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Effect of Acute Exercise-Induced Fatigue on Reaction Time and Hand–Eye Coordination in Collegiate Athletes: A Cross-Sectional Study

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ABSTRACT

Background: Fatigue is an inevitable consequence of sports participation, particularly during high intensity training and competition. Acute exercise induced fatigue has been shown to impair neuromuscular performance, increasing the likelihood of errors and injury.

Purpose: To examine the effect of acute exercise induced fatigue on reaction time and hand–eye coordination in collegiate athletes.

Methods: Forty male collegiate athletes aged 18–23 years were recruited through purposive sampling. Baseline demographic and anthropometric data were collected, followed by assessment of reaction time using the ruler drop test and hand–eye coordination using the alternate hand wall toss test. Participants then performed the Bruce treadmill inclined exercise protocol to induce fatigue, validated by achieving ≥85% of predicted maximum heart rate and a Borg exertion score ≥7. Post fatigue, reaction time and coordination tests were repeated. Data were analyzed using paired t tests, with significance set at $p < 0.05$, and effect sizes calculated using Cohen's d.

Results: Following the fatigue protocol, mean reaction time showed a significant delay (pre fatigue: 0.189 ± 0.0026 s; post fatigue: 0.1937 ± 0.0026 s; mean difference: 0.0047 s; t = 6.08, $p < 0.01$; Cohen's d = 0.96). Similarly, hand–eye coordination significantly declined (pre fatigue: 29.65 ± 3.5 catches; post fatigue: 28.35 ± 3.8 catches; mean reduction: 1.3 catches; t = −4.49, $p < 0.001$; Cohen's d = 0.71).

Conclusion: Acute exercise induced fatigue adversely affects both reaction time and hand–eye coordination in collegiate athletes, likely due to combined central and peripheral fatigue mechanisms. These findings underscore the importance of incorporating fatigue management, adequate recovery, and reaction time training into athletic conditioning programs to optimize performance and reduce injury risk.

1. Introduction

Collegiate athletes represent a transitional group between recreational and elite levels. They are regularly exposed to structured training, competitive pressures, and inconsistent recovery strategies, which increases their vulnerability to performance fluctuations and injury risk (Clarke *et al.*, 2025). Unlike professional athletes, collegiate players often lack access to advanced recovery and monitoring systems, which may exacerbate fatigue related impairments. Athletic training and competition frequently push athletes to their physical limits, resulting in periods where exercise induced fatigue is unavoidable. Fatigue is commonly defined as a decline in the ability of muscle to generate force or maintain performance and arises from both central and peripheral mechanisms (Jones *et al.*, 2017). Central fatigue involves reduced neural drive from the central nervous system, while peripheral fatigue is associated with impaired muscle contractility, metabolic by product accumulation, and slower neuromuscular transmission (Clarke *et al.*, 2025). Collectively, these processes impair performance by delaying response times, reducing movement precision, and increasing the likelihood of errors and injury. Research has shown that collegiate athletes frequently experience high levels of training and competition induced fatigue, often associated with mood changes, impaired neuromuscular function, and decreased recovery capacity (Jones *et al.*, 2017). Because collegiate players balance academics, training, and competition with limited recovery resources, they may be especially at risk for fatigue related declines in skill execution and increased susceptibility to injury.

Acute exercise induced fatigue occurs immediately after bouts of intense exercise, such as sprinting, jumping, or exhaustive treadmill protocols. Studies in field and court sports, including tennis, padel, and basketball, report that acute fatigue significantly reduces motor precision, reaction speed, and technical skill execution (Bourara *et al.*, 2023; Clarke *et al.*, 2025). However, some studies have reported inconsistent findings, suggesting that the magnitude of fatigue effects may depend on the type of sport, the intensity of effort, and the outcome measures used (Jones *et al.*, 2017). Reaction time and hand–eye coordination are skill related components of physical fitness that are critical to athletic success. Reaction time refers to the ability to respond rapidly to an external stimulus, while hand–eye coordination reflects the ability to control motor output in response to visual input. Both skills are sensitive to fatigue and essential for interceptive and court based sports, where rapid and precise responses can determine match outcomes (Bourara *et al.*, 2023). Although reaction time and balance have been widely studied under fatigue, relatively fewer studies have specifically examined hand–eye coordination, despite its central role in object control sports such as cricket, basketball, and badminton.

Therefore, the present study was designed to investigate the effect of acute exercise induced fatigue on reaction time and hand–eye coordination in collegiate athletes using simple, reliable field based measures. By addressing this gap, the study aims to provide practical insights for coaches, trainers, and sports physiotherapists in developing fatigue management and injury prevention strategies for collegiate level athletes.

