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THE IMPACT OF CARBOHYDRATE LOADING ON ENDURANCE AND AGILITY IN PAKISTANI BADMINTON PLAYERS: A RANDOMIZED CONTROLLED TRIAL

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Abstract

Objective: This study investigated the effects of a 3-day carbohydrate-loading intervention on sport-specific performance measures in competitive badminton athletes, with a particular focus on gender-specific responses. Research Methodology: Conducted a randomized controlled trial with thirty-two competitive badminton players (16 male, 16 female; age 21.4±1.9 years) who were recruited from provincial training squads in Khyber Pakhtunkhwa, Pakistan. Participants were stratified by gender and randomly assigned to either: (1) an experimental Group implementing a 3-day carbohydrate-loading protocol (8-10g/kg/day), or (2) a control group maintaining habitual dietary patterns. Performance assessments included the Yo-Yo Intermittent Recovery Test (endurance) and standardized T-test (agility), administered pre- and post-intervention by blinded assessors. Results: The experimental group significantly improved their Yo-Yo intermittent test performance by 20.3% (Δ=260m, $p < 0.001$, $d = 1.32$) compared to the control group, which showed a 4.0% improvement ($p = 0.214$), demonstrating enhanced endurance capacity. Agility T-test performance also improved significantly (6.0% reduction, $p=0.003$, $d=0.89$) versus minimal change in controls (0.4%, $p=0.872$). Mixed ANOVA revealed significant time × group interactions for both Yo-Yo ($F=19.53$, $p<0.001$, $\eta p^2=0.413$) and T-test ($F=9.67$, $p=0.013$, $\eta p^2=0.259$) measures. No gender differences in intervention responsiveness were observed ($p>0.05$ for all comparisons) ($p>0.05$ for all gender comparisons). Conclusion: These findings demonstrate that short-term carbohydrate loading effectively enhances both endurance and agility performance in competitive badminton players, with comparable benefits observed across genders. The results support the incorporation of targeted carbohydrate periodization into badminton training programs, particularly during competition preparation phases.

Keywords: Sports Nutrition, Glycogen Super-Compensation, Racket Sports, Exercise Performance, Gender Differences, Anaerobic Capacity

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INTRODUCTION

Badminton is a high-intensity sport that demands exceptional endurance, explosive power, and rapid agility (Phomsoupha & Laffaye, 2020). In Pakistan, particularly in Khyber Pakhtunkhwa (KPK), badminton is gaining popularity, yet athletes often lack structured nutritional strategies to optimize performance. Carbohydrate (CHO) loading, a well-documented ergogenic aid, involves increasing glycogen stores before competition to delay fatigue and enhance endurance (Burke et al., 2021). However, research on its efficacy in South Asian athletes, particularly in sports like badminton, remains scarce. Given the sport's intermittent high-intensity nature, proper glycogen availability could significantly influence match performance, especially during prolonged rallies (Abian-Vicen et al., 2014).

In Pakistan, dietary habits among athletes often rely on traditional eating patterns rather than evidence-based sports nutrition (Khan et al., 2022). Many players consume inadequate carbohydrates, relying instead on protein-heavy or unbalanced meals, which may impair recovery and performance. Additionally, the hot and humid climate of Peshawar further exacerbates energy depletion, making proper fueling strategies crucial (Logan-Sprenger et al., 2015). Despite global recognition of CHO loading,s benefits, its application in Pakistani badminton players has not been empirically tested. This study seeks to bridge that gap by examining whether a 3-day CHO-loading protocol improves endurance and agility among athletes at Hayatabad Sports Complex, Peshawar.

The importance of this study lies in its potential to enhance athletic performance through practical, low-cost nutritional interventions. Unlike expensive supplements or specialized training programs, CHO loading relies on dietary adjustments, making it accessible for athletes in resource-limited settings (Jeukendrup, 2017). Given that badminton matches can last over an hour with minimal rest, optimal glycogen stores may prevent late-game performance declines (Fernandez-Fernandez et al., 2016). Moreover, this research addresses a critical gap in regional sports science literature, as most existing studies focus on Western or elite athletes, neglecting the unique physiological and cultural context of Pakistani players (Imran et al., 2021).

From a sports medicine perspective, improper nutrition contributes to early fatigue, increasing injury risks due to compromised motor control (Close et al., 2019). By establishing locally relevant guidelines, this study could help coaches and athletes in KPK adopt more effective fueling strategies. Furthermore, the findings may influence future sports nutrition policies at the collegiate and regional levels, promoting scientifically backed practices over anecdotal dietary habits.

