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Linear Speed and Cognitive-Motor Reactive Agility as Key Correlates of Elite Female Kho-Kho Performance: Evidence of an Elite Plateau



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ABSTRACT

Objective: Kho-Kho is a fast-paced traditional indigenous sport demanding explosive motor movements. While foundational physical conditioning is essential, the specific multidimensional factors differentiating match performance at the highest competitive tiers remain underexplored. The objective of this study was to evaluate the anthropometric, motor, and physiological correlates of competitive success to identify the primary predictors of performance among elite athletes.

Methods and Materials: A cross-sectional observational design was employed, recruiting 30 national-level female Kho-Kho players. Multidimensional profiling included Body Mass Index, resting heart rate, reaction time, speed, agility, and explosive strength. In-game performance was concurrently evaluated during a competitive event by expert coaches using a structured Likert-scale assessment. Data were analyzed using Pearson's product-moment correlation coefficients following the verification of parametric assumptions.

Results: The correlational analysis revealed a statistically significant inverse relationship between match performance and both linear speed ($r = -0.379$, $p = 0.039$) and cognitive-motor reactive agility ($r = -0.417$, $p = 0.022$). Conversely, foundational metrics such as agility, explosive strength, and resting heart rate did not demonstrate statistically significant correlations.

Conclusion: These findings suggest an elite plateau at the national level, where raw linear velocity and cognitive-motor reactive agility — rather than generalised physical traits — differentiate performance. Coaches should therefore integrate targeted neuro-cognitive and overspeed training protocols.

Keywords: Kho-Kho, multidimensional correlates, performance analytics, elite plateau, cognitive-motor reactive agility, linear speed.

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1. Introduction

Kho-Kho, one of India's most distinguished traditional team sports, is deeply ingrained in the region's cultural heritage and demands explosive physical fitness, continuous mobility, and tactical acumen (1). Success in this fast-paced indigenous game relies heavily on foundational motor abilities; specifically, the interplay between linear speed and multi-directional agility is considered essential for executing both offensive chases and defensive evasions (2). Furthermore, explosive lower-body strength and rapid reactive abilities are frequently cited as primary prerequisites for competitive participation, particularly among female athletes navigating the physical rigors of the sport (3).

However, as competitive standards elevate, the modern paradigm of sports science has increasingly shifted its focus toward the cognitive dimensions of athletic performance (4). The capacity to rapidly process environmental stimuli—measured practically as reaction time—has a profound impact on an athlete's overall agility and match execution (5). The integration of these cognitive metrics with traditional physical indicators forms the basis of contemporary sports performance analytics (6). Consequently, researchers have extensively investigated the relationship between basic anthropometric components, such as Body Mass Index (BMI), and general motor abilities to identify baseline athletic profiles (7). Broad evaluations of selected physical fitness variables across various indigenous sports, including Kabaddi and wrestling, have historically guided generalized training methodologies (8). Similarly, the analysis of physiological parameters, such as resting heart rate, has been utilized to gauge the baseline cardiovascular readiness of inter-varsity players (9).

Despite this extensive foundation, evaluating athletic potential solely on generalized fitness metrics may be insufficient at the highest tiers of competition. Recent specific evaluations of motor performance emphasize that cognitive-motor responsiveness is a critical differentiator in fast-paced games (10). Comparative analyses across different athletic disciplines consistently highlight that superior reaction time often separates elite performers from their sub-elite counterparts (11). Recognizing this distinction is highly significant for the formulation and successful implementation of strategic planning for sports development within Indian universities and national federations (12).

At the national level, foundational traits often reach a homogeneity described as an “elite plateau” — a pattern previously noted in indigenous sports." In this context, the specific role of cognitive-motor reactive agility and linear speed becomes particularly important for on-field success (13). Identifying these exact multidimensional correlates is not only crucial for elite talent identification but also for promoting targeted, healthy physical movement levels among female athletes and university students (14). Furthermore, such data-driven approaches support the development of broader healthy lifestyle frameworks and specialized performance scales tailored for athletes training across diverse regional conditions (15).

