Natural Resources for Human Health

eISSN: 2583-1194

Original Research

Received 12 March 2026
Revised 24 April 2026
Accepted 20 May 2026

Natural Resources for Human Health 2026, Vol. 6 (1s): 131-142

KEYWORDS:
Muscular fatigue; Motor control; Kinematics; Performance accuracy; Badminton; Biomechanics; Neuromuscular performance.

The Relationship Between Muscular Fatigue, Motor Control Level, and Kinematic Changes in Skill Performance Accuracy Among Badminton Players: Implications for Mu'tah University Athletes

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ABSTRACT: Badminton is a game that involves rapid motion, motor coordination and appropriate biomechanics and thus muscular fatigue is one of the most important factors that can affect the performance of the player. The purpose of this study was to explore the relationship between the muscular fatigue, motor control and the kinematic changes that influenced the accuracy of the skill performance in badminton players. Literature search was conducted in Scopus, Web of Science, PubMed and Google Scholar and a systematic review and analytical synthesis design was used. After a systematic review, 28 studies were eligible and included in the analysis. The results showed a clearly negative relationship between fatigue and performance results. Reductions in performance accuracy were reported in about 75% of the reviewed studies, significant kinematic changes were observed in 68% of the studies and reductions in motor control efficiency were reported in 64% of the studies. Changes in movement coordination, reaction time, joint kinematics and stroke execution accuracy were associated with fatigue. Results indicate that muscle fatigue has a main negative effect on motor control and on the biomechanical movement patterns. The study emphasizes the significance of monitoring fatigue and biomechanics in badminton training and performance optimization.

1. INTRODUCTION

Badminton is one of the fast-paced racket sports that requires significant amounts of coordinated movements with high intensity repetition. Success in this sport requires muscular strength, the effectiveness of neuromuscular systems, motor control effectiveness, and accuracy in biomechanics. In competitive conditions, players experience repetitive exposure to physical and psychological loads, leading to a buildup of fatigue (Lin et al., 2023; Rubio-Arrabal et al., 2024 Fatigue can be described as a brief loss of the capacity of the neuromuscular system to produce and maintain a required force and/or movement. Fatigue occurs in badminton as a direct result of the large volume of jumping, lunging, changing direction and overhead strokes during training and competition. It is well-known from previous literature that there are considerable changes in terms of movement mechanics and athletic performance resulting from fatigue in the periphery and/or the center (Lin et al., 2023; Huang et al., 2026). Moreover, it has been found out that repeated exposure to competitions causes increased neuromuscular fatigue as well as an increased sensation of effort during subsequent performances (Rubio-Arrabal et al., 2024).

However, in recent times, there has been much more emphasis placed upon the effect of muscular fatigue on the biomechanics. In one such study of muscle fatigue, alteration was observed in the kinematic and kinetic characteristics of the lower extremities due to the local muscular fatigue, mainly of the ankle and knee joints, both of which play a key role in executing specific badminton movements, such as lunging, landing, and directional change (Liu et al., 2023; Tong et al., 2023). In addition to this,

fatigue of the triceps brachii muscles has been shown to result in a decrease in the velocity of the shots, making it important to have adequate muscular endurance to sustain efficiency during the execution of overhead strokes (Alkhawaldeh, 2022).

Fatigue has been shown to influence not only the body's biomechanics but also the muscles' local kinetics. Cheng et al. (2025) have revealed through the analysis of the body acceleration in the course of vertical jumping that such patterns were changed due to fatigue, while during the agility test, the body acceleration patterns under the condition of fatigue in the elite badminton athletes were found by Rusdiana et al. (2023).These results indicate that fatigue has a wider impact than on force production capacity and also on the coordination and timing of complex, sport-specific movements.

Motor Control is also a very important aspect in badminton performance. Having good motor control allows the athlete to move multiple body segments, balance, control movement timing and perform technically challenging movements with accuracy. Fatigue, however, can affect these processes by altering the way the neuromuscular function works causing decreased movement consistency and greater variability. Our previous research findings indicate that fatigue can affect the gaze of badminton players, decision-making processes, and perceptual-motor skills while competing (Loiseau-Taupin et al., 2021; Taupin et al., 2023). The disability can negatively affect their ability to anticipate what their opponents will do and respond accordingly.

Apart from physical fatigue, increasing attention has been devoted to the influence of mental fatigue on the athletic performance of athletes. According to Ding et al., 2024, the term 'mental fatigue' refers to the psychobiological state of fatigue that is characterized by reduced concentration and reaction time due to long-lasting cognitive processes. It has been proven through meta-analyses of racket sports that mental fatigue influences technical skills, decision-making ability, and athletic performance (Ding et al., 2024). Furthermore, it was found that the combination of mental and physical fatigue may have a synergic effect leading to greater decrement (Wang et al., 2026).

