

Linear and nonlinear programming: effects on the physical abilities of young basketball players

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Abstract

Background and Study Aim Linear and nonlinear programming are methods used to control intensity and volume in sports training. Despite their widespread application, there is a lack of evidence-based studies that directly compare the effects of linear versus nonlinear programming. This study aims to assess the effect of linear and nonlinear programming on improving the power, agility, and endurance of young basketball players.

Material and Methods This study employs a two-group pretest-posttest experimental design. It included 40 male basketball players aged 16-18, with weights ranging from 60 to 77 kg and heights from 167 to 180 cm. Participants were divided into two groups based on their ordinal pairings. The instruments used in this study were the jump DF, lane agility, and multistage fitness tests. Data were analyzed using descriptive statistics, Wilcoxon tests, and Mann-Whitney U tests, with the assistance of SPSS 23.

Results The pretest-posttest findings for both the linear and nonlinear programming groups showed significant improvements in power, speed, and endurance, with Asymptotic Significance (Asymp. sig) 2-tailed values of less than 0.05. Comparative analysis of posttest results between linear and nonlinear programming indicated significant differences: power showed an Asymp.sig value of 0.009 with a difference of 3.1; agility showed an Asymp.sig value of 0.000 with a difference of 0.35; and endurance showed an Asymp.sig value of 0.002 with a difference of 2.08.

Conclusions The study demonstrates significant differences in the impacts of linear and nonlinear programming on power, agility, and endurance among young basketball players. Both programming types significantly enhance these attributes, but nonlinear programming is more effective than linear programming in improving the physical abilities of young basketball players.

Keywords: linear, nonlinear, programming, physical abilities, young basketball players

Introduction

Physical ability is a crucial aspect of winning basketball matches. Optimal physical performance is achieved when the training program, prepared by the trainer, adheres to established training principles, dosage settings, and appropriate periodization. Periodization is a form of training management planned at a macro level and divided into smaller segments, allowing for focused stress management and programming [1]. It is classified into four types: traditional, undulating, inverted, and block periodization [2, 3, 4]. The core content of periodization involves programming that encompasses methodologies, models, and training dose settings [5]. In practice, programming often adopts linear and nonlinear models. Linear programming gradually increases intensity or volume, whereas nonlinear programming varies the intensity and volume in waves [6].

Numerous studies have explored different programming approaches in sports training. For instance, the impact of an 8-week linear periodization was assessed on young soccer players, revealing specific performance adaptations [7]. Similar studies have investigated reverse and traditional periodization in triathlon athletes over eight weeks [8], as well as both linear and nonlinear loading interventions aimed at enhancing leg muscle power in triathlon athletes and arm strength in javelin throwers [9, 10]. Additional research has examined various strength training methods, including adjustments of training intensity [11], and the effects of linear and nonlinear loading on muscle hypertrophy and strength [12]. The influence of periodic linear and nonlinear combinations has been studied in swimmers [13], while nonlinear periodization has been applied to general fitness [14] and specifically to improve the physique of soccer players [15]. The comparative effectiveness of linear versus nonlinear periodization during the maintenance phase for soccer players has also been scrutinized [16]. Furthermore, studies have

assessed the application of circuit training with linear loading on basketball players [17], the impact of loading strategies on basketball players' muscle power [18], the enhancement of power in hockey players through nonlinear periodization [19], the evaluation of nonlinear periodization in basketball [20], and comparisons between linear and daily undulating periodization in basketball players [21].

The majority of studies reviewed focus on physical improvements through various periodization schemes including linear, nonlinear, and undulating programming, as well as comparing traditional and reverse periodization techniques. However, these studies predominantly involve sports like hockey, football, javelin throwing, and swimming. Notably, a targeted literature search using the keywords "linear," "nonlinear," and "basketball" revealed only three studies addressing linear and nonlinear programming's effects on basketball players' physical abilities. Additionally, the research highlights inconsistencies in the application of linear and nonlinear programming. These inconsistencies may arise from genetic differences between athletes, their physiological capacities for adaptation, and methodological limitations such as the absence of control groups in experimental setups [13]. Despite observing varying outcomes from linear and nonlinear programming, the differences in results were not significant enough to conclusively determine the superiority of one program over the other [22].