Despite the known benefits of carbohydrate loading in sports, there is limited empirical evidence on its effectiveness for badminton players in Pakistan. Many athletes in KPK follow suboptimal dietary practices due to a lack of awareness, cultural food preferences, or limited access to sports nutritionists (Khan et al., 2022). This nutritional gap may hinder performance, particularly in endurance and agility-based tasks essential for competitive badminton. Without proper glycogen stores, players experience premature fatigue, reduced sprint capacity, and slower recovery between points (Abian-Vicen et al., 2014). Given the rising competitiveness of badminton in Pakistan, there is a pressing need to investigate whether CHO loading can serve as a practical intervention to enhance performance metrics. The primary purpose of this study is to scientifically investigate whether a 3-day carbohydrate-loading protocol enhances endurance and agility performance in competitive badminton players from Khyber Pakhtunkhwa, Pakistan. By employing a randomized controlled trial design at Hayatabad Sports Complex, Peshawar, this research aims to provide evidence-based data on how strategic nutritional interventions can optimize athletic performance in Pakistan's unique sports environment. Additionally, the study seeks to bridge the knowledge gap in South Asian sports nutrition research while offering practical dietary recommendations that are culturally appropriate and accessible for developing regions.

LITERATURE REVIEW

The relationship between carbohydrate (CHO) intake and athletic performance has been extensively studied in endurance sports, yet research specific to badminton, a high-intensity intermittent sport, remains limited, particularly in South Asian contexts. Badminton demands rapid bursts of explosive movement, agility changes, and sustained aerobic capacity, with matches often exceeding 60 minutes in duration (Phomsoupha & Laffaye, 2020). Glycogen depletion during prolonged play can impair reaction time and stroke precision, particularly in the later stages of matches (Abian-Vicen et al., 2014). This underscores the potential value of CHO loading, a strategy proven to enhance glycogen storage by 20–40% when athletes consume 8–12 g/kg/day of CHO for 36–48 hours pre-competition (Burke et al., 2011). However, existing studies have predominantly focused on Western athletes, leaving gaps in understanding their efficacy for Pakistani players, who often face nutritional challenges such as protein-heavy traditional diets and limited access to sports nutrition guidance (Khan et al., 2022).

The physiological demands of badminton align closely with the benefits of CHO loading. Research on intermittent sports like soccer demonstrates that elevated glycogen stores delay fatigue during repeated sprints (Balsom et al., 1999), a finding likely applicable to badminton, with its stop-start nature. A 2021 meta-analysis by Vigh-Larsen et al. confirmed that CHO loading improves endurance in racket sports, though agility-specific outcomes remain understudied. This is critical for badminton, where agility—measured via tests like the T-test correlates strongly with on-court success (Muniroglu & Subak, 2018). Notably, no studies have examined these effects in Pakistan's climatic conditions, where heat and humidity may accelerate glycogen depletion (Logan-Sprenger et al., 2015).

Cultural and logistical barriers further highlight the need for localized research. Pakistani athletes frequently rely on carbohydrate sources like rice and chapati, but timing and portioning are rarely optimized for performance (Imran et al., 2021). While CHO loading is cost-effective, its adoption requires education to overcome misconceptions, such as the belief that high-protein diets alone suffice for strength sports (Close et al., 2019). Previous interventions in similar settings (e.g., India's badminton players) showed 12–15% improvements in endurance after CHO manipulation (Majumdar et al., 2017), suggesting potential applicability to Pakistan. However, regional differences in diet, training norms, and body composition necessitate tailored investigations.

This study addresses these gaps by evaluating CHO loading, its impact on both endurance (Yo-Yo test) and agility (T-test) in KPK's badminton athletes. By incorporating athlete feedback on dietary adherence, it also explores practical implementation challenges, a dimension often overlooked in sports nutrition research. The findings could redefine nutritional strategies for racket sports in resource-limited environments while contributing to the global dialogue on equitable sports science research.

RESEARCH METHODOLOGY

STUDY SETTING AND FACILITIES

The research was conducted at the Hayatabad Sports Complex in Peshawar, KPK, a premier badminton training facility recognized by the Pakistan Badminton Federation. The complex provided two international-standard badminton courts with BWF-approved synthetic flooring and competition-level lighting systems. Environmental conditions were carefully monitored throughout the study period, with temperature maintained at 25-28°C and relative humidity at 60% to simulate tournament conditions. The on-site sports science laboratory was equipped with precision measurement instruments, including digital skinfold calipers (Harpenden, ±0.2mm accuracy) and a multi-frequency bioelectrical impedance analyzer (InBody 270) for body composition assessment. A dedicated testing area was established with permanently marked positions for the T-test agility assessment and Yo-Yo intermittent recovery test. The medical support team consisted of a sports physician and two certified physiotherapists who supervised all testing sessions to ensure participant safety and protocol adherence.

RESEARCH DESIGN

The study employed a stratified, randomized controlled trial design with a parallel-group structure. Participants were first stratified by gender to ensure equal representation, then randomly allocated using computer-generated randomization sequences to either the experimental or control group. The experimental group (n=16, 8 male and 8 female) received the carbohydrate-loading intervention while maintaining their regular training schedule. The control group (n=16, 8 male and 8 female) followed their habitual dietary patterns while participating in identical training sessions. This design allowed for direct comparison between groups while controlling for training variables. The double pretest-posttest structure included baseline measurements, a 3-day intervention period, and follow-up testing to assess both immediate and sustained effects of the nutritional intervention.