2. Methodology

2.1. Study Design, Setting, Participants, and Period of Study

This study was designed as a cross sectional study and conducted at Sri Ramakrishna Institute of Paramedical Sciences, Coimbatore, Tamil Nadu, India. A total of 40 participants were recruited using a purposive sampling method, and data collection was carried out between January 2025 and April 2025, covering a continuous four month period. The materials required for the study included a 30 cm ruler, tennis ball, treadmill with integrated monitoring system, and SpO_2 probe. Heart rate was monitored using a chest strap sensor integrated with the treadmill console. A data collection sheet and informed consent forms were used to ensure ethical participation. The protocol was reviewed, and informed consent was obtained from all participants prior to data collection. Ethical approval was not required because this was an observational study.

2.2. Criteria for Selection of Participants

Participants included in the study were collegiate male athletes between the ages of 18 and 23 years who engaged in sporting activities such as football, badminton, volleyball, basketball, cricket, table tennis, athletics, and throw ball. Only athletes who had participated in inter collegiate sports events and provided written informed consent were included. Participants were excluded if they had a history of neurological, psychiatric, or vestibular disorders, or had sustained upper extremity injuries or undergone surgeries within the past six weeks. Participants who were involved in sport specific training programs or if they were elite or professional players were excluded. Athletes with cardiovascular, respiratory, visual, or motor impairments that could interfere with testing or contraindicate exercise were also excluded.

2.3. Procedure

Collegiate athletes were selected from Sri Ramakrishna Institute of Paramedical Sciences based on the inclusion and exclusion criteria. After a detailed explanation of the research procedure, informed consent was obtained from each participant. Baseline examination included demographic details and anthropometric measurements such as BMI and hand dominance. Following this, simple reaction time was assessed using the ruler drop test, and hand–eye coordination was measured using the wall toss test. Participants then performed a Bruce treadmill inclined exercise test as a fatigue protocol on a treadmill, with speed and incline increasing every two minutes. Immediately after the fatigue protocol, the reaction time and hand–eye coordination tests were repeated using the same procedures. All data were recorded systematically and subjected to statistical analysis.

2.4. Outcome Measures

2.4.1. Reaction Time

Reaction time was assessed using the ruler drop test, as shown in Figure 1(a), a simple and reliable field based measure of neuromuscular responsiveness. The participant was seated with the forearm resting on a table and the hand extended beyond the edge. A 30 cm ruler was held vertically by the assessor between the participant's thumb and index finger, aligned at the zero mark, but not in contact with the fingers. Without prior warning, the ruler was released, and the participant attempted to catch it as quickly as possible. The distance the ruler fell was recorded in centimeters and converted to time in seconds using the standard free fall equation: $t = \sqrt{(2d / g)}$, where d is the distance in meters and g is the acceleration due to gravity ($9.8\ m/s^2$). Three trials were conducted, and the average reaction time was calculated for analysis.

2.4.2. Hand–Eye Coordination

Hand–eye coordination was measured using the alternate hand wall toss test, as shown in Figure 1(b). Each participant stood two meters from a smooth wall and threw a tennis ball underarm against the wall with one hand, attempting to catch it with the opposite hand. The ball was then thrown back in the same manner, alternating hands continuously. The total number of successful catches achieved within 30 seconds was recorded. The test was performed once, and the score was used as the measure of hand–eye coordination.

Figure 1: Ruler Drop Test (Left panel) and Alternate-Hand Wall Toss Test (Right panel)

2.5. Fatigue Protocol

The Bruce Treadmill Inclined Exercise Test was used as the fatiguing protocol, as shown in Figure 2. Subjects completed the Bruce treadmill graded exercise test, beginning at a speed of 2.7 km/h with a 10% incline. Both treadmill speed, progressing from 2.7 km/h in stage 1 to 12 km/h in stage 10, and incline, increasing by 2% at each stage, were systematically increased every 2 minutes until participants reached volitional exhaustion. The test was considered valid if participants achieved at least 85% of their predicted maximum heart rate, calculated as 220 – age. Termination criteria included the occurrence of severe symptoms such as chest pain, extreme fatigue, or dyspnea, upon which the test was stopped immediately for safety.

Alongside heart rate monitoring, subjective perception of exertion was recorded using the Borg Scale (0–10) at the end of each stage. Participants who reported exertion scores above 7, corresponding to "very hard" to "extremely hard," were considered valid.

2.6. Statistical Tools

The Shapiro Wilk test was employed to assess the normality of data distribution for each variable. As all outcome measures were normally distributed, paired t tests were used to compare pre fatigue and post fatigue values for reaction time and hand–eye coordination. Effect sizes for the paired comparisons were calculated using Cohen's d. A significance level of $p < 0.05$ was considered statistically significant, and results were presented with corresponding 95% confidence intervals.