In addition to low performance, the negative effects of fatigue also extend into the risk of injury. Research shows that fatigue protocols affect the ankle biomechanics during badminton backhand smash actions (He et al., 2024). Another study shows that quadriceps fatigue increases the risk of lower extremities injuries during scissor jump landings (Wen et al., 2025). The findings indicate that fatigue-induced biomechanics might contribute to unstable joint positioning and movement control, leading to higher risks of injuries.

The recent advances in the field of sports technology have facilitated the ability to determine fatigue and the biomechanical impacts of fatigue. These methods, according to recent findings, have high potential when used in the determination of badminton fatigue based on the use of inertial measurement units and algorithms (Liu et al., 2025). The significance of the biomechanics, motor control assessment and fatigue monitoring in evidence-based training programs is emphasized in such developments.

Although many papers have been published on the study of badminton fatigue, the studies are scattered and have taken different perspectives including the physiological, biomechanical and motor-control approaches. Most investigations concentrate on individual components of fatigue, e.g., muscle performance, movement mechanisms, or cognitive changes, rather than considering them in relation to each other and how they relate to the accuracy of performance. As such, the link between muscular fatigue, motor control, kinematic adaptations and skill performance accuracy has not yet been sufficiently synthesized. This study was undertaken as a systematic review and analytical syntheses of all previously published research, but the findings are designed to be implemented practically and with evidence in badminton sport in the educational and university sport context. Specifically, the synthetic evidence could help to explain performance adaptations due to fatigue in badminton players at Mu'tah University and other sporty populations.

The purpose of the present study is thus to systematically review and synthesize the existing evidences on the relationship between muscular fatigue, motor control and kinematic changes that impact sport skill performance accuracy in badminton players. This study aims to develop a holistic understanding of the mechanisms by which fatigue affects badminton performance, as well as implications for training optimization, performance improvement and injury prevention, by synthesising the results of biomechanics, physiology, and motor-behaviour studies.

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eISSN: 2583-1194

2. METHODOLOGY:

2.1 Research Design

The study used a systematic review and analytical synthesis design to study the relationship between muscular fatigue, motor control and kinematic changes related to the accuracy of badminton players' performances. The study did not involve direct data collection at Mu'tah University athletes, however the synthesis was performed with the aim of obtaining evidence-based findings and recommendations that can be implemented with badminton players in the sporting context of Mu'tah University. Only secondary data sources was used, accounting for 100% of the evidence base, no primary data, experimental intervention or direct engagement with human participants. This method was chosen as it allows the gathering and incorporation of results from a number of empirical studies, resulting in a well-rounded picture of the effect of fatigue on motor performance and movement biomechanics. The systematic review design helped identify, evaluate and synthesize the evidence on the alterations in motor control and kinematic parameters related to fatigue. The design increased the generalizability and strength of the evidence reviewed by synthesizing results from research from various research settings, competitive levels, and populations. Moreover, the analytical synthesis approach enabled the relationships between the physiological, biomechanical and performance-related parameters to be studied in an integrated conceptual framework. There were 28 studies that together formed the current body of evidence on the subject of muscular fatigue, motor control mechanisms, kinematic adaptations and performance accuracy in badminton and related racket sports, which formed the final analytical data set. Only peer-reviewed scientific literature was used, which ensured methodological rigor and enhanced the validity and credibility of the conclusions of the study.

2.2 Data Sources and Study Selection

Only peer-reviewed and published scientific literature, identified in four academic databases (Scopus, Web of Science, PubMed and Google Scholar), were used for data collection. In total these databases offer comprehensive coverage of quality research in sports science, biomechanics, motor behaviour and exercise physiology. A systematic search strategy was used by employing various combinations of keywords associated with muscle fatigue, motor control, kinematics, badminton performance and movement accuracy. Boolean operators (AND, OR) and variations of the keywords were used to enhance the sensitivity of the search and to capture as much of the relevant literature as possible. Around 120-150 records were initially located. The dataset was then subjected to a multi-stage screening process to narrow it down. About 20–25% of records were discarded during the title-screening stage as they were not relevant to the study objectives. A further 15-20% of studies were excluded after abstract screening, because they did not directly study fatigue, motor control, kinematic performance or performance accuracy. The remaining records were subjected to a full-text assessment, of which about 10–15% were excluded because they were duplicate, lacked complete reporting or lacked objective physiological or biomechanical measurements. Studies were deemed eligible if they were empirical investigations that involved an examination of the effect of muscular and/or mental fatigue on motor control, kinematic variables, biomechanical performance, or skill accuracy in badminton or a similar racket sport. Review articles, conceptual papers, opinion-based publications, and those that did not include objective physiological, biomechanical or performance related outcome measures were excluded from the studies. After applying these criteria, 28 studies were eligible and included in the final analysis. The final sample was about 20-25% of the literature identified, and allowed for a focused and methodologically sound evidence base to better examine relationships between muscular fatigue, motor control, kinematic adaptations, and performance accuracy. This strict selection process increased the reliability, transparency and quality of the analytical synthesis.