PARTICIPANT SELECTION

Participant recruitment followed a rigorous selection process to ensure sample homogeneity. Thirty-two competitive badminton players (16 male, 16 female) aged 18-25 years were selected from provincial training squads and university sports programs. Selection criteria emphasized competitive experience (minimum 3 years of regular tournament participation) and training consistency (at least 5 structured training sessions per week). The gender-balanced sample was intentionally designed to allow for gender-specific analysis of intervention effects. Exclusion criteria were carefully implemented to control for confounding variables, including any history of metabolic disorders, recent musculoskeletal injuries (within 6 months), or use of performance-enhancing supplements. Written informed consent was obtained after full disclosure of study procedures and potential risks.

INTERVENTION PROTOCOL

The experimental intervention consisted of a scientifically validated carbohydrate-loading protocol adapted for badminton athletes. During the 3-day loading phase, participants consumed 8-10g of carbohydrates per kilogram of body weight daily, with gender-specific adjustments: male athletes followed the upper range (9-10g/kg) while female athletes followed the lower range (8-9g/kg) to account for physiological differences in glycogen storage capacity. Dietary compliance was ensured through multiple verification methods, including weighed food records, 24-hour dietary recalls, and periodic monitoring by research nutritionists. The control group maintained their normal dietary patterns but recorded all food intake to document potential variations. Both groups continued their identical training regimens supervised by certified badminton coaches to maintain training load consistency throughout the study period.

PERFORMANCE TESTING PROCEDURES

Standardized testing protocols were implemented for all performance assessments. The Yo-Yo intermittent recovery test was conducted on the badminton courts using professional audio equipment to ensure precise pacing. Participants completed shuttle runs between markers placed exactly 20 meters apart, with speed increments dictated by standardized audio cues. The T-test agility assessment used permanently fixed cone markers arranged in a precise T-formation (5m × 10m × 5m) to ensure measurement consistency across all testing sessions. All tests were administered at the same time of day (±1 hour) for each participant to control for circadian rhythm effects. Pretesting familiarization sessions were conducted to minimize learning effects, and all assessments were supervised by the same team of certified fitness testers to maintain inter-rater reliability.

DATA COLLECTION AND MANAGEMENT

A comprehensive data collection system was implemented to ensure research quality. Anthropometric measurements, including height, weight, and body composition, were taken using calibrated instruments following ISAK protocols. Performance data was recorded electronically using laser timing gates (Brower Timing Systems) for the T-test and digital audio recording for the Yo-Yo test. All data was double-entered into a secure electronic database with range checks and validation rules to ensure accuracy. Participants ' dietary records were analyzed using nutrition analysis software (Nutritics) with the Pakistani food composition database. Regular data audits were conducted to identify and correct any discrepancies in the dataset.

STATISTICAL ANALYSIS PLAN

The statistical analysis employed a mixed-model approach to account for both within-subject and between-subject effects. All variables were first examined for normality using Shapiro-Wilk tests. Descriptive statistics, including means, standard deviations, and 95% confidence intervals, were calculated for all outcome measures. Primary analysis used repeated measures Paired Sample-t-Test, independent sample t_Test, and ANOVA with time (pre-post) as the within-subjects factor and group (experimental-control) as the between-subjects factor, including gender as a moderator variable. Effect sizes were calculated using partial eta-squared (η^2) for ANOVA models and Cohen's d for pairwise comparisons. Post-hoc tests used the Bonferroni correction for multiple comparisons. Secondary analysis included Pearson correlations between dietary adherence measures and performance outcomes. All analyses were conducted using SPSS version 26 with α set at 0.05 for statistical significance.

ETHICAL CONSIDERATIONS

The study protocol received full ethical approval from the institutional review board of the University of Peshawar (Ref: UP/IRB/2023/SP-45). The ethical review process included evaluation of potential risks, benefit-risk ratio, and participant protection measures. All participants provided written informed consent after receiving detailed information about study procedures, potential discomforts, and their rights as research subjects. Special consideration was given to female participants regarding menstrual cycle tracking and its potential impact on performance. Confidentiality was protected through the use of coded identifiers and secure data storage compliant with GDPR principles. An independent data safety monitoring board reviewed adverse events and protocol compliance throughout the study duration. Participants retained the right to withdraw at any time without penalty to their athletic standing or access to training facilities.

RESULTS

Overview

The study examined the effects of a 3-day carbohydrate (CHO) loading protocol on endurance and agility performance in competitive badminton players. Data analysis followed a systematic approach, beginning with anthropometric characterization, normality testing, descriptive comparisons, and concluding with inferential statistics. All statistical procedures were conducted using SPSS version 26, with $\alpha = 0.05$ set as the significance threshold.

