditioning experts designed the training plan and periodization according to the rules of the National Strength and Conditioning Association [6]. This training program was performed in addition to a badminton training routine of the athletes. The plan is described in Table 2, whereas a description of the specific routines is described below.

Before each workout, the players performed a standardized warm-up routine consisting of exercises such as hip in and out, leg swings, knee to chest to lunge, ankle mobility (three directions), world's greatest stretch, supine scorpion stretches, scapula push-ups. There were six to eight repetitions in a single set for each exercise.

On the other hand, the selected activation exercises included glute bridges, clam shells, banded upper body activation, banded knee lifts, sidekicks, front kicks, back kicks, high plank holds, superman holds, single leg balance exercises, and overhead squats. Each exercise was performed for six to eight repetitions in a single set. The detailed training plan and exercises are mentioned in Figure 2.

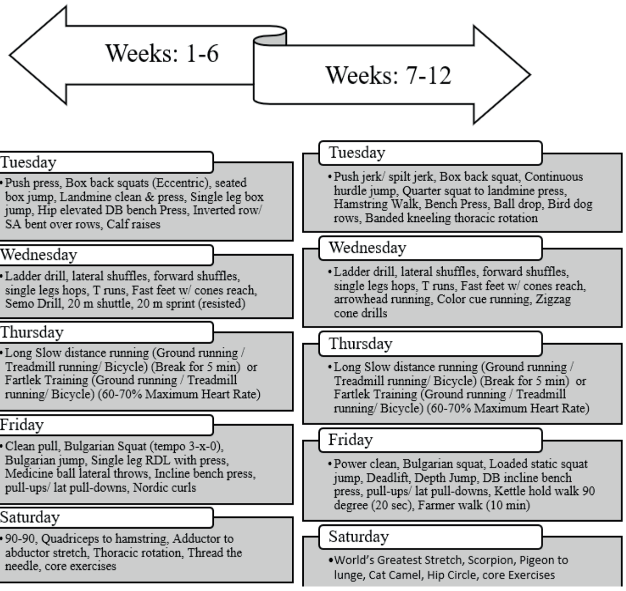


Figure 2. The detailed training plan and exercises

Statistical analysis

The data is presented as Mean ± SD. Normality of the obtained values was checked using the Shapiro–Wilk normality tests in the GraphPad Prism software. The data was analyzed using the paired t-tests to compare the values before and after the training program.

Results

This study revealed significant improvements in various physical parameters following the intervention program. There was a significant enhancement in handgrip strength, with an increase of 13.66% in a left hand and 19.66% in a right hand. A significant improvement in agility was observed, which was approximately 10.15%. Positive effects of the training were observed in terms of flexibility, dynamic balance, and aerobic capacity, which were found to be statistically insignificant. These observations are depicted in Table 3 and Figure 3.

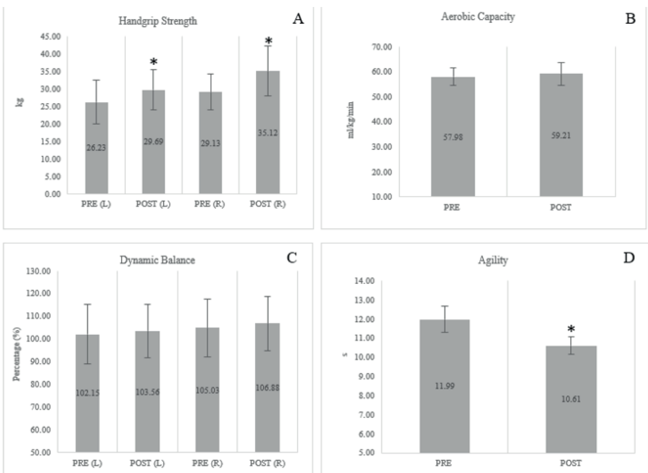
Table 2. Weekly training program

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Rest	full-body strength and plyometric training	speed, agility, and quickness	aerobic conditioning	full-body strength and plyometric training	mobility, balance, and core

