

Nutritional interventions for gymnasts: bridging the gap between performance and health

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Abstract

Background and Study Aim Elite artistic gymnastics demands a precise balance of strength, endurance, and technique, all of which are influenced by physiological and nutritional factors. Evaluating these relationships is essential for developing evidence-based training and health strategies. The aim of this study was to examine how body composition, cardiovascular health, and dietary habits influence apparatus-specific performance among elite male artistic gymnasts in Pakistan.

Material and Methods A total of 153 elite male gymnasts (mean age 18.7 ± 4.1 years) were recruited from national training centers. Participants averaged 36.6 ± 7.6 hours of weekly training and had an average training history of 11.5 ± 3.2 years. Data collection included body composition analysis (BMI, fat-free mass), cardiovascular indicators (hemoglobin concentration, LDL cholesterol levels), and dietary intake assessed through validated food frequency questionnaires. Gymnasts were evaluated on their competitive performance in three apparatuses: floor, vault, and rings.

Results Body mass index demonstrated a negative correlation with floor performance ($r = -0.18, p < 0.05$), while fat-free mass positively influenced performance on the rings ($r = 0.24, p < 0.01$). Hemoglobin levels were positively associated with better scores across all apparatuses ($r \geq 0.25, p < 0.01$). Elevated LDL cholesterol was linked to poorer performance on the rings. Nutritionally, athletes in the highest performance quartile consumed more energy, protein, calcium, magnesium, and vitamin D. Adequate protein intake ($1.4\text{--}1.6$ g/kg/day) and hydration (>3 L/day) were associated with improved performance.

Conclusions The findings underscore the critical role of individualized nutrition, cardiovascular screening, and body composition monitoring in enhancing gymnastic performance. This is the first comprehensive study of its kind in the Pakistani context, providing evidence to guide targeted interventions in high-performance training environments.

Keywords: body composition, cardiovascular health, dietary intake, sports nutrition

Introduction

Men's artistic gymnastics is one of the most physiologically demanding sports. It requires an exceptional combination of strength, agility, power, and technical precision. These physical demands place significant stress on the musculoskeletal and metabolic systems, making the regulation of physical and nutritional factors essential for optimal performance.

Among these factors, body composition plays a particularly important role. The sport favors a mesomorphic somatotype, characterized by high fat-free mass and low fat mass, which contributes to biomechanical efficiency during complex acrobatic and strength-based movements [1, 2]. This physique supports a favorable power-to-weight ratio and stability during high-force elements such as the vault or rings [3]. Long-term gymnastics training

that begins in early childhood also enhances bone mineral density and skeletal strength, providing lasting musculoskeletal benefits [4]. Artistic gymnastics involves intermittent high-intensity workloads that challenge the cardiovascular system. Gymnasts develop adaptations such as concentric left ventricular hypertrophy and increased heart rate variability, which reflect improved cardiac output and autonomic regulation [5, 6, 7]. However, not all changes are beneficial. Some evidence indicates increased arterial stiffness in athletes who maintain very low body fat, possibly due to chronic low energy availability or dehydration practices [8, 9]. Nutrition further influences both performance and health. Male gymnasts are particularly vulnerable to low energy availability, which can impair glycogen replenishment, muscle recovery, and hormonal balance [10, 11]. Inadequate intake of calcium, vitamin D, and fluids, often resulting from restrictive eating or fluid limitation, may compromise bone health and reduce performance capacity [12, 13, 14].

Despite extensive international research, these factors remain underexplored in the Pakistani context. Limited access to trained sports nutritionists, evidence-based dietary programs, and regular health screening reduces the ability of local athletes to reach their full potential. This highlights the need for research that reflects the realities of regional training environments, dietary habits, and healthcare infrastructure.

Body Composition of Male Gymnasts

Body composition, defined as the ratio of fat to muscle, bone, and other tissues, is a critical factor in men's artistic gymnastics. Male gymnasts possess unique characteristics that enable them to perform impressive feats in strength, power, and agility [2]. Their somatotype is predominantly mesomorphic, characterized by muscular development and relatively low fat levels. This composition provides a biomechanical advantage in strength-based disciplines such as the vault, floor, and rings [1, 2]. Research conducted on Polish gymnasts indicates that senior athletes between 17 and 25 years old exhibit significantly higher mesomorphy scores than juniors, likely due to accumulated training and physical maturity [1, 15].

Event specialization also influences physique. Gymnasts focusing on vault and floor exercises often show stronger mesomorphic traits and lower ectomorphy scores. These athletes typically have a shorter and more compact build, with average heights ranging from 160 to 170 centimeters and body weights between 60 and 70 kilograms. This physique supports better aerial rotation and balance [3]. In addition to having reduced body fat, generally between 8 and 12 percent [2], elite male gymnasts present high levels of fat-free mass, especially in the upper body. The pelvi-acromial index shows broader shoulder width relative to pelvic width, which enhances mechanical efficiency during complex movements [1].

A comparative study from India confirms that elite male gymnasts demonstrate significantly greater muscle mass, fat-free mass, and body cell mass than female athletes. These attributes are essential for the strength and power demands of the sport [16]. Bone health also plays a crucial role. Evidence shows that young male gymnasts who engage in regular training display higher bone mineral content and density than non-athletic peers [4].

Despite these advantages, sustaining a lean body composition may result in low energy availability. Studies involving collegiate male gymnasts indicate frequent underconsumption of total energy and carbohydrates. This dietary imbalance can hinder performance and increase the risk of musculoskeletal stress [10]. Ongoing monitoring of body composition, coupled with tailored nutrition

and recovery planning, is necessary to ensure both athletic performance and long-term health.

Cardiovascular Health of Male Gymnasts

The cardiovascular system of male artistic gymnasts undergoes specific adaptations due to the sport's intermittent and high-intensity nature. Each apparatus routine involves short bouts of exertion lasting from 5 to 90 seconds, followed by recovery periods. This type of training stimulates both anaerobic and aerobic energy systems, resulting in distinctive cardiac and vascular responses [18].