ANTHROPOMETRIC VARIABLES

Table 1: Presents baseline anthropometric characteristics by group and gender. The experimental and control groups showed comparable physical profiles, confirming successful randomization.

Variable	Experimental Group (n=16)	Control Group (n=16)	p-value
Male (n=8 per group)			
Age (years)	21.5 ± 1.8	21.8 ± 1.6	.672
Height (cm)	175.2 ± 5.3	174.6 ± 4.9	.781
Weight (kg)	68.4 ± 6.2	67.9 ± 5.8	.845
BMI (kg/m²)	22.3 ± 1.7	22.1 ± 1.5	.752
Female (n=8 per group)			
Age (years)	20.9 ± 2.0	21.2 ± 1.9	.721
Height (cm)	162.4 ± 4.8	161.9 ± 4.5	.803
Weight (kg)	58.3 ± 5.1	57.8 ± 4.9	.812
BMI (kg/m²)	21.8 ± 1.6	21.6 ± 1.4	.764

The baseline anthropometric data presented in Table 1 demonstrate successful randomization between experimental and control groups, which is crucial for ensuring the internal validity of the study. For male participants, the experimental and control groups showed nearly identical mean values across all measured parameters: age (21.5 vs 21.8 years), height (175.2 vs 174.6 cm), weight (68.4 vs 67.9 kg), and BMI (22.3 vs 22.1 kg/m²). The high p-values (ranging from .672 to .845) confirm there were no statistically significant differences between groups at baseline. This homogeneity is particularly important as it suggests any subsequent performance differences can be more confidently attributed to the carbohydrate-loading intervention rather than pre-existing physical characteristics.

Similarly, female participants in both groups exhibited comparable anthropometric profiles, with no significant differences in age (20.9 vs 21.2 years), height (162.4 vs 161.9 cm), weight (58.3 vs 57.8 kg), or BMI (21.8 vs 21.6 kg/m²). The consistency in physical characteristics between groups (all p-values > .72) strengthens the study design by minimizing potential confounding variables. The careful gender stratification in randomization is evident through the distinct yet balanced physical profiles between male and female participants, which appropriately reflects typical physiological differences between genders in athletic populations. These baseline results provide confidence that subsequent performance outcomes can be reasonably compared between groups, as any observed changes are unlikely to be influenced by initial differences in body composition or physical characteristics.

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The successful randomization is particularly noteworthy given that even small differences in baseline characteristics could potentially influence outcomes in sports performance studies. The comparable BMI values across groups (ranging from 21.6 to 22.3 kg/m²) suggest all participants fell within the normal weight range for athletes, which is important as both underweight and overweight status could affect glycogen storage capacity and exercise performance. The tight age range (20.9-21.8 years) indicates the study examined a developmentally homogeneous group of young adult athletes, reducing potential age-related variations in metabolic response to carbohydrate loading.

NORMALITY STATISTICS

TABLE 2: NORMALITY TEST RESULTS (SHAPIRO-WILK)

Variable	Experimental Group (W)	Control Group (W)	p-value
Yo-Yo Test (pre)	.941	.928	.221
Yo-Yo Test (post)	.952	.937	.185
T-Test (pre)	.923	.916	.302
T-Test (post)	.931	.925	.276

The Shapiro-Wilk test results presented in Table 2 provide essential information about the distribution characteristics of our performance variables, which is fundamental for selecting appropriate statistical tests. For all measured variables - both pre- and post-intervention Yo-Yo test and T-test results - the W statistics ranged between 0.916 and 0.952 across experimental and control groups. These values all approach the ideal value of 1.0, indicating strong normality of distribution. More importantly, the associated p-values for all variables exceeded our α level of 0.05, ranging from .185 to .302, providing statistical confirmation that our data did not significantly deviate from a normal distribution. These normality findings have several important implications for our analysis. First, they validate our use of parametric statistical tests (such as t-tests and ANOVA), which assume normally distributed data. The consistent normality across both groups suggests that any performance differences we observe are likely due to true intervention effects rather than distributional anomalies. Second, the similar normality patterns between experimental and control groups reinforce the comparability of our groups that was established in the anthropometric analysis. Third, the maintenance of normality in post-intervention measures indicates that the carbohydrate-loading protocol did not create skewed distributions in performance outcomes, which might have occurred if the intervention had dramatically improved only certain participants. The robustness of these normality results across all performance measures gives us confidence in the reliability of our subsequent parametric analyses. It s particularly noteworthy that both our endurance measure (Yo-Yo test) and agility measure (T-test) showed this consistency, as it suggests our selected performance tests produced data that were well-behaved statistically. This strengthens our ability to draw valid conclusions about the intervention effects across different aspects of badminton performance. The consistent normality also suggests that our sample size, while modest, was adequate to capture the underlying distribution of performance characteristics in this athletic population.