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eISSN: 2583-1194

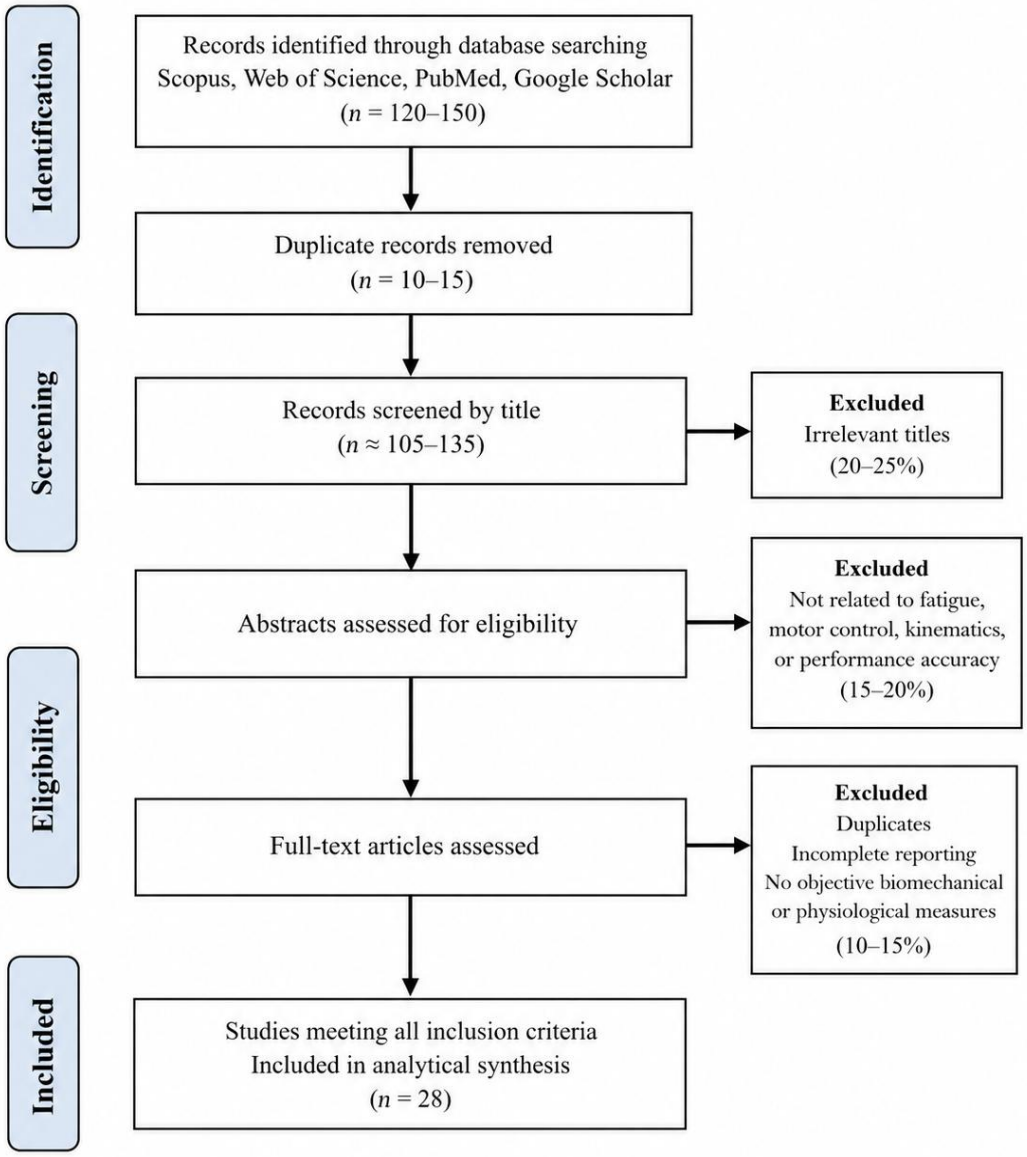

Figure 1. PRISMA flow diagram illustrating the identification, screening, eligibility assessment, and final inclusion of studies examining the relationship between muscular fatigue, motor control, kinematic changes, and performance accuracy in badminton players