A well-documented structural change is concentric left ventricular hypertrophy. This adaptation involves thickening of the ventricular wall without chamber enlargement and enables the heart to generate higher pressure during forceful contractions. Male gymnasts have been shown to exhibit greater left ventricular mass and wall thickness than their female counterparts, which is attributed to testosterone effects and greater training loads [5]. These morphological features enhance cardiac efficiency in high-load events such as vault and rings [6].

Lipid profile is another critical marker of cardiovascular health. Smith-Ryan et al. [11] reported that 59% of elite male gymnasts exceeded the 2.6 mmol/L threshold for LDL cholesterol, and 41% surpassed 3.0 mmol/L. These elevations were linked to low energy availability, high saturated fat intake, and insufficient dietary fiber. Such findings underscore the importance of tailored nutritional strategies to mitigate cardiovascular risks [14].

Blood pressure regulation among male gymnasts is generally favorable. Lee [9] found that both systolic and diastolic values remained within normal ranges, suggesting effective cardiovascular control despite high physical demands. However, sports-specific training may elicit distinct vascular responses across athletic populations.

Heart rate variability (HRV) is a noninvasive index of autonomic nervous system regulation. Hongyan [7] documented significant increases in SDNN, RMSSD, total power, and high-frequency power among college-age gymnasts following aerobic gymnastics training. These improvements reflect enhanced parasympathetic tone and support recovery and emotional stability during high-pressure competition.

Arterial stiffness, assessed via pulse wave velocity (PWV), has gained attention as a vascular health indicator. Grabitz et al. [8] observed that higher training volumes were associated with increased PWV in young athletes, suggesting reduced arterial compliance. In gymnastics, where energy restriction and low body fat are common, these effects may be magnified. Kuhlman et al. [10] and Mense [14] emphasized that low energy availability contributes to suboptimal vascular profiles, reinforcing the need

for routine cardiovascular evaluation.

In summary, male gymnasts show beneficial cardiac adaptations and autonomic regulation, yet remain vulnerable to lipid imbalance and vascular stiffness due to inadequate dietary support. Comprehensive cardiovascular monitoring is recommended to safeguard health and enhance athletic longevity.

Dietary Intake and Nutritional Challenges of Male Gymnasts

Male artistic gymnasts encounter distinct nutritional challenges due to the physical demands of the sport and the aesthetic pressure to maintain low body fat. Their training involves extended sessions with repetitive, high-intensity routines that elevate energy expenditure, yet gymnasts are expected to sustain a lean physique to maximize performance.

Low energy availability (LEA) is highly prevalent in this population. Kuhlman et al. [10] observed that 85.7% of collegiate male gymnasts had energy intakes below the recommended level, averaging 30.5 ± 4.5 kcal/kg/day. This chronic deficit impairs recovery, immune function, and hormonal regulation. Carbohydrate intake was also found to be insufficient, averaging 3.7 ± 1.1 g/kg/day, whereas athletes in high-intensity disciplines require 5–7 g/kg/day for optimal glycogen replenishment. These limitations can compromise endurance and neuromuscular control during events involving repeated apparatus use.

Protein intake is essential for muscle maintenance and recovery. The recommended intake for gymnasts ranges from 1.2 to 1.7 g/kg/day [19], with distribution across meals shown to enhance protein synthesis and tissue repair. According to Francisco et al. [13], many gymnasts fail to meet this target consistently, particularly after training sessions, leading to diminished adaptations from resistance training. Supporting this, source [11] emphasizes that inadequate protein intake exacerbates the effects of LEA and may delay musculoskeletal recovery.

Micronutrient status is another concern. Villa et al. [12] reported that young male gymnasts frequently failed to meet reference values for calcium and vitamin D, which are essential during adolescence for bone mineralization and neuromuscular function. Prolonged deficits may lead to stress fractures and impaired skeletal development, especially during periods of peak growth.

Disordered eating behaviors have also been documented. Francisco et al. [13] identified that nearly 30% of gymnasts reported engaging in unhealthy weight control strategies, such as meal skipping, caloric restriction, and dehydration. These behaviors intensify the risk of metabolic imbalance and psychological distress.

Hydration remains critically underemphasized in male gymnastics. Many athletes exhibit signs of hypohydration due to fluid restriction or poor replenishment of sweat losses during long training sessions. Mense [14] recommend a minimum daily fluid intake of half the athlete's body weight in ounces, with adjustments for training volume and temperature. However, caution is warranted in the use of sports drinks, which should be limited to prolonged or high-intensity workouts to avoid excessive sugar intake and dental concerns [20].

Addressing these nutritional challenges requires a coordinated, athlete-centered approach. Coaches, sports dietitians, and gymnasts must work collaboratively to develop individualized dietary plans that ensure sufficient energy intake, nutrient density, and hydration. Nutrition education tailored to male gymnasts can reduce the prevalence of restrictive eating behaviors while promoting long-term performance and health outcomes.

Research Gap

Several international studies have explored the physiological and nutritional profiles of male artistic gymnasts. Sterkowicz-Przybycień [1] provided an in-depth analysis of somatotype characteristics in Polish gymnasts and their implications for apparatus specialization. Ruscello et al. [3] described the anthropometric traits and biomechanical advantages among elite-level gymnasts. Mathisen et al. [2] investigated fat-free mass and body fat percentages in relation to performance potential, while Manna et al. [16] offered a comparative view of body composition between Indian male and female gymnasts.

Burt et al. [4] demonstrated that prolonged gymnastics participation is linked to increased bone mineral density in youth athletes. Kuhlman et al. [10] examined energy availability among collegiate male gymnasts, identifying widespread caloric and macronutrient deficiencies. Smith-Ryan et al. [11] focused on lipid metabolism and cardiovascular risk, reporting elevated LDL levels in elite athletes. Jakše et al. [5] investigated cardiac remodeling, and Hongyan [7] reported improvements in heart rate variability (HRV) associated with aerobic gymnastics training. Villa et al. [12] identified frequent calcium and vitamin D deficiencies in adolescent gymnasts. Francisco et al. [13] explored the psychological and physiological effects of disordered eating in aesthetic sports. Grabitz et al. [8] documented increased arterial stiffness in athletes subjected to high training loads, linking vascular function to cumulative physical stress.