Therefore, to address the gap in understanding the specific factors associated with performance once foundational traits have plateaued, the aim of this study was to evaluate a comprehensive multidimensional profile—encompassing BMI, speed, agility, resting heart rate, cognitive-motor reactive agility, and explosive strength—and to identify their correlational relationships with match performance among elite female Kho-Kho athletes.

2. Methods and Materials

Study Design and Participants A cross-sectional, observational study design was employed to evaluate the multidimensional correlates of competitive Kho-Kho performance. The sample comprised 30 elite female Kho-Kho players (Mean age = 23.1 ± 3.0 years; Range = 18–28 years) actively competing at the national level.

Anthropometric and Physiological Assessments Testing was conducted under standardized conditions prior to the commencement of intense competitive matches to prevent fatigue-related bias.

Testing was conducted on the same morning as the competitive matches (approximately 2–4 hours prior) under standardised indoor conditions at the national competition venue (standard Kho-Kho playing surface, 22–25 °C). The fastest of two trials was recorded for the 50 m dash and agility test; the best of three attempts was used for explosive strength.

- **Body Mass Index (BMI):** Standing height was measured to the nearest 0.1 cm using a calibrated stadiometer (Bio+Plus®, India), and body mass was recorded to the nearest 0.1 kg using a digital weighing scale (Glass Heuer HD 201, India). BMI was subsequently calculated utilizing the standard formula:

weight in kilograms divided by the square of height in meters (kg/m^2).

- **Resting Heart Rate (RHR):** Cardiovascular baseline efficiency was assessed using the manual radial pulse method. Following a five-minute seated rest period, the radial pulse was palpated and counted for 30 seconds, then multiplied by two to determine the beats per minute.
- **Motor and Cognitive-Motor Assessments** A battery of standardized physical fitness tests was administered to evaluate the specific motor demands of Kho-Kho.
- **Speed:** Linear velocity was measured using the standardized 50-meter dash. Athletes initiated the sprint from a standing start behind the line, and completion time was recorded to the nearest tenth of a second using digital stopwatches (Nivia, Jalandhar, India).
- **Agility:** Multi-directional movement and deceleration capabilities were evaluated using the 10 x 4-yard shuttle run test. Athletes sprinted between two parallel lines placed 30 feet apart to retrieve and return two wooden blocks, with the best time of two trials recorded.
- **Explosive Strength:** Lower-body explosive power was measured via the standing broad jump. Athletes performed a two-footed horizontal jump from a static position behind a take-off line, and the maximum distance achieved across three attempts was recorded in meters.
- **Cognitive-Motor Reactive Agility (CMRA):** Cognitive-motor responsiveness was assessed using a custom reactive agility test. The testing arena consisted of a 10 m diameter circle divided into five zones (A–E), each marked with a uniquely coloured cone. Upon a verbal auditory cue naming one of the five colours, the athlete sprinted from the centre to the corresponding cone and back to the centre. A single fully randomised sequence of all five colours was presented. Total time (seconds) for the complete sequence was recorded. This protocol combines cognitive choice, acceleration, deceleration, and directional change and is therefore best conceptualised as a measure of cognitive-motor reactive agility rather than isolated reaction time. No published reliability or validity data exist for this custom cognitive-motor reactive agility test; therefore,

test-retest reliability was not assessed in the present study and this is noted as a limitation.

In-Game Performance Evaluation Overall Kho-Kho match performance served as the primary dependent variable. Performance was evaluated concurrently during competitive gameplay by a panel of three highly experienced, National Institute of Sports (NIS) accredited coaches. Utilizing a structured 5-point Likert scale, the experts independently rated each athlete across six fundamental, sport-specific skill categories: Sudden Attack, Mix Chain, Ring Game, 3-6 Up, Pole Dive, and Sky Dive. The scores from the three judges were aggregated to produce a singular, comprehensive Overall Performance Score for each player.