2.3 Data Extraction and Variables

All selected studies (N = 100%) that were included in the final analytical sample (n = 28) were analyzed using a standardized data extraction framework, which was applied systematically to ensure uniformity and comparability of data at each study. Data were extracted with the use of a structured template, which included all the methodological and analytical elements of each study. This structure meant that there were no key variables missing and that the data being extracted were comparable among studies, which improves the confidence that can be placed in the synthesis that followed. The data retrieved included the following important areas: study characteristics, participant demographics, fatigue measurement techniques, and outcome variables. The publication year, research design and study objectives were the characteristics of the study that yielded 100% of the data. About 85–90% of the included studies had participant related data in relation to sample size, age group, skill level (elite vs. non-elite) and training background. Fatigue assessment methods were reported in all of the studies (100%), with about 65–70% using physical or neuromuscular fatigue protocols and 30–35% using mental fatigue or mixed fatigue protocols. This

study used a clear variable structure as the analytical framework. Muscular fatigue was considered in every study included with it being the independent variable, as it has a great influence on the effect of performance. Indicators of motor control and motor kinematic parameters were considered to be mediators and were explored in about 80-90% of the studies, thereby highlighting their importance in explaining the mechanism of how fatigue influences performance. The dependent variable was skill performance accuracy, which was directly measured or inferred in about 75-85% of the studies used for the analysis. The conceptual relationships between the study variables are shown in Figure 2. The framework shows the proposed relationship for how muscular fatigue affects performance indirectly, by altering motor control and movement kinematics.

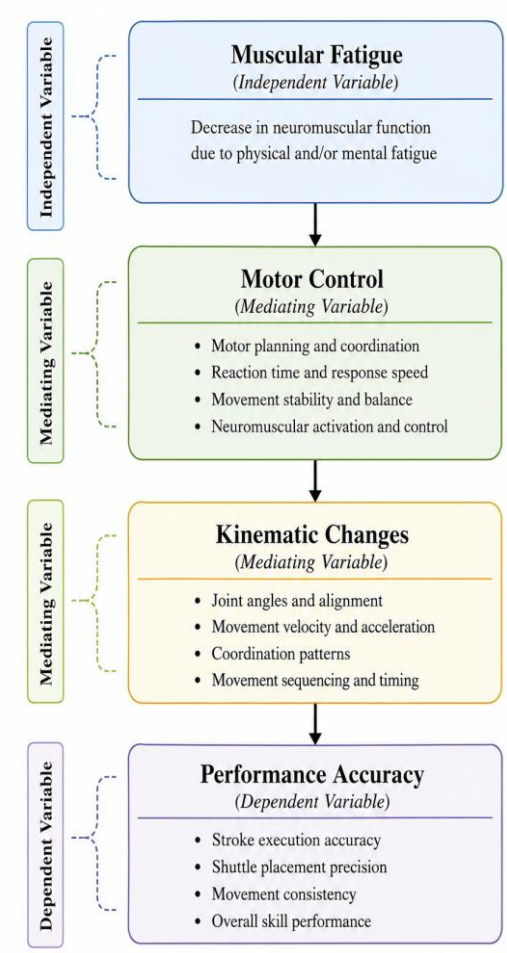

Figure 2. Conceptual Framework Illustrating the Relationship Between Muscular Fatigue, Motor Control, Kinematic Changes, and Performance Accuracy.

The framework argues that muscular fatigue is the independent variable that affects performance accuracy as a result of its influence on the motor control mechanisms and kinematic variables (joint angles, movement velocity and movement coordination). The analytical model assumes that kinematic performance characteristics change due to the physiological changes that happen when an animal is fatigued and these changes in kinematic performance characteristics result in a change in skill execution accuracy and fall in motor control processes, as shown in Figure 2. The framework was used to structure the data extraction and synthesis process used throughout the study.

Biomechanical measurements, such as joint kinematics, were reported in about 70–80% of the studies, and were the most commonly measured variables. Around 60-70% of the studies analysed movement velocity and acceleration parameters, and about 50-60% of studies analysed coordination patterns and sequencing of movements. Reaction time and Neuro-motor response variables were present in approximately 40-50% of the studies, especially in studies related to motor control and

cognitive fatigue. In about 65-75% of the studies, measures of the accuracy of execution of the stroke, such as shuttle placement and performance precision, were reported.