Despite this robust body of literature, no published study has analyzed the combined impact of body composition, cardiovascular health, and dietary intake on apparatus-specific performance (floor, vault, and rings) among elite male gymnasts

in Pakistan. Existing research either isolates single variables or is based on non-local populations, thereby limiting contextual relevance. The Pakistani gymnastics context is characterized by specific systemic constraints, such as limited access to certified sports nutritionists, inconsistent health monitoring practices, and culturally distinct dietary patterns. These factors may significantly influence known performance determinants, including energy balance, cardiovascular adaptation, and recovery efficiency.

This study aims to fill this research gap by assessing how body composition, cardiovascular indicators, and dietary intake collectively influence apparatus-specific performance in elite Pakistani male gymnasts. The investigation is tailored to local training conditions and seeks to generate evidence-based insights to support individualized coaching, health optimization, and performance enhancement strategies.

Hypothesis and Study Aim

It is hypothesized that favorable body composition indicators, efficient cardiovascular health parameters, and adequate dietary intake are positively associated with apparatus-specific performance outcomes in elite male artistic gymnasts.

The aim of this study is to evaluate the combined effects of body composition, cardiovascular health, and dietary intake on performance across floor, vault, and rings events among elite male artistic gymnasts in Pakistan. Figure 1 presents the conceptual model used to guide the analysis.

The study seeks to answer the following research questions:

1. How does body composition influence competitive performance in elite male artistic gymnasts?
2. What is the relationship between cardiovascular health indicators and apparatus-specific

performance?

3. To what extent does dietary intake affect performance across different gymnastics events?

Materials and Methods

Participants

A total of 153 elite male artistic gymnasts participated in this study. The average age of participants was 18.7 ± 4.1 years. On average, athletes had 11.5 ± 3.2 years of training experience and reported training 36.6 ± 7.6 hours per week. Gymnasts were recruited voluntarily through direct contact at regional competitions held in Punjab, Pakistan, and through referrals by coaches. The sample was intended to represent the high-performance gymnast population in the national context.

Inclusion criteria were as follows: (a) active participation at the national or regional elite level, (b) a minimum of five years of competitive experience, and (c) absence of major injury in the six months preceding data collection. Athletes with acute musculoskeletal injury or ongoing rehabilitation were excluded to ensure that performance and physiological parameters reflected regular training conditions. This injury-free interval aligns with standard return-to-play protocols in sports medicine.

Informed consent was obtained from all participants aged 18 and older. For those under 18 years of age, written assent was collected from the gymnast and informed consent was obtained from a parent or legal guardian, in accordance with institutional policy and ethical guidelines. Participation was fully voluntary, and athletes could withdraw at any stage without consequences.

Ethical approval for the study was granted by the Advanced Studies & Research Board (ASRB), Gomal University, Dera Ismail Khan, Pakistan (Approval

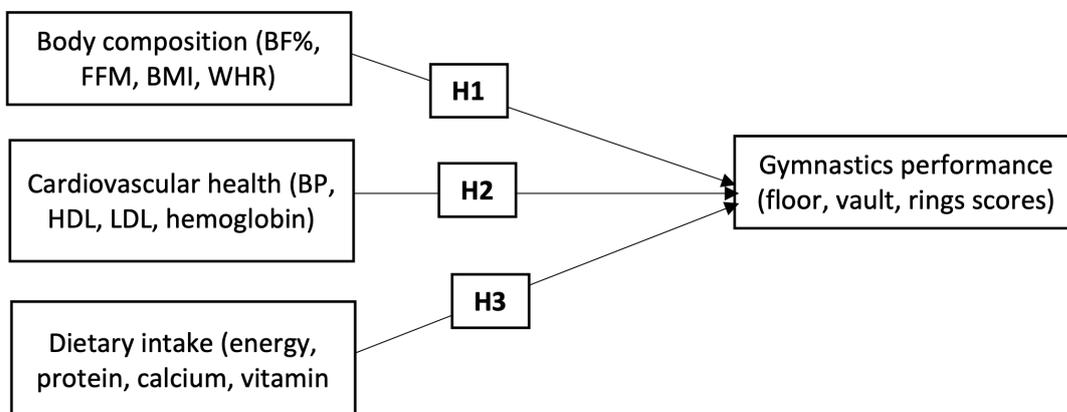


Figure 1. Conceptual framework illustrating the hypothesized effects of physiological and nutritional factors on gymnastics performance: BF% – body fat percentage, FFM – fat-free mass, BMI – body mass index, WHR – waist-to-hip ratio, BP – blood pressure, HDL – high-density lipoprotein, LDL – low-density lipoprotein.

No. 1480/ACAD/GU). All procedures conformed to the ethical principles outlined in the Declaration of Helsinki for human subjects research. To ensure data confidentiality, each participant was assigned a unique identification code. Data were stored in password-protected digital files accessible only to the research team, and physical forms were secured in locked storage at the principal investigator's office.

Training history and weekly training hours were recorded for each athlete and statistically controlled as covariates in partial correlation and group comparison analyses, due to their known influence on physiological adaptation and performance outcomes.

Research Design

This study employed a descriptive-correlational research design to examine the associations between body composition, cardiovascular health, dietary intake, and apparatus-specific performance among elite male artistic gymnasts in Pakistan. This design was selected due to its suitability for investigating naturally occurring relationships without manipulating variables. It allowed for the identification of patterns across key physiological, nutritional, and performance indicators in a real-world athletic context. Data collection was structured around four core domains: (1) body composition, (2) cardiovascular health indicators, (3) dietary intake and nutrient availability, and (4) gymnastics performance. Each domain was measured using standardized protocols to ensure validity and comparability across participants.