Table 3. Descriptive statistics of the variables collected before and after the badminton players training

Variables	Pre-training (n = 10)	Pre-training (n = 10)
Flexibility (cm)	36.67 ± 12.61	37.67 ± 10.77
Handgrip strength (kg)	left – 24.88 ± 6.05*	left – 28.28 ± 5.64*
	right – 28.35 ± 4.85*	right – 33.92 ± 6.66*
Lower quarter Y Balance Test (%)	left – 102.94 ± 12.94	left – 104.04 ± 11.57
	right – 106.29 ± 12.83	right – 107.61 ± 12.28
Agility (s.)	11.91 ± 0.69*	10.70 ± 0.45*
Aerobic capacity (ml/kg/min)	57.72 ± 3.50	58.16 ± 4.09

Values are expressed as Mean ± SD.
* $p < 0.05$



Note: PRE – pre-training, POST – post-training, L – left, R – right
Values are represented as Mean ± SD.
* $p < 0.05$

Figure 3. Changes in (A) handgrip strength, (B) aerobic capacity, (C) dynamic balance, (D) agility after the customized training plan

Discussion

In high-performance sports periodization is a methodical strategy designed to maximize effectiveness of a training program, leading up to a scheduled competition by carefully adjusting training volume and intensity over time. Conversely, nonperiodized training lacks planned variations in training variables in terms of volume and intensity. Currently, two main models of periodization are used by athletes and coaches: linear periodization and nonlinear periodization, also known as undulating periodization [30]. Undulating periodization involves regular fluctuations in exercise intensity and volume, which can occur daily or weekly, and relies on maximal repetitions to measure intensity levels. There are two models within undulating periodization, i.e. daily undulating periodization and weekly undulating periodization. These models can be adapted to athletes based on individual needs, developmental level, and overall strengths and weaknesses. This type of periodization has been proposed to result in superior physiological and performance adaptations [7, 22]. A study conducted on tennis players demonstrated that an undulating periodization program improved strength, power, and local muscle endurance [15].

The present study investigated effectiveness of an undulating training program based on a scientific evaluation of physical and physiological variables of junior badminton players. Because badminton demands quick direction changes, jumps, forward lunges, rapid arm movements, and a variety of postural positions, players must demonstrate good balance and agility while performing rapid postural actions across a court.

Anticipated outcomes of this study are an enhancement of strength and power related characteristics because of improved contractility of muscles, besides an increase in an amount of contractile protein through strength training [5]. The results of this study indicated that 12 weeks of core strengthening had a positive effect on improving dynamic balance of the badminton players. The possible reasons for this outcome may be that core muscles play a crucial role in stabilizing a spine and trunk during movements involving lower and upper extremities, such as jumping, running, and throwing. Improving core muscle strength could potentially enhance dynamic balance and coordination between lower and upper extremities, and it may also help to reduce and prevent lower extremities and knee joints injuries. In summary, core strengthening may contribute to strengthening of pelvic girdle muscles, including abdominals and an erector spinae [21]. Flexibility and strength of hip and thigh muscles, which influence limbs movements in a direction of a target, may affect reach distances when an athlete stands in a single-limb position during the YBT.