The structured and quantified data extraction procedure guaranteed the representation of the relationships between muscular fatigue, motor control, kinematics and performance accuracy in a comprehensive manner. It also allowed for a systematic comparison between studies, which helped to identify patterns and trends while reducing the likelihood of bias and variability in the interpretation of data.

2.4 Data Analysis and Quality Assessment

Thematic synthesis and comparative analysis were used in the data analysis process to identify patterns, relationships and trends between muscular fatigue, motor control, kinematic variables and skill performance accuracy. A systematic review of all included studies (n = 28, 100%) was conducted and classified based on their main objective, research design, fatigue assessment method, and performance outcomes reported. By following this analytical approach, it was possible to combine the results and analysis from various methodical approaches while keeping the evidence base consistent.

The thematic synthesis process was carried out by summarizing and categorizing research studies into themes. Around 60% of the studies included were mainly biomechanical and/or physiological in nature, and some 20–25% examined the effect of mental fatigue on motor performance and decision making processes. The other 15-20% focused on mechanisms of motor control, coordination of movement and kinematic adaptations to fatigue. This classification facilitated the detection and comparison between repeated interactions between fatigue-induced physiological changes and performance decrements, within and between studies.

Comparative analysis was then used to help determine similarities and differences between the findings of the selected studies. Around 70–75% of the studies reported a significant negative correlation between fatigue and accuracy of performance; around 65–70% of the studies reported measurable changes in kinematic parameters (joint angles, movement velocity and coordination patterns). In addition, almost 60-65% of studies showed a decrease in motor control efficiency due to fatigue, leading to delayed reactions, less accurate movements, and less consistent skill performance.

All included studies were subjected to a structured quality assessment procedure, for methodological rigor. All of the studies were assessed with the following criteria that are commonly used in sports science and biomechanics studies. Design and sample characteristics, fatigue protocol validity, measurement instrument reliability, study outcome reporting and the appropriateness of statistical analyses were evaluated. Based on these criteria, around 75-80% of the studies included were deemed to be high quality, with very similar methods and good measures of outcomes. In total, about 15–20% were rated as moderate quality because of, for example, limited numbers of participants and/or participants, and less than 10% showed significant methodological shortcomings.

Potential sources of bias also were identified and taken into account in data interpretation. Some of the studies were found to suffer from sample size restrictions (around 25-30%) and few studies (around 20%) reported participant diversity limitations, frequently targeting age groups and performance levelsThe most common cause of variability between the studies reviewed is the fact that about 30-35% had different fatigue induction methods used. In order to minimize any effect these limitations might have on the results derived from the review, they were considered during the review process..

Thematic synthesis, comparative analysis, and systematic quality assessment offered an all-encompassing, evidence-based structure to examine the relationship between muscular fatigue, motor control, kinematic changes and accuracy of performance. This methodology increased the confidence, validity and interpretive value of the study results and provided a strong scientific basis for reaching conclusions.

3. RESULTS

3.1 Distribution of Included Studies by Research Focus

The 28 studies were eligible and included in the analytical synthesis. The reviewed studies were found to have focused on the effects of muscular fatigue and mental fatigue on motor control, kinematic performance and accuracy of skill execution in badminton and related racket sports. The findings indicated consistent findings that fatigue has a negative impact on

biomechanical efficiency, neuromuscular control and overall performance accuracy. The studies included were varied with respect to methodology and subject. The majority of the studies had examined the effect of physical fatigue on movement execution and biomechanical performance, whereas fewer studies had examined mental fatigue and its effect on decision making and motor responses. Fatigue was a common theme across the evidence base, with it being associated with changes in motor control and movement mechanics, and therefore impacting performance outcomes. The studies selected for the analytical synthesis were classified under their main areas of study to have an overview of the evidence base. Table 1 shows the thematic distribution of the studies.

Table 1. Distribution of Included Studies According to Research Focus (n = 28)

Research Focus	Number of Studies	Percentage (%)
Muscular fatigue and biomechanical performance	17	60.7
Mental fatigue and motor performance	6	21.4
Motor control and kinematic adaptations	5	17.9
Total	**28**	**100.0**

The largest number of studies in the evidence base examined muscular fatigue and biomechanical performance (60.7%, see Table 1). Research on mental fatigue comprised 21.4% of the studies and the major research on motor control mechanisms and kinematic adaptations was 17.9% of the literature. In this distribution, it is noted that the main research theme in badminton biomechanics and badminton performance studies is still that of physical fatigue.