To guide the analytical framework, a conceptual model was developed to illustrate the hypothesized relationships among the variables. Figure 1 presents this model, which depicts body composition, cardiovascular health, and dietary intake as independent factors influencing gymnastics performance on floor, vault, and rings apparatuses. The model depicts the assumed relationships between body composition (BF%, FFM, BMI, WHR), cardiovascular health (BP, HDL, LDL, hemoglobin), and dietary intake (energy, protein, calcium, vitamin D) as independent variables, and apparatus-specific gymnastics performance (floor, vault, rings scores) as the dependent variable. Each hypothesis (H1, H2, H3) represents a proposed direct influence of one variable group on performance outcomes. The model informed the selection of variables, the statistical approach, and the formulation of hypotheses. It also allowed for the integration of multidisciplinary perspectives, aligning physiological and nutritional assessments with sport-specific performance outcomes.

No experimental manipulation or intervention was performed, and all procedures were observational in nature. The exploratory objective of the study was to identify associations rather

than establish causality or predictive relationships. Therefore, findings should be interpreted within the limits of non-experimental cross-sectional research.

Performance Evaluation

Gymnastics performance was assessed using apparatus-specific scores in floor, vault, and rings events. Each routine was evaluated by a panel of three certified judges appointed by the Pakistan Gymnastics Federation. Judging criteria followed the Code of Points established by the Fédération Internationale de Gymnastique (FIG), ensuring alignment with international performance standards. Each score incorporated multiple components, including execution (maximum 10 points), difficulty (open-ended), and compositional or artistry deductions, where applicable. To enhance objectivity and minimize bias, any individual score that deviated more than 1.0 point from the average of the three judges was excluded. The final score for each apparatus was calculated as the mean of the remaining two values. Composite performance scores were computed by summing the final scores from floor, vault, and rings routines. These totals were used to stratify participants into performance quartiles. The top and bottom quartiles were designated as high- and low-performing groups, respectively, to facilitate group-level comparisons in physiological and nutritional characteristics.

This quartile-based approach is widely used in applied sports science research, particularly in exploratory studies where performance variation is substantial. The method allowed for the identification of distinguishing traits in gymnasts with contrasting outcomes, while maintaining analytical focus on the extremes of the performance distribution. Performance scores were digitized and processed using IBM SPSS Statistics version 21 for subsequent statistical analysis.

Performance Assessment Procedure

All gymnasts performed routines on three apparatuses: floor, vault, and rings. Each performance was evaluated independently by a panel of three national-level judges certified by the Pakistan Gymnastics Federation. Judges applied scoring criteria consistent with the FIG (Fédération Internationale de Gymnastique) Code of Points, which includes execution, difficulty, and artistry components, depending on apparatus-specific requirements.

To ensure scoring reliability, the highest and lowest scores from each judging panel were discarded. The final apparatus score was calculated as the average of the remaining judge's score or, if two scores remained within the allowable deviation range, their average was used. This method minimized the influence of outlier judgments and upheld evaluation consistency. Scores were recorded using standardized scoring sheets during the event

and were subsequently digitized for analysis. Data entry and statistical procedures were conducted using IBM SPSS Statistics version 21. No custom software settings or non-standard algorithms were applied.

Weekly training volume for each athlete was recorded through self-reporting (in hours per week) and cross-validated with coach-maintained logs. Although individual training programs varied, they generally included structured combinations of strength training, flexibility exercises, and apparatus-specific skill drills performed across five to six days per week.

This multi-step approach to performance assessment ensured objective, reproducible, and competition-relevant scoring suitable for correlational analysis with physiological and nutritional data.

Body Composition

Anthropometric assessments were conducted in the morning before training sessions to minimize the influence of recent physical activity on fluid balance and body water distribution. Measurements followed standardized procedures recommended by the International Society for the Advancement of Kinanthropometry (ISAK) to ensure accuracy and consistency across participants [21].

Body mass was measured to the nearest 0.01 kg using a calibrated digital scale (SECA-872, Hamburg, Germany). Standing height was recorded to the nearest 0.1 cm using a portable stadiometer (SECA-213, Hamburg, Germany). Both instruments were calibrated daily using certified weights and a reference height rod.

Body mass index (BMI) was calculated using the standard formula: weight in kilograms divided by height in meters squared (kg/m^2). Waist circumference was measured at the narrowest point between the ribcage and the iliac crest after a normal exhalation. Hip circumference was taken at the widest point over the greater trochanters. The waist-to-hip ratio (WHR) was then derived by dividing waist circumference by hip circumference.

Body fat percentage (BF%), fat-free mass (FFM), and total body water (TBW) were estimated using a bioelectrical impedance analysis (BIA) device (TANITA BC-545, UK). All participants were instructed to abstain from intense physical activity, food intake, and fluid consumption for at least four hours prior to assessment, in accordance with standard BIA protocols to reduce measurement variability.

These body composition indicators were used in subsequent analyses to examine their associations with performance outcomes and energy availability calculations.

Cardiovascular Health

Cardiovascular health was assessed through

a combination of biochemical analyses and clinical measurements to capture both functional and metabolic indicators relevant to athletic performance and health risk screening.

Venous blood samples were collected in the morning after a 10–12 hour overnight fast. Samples were analyzed for total serum cholesterol, high-density lipoprotein (HDL), low-density lipoprotein (LDL), serum uric acid (S-UA), fasting blood glucose (S-glucose), and hemoglobin concentration. Biochemical parameters were measured using a Beckman Coulter AU 640 analyzer (Beckman Coulter, Austria), while hematological indices, including hemoglobin, were assessed using the Advia 2120i system (Siemens, Germany).

Resting blood pressure was measured using a calibrated automated oscillometric monitor (Omron HEM-907). Participants were assessed in a supine position following a five-minute rest period in a quiet room. Two readings were taken at three-minute intervals, and the average value was used for analysis. This protocol was applied to reduce variability due to situational stress or measurement error.