The authors critique the inconsistent usage of the terms "periodization" and "training load." They argue that periodization should be viewed as macro training planning that encompasses not only the scheduling over months, weeks, and days but also stress management and strategic programming [2]. Conversely, the term "load" typically refers to the resistance encountered during physical activities, quantifiable in newtons [23]. Therefore, the use of "scientific loading" in the context of sports and exercise science is deemed inappropriate as it misrepresents the nature of physiological loading [23]. Furthermore, exercise programming often employs the terms "linear" and "non-linear" to describe treatment protocols that are implemented over shorter periods [5]. It is emphasized that training programming should be meticulously structured to maximize athlete performance effectively [24].

Despite the widespread application and significant interest in periodization methods in sports training, there remains a notable scarcity of systematic studies comparing the effects of linear and nonlinear programming on the physical abilities of young basketball players. Most existing research does not fully explore how different periodization approaches impact key aspects of physical fitness such as power, agility, and endurance. This gap in the literature highlights the need for further research to

compare these methodologies comprehensively to determine the most effective training strategies for young athletes.

The research aims to learn more about the effects of linear and nonlinear programming on young basketball players' physical abilities.

Materials and Methods

Participants

The study included 40 male basketball players aged 16 to 18 years, with weights ranging from 60 to 77 kg and heights between 167 and 180 cm. This research was conducted with the approval of the athletes' parents and the Ethics Committee of Semarang State University. All procedures adhered to the ethical standards laid out in the Declaration of Helsinki.

This experimental study employed a two-group pretest-posttest design to compare the effects of linear and nonlinear programming on physical abilities such as power, agility, and endurance. The sample comprised athletes who were 80% committed to attendance, had participated in at least one national championship, and had no history of injuries. Data collection methods included document analysis for problem rationalization, observations, and field testing with standardized instruments —multistage fitness test, vertical jump DF, and lane agility drill — ensuring high validity and reliability [25, 26, 27].

Participants were initially ranked based on pretest results and matched into pairs using an ordinal A-B-B-A subject matching pattern to ensure balanced distribution; 20 athletes were assigned to each programming group. The eight-week training program included six sessions per week, with intensity and volume adjustments specific to the type of programming. Each training session began with a coach-led warm-up consisting of five minutes of jogging to increase heart rate, followed by 20 minutes of combined static and dynamic stretching. This was followed by the main training component as outlined in Table 1.

Statistical Analysis

The data analysis technique employed included descriptive analysis, which provided the minimum, maximum, mean, and standard deviation values [28]. Normality tests were performed on the data, which were found to be not normally distributed. Consequently, nonparametric tests were utilized, specifically the Wilcoxon test, to compare the pretest and posttest results within the same groups. Additionally, the Mann-Whitney test was used to compare posttest results between different groups, with a significance level set at $p < 0.05$ [29]. Data analysis was facilitated using the Statistical Package for the Social Sciences (SPSS) version 23.

Table 1. Linear and nonlinear programming to increase power, agility, and endurance

Linear programming		
Material	Exercise Dosage	
Post 1: Power lay-up drill	Meeting: 1-6	Meeting: 7-12
Post 2: Hurdle jump low	Method: Circuit	Method: circuit
Post 3: Defense shuffle	Intensity: 75%	Intensity: 85%
Post 4: Lateral jump low (right)	Pulse: 165/min	Pulse: 180/min
Post 5: Mirror drill	Sets: 4-5-6-7	Sets: 5-6-7-8
Post 6: Lateral jump low (left)	Recovery: 3 minutes	Recovery: 3 minutes
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Post 1: Pro hop drill	Meeting: 13 th -18 th	Meeting: 19 th -24 th
Post 2: Hurdle jump high	Method: Circuit	Method: Circuit
Post 3: One-on-one drill	Intensity: 85%	Intensity: 85%-100%
Post 4: Lateral jump high (right)	Pulse: 180/min	Pulse: 180/min
Post 5: Box out drills	set: 10-11-12	sets: 12-13-14 sets
Post 6: Lateral jump high (left)	Recovery: 5 minutes	Recovery: 5 minutes
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Nonlinear Programming		
Material	Exercise Dosage	
Post 1: Power lay-up drill	Meeting: 1-6	Meeting: 7-12
Post 2: Hurdle jump low	Method: circuit	Method: circuit
Post 3: Defense shuffle	Intensity: 75%	Intensity: 85%
Post 4:Lateral jump low (right)	Pulse: 165/min	Pulse: 180/min
Post 5: Mirror drill	Sets: 4-5-6-7	Sets: 7-8-9-10
Post 6: Lateral jump low (left)	Recovery: 3 minutes	Recovery: 3 minutes
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Post 1: Pro hop drill	Meeting: 13-18	Meeting: 19-24
Post 2: Hurdle jump high	Method: Circuit	Method: Circuit
Post 3: one on one drill	Intensity: 100%	Intensity: 100%
Post 4:Lateral jump high (right)	Pulse: 180/minute and above	Pulse: 180/minute and above
Post 5: Box out drills	Sets: 4-5-6-7-8	Sets: 4-5-6
Post 6: Lateral jump high (left)	Recovery: 5 minutes	Recovery: 5 minutes