Figure 2: Bruce Treadmill Inclined Exercise Test

3. Results

3.1. Participant Demographics and Baseline Characteristics

A total of 40 collegiate male athletes aged 18–23 years were recruited and completed the study protocol. All participants were statistically homogeneous, and their demographic data are shown in Table 1. The mean age of participants was 20.4 ± 1.3 years, with an average height of 171.8 ± 6.1 cm and weight of 65.2 ± 7.4 kg. All participants were recreational level athletes involved in regular sporting activities. No adverse events or dropouts occurred during testing.

Table 1: Demographic Details of Participants

Variable	Mean ± SD
Age (years)	19.9 ± 1.3
Height (cm)	170 ± 5.7
Weight (kg)	63.5 ± 6.1
BMI (kg/m²)	21.5 ± 1.7
Years of Training	3.7 ± 1.7
Dominant Side (R/L)	28/2

3.2. Within Group Analysis: Pre and Post Fatigue Performance

3.2.1. Reaction Time

The mean pre fatigue reaction time was 0.189 ± 0.0026 seconds. Following the Bruce treadmill fatigue protocol, post fatigue values increased to 0.1937 ± 0.0056 seconds. The mean difference of 0.0047 seconds was statistically significant ($t = 6.08$, $p < 0.01$), with a large effect size (Cohen's d = 0.96), indicating substantial impairment in neuromuscular responsiveness under fatigue conditions, as shown in Table 2.

3.2.2. Hand–Eye Coordination

Pre fatigue hand–eye coordination scores averaged 29.65 ± 3.5 catches on the alternate hand wall toss test. Post fatigue scores declined to 28.35 ± 3.8 catches, representing a mean reduction of 1.3 catches. This decrease was statistically significant ($t = -4.49$, $p < 0.001$), with a medium effect size (Cohen's d = 0.71), as shown in Table 2.

3.3. Effect Size and Practical Relevance

The large effect size for reaction time suggests that even brief bouts of acute fatigue can meaningfully impair response speed, with potential implications for performance in fast paced game situations. The moderate effect size for hand–eye coordination further highlights the vulnerability of fine motor control under fatigue. Together, these results emphasize the practical importance of fatigue management strategies in reducing errors and injury risk among collegiate athletes.

3.4. Adverse events and compliance

All participants completed the fatigue protocol and outcome measures without injury, discomfort, or early termination. Compliance with the study protocol was 100%.

Table 2: Data for Reaction Time and Hand–Eye Coordination of Participants

Outcome Measure	Pre Fatigue (Mean ± SD)	Post Fatigue (Mean ± SD)	Mean Difference	Calculated t value	Table t value	p value	Cohen's d
Reaction Time (s)	0.189 ± 0.0026	0.194 ± 0.0056	0.004725	6.08	2.02	< 0.01	0.96 (large)
Hand–Eye Coordination (n)	29.65 ± 3.5	28.35 ± 3.8	−1.3	−4.49	2.02	0.0006	0.71 (medium)

3.5. Ancillary observations

Qualitative observations during testing suggested that participants reported greater perceived exertion and difficulty in maintaining focus during the post fatigue trials. Some athletes noted a subjective delay in hand response, particularly in the ruler drop test, and reduced control during the alternate hand wall toss test. These observations align with the quantitative findings of impaired neuromuscular responsiveness under fatigue conditions. Additionally, athletes with a multi sport background showed slightly more variability in coordination scores compared to single sport athletes, though this was not formally analyzed due to the small subgroup sizes. The percentage of different types of sport participation is shown in Table 3.

Table 3: Type of Sport

Type of Sport	n (%)
Volleyball	4 (10%)
Badminton	7 (17.5%)
Athletics	4 (10%)
Basketball	4 (10%)
Throwball	4 (10%)
Cricket	5 (12.5%)
Table Tennis	4 (10%)
Football	4 (10%)
Dual Sport Athletes	4 (10%)

4. Discussion

The present study found that acute exercise-induced fatigue significantly impairs reaction time and hand–eye coordination in collegiate athletes. These findings are consistent with previous reports demonstrating that fatigue adversely affects neuromuscular responsiveness, delaying reaction speed and reducing fine motor control (Bourara *et al.*, 2023; Lambrich, 2025). Bourara *et al.* (2023) reported moderate reductions in dynamic balance and reaction time in amateur padel athletes following an exhaustive Bruce treadmill protocol, emphasizing the practical significance of fatigue in skill dependent sports. Similarly, Sant'Ana *et al.* (2017) observed that taekwondo athletes exhibited slower response times and reduced strike accuracy under fatigue, highlighting that high intensity demands compromise rapid neuromuscular responses critical for technical performance. A recent meta analysis by Lambrich and Muehlbauer (2025) in tennis confirmed that fatigue produces large negative effects on both physical fitness (SMDw = −0.74) and skill execution (SMDw = −0.60), reinforcing that fatigue induced performance decrements are not confined to a single sport but are generalizable across multiple athletic domains. Comparable trends have been noted in indoor team sports such as basketball and volleyball, where recurrent high intensity actions lead to delayed neuromuscular activation, poor timing, and increased injury susceptibility (Clark *et al.*, 2025).