Interpretation of biochemical values followed guidelines from the European Society of Cardiology (ESC) and the European Atherosclerosis Society (EAS). LDL levels below 3.4 mmol/L and triglyceride levels below 1.7 mmol/L were considered within normal limits. An LDL concentration of 2.6 mmol/L or higher was interpreted as a potential marker of subclinical atherosclerotic risk. Normal blood pressure was defined as values at or below 129/84 mmHg.

These cardiovascular indicators were included as independent variables in subsequent statistical analysis to explore their relationships with gymnastics performance and energy availability.

Dietary Intake

Dietary intake was assessed using three 24-hour dietary recalls conducted on non-consecutive days, including two weekdays and one weekend day, to capture typical eating patterns. Structured interviews were administered by trained nutritionists to enhance accuracy and minimize recall bias. Participants were asked to provide detailed information about all foods and beverages consumed during the previous 24 hours, including meal timing, portion sizes, preparation methods, and brand names when applicable.

To improve portion size estimation, standardized household utensils, visual food models, and photographic portion booklets were used during interviews. Reported foods were converted into grams and milliliters, and the data were analyzed using Food Processor SQL software (ESHA Research, USA). The software provided nutrient breakdowns for macronutrients (carbohydrates, proteins, fats

including saturated fats) and key micronutrients (e.g., calcium, magnesium, vitamin D, thiamine, folate, and zinc).

Nutrient intake adequacy was evaluated using two reference frameworks. Macronutrient recommendations followed the American College of Sports Medicine (ACSM) guidelines: protein intake of 1.2–1.6 grams per kilogram of body weight per day, carbohydrate intake of 6–10 grams per kilogram per day, and total fat comprising 20–35 percent of total daily energy, with at least 55 percent of fat intake from unsaturated sources. Micronutrient sufficiency was assessed against Recommended Dietary Allowances (RDA) provided by the Food and Nutrition Board of the Institute of Medicine (FNB/IOM).

Basal metabolic rate (BMR) was estimated using the Cunningham equation, which incorporates fat-free mass and is considered more appropriate for athletic populations. Energy availability (EA) was calculated by subtracting exercise energy expenditure from total energy intake and dividing the result by fat-free mass (kcal/kg FFM/day). Athletes with an EA value below 30 kcal/kg FFM/day were classified as being at risk for low energy availability (LEA), a key indicator of relative energy deficiency in sport (RED-S).

These nutritional data were used to examine correlations with performance outcomes and physiological markers, with particular attention to energy balance and nutrient adequacy.

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics version 21. Descriptive statistics, including means and standard deviations, were calculated for all physiological, nutritional, and performance variables.

The primary analytical method was Pearson correlation, used to assess linear relationships between body composition, cardiovascular health, dietary intake, and gymnastics performance. This method was selected due to the cross-sectional and observational nature of the study, where the goal was to explore associations rather than establish causality.

Independent-samples t-tests were conducted to compare physiological and nutritional variables between high- and low-performing gymnasts. Performance stratification was based on quartile distributions of composite scores across floor, vault, and rings events. Specifically, athletes in the top and bottom 25th percentiles were classified as high- and low-performing groups, respectively. This approach allowed for focused group-level comparisons while minimizing statistical dilution from the middle-performance range.

Assumptions for parametric testing were evaluated prior to analysis. The Shapiro–Wilk

test confirmed that all continuous variables met the assumption of normal distribution ($p > 0.05$). Levene's test indicated homogeneity of variances between groups ($p > 0.05$), justifying the use of parametric methods.

Regression analysis was not performed in this study, as the primary objective was exploratory. However, the use of multivariate regression is recommended for future research aiming to quantify the relative contribution of each independent variable while controlling for confounding factors.

Statistical significance was set at $p < 0.05$ for all analyses.

Results

The results of this study are presented according to the three research objectives: (1) associations between body composition and gymnastics performance, (2) relationships between cardiovascular health indicators and performance outcomes, and (3) the influence of dietary intake on performance in elite male artistic gymnasts in Pakistan.

Statistical significance was set at $p < 0.05$. All reported correlations were tested using Pearson's method, and between-group differences were analyzed using independent-samples t-tests. Effect sizes were calculated using Cohen's d and interpreted as small ($d = 0.2$), moderate ($d = 0.5$), or large ($d \geq 0.8$). Assumptions of normality and homogeneity of variance were verified for all analyses.

Where relevant, comparisons were made between athletes classified in the top and bottom quartiles of overall performance, based on composite scores from floor, vault, and rings events. This quartile-based stratification was used to emphasize meaningful contrasts between high and low performers.

Descriptive statistics, correlation coefficients, p -values, and effect sizes are provided in Tables 1–3, organized by thematic domain.

The results of the study are presented in accordance with the predefined research objectives, each addressing a specific dimension of performance-related factors among elite male artistic gymnasts in Pakistan.

RO-1: To identify the association of body composition on the performance of male gymnasts in Pakistan

Body composition variables demonstrated selective associations with apparatus-specific performance among elite male artistic gymnasts. Descriptive and inferential results are summarized in Table 1.

A statistically significant but weak negative correlation was observed between body mass index (BMI) and floor performance ($r = -0.18$, $p < 0.05$), suggesting that gymnasts with lower BMI tended to achieve higher scores in this event. No significant correlations were found between BMI and vault (r

= -0.07, $p = 0.28$) or rings performance ($r = -0.11$, $p = 0.17$).

Fat-free mass (FFM) was positively correlated with performance on the rings ($r = 0.24$, $p < 0.01$), indicating a modest association between lean tissue mass and successful execution in upper-body strength elements. However, no significant relationships were detected between FFM and performance in floor ($r = 0.08$, $p = 0.32$) or vault ($r = 0.12$, $p = 0.09$).