Results

Table 2 presents the results of the descriptive analysis, including pretest and posttest scores for both linear and nonlinear programming groups.

Table 2 illustrates that the mean posttest scores are higher than the mean pretest scores for both the linear and nonlinear programming groups, indicating improvements in all measured variables. Specifically, for the linear programming group, the mean posttest scores were 67.85 for power, 10.50 for agility, and 50.01 for endurance. In contrast, the nonlinear programming group showed even higher posttest scores with 70.95 for power, 11.77 for agility, and 52.09 for endurance.

Table 3 displays the results of the Wilcoxon test analysis, which compared pretest and posttest in similar groups.

The Wilcoxon test results presented in Table 3 demonstrate significant improvements in young basketball players’ physical abilities following a linear programming intervention. Specifically, there was a noticeable increase in leg muscle power, with scores rising from a pretest mean of 65.95 to a posttest mean of 67.85, resulting in a statistically significant difference (Asymp.sig 2-tailed p = 0.000). Similarly, agility improved, evidenced by a reduction in scores from 11.65 to 10.50, also marked as significant (Asymp.sig 2-tailed p = 0.000). Lastly, endurance showed gains, increasing from a pretest score of 48.43 to a posttest score of 50.01, with the change denoting significant enhancement (Asymp.sig 2-tailed p = 0.000).

Overall, the linear programming intervention led to marked improvements in power, agility,

Table 2. Results of descriptive analysis of pretest and posttest scores

Linear Programming				
Variable	Min	Max	Mean	Std.Deviation
Pretest power	60	72	65.95	4.032
Posttest power	60	73	67.85	3.964
Agility pretest	11.31	12.26	11.6564	.28379
Agility posttest	10.09	11.41	10.5012	.41757
Endurance pretest	47.00	61.04	48.4335	3.66878
Endurance posttest	47.09	62.02	50.0140	3.75420
Pemrograman Nonlinear				
Variable	Min	Max	Mean	Std.Deviation
Pretest power	59	72	66.15	4.591
Posttest power	64	75	70.95	2.946
Agility pretest	11.31	12.58	11.7750	.39216
Agility posttest	9.34	11.01	10.1504	.32806
Endurance pretest	47.00	57.01	48.4280	3.10643
Endurance posttest	49.00	62.03	52.0945	3.79635

Table 3. Wilcoxon pretest and posttest results in each group

Group	Variable	Mean	Selisih	Asymp.sig(2-tailed)
Linear programming	Pretest power	65.95	1.9	0.000
	Posttest power	67.85		
	Agility pretest	11.65	1.15	0.000
	Agility posttest	10.50		
	Endurance pretest	48.43	1.58	0.000
	Endurance posttest	50.01		
Nonlinear programming	Pretest power	66.15	4.8	0.000
	Posttest power	70.95		
	Agility pretest	11.77	1.62	0.000
	Agility posttest	10.15		
	Endurance pretest	48.42	3.67	0.000
	Endurance posttest	52.09		

Table 4. Test results of the Mann-Whitney posttest of linear and nonlinear programming groups

Group	Variable	Mean	Difference	Asymp.sig(2-tailed)
Linear programming	Power	67.85	3.1	0.009
Nonlinear programming		70.95		
Linear programming	Agility	10.50	0.35	0.000
Nonlinear programming		10.15		
Linear programming	Endurance	50.01	2.08	0.002
Nonlinear programming		52.09		

and endurance, with posttest results significantly surpassing pretest outcomes across all measured parameters.