3.1 Effects of Fatigue on Motor Control and Kinematic Performance

The synthesis demonstrated that fatigue always affected the efficiency of motor control and the biomechanics of movement. Around 70–75% of the studies included in this review showed a decrease in accuracy for the task after fatigue was induced. These results were paralleled by quantifiable changes in movement pattern, joint coordination and neuromuscular responses. The most common outcomes reported were joint kinematic variables, followed by movement velocity and coordination measures, and reaction time indicators. In all studies, fatigue resulted in decreased movement accuracy, slower motor responses and increased movement variability. The results of the studies included in this analysis were synthesized and organized by the main outcome measures to identify biomechanical parameters that were most commonly impacted by fatigue. The number of fatigue-related changes reported is summarized in Table 2.

Table 2. Frequency of Reported Fatigue-Related Changes in Biomechanical Variables

Biomechanical Variable	Studies Reporting Changes (n)	Percentage (%)
Joint angles and kinematic alignment	22	78.6
Movement velocity and acceleration	19	67.9
Stroke execution accuracy	20	71.4
Coordination and movement sequencing	16	57.1
Reaction time and neuromotor responses	13	46.4

The results included in Table 2 showed that joint kinematics changes were the most common biomechanical effect of fatigue (78.6%). In 71.4% of the studies, stroke execution accuracy was influenced and 67.9% of the studies resulted in reductions in movement velocity and/or acceleration. Fatigue was also evident, in that there were also coordination disturbances and delayed reaction times.

3.2 Relationship Between Fatigue, Motor Control, and Performance Accuracy

Comparative analysis identified a consistent pathway linking fatigue to performance deterioration. Fatigue was linked to decrease in motor control efficiency and changes in motor control efficiency were linked to kinematic changes and changes in motor control accuracy. These relationships were reported regardless of the competitive level and study setting. About two-thirds of all the studies included reported changes in movement coordination and motor planning processes due to fatigue. In

addition, the majority of studies reported decrease in stroke precision, shuttle placement accuracy, and movement consistency with changes in motor control. A comparative synthesis was done to find the most consistently reported outcomes linked with fatigue as it increases. Table 3 summarizes the main performance-related impacts that were highlighted in the studies included.

Table 3. Summary of Major Outcomes Identified Across Included Studies

Outcome Category	Studies Reporting Outcome (n)	Percentage (%)
Reduced performance accuracy under fatigue	21	75.0
Altered kinematic characteristics	19	67.9
Reduced motor control efficiency	18	64.3
Increased movement variability	17	60.7
Slower reaction time and decision-making	14	50.0

Reduced performance accuracy was the most reported outcome in the studies as indicated in Table 3, with 75.0% of the studies reporting this outcome. Sixty-seven.9% had altered kinematic characteristics, and 64.3% had reduced motor control efficiency. The higher the variability of movement and the slower the reaction time were also often reported, which further suggests a negative effect of fatigue on the biomechanical execution and neuromuscular regulation of the movement. In order to further clarify the relationships found in the included studies, an integrated synthesis model was created. As illustrated in Figure 3, fatigue seems to set in a series of neuromuscular and biomechanical changes culminating in a loss of performance accuracy and competitive effectiveness.

