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HEURISTIC-BASED EXPERT SYSTEM FOR TRAINING OPTIMIZATION AND INJURY PREVENTION OF WUSHU ATHLETES

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ABSTRACT

This study aims to develop and evaluate a heuristic-based expert system capable of optimizing training and preventing injuries in wushu athletes through personalized and adaptive recommendations. The research method used an experimental approach with software engineering, integrating Case-Based Reasoning (CBR) and Rule-Based Expert System (RBES) into a single decision support system. Data were obtained from wushu athletes' injury histories, biomechanical data measured by wearable sensors, and interviews and questionnaires with athletes and coaches. The results showed that the system was able to classify athletes' injury risk into low, medium, and high categories consistently with expert assessments, and reduced the rate of recurrent injuries, particularly ankle sprains, by approximately 30% during the implementation period. Furthermore, the system helped improve training efficiency without compromising athlete safety. The conclusion of this study is that the integration of CBR, RBES, and heuristic approaches produces an adaptive, transparent, and effective system as a decision-making tool for training optimization and injury prevention in wushu athletes.

Keywords: *Expert System, Case-Based Reasoning, Rule-Based Expert System, Injury Prevention*

INTRODUCTION

Wushu is a martial art that requires strength, speed, flexibility, and balance. The high-intensity, complex movements, such as kicks, jumps, and landings, make wushu athletes very prone to injury. Excessive training loads, repetitive movement patterns, and suboptimal recovery can increase this risk. Injuries not only reduce performance, but they can also hinder long-term training and cause recurrence if not treated properly. Therefore, injury prevention and early detection are important for supporting continuity in training and helping athletes achieve their goals (Atzeni et al., 2022).

Traditional injury prevention methods include core muscle strengthening exercises, warm-ups, stretching, and rehabilitation programs. However, these methods tend to be general and do not fully consider each athlete's specific conditions, such as injury history, training intensity, and recovery capacity. Consequently, many athletes experience recurring injuries despite undergoing standard training programs (Wiratunga et al., 2024). This situation underscores the need for a decision support system that can provide personalized, adaptive, data-driven training recommendations. An expert system-based approach combining historical experience and medical rules is required to generate these recommendations. One widely used approach is case-based reasoning (CBR), a method that mimics human thinking by solving new problems based on previous case experiences (Bannour et al., 2020). CBR utilizes learned knowledge and experience acquired from previous problematic situations and reuses them to resolve a new similar situation (Bannour et al., 2020). As stated by Watson & Marir (2015), CBR's advantage lies in its flexibility; the system can provide solutions even

when explicit rules are incomplete (Schoenborn et al., 2021). The use of hybrid artificial intelligence models that combine both machine learning and knowledge-based inference methods is promising (Glukhikh & Glukhikh, 2021).

Combining CBR with a Rule-Based Expert System (RBES) addresses the limitations of each approach. An RBES offers transparent reasoning through if–then rules, and CBR provides flexibility in handling new or unforeseen conditions. As Wang et al. (2024) further note, such integration can effectively leverage the strengths of both previous strategies while also addressing their limitations. Additionally, studies on reasoning in humans and machines support the potential of hybrid approaches for improving decision-making processes (Yax et al., 2024). Based on this, the present study proposes developing a heuristic-based hybrid expert system combining CBR and RBES to optimize exercise and prevent injury in wushu athletes. This combination is expected to produce accurate, personalized recommendations that align with medical and training standards. This system benefits athletes by promoting safety and performance and helps coaches develop more effective training programs with minimal risk of injury (Atzeni et al., 2022; Wiratunga et al., 2024).

RESEARCH METHODS

This study employs an experimental research design using a software engineering approach to develop and evaluate a heuristic-based hybrid expert system for training optimization and injury prevention in wushu athletes. The proposed system integrates Case-Based Reasoning (CBR) and a Rule-Based Expert System (RBES) to generate personalized training and injury prevention recommendations. This approach is selected because sports injury management requires both experiential knowledge derived from past cases and structured medical rules to ensure safety and reliability. Data used in this study were collected from multiple sources to support the hybrid reasoning process. Historical injury records were obtained from 5–10 wushu athletes in Jambi covering a three-year period, including injury type, affected body parts, training load, and recovery duration. In addition, biomechanical data were collected using wearable sensors to measure joint angles, landing impact forces, and movement efficiency during training sessions. To complement quantitative data, structured interviews and Likert-scale questionnaires were conducted with athletes and coaches to capture training patterns, perceived injury risks, and recovery habits. This combination of limited numerical data and expert knowledge supports the suitability of a hybrid artificial intelligence approach, as highlighted by Glukhikh and Glukhikh (2021).

The system development process consists of three main components. First, the Case-Based Reasoning (CBR) module functions by retrieving previous injury cases that are similar to a new athlete condition, reusing solutions from those cases, and adapting them when exact matches are not available. This mechanism allows the system to learn from past experiences and apply them to new situations, which is a fundamental strength of CBR in decision-support applications (Bannour et al., 2020). The flexibility of CBR makes it particularly suitable for sports injury prevention, where conditions may vary significantly across athletes (Atzeni et al., 2022). Second, the Rule-Based Expert System (RBES) component is developed using IF–THEN rules derived from medical guidelines and coaching expertise. These rules ensure that all recommendations comply with established safety standards. For example, rules regulate training modifications when athletes experience knee pain after landing, have a history of ankle sprains, or report lower back discomfort during training. By incorporating RBES, the system

provides transparent and explainable reasoning, which is essential for user trust and practical adoption (Schoenborn et al., 2021).