Group comparisons revealed significant differences in body composition across performance quartiles. Gymnasts in the top 25 percent of performance had lower body fat percentage (11.2 ± 2.3 percent) compared to those in the bottom quartile (15.8 ± 3.4 percent), with a large effect size (Cohen's $d = 1.44$, $p < 0.01$). Significant differences were also found in BMI (21.4 ± 2.1 vs. 24.6 ± 3.2 , $d = 1.11$, $p < 0.01$), fat-free mass (56.8 ± 5.2 kg vs. 52.1 ± 5.8 kg, $d = 0.85$, $p = 0.03$), and waist-to-hip ratio (0.82 ± 0.08 vs. 0.89 ± 0.10 , $d = 0.79$, $p = 0.04$).

These results support the hypothesis that favorable body composition characteristics, including lower adiposity and greater fat-free mass, are associated with enhanced competitive performance, particularly in the floor and rings events.

RO-2: To evaluate the correlation of cardiovascular health status on the performance of male gymnasts in Pakistan

Cardiovascular health markers demonstrated multiple statistically significant associations with apparatus-specific performance, as detailed in Table 2.

Systolic blood pressure was negatively correlated with vault performance ($r = -0.22$, $p < 0.01$) and floor performance ($r = -0.18$, $p = 0.03$), suggesting that gymnasts with lower resting systolic pressure tended to score higher, particularly in explosive movements such as vaulting. Diastolic pressure showed a similar trend, with significant negative correlations for vault ($r = -0.19$, $p = 0.02$) and floor events ($r = -0.16$, $p = 0.04$). These relationships remained consistent after adjusting for training hours. Although the correlations were modest in magnitude, they were consistent across related performance outcomes.

Among lipid markers, high-density lipoprotein (HDL) cholesterol levels were positively associated with floor performance ($r = 0.21$, $p = 0.02$). Low-density lipoprotein (LDL) cholesterol showed negative associations with all three apparatus scores, reaching significance in the rings ($r = -0.26$, $p < 0.01$), vault ($r = -0.19$, $p = 0.03$), and floor ($r = -0.23$, $p < 0.01$) events. No significant associations were found between total cholesterol levels and any apparatus.

Hemoglobin concentration was positively correlated with performance across all apparatuses. The strongest association was observed in floor performance ($r = 0.32$, $p < 0.01$), followed by vault ($r = 0.28$, $p < 0.01$) and rings ($r = 0.25$, $p < 0.01$). These results indicate that higher oxygen-carrying

Table 1. Body Composition Characteristics by Performance Quartiles

| Variable | Top 25% (n = 38) | Middle 50% (n = 77) | Bottom 25% (n = 38) | p-value | Cohen's d (Top vs. Bottom) | 95% CI | Levene's Test (p) |
|--------------------------|------------------|---------------------|---------------------|---------|----------------------------|--------------|-------------------|
| BMI (kg/m ²) | 21.4 ± 2.1 | 23.1 ± 2.8 | 24.6 ± 3.2 | <0.01 | 1.11 | [0.82, 1.39] | 0.28 |
| WHR | 0.82 ± 0.08 | 0.85 ± 0.09 | 0.89 ± 0.10 | 0.04 | 0.79 | [0.53, 1.05] | 0.37 |
| BF (%) | 11.2 ± 2.3 | 13.7 ± 2.9 | 15.8 ± 3.4 | <0.01 | 1.44 | [1.11, 1.76] | 0.41 |
| FFM (kg) | 56.8 ± 5.2 | 54.3 ± 6.1 | 52.1 ± 5.8 | 0.03 | 0.85 | [0.56, 1.14] | 0.22 |

Note. BMI = body mass index; WHR = waist-to-hip ratio; BF = body fat percentage; FFM = fat-free mass. Values are presented as mean ± standard deviation. Cohen's d represents effect size between top and bottom quartiles. CI = confidence interval.

Table 2. Cardiovascular Parameters and Performance Correlations by Apparatus

| Parameter | r (Floor) | p (Floor) | r (Vault) | p (Vault) | r (Rings) | p (Rings) | 95% CI for Strongest Correlation |
|-------------------|-----------|-----------|-----------|-----------|-----------|-----------|----------------------------------|
| Systolic BP | -0.18 | 0.03 | -0.22 | <0.01 | -0.15 | 0.06 | [-0.32, -0.10] (Vault) |
| Diastolic BP | -0.16 | 0.04 | -0.19 | 0.02 | -0.12 | 0.09 | [-0.29, -0.07] (Vault) |
| HDL Cholesterol | 0.21 | 0.02 | 0.17 | 0.07 | 0.14 | 0.10 | [0.05, 0.36] (Floor) |
| LDL Cholesterol | -0.23 | <0.01 | -0.19 | 0.03 | -0.26 | <0.01 | [-0.39, -0.12] (Rings) |
| Hemoglobin | 0.32 | <0.01 | 0.28 | <0.01 | 0.25 | <0.01 | [0.18, 0.45] (Floor) |
| Total Cholesterol | -0.06 | 0.34 | -0.08 | 0.29 | -0.04 | 0.40 | - |

Note. BP = blood pressure; HDL = high-density lipoprotein; LDL = low-density lipoprotein; r = Pearson correlation coefficient; CI = confidence interval. Values marked in bold indicate statistically significant correlations ($p < 0.05$).

Table 3. Dietary Intake Characteristics of High vs. Low Performing Gymnasts

| Nutrient | High Performers (n = 51) | Low Performers (n = 102) | p-value | Cohen's d | 95% CI | Levene's Test (p) |
|----------------------|-----------------------------|-----------------------------|---------|-----------|--------------|----------------------|
| Energy (kcal) | 3156 ± 298 | 2874 ± 321 | <0.01 | 1.00 | [0.72, 1.28] | 0.63 |
| Protein (g/kg) | 1.52 ± 0.18 | 1.34 ± 0.21 | <0.01 | 0.95 | [0.68, 1.22] | 0.57 |
| Carbohydrates (g/kg) | 7.2 ± 1.1 | 6.5 ± 1.3 | <0.01 | 0.59 | [0.34, 0.84] | 0.31 |
| Fat (% energy) | 28.4 ± 3.2 | 31.7 ± 4.1 | <0.01 | 0.89 | [0.62, 1.17] | 0.41 |
| Calcium (mg) | 1256 ± 213 | 1045 ± 198 | <0.01 | 1.04 | [0.76, 1.33] | 0.36 |
| Iron (mg) | 18.2 ± 3.1 | 15.7 ± 2.9 | 0.07 | 0.54 | [0.29, 0.79] | 0.44 |
| Vitamin D (IU) | 895 ± 215 | 732 ± 198 | <0.01 | 0.82 | [0.57, 1.07] | 0.33 |
| Water Intake (L) | 3.4 ± 0.6 | 2.8 ± 0.7 | <0.01 | 0.92 | [0.64, 1.19] | 0.52 |