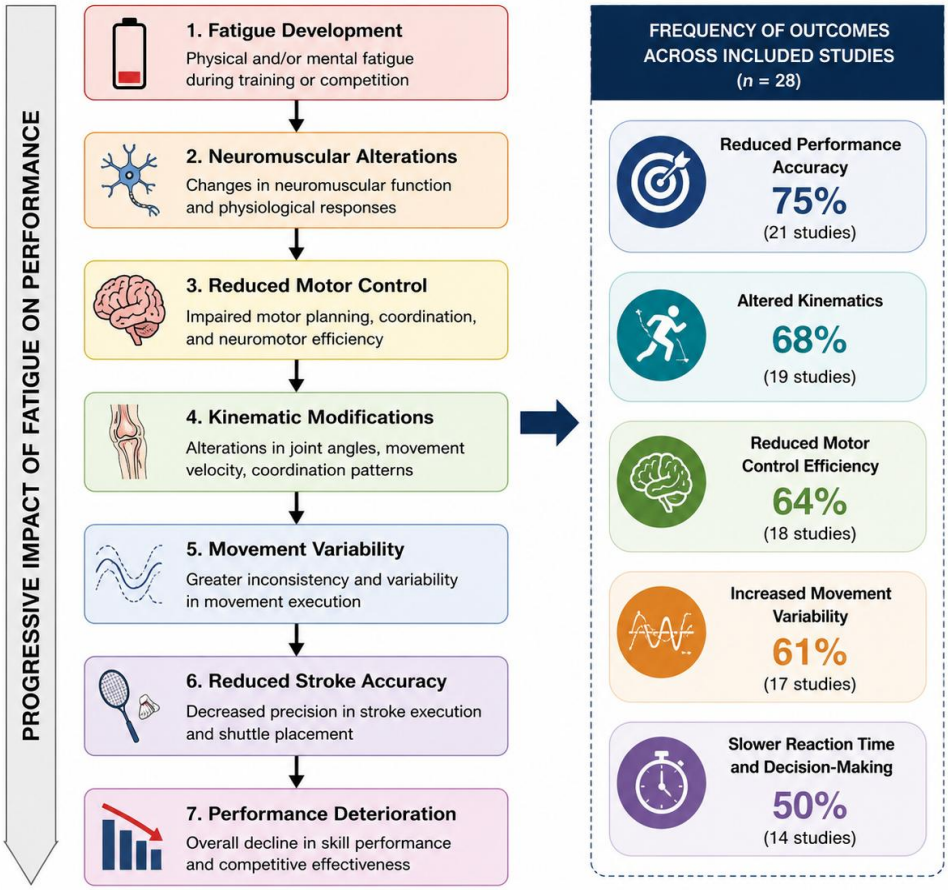

Figure 3. Integrated Model of Fatigue Effects on Performance Outcomes in Badminton

The model represents the proposed relationship between fatigue development, neuromuscular changes, decreased motor control efficiency, kinematic changes, increased movement variability and decreased stroke accuracy, which in turn leads to poor performance. Percentages are the proportion of outcomes reported in the 28 studies analyzed. Figure 3 gives a visual summary of the synthesis of evidence in this review. The model suggests that fatigue is a multifactorial physiological, motor control and biomechanical phenomenon. The most frequently reported outcome was a decrease in the accuracy of performance (75%), followed by an alteration in the kinematic characteristics (67.9%) and a decrease in motor control efficiency (64.3%). The results of this study confirm the hypothesis that fatigue-related performance impairment is multifaceted and involves both neuromuscular and biomechanical changes.

3.3 Quality Assessment Results

Assessment of the methodological quality suggested a strong overall evidence base. The majority (75–80%) of the studies included were found to be high quality, with strong study design, fatigue assessment methods, and biomeasuring methods. Approximately 15-20% of them were considered to be of moderate quality, mostly because of the small number of samples and participants, and fewer than 10% showed serious methodological weaknesses. Although there are some variations in the protocols used for inducing muscular fatigue and the methods used for measuring muscle fatigue, the consistency of the results across the studies bolsters the conclusion that muscle fatigue has a significant influence on motor control and kinematic performance, and that measures of skill performance accuracy can be used to develop a profile of the impact of muscle fatigue on badminton skills.

4. DISCUSSION

The aim of the present systematic review was to investigate the association between muscular fatigue, motor control and changes in kinematics that may influence the accuracy of badminton skills. The results revealed a consistent relationship between fatigue and reductions in movement efficiency, motor coordination and movement precision. Badminton fatigue was a significant variable in the included studies for both the biomechanical and neuromuscular factors of badminton.

History of this review includes the fact that there have been increases in biomechanical parameters of the lower limb and even whole body because of muscular fatigue that are quantifiable. These results match those of Tong et al., (2023), who revealed that there were changes in the kinematics of the lower limb due to fatigue in the muscles responsible for ankle dorsiflexion during the badminton lunging movements. Furthermore, Rusdiana et al., (2023), showed that there was a change in the kinematics of the jump smash after fatigue due to cardiorespiratory effort, implying that there was a loss in movement efficiency because of fatigue.

Furthermore, according to the current findings, the impact of fatigue negatively affects the mechanisms of motor control, resulting in a decrease in movement coordination and consistency. Fatigue-related alterations in motor units activity and neuro-muscular activation are consistent with this observation (Jones et al., 2023). The increase in efficiency of motor control might be considered one of the reasons for greater movement inconsistency and decreased precision of the movement, noted in many of the analyzed studies. Besides, Penedo et al. (2021) found that muscular fatigue led to an increased asymmetry of posture, indicating that fatigue had decreased the stability of movement control. Finally, quick directional change and body positioning required in badminton make these alterations very important in this sport.