On the other hand, plyometric exercises can enhance both peripheral and central neural adaptations, leading to increased joint proprioception [23]. A muscle spindle and Golgi tendon organs are receptors crucial for stretch reflex and muscle contraction control. Active stretching of elastic components generates elastic potential energy that contributes to muscle fiber contraction. Neurophysiological adaptations resulting from plyometric training contribute to significant power improvement. Plyometric training enhances motor unit activation, neural adaptation, and a force development rate, improving agility and speed. Increased power facilitates force production during sprinting, reducing sprint time and improving speed. The present study's findings indicate a significant improvement in agility with a 12-week plyometric training regimen. Another study showed that progressive plyometric training significantly improved lower limb muscle power, thereby influencing badminton players' agility. A potential increase in power output was identified as a crucial factor in improving agility. Coaches or trainers may employ a progressive plyometric training regime to increase lower limb muscles strength, consequently improving agility in badminton athletes [14]. Another pilot study showed that 12 weeks of balance training combined with plyometric training can strengthen dynamic balance ability and improve quickness performance in elite male badminton players [29]. Another study reported that a 6-week plyometric training program increased knee proprioception and dynamic balance in female badminton players [2]. These results have showed the vital role of plyometric training in elevating performance in sports that demand acceleration, deceleration, and direction changes. Furthermore, it is well known that agility requires development of muscular components such as strength and power to enhance lateral velocity changes [9]. Thus, the current study's results show a significant improvement in the overall performance of the YBT, the SEMO agility test and the handgrip strength test after 12 weeks of training, which aligns with the previous research findings.

Enhanced flexibility in the badminton players that resulted from 12 weeks of the consistent mobility exercises within the current study may contribute to improved maximal strength, an ability to effectively utilize the stretch-shortening cycles and correct movement patterns throughout a required range of motion [17].

In badminton competition, quickness is a key factor in achieving exceptional performance. It requires not only lower limb strength for altering body direction, but also effective dynamic balance to regulate body posture, thereby overcoming inertial effects induced by acceleration and deceleration during directional changes [26]. The SAQ training is an effective method for enhancing athletic performance and has a significant effect on improving agility, speed, and dynamic balance. Studies have showed that the SAQ training is versatile and can be employed to boost speed or strength, enhancing ability to produce maximal force during high-speed movements. The advantages of the SAQ training include increased linear and horizontal muscle power as well as reactive force, and time. Neuromuscular stimulation during exercises, involving rapid changes of directions and muscular contractions, leads to alterations in alpha motor neuron impulse velocity. This contributed to development of control and improved dynamic balance. The enhanced balance may be linked to improved ankle and hip muscles strength, thereby enhancing postural stability [25]. The present study indicates that the SAQ training may have a significant effect on improving agility, speed, and dynamic balance in badminton players.

A badminton match places significant demands on a player's aerobic capacity, because of variations in individual physical fitness and the introduction of the new scoring model. Under such circumstances, pace of a competition noticeably quickens, and multiple rallies frequency steadily rises. This forces players to withstand prolonged periods of rapid and repeated accelerations and decelerations [10]. A research study highlighted that badminton players typically achieve an average heart rate exceeding 90% of their maximum heart rate (HRmax) during competitive matches. The involved energy systems show a reliance of 60-70% on the aerobic system and 30% on the anaerobic system, with a pronounced demand for alactic metabolism, placing a significant strain on both aerobic and anaerobic capacities [18]. This study included long slow distance running at 60-70% of the athletes' HRmax and fartlek training for improving aerobic endurance. The fartlek training technique involves starting with a slow run, followed by intensive short sprints of medium distance running with consistently high speed. This pattern alternates with periods of sprinting, jogging, and sprinting again, creating a varied and dynamic workout. The fartlek training is a type of an aerobic endurance exercise and can be performed to enhance aerobic endurance. One study conducted on badminton players showed that the fartlek training significantly increased $\dot{V}O_2$ max of athletes [27].

Conclusions

This study showed that customized training routines might induce a significant effect on improving handgrip strength and keeping badminton players more agile on a court. Other studied variables may also show significant positive responses if the badminton players continue their training routine with customized modulation according to the strength and conditioning coaches. The insights gained from this research will ultimately guide a formulation of future training for junior badminton players, focusing on undulating periodization that may elicit positive effects.

Based on individual's training history, a choice of a different periodization model could introduce a novel stimulus, potentially resulting in greater adaptations. Consequently, coaches should modify a chosen periodization model to facilitate ongoing gains in selected variables of badminton players over the long term.