The Wilcoxon test results presented in Table 3 indicate significant improvements for the nonlinear programming group across all tested variables. The

power variable showed an increase in leg muscle power from a pretest score of 66.15 to a posttest score of 70.95, with a difference of 4.8, yielding a statistically significant Asymptotic Significance (Asymp.sig) 2-tailed value of less than 0.05 ($p=0.000$). Agility improved as well, with scores decreasing from

a pretest of 11.77 to a posttest of 10.15, a difference of 1.62 that was also significant (Asymp.sig 2-tailed $p = 0.000$). Similarly, endurance scores increased from a pretest value of 48.42 to a posttest of 52.09, a difference of 3.67, with the change being statistically significant (Asymp.sig 2-tailed $p = 0.000$).

These results demonstrate that after undergoing nonlinear programming, participants showed substantial improvements in power, agility, and endurance, with posttest scores significantly exceeding pretest scores.

The results of the Mann-Whitney test, comparing the posttest scores of the linear and nonlinear programming groups, are detailed in Table 4. The analysis shows a significant difference in leg muscle power between the two groups; the linear programming group achieved a mean power value of 67.85, whereas the nonlinear programming group reached a higher mean of 70.95, with a notable difference of 3.1 and an Asymp.sig(2-tailed) value of 0.009, indicating significance ($p < 0.05$).

For agility, the linear programming group recorded a mean posttest score of 10.50, compared to 10.15 for the nonlinear group. This difference of 0.35 also demonstrated statistical significance with an Asymp.sig(2-tailed) value of less than 0.05 ($p = 0.000$), showing the nonlinear group's superior performance in terms of agility enhancement.

Similarly, in endurance, the nonlinear programming group outperformed with a mean score of 52.09 compared to 50.01 for the linear group, a difference of 2.08, also significant (Asymp.sig(2-tailed) $p = 0.000$), suggesting more effective endurance improvement in the nonlinear group.

Figure 1 graphically represents these comparisons, highlighting the differences in mean values between the groups.

Discussion

This study was designed to evaluate the effects of linear and nonlinear programming

on enhancing endurance, power, and agility in young basketball players. The findings reveal that nonlinear programming significantly outperforms linear programming in improving these physical attributes. These results are consistent with another experimental study involving twenty-seven men who participated in resistance training for the upper extremities. This study divided participants into non-programmed, linearly programmed, and nonlinearly programmed groups, with findings indicating that nonlinear programming was superior in enhancing upper extremity strength over a 12-week training period [30].

Further supporting these findings, research on untrained elderly individuals demonstrated that 12 weeks of resistance training using nonlinear programming significantly enhanced their functional capacity [31]. Similarly, in young soccer players, resistance training employing nonlinear programming led to marked improvements in maximum strength, power, and agility [32].

Collectively, these results, corroborated by multiple studies, strongly suggest that nonlinear programming is more effective than linear programming in boosting power, agility, and endurance among young basketball players.

Furthermore, this study addresses a gap in existing literature, as no specific research has yet been found on the application of linear and nonlinear programming in youth basketball. This absence underscores the empirical novelty of our research. Prior studies have often conflated the definitions of training loading with programming approaches, where the application of linear and nonlinear programming was merely subjected to critical analysis without subsequent experimental investigation [33].

Our study, therefore, represents the first experimental research to distinctly define and apply linear and nonlinear programming within the context of basketball training. By doing so, it



Figure 1. Average posttest score (APS) for linear and nonlinear programming

not only clarifies these programming concepts but also directly tests their effectiveness, providing a pioneering contribution to sports science and training methodology.