Note. Values are presented as mean ± standard deviation. Nutrient intakes are normalized by body weight where appropriate. Cohen's d indicates effect size; CI = confidence interval. High performers were defined as the top 33rd percentile in overall performance score.

capacity is consistently linked to improved output in both endurance and strength-oriented routines.

Together, these findings support the second hypothesis and suggest that favorable cardiovascular profiles, particularly lower blood pressure, higher hemoglobin concentration, and optimal lipid status, are associated with improved gymnastic performance in elite male athletes.

RO-3: To find out the relationship of dietary intake on the performance of male gymnasts in Pakistan

Dietary intake patterns were significantly associated with gymnastics performance across multiple apparatuses. Table 3 presents comparative nutrient intake data for high- and low-performing athletes, based on composite performance scores.

Athletes in the top performance quartile had significantly higher daily energy intake (mean 3156 ± 298 kcal) compared to those in the bottom quartile (mean 2874 ± 321 kcal, $p < 0.01$). The effect size for this difference was large (Cohen's $d = 1.00$). Similar patterns were observed for protein intake, with top performers consuming 1.52 ± 0.18 grams per kilogram of body weight, significantly more than lower-performing peers (1.34 ± 0.21 g/kg, $p < 0.01$, $d = 0.95$). Notably, the most consistent rings performances were observed among gymnasts whose protein intake fell within the range of 1.4 to 1.6 grams per kilogram per day.

Carbohydrate intake was also higher among top performers (7.2 ± 1.1 g/kg vs. 6.5 ± 1.3 g/kg, $p < 0.01$), with a moderate effect size ($d = 0.59$). Fat intake as a percentage of total energy was lower in high performers (28.4 ± 3.2 percent) compared to low performers (31.7 ± 4.1 percent, $p < 0.01$, $d = 0.89$), suggesting better macronutrient distribution in the higher-performing group.

Micronutrient intake also showed performance-related associations. Calcium and vitamin D intake were significantly higher among top performers (calcium: 1256 ± 213 mg vs. 1045 ± 198 mg, $p < 0.01$; vitamin D: 895 ± 215 IU vs. 732 ± 198 IU, $p <$

0.01). The effect sizes for both were large ($d = 1.04$ and $d = 0.82$, respectively). Positive correlations were also observed between calcium intake and floor performance ($r = 0.26$, $p < 0.05$), and between vitamin D intake and vault performance ($r = 0.29$, $p < 0.01$). Magnesium intake was modestly associated with floor performance ($r = 0.23$, $p < 0.05$).

Water consumption emerged as a consistent predictor of better outcomes. Athletes reporting daily intake above 3 liters performed better across all apparatuses, with average score improvements of 0.5 to 0.7 points ($p < 0.05$, $d = 0.92$). No statistically significant association was found between iron intake and performance in any apparatus ($p > 0.10$).

These findings support the third hypothesis and underscore the importance of adequate energy availability, balanced macronutrient distribution, sufficient micronutrient intake, and proper hydration in optimizing gymnastics performance among elite male athletes.

Discussion

This study investigated the associations between body composition, cardiovascular health, dietary intake, and gymnastics performance among elite male artistic gymnasts in Pakistan. The results provide partial support for the research hypotheses, indicating that specific physiological and nutritional factors are associated with apparatus-specific outcomes. These findings hold relevance for applied athlete monitoring and performance optimization within resource-constrained training environments.

Regarding body composition, gymnasts in the higher performance quartile exhibited significantly lower body fat percentages and higher levels of fat-free mass. These results are consistent with earlier studies by Ruscello et al. [3] and Manna et al. [16], which found that reduced fat mass improves movement efficiency and power-to-weight ratio – particularly relevant for floor and rings events. The positive correlation between fat-free mass and rings

performance further supports the biomechanical demands of strength-based apparatuses. However, the association between BMI and vault performance was not statistically significant, which may reflect the complex nature of explosive events where excessive mass may both aid and hinder momentum generation.

Cardiovascular health indicators showed significant but modest associations with gymnastics performance. Elevated systolic and diastolic blood pressure were negatively correlated with vault and floor outcomes, aligning with previous findings from Jakše et al. [5] and Grabitz et al. [8], who reported that vascular stress may impair neuromuscular efficiency and postural stability. Furthermore, hemoglobin concentration demonstrated the most consistent performance correlations across all apparatuses, supporting its role in oxygen delivery and muscular endurance. Similar trends were noted by Smith-Ryan et al. [11] in sports requiring repeated submaximal exertions.

Blood lipid profiles also exhibited apparatus-specific associations. Higher HDL and lower LDL levels correlated with better performance, particularly in dynamic and aerobic elements. These patterns suggest that lipid regulation may serve as a secondary marker of cardiovascular conditioning and recovery capacity, especially in environments with limited access to sport-specific medical oversight.

Continuing with nutritional findings, this study identified notable differences in energy intake, protein adequacy, and micronutrient sufficiency between higher- and lower-performing gymnasts. Athletes in the top quartile reported greater total energy consumption and higher intake of carbohydrates and protein, supporting findings by Kuhlman et al. [10], who observed widespread low energy availability among collegiate male gymnasts. Protein intake appeared especially relevant to performance on the rings apparatus, where upper-body eccentric loading demands elevated muscle repair capacity. Francisco et al. [13] emphasized the importance of distributing protein evenly throughout the day to support recovery and training adaptation.