Acknowledgments

The authors are grateful for the involvement and contributions of all the staff of the Abhinav Bindra Targeting Performance (ABTP) and the Abhinav Bindra Foundation (ABFT). Special recognition goes to the conditioning experts of ABTP and SAI Badminton Academy as well as the physiotherapists of these centers who provided training to the badminton athletes. Our heartfelt thanks also go to every member of the SAI Badminton Academy for their dedication and support in this endeavor. Most importantly, this study would not have been possible without the support of the Department of Youth Affairs and Sports, Odisha; Rungta Mines and Abhinav Futuristics Private Limited (AFL), Mohali.

Conflict of Interest

The authors declare no conflict of interest.

References

1. Aktas S, Guven F, Er Y. Effects of badminton training on some physical parameters in badminton players aged 10 to 12 years. TJSE. 2017;19(3):345-349. https://doi.org/10.15314/tsed.349484
2. Alikhani R, Shahrjerdi S, Golpaigany M, Kazemi M. The effect of a six-week plyometric training on dynamic balance and knee proprioception in female badminton players. J Can Chiropr Assoc. 2019;63(3):144-153.
3. Apriantono T, Herman I, Winata B, Hidayat II, Hasan MF, Juniarsyah AD, et al. Physiological characteristics of Indonesian junior badminton players: men's double category. Int J Hum Mov Sports Sci. 2020;8(6):444-454. https://doi.org/10.13189/saj.2020.080617
4. Aydoğmuş M, Arslanoğlu E, Özmen T. Effect of badminton specific training versus badminton match on aerobic fitness. TOJRAS. 2015;4(2):12-15.
5. Azeez M, Albayati K, Kaya Y. The effect of 12-week different training methods applied to badminton athletes on some basic motoric properties. European Journal of Fitness, Nutrition and Sport Medicine Studies. 2022;3(1). https://doi.org/10.46827/EJFNSM.V3I1.139
6. Baechle TR, Earle RW. Essentials of strength training and conditioning. Champaign, IL: Human Kinetics; 2008.
7. Bompa TO, Bompa T, Buzzichelli CA. Library of Congress Cataloging-in-Publication Data Periodization Training for Sports. Champaign: Human Kinetics; 2015.
8. Campos BD, Angioluci F, Daros B, Mastrascusa L, Dourado V, Carlos A, et al. Anthropometric profile and motor performance of junior badminton players. Braz J Biomotricity. 2009;3:146-151.
9. Chandra S, Sharma A, Malhotra N, Rizvi MR, Kumari S. Effects of plyometric training on the agility, speed, and explosive power of male collegiate badminton players. J Lifestyle Med. 2023;13(1):52-58. https://doi.org/10.15280/jlm.2023.13.1.52
10. Faude O, Meyer T, Rosenberger F, Fries M, Huber G, Kindermann W. Physiological characteristics of badminton match play. Eur J Appl Physiol. 2007;100(4):479-485. https://doi.org/10.1007/s00421-007-0441-8
11. Fu Y, Liu Y, Chen X, Li Y, Li B, Wang X, et al. Comparison of energy contributions and workloads in male and female badminton players during games versus repetitive practices. Front Physiol. 2021;12. https://doi.org/10.3389/fphys.2021.640199
12. Green R, West AT, Willems MET. Notational analysis and physiological and metabolic responses of male junior badminton match play. Sports. 2023;11(2):35. https://doi.org/10.3390/sports11020035
13. Guo Z, Huang Y, Zhou Z, Leng B, Gong W, Cui Y, et al. The effect of 6-week combined balance and plyometric training on change of direction performance of elite badminton players. Front Psychol. 2021 Jun 10;12. https://doi.org/10.3389/fpsyg.2021.684964
14. Irawan D. Six weeks progressive plyometrics training on badminton player's agility. Adv Health Sci Res. 2017;10:18-21. https://doi.org/10.2991/HSIC-17.2017.4
15. Kerr A. The physiological demands of tennis and how to train them: a case study of a sub elite female tennis player. J Strength Cond Res. 2015;23(1):25-37.
16. Léger LA, Mercier D, Gadoury C, Lambert J. The multistage 20 metre shuttle run test for aerobic fitness. J Sports Sci. 1988;6(2):93-101. https://doi.org/10.1080/02640418808729800
17. Lieshout KA van, Lombard AJJ. Fitness profile of elite junior South African badminton players. Afr J Phys Act Health Sci. 2003;9(3):114-120. https://doi.org/10.4314/ajpherd.v9i3.24643
18. Liu H, Leng B, Li Q, Liu Y, Bao D, Cui Y. The effect of eight-week sprint interval training on aerobic performance of elite badminton players. Int J Environ Res Public Health. 2021;18(2):1-11. https://doi.org/10.3390/IJERPH18020638
19. Malwanage KT, Senadheera VV, Dassanayake TL. Effect of balance training on footwork performance in