Statistical Analysis All statistical analyses were performed using SPSS software. Descriptive statistics, including means and standard deviations (SD), were computed to summarize the anthropometric, physiological, and performance data. Prior to inferential analysis, the normality of the data distribution was formally verified using the Shapiro-Wilk test, and the homogeneity of variances was confirmed via Levene's test. Pearson's product-moment correlation coefficients (r) were utilized to determine the strength and direction of the linear relationships. Because six correlations were performed, we note that after Bonferroni correction (adjusted $\alpha = 0.0083$) the associations were marginally non-significant; results are therefore interpreted at the conventional $\alpha = 0.05$ level, with this caveat noted in the limitations. Multiple linear regression was not conducted; therefore the independent contribution of each variable (after controlling for the others) could not be determined.

3. Results

The primary objective of the statistical analysis was to identify the specific multidimensional variables associated with competitive success among elite female Kho-Kho athletes. Pearson's product-moment correlation coefficients (r) were computed to assess the linear relationship between the athletes' overall in-game performance scores and six selected variables: Body Mass Index (BMI), Linear Speed, Agility, Resting Heart Rate (RHR), Cognitive-Motor Reactive Agility (CMRA), and Explosive Strength (ES).

Table 1 details the baseline descriptive statistics for the elite cohort. The relatively narrow standard deviations across variables such as BMI (± 1.41) and Agility (± 0.76) highlight a highly homogeneous sample, indicative of the

standardized physical conditioning present at the national level.

The mean overall performance score was 67.27 ± 11.64 (range 49–93). The consolidated findings of this correlational analysis are presented in Table 2 (see end of

manuscript). The two significant correlations were of moderate magnitude according to Cohen’s guidelines. The correlation matrix reveals a distinct bifurcation in the correlational strength of the variables tested, highlighting the specific traits that differentiate elite-level execution:

Table 1. Descriptive Statistics of Anthropometric, Physiological, and Motor Variables of Elite Female Kho-Kho Players (N=30)

Variable	Mean	Standard Deviation	Minimum	Maximum
Overall Performance (Score)	67.27	± 11.64	49	93
Reaction Time (Seconds)	20.25	± 2.93	16.52	26.66
Linear Speed (Seconds)	9.61	± 0.83	8.04	11.84
Body Mass Index (kg/m ²)	19.34	± 1.41	16.9	21.9
Explosive Strength (Meters)	1.65	± 0.24	1	1.95
Resting Heart Rate (BPM)	64.97	± 7.37	52	76
Agility (Seconds)	11.45	± 0.76	10.3	12.73

1. The Significant Correlates: A statistically significant inverse relationship was observed between cognitive-motor reactive agility and overall match performance ($r = -0.417$, 95% CI [-0.68, -0.07], $p = 0.022$). In the context of this temporal metric, a lower score indicates a faster neurological response to a stimulus; this negative correlation indicates that athletes with faster cognitive-motor reactive agility achieved higher in-game performance ratings.

Similarly, linear speed demonstrated a significant negative correlation with performance ($r = -0.379$, 95% CI [-0.65, -0.02], $p = 0.039$). This indicates that lower 50-meter sprint times (i.e., higher raw running velocities) were associated with higher performance ratings. These findings align with recent literature (2, 5), which similarly identifies linear velocity and cognitive-motor reactive agility as key correlates of performance in fast-paced indigenous sports.

2. The "Elite Plateau" Variables (Not Statistically Significant): Conversely, foundational anthropometric and physiological metrics did not reliably predict performance variations within this highly trained cohort. Body Mass

Index ($r = -0.270$, 95% CI [-0.57, 0.10], $p = 0.14$) and Resting Heart Rate ($r = -0.150$, 95% CI [-0.48, 0.22], $p = 0.43$) showed weak, non-significant correlations. Unlike broader evaluations of sub-elite players (7, 9) that show strong correlations between general fitness and performance, our data indicates that once athletes reach the national standard, minor variations in these baseline traits are no longer significantly associated with match success.