DESCRIPTIVE STATISTICS (PRE- AND POST-INTERVENTION)

***TABLE 3:* PRE-INTERVENTION PERFORMANCE SCORES**

Variable	Experimental Group	Control Group	p-value
Yo-Yo Test (m)	1280 ± 215	1245 ± 198	.621

Variable	Experimental Group	Control Group	p-value
T-Test (s)	10.45 ± 0.82	10.52 ± 0.76	.804

The baseline performance data presented in Table 3 demonstrate excellent comparability between the experimental and control groups prior to the carbohydrate-loading intervention. For the Yo-Yo Intermittent Recovery Test, the experimental group recorded a mean distance of 1280 ± 215 meters compared to 1245 ± 198 meters in the control group (p = .621). This non-significant difference (p > .05) indicates that both groups began the study with equivalent levels of endurance capacity, which is crucial for attributing any post-intervention differences to the experimental treatment rather than pre-existing variations in fitness. Similarly, the T-test agility scores showed no significant baseline differences between groups, with the experimental group completing the test in 10.45 ± 0.82 seconds versus 10.52 ± 0.76 seconds for controls (p = .804). The nearly identical means and overlapping standard deviations suggest homogeneous starting points for agility performance. These results, combined with the previously established anthropometric similarities, provide strong evidence that the randomization process successfully created equivalent groups across all relevant performance measures.

***TABLE 4:* POST-INTERVENTION PERFORMANCE SCORES**

Variable	Experimental Group	Control Group	p-value
Yo-Yo Test (m)	1540 ± 185	1295 ± 203	**.001**
T-Test (s)	9.82 ± 0.71	10.48 ± 0.79	**.013**

The post-intervention results in Table 4 reveal significant performance improvements in the experimental group following the carbohydrate-loading protocol. For the Yo-Yo Intermittent Recovery Test, the experimental group demonstrated a marked increase in endurance capacity, achieving 1540 ± 185 meters compared to 1295 ± 203 meters in the control group (p = .001). This statistically significant difference (p < .01) represents a clinically meaningful 19.1% improvement in the experimental group versus only a 4.0% change in controls, strongly supporting the efficacy of the carbohydrate-loading intervention for enhancing badminton-specific endurance performance. The substantial effect size (Cohen's d = 1.28) further confirms the practical significance of these findings for competitive athletes.

Similarly, the T-test agility results showed significant between-group differences post-intervention, with the experimental group completing the test in 9.82 ± 0.71 seconds compared to 10.48 ± 0.79 seconds for controls (p = .013). This 6.3% improvement in agility performance among carbohydrate-loaded athletes suggests that the intervention may benefit not just endurance but also sport-specific movement patterns requiring rapid changes of direction. The maintenance of relatively tight standard deviations in both groups indicates consistent responses to the intervention among participants, rather than the results being driven by outlier performances.

INFERENTIAL STATISTICS

***TABLE 5:* PAIRED SAMPLES T-TEST RESULTS FOR MALE PARTICIPANTS**

Group	n	Variable	Pre-test	Post-test	Mean Difference	t-value	p-value	Cohen, S.D
Experimental	8	Yo-Yo (m)	1320 ± 198	1585 ± 167	265 ± 42	6.27	<.001	1.52
		T-Test	10.32 ±	9.71 ±	-0.61 ± 0.15	-4.05	.002	0.98

Group	n	Variable	Pre-test	Post-test	Mean Difference	t-value	p-value	Cohen, S.D
		(s)	0.75	0.68				
Control	8	Yo-Yo (m)	1275 ± 187	1305 ± 192	30 ± 28	1.07	.312	0.26
		T-Test (s)	10.48 ± 0.81	10.45 ± 0.79	-0.03 ± 0.12	-0.25	.809	0.06

The paired samples t-test results for male participants (Table 5) demonstrate striking differences in training adaptation between the experimental and control groups. Male athletes in the carbohydrate-loading group exhibited substantial improvements in both endurance and agility measures following the intervention. For the Yo-Yo Intermittent Recovery Test, these athletes improved their performance by 265 ± 42 meters ($t = 6.27$, $p < .001$), representing a remarkable 20.1% increase in endurance capacity. The exceptionally large effect size ($d = 1.52$) indicates this improvement has major practical significance for competitive performance. Similarly, their T-test agility performance improved by 0.61 ± 0.15 seconds ($t = -4.05$, $p = .002$), a 5.9% enhancement that would likely translate to meaningful on-court advantages during match play. In contrast, male control group participants showed minimal changes in performance measures during the same period. Their Yo-Yo test results increased by only 30 ± 28 meters ($t = 1.07$, $p = .312$), representing a non-significant 2.4% improvement, while their T-test performance showed virtually no change (-0.03 ± 0.12 seconds, $t = -0.25$, $p = .809$). The negligible effect sizes ($d = 0.06$-0.26) confirm these trivial changes would have no meaningful impact on competitive performance. These results provide compelling evidence that carbohydrate loading specifically enhanced physiological adaptations in male badminton athletes beyond what could be expected from normal training alone. The dramatic improvements in the experimental group likely reflect several physiological mechanisms: (1) enhanced glycogen availability supporting prolonged high-intensity efforts during the Yo-Yo test, (2) better maintenance of movement technique and reaction time during the agility test due to sustained energy availability, and (3) potentially improved recovery between high-intensity bouts.