Although reaction time has been widely examined under fatigue, fewer studies have explored its effect on hand–eye coordination, an equally vital component of athletic skill. The present findings demonstrate that coordination was significantly compromised post fatigue, supporting evidence that perceptual–motor integration deteriorates following exhaustive activity (Kaluga *et al.*, 2020). Moreover, athletes involved in hand dominant sports displayed superior baseline coordination yet still exhibited measurable declines after acute exhaustion. Similarly, Pavelka *et al.* (2020) found that mixed martial arts fighters displayed delayed and inconsistent reaction times after supramaximal fatigue, echoing the greater variability observed in the current study's participants.

The physiological basis for these impairments involves both central and peripheral mechanisms. Central fatigue reflects a decline in voluntary neural drive, leading to decreased motor unit recruitment and cortical excitability (Gandevia, 2001; Muñoz Gracia *et al.*, 2025). Peripheral fatigue results from intramuscular metabolic disturbances such as lactate accumulation, ionic imbalance, and reduced calcium sensitivity that collectively diminish contractile efficiency. These processes disrupt neuromuscular coordination and sensorimotor feedback, culminating in delayed reaction and reduced accuracy (Clarke *et al.*, 2025). These results underscore the complex, multifactorial nature of fatigue induced neuromuscular impairment. Inadequate recovery may compound these effects, leading to sustained performance deficits and greater injury risk (Jones *et al.*, 2017). Training load monitoring and recovery optimization are therefore critical components of fatigue management. Jones *et al.* (2017) concluded that excessive training stress without sufficient recovery significantly increases overuse injuries and performance loss. Recent reviews further recommend the use of multimodal assessment techniques, including jump tests, electromyography, and computerized reaction time systems to better distinguish central from peripheral fatigue mechanisms and enhance the precision of athlete monitoring (Muñoz Gracia *et al.*, 2025).

From an applied perspective, the current findings highlight the importance of integrating fatigue monitoring and reaction time training into conditioning programs for collegiate athletes. By incorporating structured recovery protocols and sport specific drills that simulate fatigue, coaches and physiotherapists can enhance neuromuscular resilience and reduce fatigue related performance errors.

5. Strengths, Limitations, and Future Directions

A strength of this study is the use of simple, low cost, and field based outcome measures that can be easily replicated in applied sports settings. This enhances the translational value of the findings for grassroots and collegiate athletes who may not have access to advanced laboratory equipment. This study was limited by its relatively small sample size, single institution setting, and inclusion of only male athletes. The use of simple field based measures such as the ruler drop and wall toss tests, while practical, may not capture subtle neuromuscular or cortical changes. Furthermore, this study did not conduct subgroup analyses, such as single sport versus dual sport athletes.

Future research should recruit larger, gender diverse samples, employ advanced assessment tools such as motion capture or electromyography systems, and explore the long term adaptation of reaction time and coordination across varying training loads. Examining the effects of fatigue in sport specific contexts may further enhance understanding of its implications for athletic safety and performance optimization.

6. Conclusion

This cross sectional study demonstrated that acute exercise-induced fatigue significantly impairs both reaction time and hand–eye coordination in collegiate athletes. The results carry clinical and practical significance. Coaches and students should recognize that fatigue not only limits gross motor performance but also compromises neuromuscular precision, increasing the risk of performance errors and injury. Incorporating fatigue management strategies, such as adequate recovery periods, conditioning drills that simulate fatigue, and reaction time training, may help mitigate these effects and enhance performance resilience. The use of simple, field based tests provides practical evidence that can be readily applied in sports training and rehabilitation settings.

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Authorship Contribution

Methodology, Data Collection, Data Analysis, and Writing: Keerthana.S

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Ethical Approvals

The authors declare that ethical approval was not required because this was an observational study.

Declarations

The authors declare that this work is original and has not been submitted elsewhere for publication. All data, methodologies, and system components have been developed and reported in adherence to academic standards. All referenced materials have been duly cited, and the authors accept full responsibility for the integrity and accuracy of the findings presented.

Conflict of Interest

The authors declare no conflict of interest related to this study.

Data Availability Statement

Authors declare that the data supporting the conclusions of this study can be obtained upon request from the corresponding author, K.S. The data are not publicly accessible due to information that may compromise the privacy of research participants.

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