Most notably, generalized motor abilities such as Explosive Strength ($r = -0.150$, 95% CI [-0.48, 0.22], $p = 0.42$) and Agility ($r = -0.070$, 95% CI [-0.42, 0.30], $p = 0.67$) failed to reach statistical significance. This pattern supports the elite-plateau interpretation: because national-level female Kho-Kho athletes undergo rigorous, standardized training, their baseline agility and lower-body power are uniformly highly developed (evidenced by the narrow standard deviations in Table 1). Consequently, these traits level out across the playing field, leaving raw linear speed and cognitive-motor reactive agility as the key correlates of performance at the elite level.

Table 2. Pearson's Correlation Coefficients between Multidimensional Correlates and Overall Kho-Kho Performance

Predictor Variable	Pearson Correlation (r)	95% Confidence Interval	Sig. (2-tailed) p-value	Statistical Significance
Cognitive-Motor Reactive Agility (CMRA)	-0.417*	[-0.68, -0.07]	0.02	Significant ($p < 0.05$)
Linear Speed (50m)	-0.379*	[-0.65, -0.02]	0.03	Significant ($p < 0.05$)
Body Mass Index (BMI)	-0.27	[-0.57, 0.10]	0.14	Not Significant
Explosive Strength (ES)	-0.15	[-0.48, 0.22]	0.42	Not Significant
Resting Heart Rate (RHR)	-0.15	[-0.48, 0.22]	0.43	Not Significant
Agility (Shuttle Run)	-0.07	[-0.42, 0.30]	0.67	Not Significant

*Correlation is significant at the 0.05 level (2-tailed)

Effect-size interpretation (Cohen, 1988): $|r| = 0.10-0.29$ small, $0.30-0.49$ moderate, ≥ 0.50 large.

4. Discussion

The present study investigated the multidimensional correlates of competitive success among elite female Kho-Kho athletes. The most salient finding of this research is the distinct bifurcation between cognitive-motor reactive agility and foundational physiological conditioning, which is consistent with an elite plateau at the national level.

Our analysis revealed that linear speed and cognitive-motor reactive agility were the only variables significantly correlated with overall match performance. In the highly dynamic and unpredictable environment of Kho-Kho, where athletes must constantly adapt to the evasive and offensive behaviors of opponents (1), raw linear velocity is paramount. The significant negative correlation between 50-meter sprint times and performance ratings ($r = -0.379$) demonstrates that faster sprinting capabilities directly enhance the execution of rapid chases and sudden retreats. This aligns with recent observations that linear speed is a critical determinant of performance efficacy in fast-paced indigenous sports, particularly among adolescent and adult female competitors (2, 5).

Furthermore, the significant correlation between cognitive-motor reaction time and in-game success ($r = -0.417$) highlights the immense neurological demands of the sport. At elite tiers of competition, physical prowess alone is insufficient; athletes must process visual and auditory stimuli and translate them into biomechanical actions instantaneously (4, 10). Superior perceptual-motor responsiveness allows players to anticipate tactical movements and execute tagging or dodging maneuvers fractions of a second faster than their opponents. This finding is corroborated by broader sports performance analytics, which increasingly emphasize the integration of cognitive indicators alongside traditional physical metrics to accurately evaluate athlete potential (6, 11, 16).

Contrary to traditional training paradigms that heavily emphasize generalized motor abilities, variables such as agility ($r = -0.070$) and explosive lower-body strength ($r = -0.150$) did not significantly correlate with match performance in this elite cohort. While previous literature has thoroughly established the foundational importance of multi-directional agility (13) and explosive leg power (3, 7) for Kho-Kho players, our findings suggest that these specific traits function as prerequisites for national-level selection rather than as active performance differentiators during elite matches.

Because national-level female athletes undergo rigorous, standardized physical conditioning, their baseline agility and explosive strength are uniformly highly developed. This creates a physiological ceiling or "elite plateau" (8). Consequently, these traits level out across the playing field. Similarly, baseline anthropometric parameters (BMI) and physiological markers (Resting Heart Rate) failed to predict competitive success. Once athletes achieve the optimal body composition and cardiovascular endurance required for sustained, high-intensity play, minor variations within those normal, elite ranges do not dictate superior on-field execution (9).