TABLE 6: **PAIRED SAMPLES T-TEST RESULTS FOR FEMALE PARTICIPANTS**

Group	n	Variable	Pre-test	Post-test	Mean Difference	t-value	p-value	Cohen, S.D
Experimental	8	Yo-Yo (m)	1240 ± 232	1495 ± 203	255 ± 53	4.81	<.001	1.17
		T-Test (s)	10.58 ± 0.89	9.93 ± 0.74	-0.65 ± 0.21	-3.10	.008	0.75
Control	8	Yo-Yo (m)	1215 ± 209	1285 ± 214	70 ± 35	2.00	.073	0.48
		T-Test (s)	10.56 ± 0.71	10.51 ± 0.80	-0.05 ± 0.14	-0.36	.728	0.09

The performance data for female participants (Table 6) reveals significant improvements in the experimental group following carbohydrate loading, though with some notable gender-specific patterns. Female athletes in the experimental group demonstrated a 255 ± 53 meter improvement in Yo-Yo test performance ($t = 4.81$, $p < .001$), representing a substantial 20.6% enhancement in endurance capacity. This improvement, while slightly smaller in absolute terms compared to males (255m vs 265m), actually represents a marginally greater percentage improvement due to females' lower baseline scores. The large effect size (d = 1.17) confirms the practical significance of this endurance enhancement for competitive female players. For agility performance, experimental group females improved their T-test time by 0.65 ± 0.21 seconds (t = -3.10, p = .008), a 6.1% improvement that slightly exceeded the male experimental group's gains (0.61s). The medium effect size (d = 0.75) suggests this agility improvement, while statistically significant, may be somewhat less consistent across individuals compared to the endurance benefits. This pattern differs from the male results where agility improvements showed a larger effect size (d = 0.98), potentially indicating gender-specific responses in neuromuscular adaptation to carbohydrate loading. Control group females showed a non-significant 70 ± 35 meter improvement in Yo-Yo performance (t = 2.00, p = .073), representing a 5.8% change that approached but did not reach statistical significance. Their T-test performance showed virtually no change (-0.05 ± 0.14 seconds, t = -0.36, p = .728), mirroring the male control group's results. The moderate effect size for endurance (d = 0.48) in female controls may reflect natural training adaptations during the study period, though clearly of much smaller magnitude than the experimental group's gains. These findings suggest that female badminton players benefit similarly to males from carbohydrate loading in terms of percentage improvements, though with some potentially important gender-specific characteristics. The slightly greater relative improvement in female endurance performance may reflect gender differences in substrate utilization during exercise, with some research suggesting females may be more efficient at glycogen sparing during prolonged activity. The agility results indicate that while females showed excellent responsiveness to the intervention, the neuromuscular benefits may be somewhat more variable than in males, possibly related to hormonal influences on glycogen metabolism or neuromuscular control.

TABLE 7: **GENDER COMPARISON OF INTERVENTION EFFECTS**

Variable	Male Δ Score	Female Δ Score	t-value	p-value	Effect Size (d)
Yo-Yo (m)	265 ± 42	255 ± 53	0.48	.634	0.17
T-Test (s)	-0.61 ± 0.15	-0.65 ± 0.21	-0.52	.608	0.19

The gender comparison analysis (Table 7) reveals no statistically significant differences in how male and female badminton players responded to the carbohydrate-loading intervention. For the Yo-Yo test improvements, males showed a 265 ± 42 meter increase compared to 255 ± 53 meters in females (t = 0.48, p = .634), with a negligible effect size (d = 0.17). Similarly, agility improvements measured by the T-test were nearly identical between genders, with males improving by 0.61 ± 0.15 seconds and females by 0.65 ± 0.21 seconds (t = -0.52, p = .608, d = 0.19).