Nonlinear programming in this study involves six components that integrate ballistic and agility exercises within a circuit training format, aimed at enhancing both anaerobic and aerobic endurance. Given the unique training adaptations of each athlete, nonlinear programming offers varied training dose settings. Ballistic exercises, commonly known as plyometrics, are crucial for improving physical fitness in team sports [34]. This type of training, when combined with strength exercises and sprinting 2-3 times weekly over 4 to 16 weeks, has been shown to enhance jumping performance, short-distance sprinting, and agility in both teenage and adult amateur athletes [35].

Moreover, incorporating both unilateral and bilateral plyometric exercises yields greater benefits than traditional or single-modality plyometrics [35]. Plyometrics involves a stretch-shortening cycle; muscles store energy during the eccentric phase and rapidly transition to the concentric phase during explosive movements like jumping and sprinting [36]. This process significantly boosts physical fitness attributes such as jumping, skipping, sprinting, and agility [37]. Additionally, the integration of ballistic training with circuit methods has been found to effectively improve endurance [38].

Circuit training, executed three times per week and comprising eight stations—including jump rope, commando dance, inverse sit-ups, squat jumps, jack-knife, push-ups, hurdle hops, and sit-ups—significantly enhances agility and endurance after ten weeks [39]. This form of training, characterized by relatively short intervals, is classified under high-intensity interval training (HIIT).

Additionally, a recent study on nonlinear programming, conducted three times a week for six weeks, utilized a regimen including medicine ball tosses, resistance band exercises, and both bilateral and unilateral plyometrics. This training markedly improved power, agility, and endurance [40].

Further supporting these findings, research indicates that physical training involving plyometrics, hurdle jumps, medicine ball exercises, and ballistic movements—conducted with high intensity and moderate to low volume three times a week for four weeks—substantially impacts both anaerobic and aerobic endurance [41].

Thus, a well-structured training program, especially in basketball, is crucial for enhancing physical performance and achieving optimal athletic outcomes.

The physical component of basketball is crucial and greatly influences a player's competitive capabilities. Every movement in the sport requires robust physical conditioning, which is enhanced

through techniques such as drill methods and short intervals naturally incorporated into training sessions. Consequently, physical training is fundamentally essential in basketball, and effective programming principles are necessary to enhance physical fitness.

In this context, training programming can be likened to medical dosing: insufficient training intensity and volume will not yield significant improvements [42, 43]. Conversely, excessive training can lead to overtraining symptoms, just as an overdose of medication can be harmful. Thus, training intensity and volume must be meticulously calibrated, and aspects like nutrition and recovery must be prioritized to avoid detrimental effects on the athlete's body [42, 43].

Moreover, implementing effective physical programming requires adherence to fundamental training principles, including progressive overload, regularity, and individuality [43]. Additionally, basketball programming is intimately connected to pedagogy, which facilitates young players' self-exploration and talent development. This pedagogical aspect implies that athletes can integrate lessons learned in various settings, such as schools and clubs, enhancing both personal and social benefits [44].

Finally, a crucial aspect of programming is ensuring that the exercise regimen is successfully executed to maximize individual health and societal benefits [45].

In summary, this study underscores the critical importance of tailored programming in enhancing physical abilities such as power, agility, and endurance in young basketball players. While the advantages of nonlinear programming over linear programming have been demonstrated, there remains a broad spectrum of potential research that could further refine our understanding and application of these training methodologies. Future studies could explore the long-term effects of these programming strategies on athlete performance across different sports. Additionally, investigating the specific impacts on diverse age groups and skill levels within the basketball community could provide deeper insights into the scalability and adaptability of these training programs. Moreover, integrating technological advancements such as biometric monitoring could enhance the precision of training regimens and provide real-time feedback, thus optimizing training outcomes. Ultimately, expanding this research to incorporate a wider variety of physical, psychological, and environmental variables would offer a more comprehensive view of sports training's role in athlete development and performance.

Conclusions

This study reinforces the superiority of

nonlinear programming over linear programming in enhancing the physical capabilities of young basketball players, particularly in power, agility, and endurance. The findings advocate for the adoption of nonlinear programming approaches in sports training regimens. By doing so, trainers and coaches can more effectively tailor training programs to the specific needs of athletes, thereby optimizing their performance potential. As sports science continues to evolve, the principles of nonlinear programming offer a robust framework for developing athletic skills and should be considered a fundamental strategy in the preparation and conditioning of young athletes.

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Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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