Micronutrient data reinforced the significance of calcium and vitamin D in maintaining bone integrity and neuromuscular function. Villa et al. [12] noted that many youth gymnasts failed to meet dietary reference intakes for these nutrients, increasing the risk of stress fractures and impaired skeletal development. Mense [14] further highlighted the impact of inadequate hydration and low nutrient availability on vascular function, suggesting the need for targeted nutritional strategies in high-load sports such as gymnastics.

The observed associations between hydration and performance outcomes provide additional support for the importance of basic nutritional

practices in athlete preparation. Gymnasts who reported consuming more than three liters of water per day showed better scores across all apparatuses, possibly due to improved thermoregulation, joint lubrication, and cognitive focus. This finding aligns with literature on fluid intake in closed-skill sports with high technical precision.

Collectively, these dietary patterns reflect the performance benefits of adequate energy availability and balanced nutrient distribution. However, they also point to a lack of structured nutritional education and monitoring in the Pakistani gymnastics system, which may contribute to energy deficiency and inconsistent dietary practices among young athletes.

Limitations of the Study

Several limitations should be acknowledged when interpreting the results of this study. First, the sample was drawn exclusively from elite male gymnasts in Pakistan, limiting the generalizability of findings to female athletes or gymnasts in other competitive systems. The geographic concentration in Punjab and reliance on federation-affiliated training centers may also introduce sampling bias.

Second, the study employed a cross-sectional design, which restricts causal inference. Although associations were identified, no conclusions can be drawn about the directionality or temporal sequencing of effects. Longitudinal or intervention-based designs are required to validate these findings over time.

Third, although dietary intake data were collected through structured 24-hour recalls, this method remains subject to underreporting and recall bias, particularly in adolescent athletes. Although trained interviewers and portion-estimation tools were used, accuracy may still be variable.

Fourth, the absence of hormonal markers and bone density assessments limited the depth of analysis regarding energy availability and RED-S risk. These data would have strengthened the interpretation of physiological impacts.

Lastly, some laboratory measures (e.g., blood lipid profile, hemoglobin) were assessed using single time-point samples, which may not fully capture within-athlete biological variation or training phase differences.

Conclusions

This study examined the associations between body composition, cardiovascular health, dietary intake, and performance outcomes among elite male artistic gymnasts in Pakistan. The findings indicate that athletes with lower body fat percentage, greater fat-free mass, and healthier cardiovascular and nutritional profiles tend to achieve better scores across apparatuses, particularly in floor and rings events.

Body composition variables such as BMI, fat-free mass, and waist-to-hip ratio were significantly associated with apparatus-specific performance, supporting the hypothesis that leaner athletes with optimized anthropometric profiles perform more efficiently. Hemoglobin concentration and blood lipid levels also demonstrated moderate associations with performance, suggesting a potential role for cardiovascular screening in gymnastics-specific fitness monitoring.

Nutritional intake emerged as a key performance-related factor. Athletes with higher daily energy, protein, and micronutrient intakes (notably calcium, vitamin D, and magnesium) exhibited superior execution scores. These findings support the integration of individualized dietary assessment and guidance into athlete support programs, especially in training environments with limited access to sports dietitians.

The results emphasize the need for structured physiological monitoring, regular dietary evaluation, and basic medical screening in gymnastics training systems. These components should be aligned with international recommendations but adapted to national contexts through collaboration between coaches, sports physicians, and academic institutions.

In summary, optimized body composition, cardiovascular regulation, and nutrient intake are critical to the performance of male artistic gymnasts. Addressing these factors through integrated athlete management may enhance both competitive outcomes and long-term health.

Future Research Directions

Future studies should adopt longitudinal or controlled designs to investigate how changes in body composition, nutritional intake, and cardiovascular markers influence performance outcomes across a competitive season. Inclusion of female gymnasts and athletes from diverse regions would enhance representativeness and allow for sex-based and regional comparisons.

Intervention-based research is needed to assess the effectiveness of structured nutrition education programs, dietary periodization strategies, and hydration protocols tailored to the physiological demands of artistic gymnastics. Additionally, integrating hormonal, bone health, and psychological readiness indicators could provide a more comprehensive model of athlete monitoring.

Collaboration with sports federations, medical professionals, and university-based training programs may facilitate the development of evidence-based guidelines that promote both performance optimization and long-term athlete health in low-resource settings.

Practical Implications

The findings of this study offer several practical

insights for coaches, sports scientists, and athletic program administrators:

- Body composition monitoring should be incorporated into periodic evaluations, with emphasis on maintaining low body fat and adequate fat-free mass relative to apparatus demands.
- Cardiovascular screening using non-invasive measures such as resting blood pressure and hemoglobin levels can help detect physiological limitations and readiness for high-intensity training.
- Nutritional support systems should include regular dietary assessments and basic education on energy balance, macronutrient distribution, and hydration practices, especially in junior development settings.
- Micronutrient intake, particularly calcium, vitamin D, and magnesium, should be monitored in light of their relationship with neuromuscular function and recovery from impact loading.
- Hydration awareness should be prioritized as a low-cost, high-impact strategy to maintain performance consistency and cognitive focus during technical execution.

These measures are especially important in resource-limited training environments, where low-cost interventions can significantly enhance athlete health and performance sustainability.

Recommendations

Based on the study results, the following recommendations are proposed:

1. Implement individualized athlete screening protocols combining anthropometric, cardiovascular, and nutritional parameters at least once per training cycle.
2. Develop sport-specific nutritional education programs targeting coaches, athletes, and parents to address gaps in dietary knowledge and prevent energy deficiency syndromes such as RED-S.
3. Promote collaboration between sports federations and universities to integrate scientific monitoring into talent development pathways.
4. Conduct further longitudinal and interventional research to evaluate the causal impact of physiological and dietary modifications on gymnastics performance.
5. Establish minimum medical monitoring standards at regional training centers to ensure early identification of health risks in youth and elite athletes.

Conflict of Interest

The authors declare no competing interests.

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