TABLE 8: **MIXED ANOVA RESULTS FOR PERFORMANCE VARIABLES**

Variable	Time Effect (F)	Group Effect (F)	Interaction (F)	ηp^2
Yo-Yo Test	28.74^{***}	6.82^{*}	19.53^{***}	.413
T-Test	14.92^{***}	3.41	9.67^{**}	.259

The mixed ANOVA analysis yielded statistically significant findings that provide compelling evidence for the effectiveness of the carbohydrate-loading intervention. For endurance performance measured by the Yo-Yo test, the results revealed three distinct effects worthy of consideration. First, the highly significant time effect ($F = 28.74$, $p < .001$) indicates that all participants showed meaningful improvements in endurance capacity throughout the study period, regardless of their group assignment. This general improvement likely reflects the combined effects of regular training and study participation. Second, the significant group effect ($F = 6.82$, $p < .05$), while present, carries less interpretive weight given our previous confirmation of baseline equivalence between groups through independent t-tests. Most importantly, the powerful time × group interaction ($F = 19.53$, $p < .001$) with its large effect size ($\eta p^2 = .413$) provides definitive evidence that the experimental group's improvement trajectory differed substantially from the control group, confirming that the carbohydrate-loading protocol specifically enhanced endurance gains beyond what could be expected from training alone. The pattern of results for agility performance, as measured by the T-test, followed a similar but somewhat less pronounced trend. A strong time effect ($F = 14.92$, $p < .001$) emerged, indicating general improvements in agility across all participants during the study period. The non-significant group effect ($F = 3.41$, $p > .05$) aligns with our baseline comparisons showing equivalent starting points between groups. Most notably, the significant interaction effect ($F = 9.67$, $p < .01$) with a medium effect size ($\eta p^2 = .259$) demonstrates that the experimental group showed greater agility improvements than could be attributed to normal training adaptations, though this effect was somewhat smaller. These findings carry important implications for both research and practice in sports nutrition. The differential responsiveness of endurance versus agility measures suggests that carbohydrate loading may have more pronounced effects on physiological systems supporting sustained performance compared to those governing rapid changes of direction. The large effect sizes, particularly for endurance measures, underscore the practical significance of these findings for competitive badminton programs. From a methodological standpoint, the robust interaction effects validate our experimental design and confirm that the observed benefits specifically resulted from the nutritional intervention rather than other confounding factors.

DISCUSSION

The present study provides compelling evidence that a 3-day carbohydrate-loading protocol significantly enhances both endurance and agility performance in competitive badminton players. Our findings demonstrate that athletes who implemented the nutritional intervention showed substantially greater improvements in Yo-Yo test performance (20.3% increase) compared to controls (4.0% increase), with similarly impressive gains in T-test agility scores (6.0% vs 0.4% improvement). These results have important implications for sports nutrition practice and athlete preparation.

The endurance enhancements align closely with existing literature on glycogen supercompensation (Burke et al., 2017), yet the significant agility improvements offer novel insights. While previous research has primarily focused on CHO loading for endurance sports, our study suggests these protocols may benefit sports requiring intermittent high-intensity efforts and rapid directional changes. This likely reflects maintained neural drive and technique precision when glycogen stores are optimized, particularly during the latter stages of matches when fatigue typically impairs performance.

Several mechanistic explanations may account for our findings. First, the increased glycogen availability likely delayed the onset of fatigue during prolonged rallies, allowing athletes to maintain higher work rates throughout the Yo-Yo test. Second, the agility improvements may stem from better-preserved phosphocreatine resynthesize between points and maintained central nervous system function - both of which are glycogen-dependent processes (Ørtenblad et al., 2018). Third, the psychological assurance of proper fueling may have enhanced perceived exertion and effort tolerance.

Notably, we found no significant gender differences in responsiveness to the intervention, challenging some previous suggestions of greater male sensitivity to carbohydrate manipulation (Tarnopolsky, 2008). This finding supports implementing similar nutritional strategies for both male and female badminton athletes, though coaches should remain attentive to individual variability in response. The study's practical applications are clear: badminton coaches and support staff should consider implementing short-term carbohydrate-loading protocols before important competitions. Our results suggest these strategies can enhance both the endurance needed for prolonged matches and the agility crucial for effective court coverage. However, practitioners should note that individualization may be necessary, as some athletes showed greater responsiveness than others.

CONCLUSION

This study provides robust evidence that a 3-day carbohydrate-loading protocol significantly enhances both endurance and agility performance in competitive badminton players. The experimental group demonstrated a 20.3% improvement in Yo-Yo test performance and a 6.0% reduction in T-test completion time compared to minimal changes in the control group. These findings confirm that glycogen optimization through strategic carbohydrate intake not only delays fatigue in prolonged matches but also supports the rapid, multidirectional movements essential for elite badminton performance. The absence of significant gender differences in intervention responsiveness suggests that this nutritional strategy can be effectively applied to both male and female athletes without modification. The large effect sizes (ηp^2 = .413 for endurance, .259 for agility) underscore the practical significance of these findings for coaches and sports nutritionists working with racket sport athletes. These results highlight the critical role of nutrition periodization in badminton preparation, demonstrating that even short-term dietary interventions can yield measurable performance benefits. Future research should investigate long-term adherence effects and potential synergies with other ergogenic strategies to further optimize athlete preparation. For immediate application, badminton programs should consider implementing pre-competition carbohydrate-loading protocols (8-10g/kg/day for 3 days) as a cost-effective, evidence-based method to enhance both endurance and on-court agility in competitive players. This study establishes carbohydrate manipulation as a key component of sports nutrition strategies for intermittent, high-intensity sports like badminton.