badminton: An interventional study. PLoS ONE. 2022; 17(11):e0277775. https://doi.org/10.1371/journal.pone.0277775
20. Ooi CH, Tan A, Ahmad A, Kwong KW, Sompong R, Ghazali KAM, et al. Physiological characteristics of elite and sub-elite badminton players. J Sports Sci. 2009;27(14):1591-1599. https://doi.org/10.1080/02640410903352907
21. Ozmen T, Aydogmus M. Effect of plyometric training on jumping performance and agility in adolescent badminton players. TJSE. 2017;19(2):222-227. https://doi.org/10.15314/tsed.319749
22. Painter KB, Haff GG, Ramsey MW, Mcbride J, Triplett T, Sands WA, et al. Strength gains: block versus daily undulating periodization weight training among track and field athletes. Int J Sports Physiol Perform. 2012;7:161-169. https://doi.org/10.1123/ijspp.7.2.161
23. Panda M, Rizvi MR, Sharma A, Sethi P, Ahmad I, Kumari S. Effect of electromyostimulation and plyometrics training on sports-specific parameters in badminton players. Sports Med Health Sci. 2022;4(4):280-286. https://doi.org/10.1016/j.smhs.2022.08.002
24. Phomsoupha M, Laffaye G. The science of badminton: game characteristics, anthropometry, physiology, visual fitness and biomechanics. Sports Med. 2015;45(4):473-495. https://doi.org/10.1007/s40279-014-0287-2
25. Prachita PW, Josheeta S. Effect of plyometric exercises versus speed agility quickness training on agility, speed, power, dynamic balance and reaction time in amateur badminton players. Int J Phys Res. 2023;11(3):4524-4530. https://doi.org/10.16965/ijpr.2023.124
26. Singh J, Raza S, Mohammad A. Physical characteristics and level of performance in badminton: a relationship study. JEP. 2011;2(5):6-9.
27. Sudiadharma S, Rahman A, Ichsani I, Bismar AR. The effect of farlek training on increasing VO 2 Max of badminton athletes. Int J Multidisc Res Anal. 2023;6(5). https://doi.org/10.47191/ijmra/v6-i5-54
28. Wong TKK, Ma AWW, Liu KPY, Chung LMY, Bae YH,Fong SSM, et al. Balance control, agility, eye-hand coordination, and sport performance of amateur badminton players: a cross-sectional study. Medicine (United States). 2019;98(2). https://doi.org/10.1097/MD.0000000000014134
29. Zhou L, Gong W, Wang S, Guo Z, Liu M, Chuang S, et al. Combined balance and plyometric training enhances knee function, but not proprioception of elite male badminton players: a pilot randomized controlled study. Front Psychol. 2022;13:947877. https://doi.org/10.3389/fpsyg.2022.947877
30. Zourdos MC, Jo E, Khamoui A V., Lee SR, Park BS, Ormsbee MJ, et al. Modified daily undulating periodization model produces greater performance than a traditional configuration in powerlifters. J Strength Cond Res. 2016;30(3):784-791. https://doi.org/10.1519/JSC.0000000000001165