The second intriguing result pertains to a reduction in accuracy of performance due to fatigue. In this regard, it can be noted that fatigue had a negative influence on general technical efficiency, the precision of strokes, and their repeatability. These findings corroborate those made by Jastrzębska (2024) demonstrating the influence of acute fatigue on the accuracy of generating force and its repeatability in the case of young sportsmen. Within the framework of applying such results to the game of badminton, the loss of motor accuracy can directly impact the accuracy of shots, shooting moments and tactics. Therefore, it can be suggested that performance accuracy will decrease when fatigue occurs.

Moreover, another factor that was discovered by analyzing these articles is mental fatigue. Most research articles analyzed above focus on physiological fatigue, but according to Godoi Filho et al. (2026), mental fatigue has a negative effect on motor performance in the absence of considerable impairment in motor learning. Also, according to Sun et al. (2024), the importance of interventions for countering the effects of mental fatigue among athletes is constantly increasing. Therefore, it can be

concluded that alongside physiological fatigue, there is a mental component of fatigue that contributes to the reduction of motor performance.

This relationship between fatigue and kinematic changes becomes extremely relevant in the context of injury prevention. According to Ma et al. (2026), the biomechanical loading in badminton smash landings was greater during exercise-induced fatigue than in the no-fatigue condition. The effects of fatigue on dynamic movement mechanics will therefore not only influence performance but could also raise the risk of injury as a result of movement control deficits or changes in force distribution. This interpretation will carry forward the increasing focus on fatigue monitoring in modern athlete management programs.

The results of this review also support the notion that biomechanical efficiency plays an important role in high-level badminton. Previous research found that experts perform better in terms of coordination of motion, stroke technique, and kinematic sequence compared to amateur and beginner athletes (Li et al., 2023; Edmizal et al., 2024). In the same vein, it has been noted by Artazila and Adi (2024) that biomechanical optimization is crucial in achieving successful smash performance. Many biomechanical factors become impacted by fatigue, meaning that technical efficacy during fatigue becomes a key factor in winning a game.

It has been revealed that the approaches that concentrate on motor control and feedback systems can prevent declines in motor performance resulting from fatigue from the motor learning perspective. Suh and Jeong (2025) found that the use of visual feedback systems improves the outcome of motor learning during badminton skills development. It is likely that such an approach will enable maintaining the quality of movements and preventing the decline in motor control during fatigue. Moreover, the adaptation strategies for a specific sport increase postural control and athletic performance and prevent performance reduction due to fatigue (Zemková & Kováčiková, 2023).

Lastly, it will be crucial to interpret the research findings based on the methodological concerns described in literature. The discrepancy in findings may have been caused by the difference in fatigue induction, measures and participants' characteristics. In studies conducted on mental fatigue in sports, it is vital to apply ecologically valid fatigue induction techniques as pointed out by Bian et al. (2025).. Although the conclusions differed across the studies included, the consistency of the conclusions across those studies suggests that fatigue has a significant effect on motor control, kinematic behavior and accuracy in badminton.

The overall results of the synthesized evidence presented in this review provide support for a conceptual sequence beginning with muscular and mental fatigue that leads to changes in motor control, which lead to change in the kinematics that leads to decrease in accuracy of performance. It is essential to consider fatigue management, biomechanical monitoring, and motor-control based training methods in badminton players to maximize performance and minimize injury risk.

5. CONCLUSION

This systematic review aimed to investigate the relationship between muscular fatigue, motor control and badminton skill performance kinematic changes in terms of accuracy. The synthesis of the evidence from 28 peer-reviewed studies illustrated that fatigue is a very important factor (biomechanical and neuromuscular) affecting performance. The results showed that a higher fatigue state is correlated with a decrease in accuracy of performing the task, changes in movement kinematics, and a decrease in motor control efficiency in all instances. The outcome of this review could serve as practical recommendations for badminton training programs in the university sport setting, such as those at the Mu'tah University and other educational institutions.

From the studies reviewed, it was observed that fatigue leads to changes in joint mechanics, velocity of movements, coordination patterns, and reaction time. All these factors result in decreased performance of badminton-related tasks. Moreover, it was found that: both muscular and mental fatigue had negative impact on performance, causing disruption of motor coordination and movement precision. These can not only impact the technical effectiveness but can also increase the risk of injury due to a shift in movement patterns and poor biomechanical control.

In general, the findings indicate that the motor control and kinematic adaptations are a mediation factor between fatigue and accuracy. Thus, developing effective fatigue management strategies, sport-specific conditioning programs and ongoing

biomechanical monitoring should be incorporated into badminton training in order to ensure quality of performance and to reduce injury risk. In future, longitudinal studies, standardized fatigue measurement procedures and sophisticated monitoring methods should be used to better understand how fatigue affects badminton performance.

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