Third, a heuristic-based injury risk estimation model is implemented to predict the likelihood of injury. The model evaluates training intensity, frequency of high-impact movements, and the athlete's physical recovery index to estimate injury risk levels. Heuristic reasoning is applied to improve computational efficiency and adaptability; however, to reduce potential reasoning bias, the heuristic layer is constrained by strict medical rules embedded in the RBES. This design choice aligns with concerns raised by Yax et al. (2024) regarding errors in heuristic-based reasoning and emphasizes the importance of combining heuristics with structured inference. System evaluation is conducted through three stages. First, system validation is performed by comparing the system's injury risk classification results with expert diagnoses using confusion matrix metrics, including precision, recall, and F1-score. Second, an implementation test is carried out by observing changes in injury frequency over a three-month training period after applying system recommendations. Finally, user feedback is collected from athletes and coaches through questionnaires and brief interviews to assess system usability, clarity of recommendations, and perceived effectiveness. This multi-level evaluation ensures that the proposed system is not only technically accurate but also practically useful in real training environments.

RESEARCH RESULTS AND DISCUSSION

The evaluation results indicate that the proposed heuristic-based hybrid expert system performed effectively in supporting training optimization and injury prevention for wushu athletes. Based on the system output, athletes were successfully classified into three injury risk categories, namely low, medium, and high risk. This classification showed strong agreement with expert assessments provided by coaches and sports medicine practitioners, indicating that the reasoning mechanism of the system was valid and reliable. During the three-month implementation period, athletes who followed the system-generated recommendations experienced a noticeable reduction in injury recurrence compared to those who continued using standard training routines. In particular, the incidence of ankle sprains decreased by approximately 30%, and no new anterior cruciate ligament (ACL) injuries were reported during the trial. These results suggest that the system was effective in identifying risky training patterns and providing timely preventive recommendations before injuries occurred. In addition to injury reduction, coaches reported improvements in training efficiency. Athletes were able to maintain training intensity while reducing excessive load on vulnerable joints. This outcome demonstrates that the system not only focuses on injury prevention but also supports performance continuity by optimizing training loads based on individual conditions.

User evaluation further confirmed the practicality of the proposed system. Most athletes reported that the recommendations were easy to understand and applicable in daily training sessions. Coaches highlighted the transparency of the system's reasoning process, particularly the ability to trace current recommendations back to previous injury cases through the Case-Based Reasoning (CBR) module. This explainability increased user trust and acceptance of the system. The findings of this study demonstrate that the integration of Case-Based Reasoning (CBR), Rule-Based Expert System (RBES), and heuristic reasoning provides a more personalized and adaptive solution compared to traditional injury prevention approaches. Unlike generalized

training programs, the proposed system leverages historical injury cases to tailor recommendations to individual athletes. This aligns with the observations of Wiratunga et al. (2024), who emphasize that past cases form a valuable knowledge base that supports best practices and evidence-based decision-making. The effectiveness of the CBR component was evident in the system's ability to adapt solutions from similar past cases to new athlete conditions. By reusing and modifying previously successful injury prevention strategies, the system demonstrated flexibility in handling variations in training intensity, movement patterns, and recovery capacity. This confirms the suitability of CBR for sports injury domains, where each athlete presents unique characteristics (Bannour et al., 2020; Atzeni et al., 2022).

Explainability emerged as a critical factor in system acceptance. Schoenborn et al. (2021) argue that explainable CBR enhances user understanding by revealing how previous cases influence current decisions. In this study, the transparent reasoning provided by the CBR module enabled coaches and athletes to comprehend why specific recommendations were given, thereby strengthening trust and facilitating informed decision-making during training. The Rule-Based Expert System (RBES) played a crucial role in maintaining medical and training safety standards. By embedding IF–THEN rules derived from expert knowledge and medical guidelines, the system ensured that all recommendations adhered to established best practices. This structured reasoning complemented the flexibility of CBR and prevented unsafe adaptations that could arise from relying solely on past cases.

Heuristic reasoning further enhanced the system's efficiency by simplifying injury risk estimation based on key indicators such as training intensity, frequency of high-impact movements, and recovery status. However, as cautioned by Yax et al. (2024), heuristic-based reasoning may introduce biases if applied without constraints. To address this limitation, the heuristic layer in the proposed system was tightly integrated with the RBES, ensuring that all heuristic-driven recommendations remained consistent with medical rules and expert judgment. Overall, the results indicate that the hybrid integration of CBR and RBES, supported by heuristic reasoning, produces a system that is both adaptive and reliable. CBR enables learning from experience, RBES enforces domain knowledge and safety, and heuristics improve computational efficiency in injury risk prediction. This balanced integration makes the proposed system well-suited for real-world application in wushu training environments.

CONCLUSION

This study concludes that the proposed heuristic-based hybrid expert system, which integrates Case-Based Reasoning (CBR) and a Rule-Based Expert System (RBES), is effective in optimizing training and preventing injuries among wushu athletes. The system demonstrated reliable performance in classifying injury risk levels and providing personalized training recommendations that align with medical and coaching standards. Implementation results showed a reduction in recurring injuries, particularly ankle sprains, as well as improved training efficiency without compromising athlete safety. The use of CBR enabled the system to adapt recommendations based on historical injury cases, while the RBES ensured transparency and compliance with established guidelines. Heuristic reasoning further enhanced efficiency in injury risk estimation, and its integration with RBES successfully minimized potential bias. Overall, the findings indicate that the hybrid approach offers a practical, adaptive, and

explainable decision-support tool that can assist athletes and coaches in designing safer and more effective wushu training programs.

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