The identification of the elite plateau and the specific multidimensional correlates of Kho-Kho performance has practical implications for strategic sports planning and talent identification within sports federations and universities (12). To maximize competitive success, coaches should pivot from predominantly training baseline agility and aerobic endurance to integrating targeted cognitive-motor drills, reactive agility protocols, and overspeed training into their daily regimens. Furthermore, establishing data-driven, empirical benchmarks for neural processing and linear speed can significantly enhance player evaluation and team selection protocols. Ultimately, promoting specialized training regimens that optimize these specific cognitive and physical traits can contribute to the broader implementation of healthy athletic movement levels (14) and support the ongoing validation of targeted healthy lifestyle and performance scales for elite competitors managing diverse regional and competitive stressors (15).

5. Limitations and Future Research

While this study provides useful insights, several limitations should be acknowledged. First, the relatively small sample size ($N=30$) limits statistical power and generalizability; wide confidence intervals also indicate some uncertainty in the magnitude of the observed relationships. Second, the cross-sectional design precludes causal inferences. Third, only bivariate correlations were performed and multiple linear regression was not conducted; therefore the unique variance explained by linear speed and cognitive-motor reactive agility (after controlling for the other variables) could not be determined. Fourth, although match performance was rated independently by three NIS-accredited coaches, inter-rater reliability was not computed, introducing potential

subjectivity. Fifth, the elite-plateau interpretation is theoretical and should be tested in future comparative studies that include sub-elite athletes. Future research should prioritise longitudinal designs, larger samples, and multiple linear (or hierarchical) regression analyses to examine the independent contributions of each variable and to test how targeted neuro-cognitive and overspeed protocols affect performance over a competitive season. Sixth, post-hoc power analysis (G*Power, two-tailed, $\alpha = 0.05$) for the observed correlations ($r \approx -0.40$, $N = 30$) indicated statistical power of approximately 0.65; future studies with larger samples are recommended to increase power.

6. Conclusion

The present study provides critical insights into the multidimensional predictors of competitive success among elite female Kho-Kho athletes. The findings indicate that while a rigorous baseline of physical and physiological fitness is mandatory for national-level participation, these generalized traits—specifically multi-directional agility, lower-body explosive strength, resting heart rate, and Body Mass Index—were not significantly associated with match performance in this elite cohort.

Consequently, the present findings indicate that raw linear velocity and cognitive-motor reactive agility are the key correlates of performance at the elite level. Athletes with faster cognitive-motor reactive agility and lower 50 m sprint times tended to achieve higher match-performance ratings. From a practical perspective, these findings necessitate a paradigm shift in advanced Kho-Kho training and talent identification methodologies. To maximize competitive potential, coaches and sports federations must evolve beyond generalized endurance and basic agility conditioning. Future training frameworks for elite athletes should prioritize specialized neuro-cognitive drills, reactive agility tasks, and overspeed training to enhance the specific motor and processing speeds required to break through the elite plateau.

Authors' Contributions

H.T. and P.P. designed and directed the project; R.C. conceived and planned the experiments. H.T., P.P., and R.C. carried out the experiments. H.T. and R.C. contributed to sample preparation. H.T., P.P., and R.C. analyzed the data and contributed to interpreting the results. H.T. took the lead in writing the manuscript with input from all

authors. All authors discussed the results and commented on the manuscript.

Declaration

None.

Transparency Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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Declaration of Interest

The authors report no conflict of interest.

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Ethical Considerations

In accordance with the ethical guidelines of the International Journal of Sport Studies for Health, the research protocol was reviewed and approved by the Institutional Ethics Committee of Amity School of Physical Education & Sports Sciences (Protocol Number: APSS/Kho Federation/2021/112/akk, Date of Approval: Sep 29 2021). Informed written consent was obtained from all participants prior to data collection, and all procedures complied with the ethical standards for human research.

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