RECOMMENDATION

Badminton players seeking a legal, science-backed performance edge should adopt this 3-day carbohydrate-loading protocol before key competitions. Coaches and nutritionists should integrate this strategy into periodized training plans, ensuring athletes enter matches with maximized energy reserves for both endurance and explosive movements. For optimal results, future applications should include individualized monitoring to fine-tune carbohydrate needs based on player metabolism, training load, and competition frequency.

REFERENCES

Abian-Vicen, J., Castanedo, A., Abian, P., & Sampedro, J. (2014). Temporal and notational comparison of badminton matches between men's singles and women's singles.

International Journal of Performance Analysis in Sport, 14(2), 42-53. https://doi.org/10.1080/24748668.2014.11868720

Balsom, P. D., Gaitanos, G. C., Söderlund, K., & Ekblom, B. (1999). High-intensity exercise and muscle glycogen availability in humans. *Journal of Applied Physiology, 86*(4), 1520-1526. https://doi.org/10.1152/jappl.1999.86.4.1520

Burke, L. M., Hawley, J. A., Wong, S. H. S., & Jeukendrup, A. E. (2011). Carbohydrates for training and competition. *Journal of Sports Sciences, 29*(sup1), S17-S27. https://doi.org/10.1080/02640414.2011.585473

Burke, L. M., Ross, M. L., Garvican-Lewis, L. A., Welvaert, M., Heikura, I. A., Forbes, S. G., Mirtschin, J. G., Cato, L. E., Strobel, N., Sharma, A. P., & Hawley, J. A. (2017). Low carbohydrate, high fat diet impairs exercise economy and negates the performance benefit from intensified training in elite race walkers. *Journal of Physiology, 595*(9), 2785-2807. https://doi.org/10.1113/JP273230

Close, G. L., Sale, C., Baar, K., & Bermon, S. (2019). Nutrition for the prevention and treatment of injuries in track and field athletes. *International Journal of Sport Nutrition and Exercise Metabolism, 29*(2), 189-197. https://doi.org/10.1123/ijsnem.2018-0290

Imran, M., Khan, S. A., & Haider, M. (2021). Dietary practices and nutritional knowledge among Pakistani athletes: A cross-sectional study. *Journal of Sports Medicine and Physical Fitness, 61*(5), 678-685. https://doi.org/10.23736/S0022-4707.20.11567-8

Khan, A., Ahmad, R., & Malik, M. A. (2022). Sports nutrition awareness and practices among university athletes in Pakistan. *Pakistan Journal of Nutrition, 21*(3), 112-120. https://doi.org/10.3923/pjn.2022.112.120

Logan-Sprenger, H. M., Heigenhauser, G. J., Killian, K. J., & Spriet, L. L. (2015). Effects of dehydration during cycling on skeletal muscle metabolism in females. *Medicine & Science in Sports & Exercise, 47*(5), 896-904. https://doi.org/10.1249/MSS.0000000000000502

Majumdar, P., Khanna, G. L., Malik, V., & Sachdeva, S. (2017). Physiological analysis to quantify training load in badminton. *British Journal of Sports Medicine, 51*(6), 427-434. https://doi.org/10.1136/bjsports-2016-096754

Muniroglu, S., & Subak, E. (2018). The effects of 8-week balance training on agility performance in badminton players. *Journal of Sports Medicine and Physical Fitness, 58*(6), 887-893. https://doi.org/10.23736/S0022-4707.17.07269-3

Muniroglu, S., & Subak, E. (2018). The effects of 8-week balance training on agility performance in badminton players. *Journal of Sports Medicine and Physical Fitness, 58*(6), 887-893. https://doi.org/10.23736/S0022-4707.17.07269-3

Ørtenblad, N., Westerblad, H., & Nielsen, J. (2018). Muscle glycogen stores and fatigue. *Journal of Physiology, 596*(6), 869-883. https://doi.org/10.1113/JP273645

Phomsoupha, M., & Laffaye, G. (2020). The science of badminton: Game characteristics, anthropometry, physiology, visual fitness and biomechanics. *Sports Medicine, 45*(4), 473-495. https://doi.org/10.1007/s40279-014-0287-2

Tarnopolsky, M. A. (2008). Sex differences in exercise metabolism and the role of 17-beta estradiol. *Medicine & Science in Sports & Exercise, 40*(4), 648-654. https://doi.org/10.1249/MSS.0b013e31816212ff

Vigh-Larsen, J. F., Haverford, M. B., & Overgaard, K. (2021). The role of muscle glycogen content and degradation in exercise performance. *Sports Medicine, 51*(5), 837-861. https://doi.org/10.1007/s40279-021-01434-9