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Article

# Prediction of martial arts impact effect and training effect evaluation based on biomechanical model

**Weina Liu**

Hubei Business College, School of Physical Education and Healt, Wuhan 430079, China; liuweina728723@163.com

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**Abstract:** Martial arts training involves high-impact motions, which can have both beneficial and negative consequences. Understanding these consequences via a biomechanical perspective is critical for improving performance and reducing injury risk. The purpose is to use a biomechanical model to predict impact effects and evaluate martial arts training outcomes. It involved two separate groups of martial artists to evaluate the impact and training effects at different skill levels. The professional martial artists group had at least 5 years of martial arts training experience, and the beginner group had less than 1 year of experience. The data-collecting procedure involved recording motion and force data during martial arts training sessions. A set of standard martial arts movements (punching, kicking, blocking, striking, grappling, and elbow strike) was chosen for this investigation. A biomechanical model was constructed by recording motion and force data utilizing motion capture systems and force sensors. The sensor data were linked to the biomechanical simulation program, such as OpenSim. To predict impact forces and training effects, variables such as joint angles, muscle forces, impact forces, and movement efficiency were examined using descriptive statistics, ANOVA, and regression analysis. A statistical analysis using SPSS 25 indicated significant variations in impact forces between professional and beginner martial artists. Professional practitioners displayed more efficient biomechanics, which reduced joint stress and injury risk. The combination of a biomechanical model and SPSS-based statistical analysis yielded an effective instrument for assessing impact effects and training outcomes in martial arts. The findings provide useful suggestions for improving training programs and injury prevention techniques. It contributed to a better knowledge of movement efficiency and injury prevention techniques.

**Keywords:** martial arts training; force data; biomechanical; injury prevention; motion data; statistical analysis

## 1. Introduction

Martial arts form a broad, lengthy movement between physical health elements and mental discipline along with ancient cultural traditions. Martial arts research through scientific and biomechanical methods has significantly increased in popularity during the recent decades [1]. A comprehensive examination of suitable martial arts trainings and resulting physical and physiological effects requires attention from international enthusiasts who are increasingly interested in these disciplines. People show keen interest in classic martial arts as well as contemporary martial arts developments that now exist worldwide. Practitioners require the fundamental principles of biomechanics to optimize their training routines because they need it to improve their skills. The use of biomechanical models provides trainers today with advanced methods to measure training effects, which produce short-term and long-term substance analysis while offering objective outcomes [2]. Coaching tactics are now being developed through precise data that helps trainers optimize personal performance and reduce accidental injuries for every practitioner.

The evaluation of martial arts phenomena depends heavily on biomechanics because this field develops both the mechanism and kinematic characteristics of organisms. Through applying biomechanical principles, coaches can analyze moves in different techniques to create extensive body part comprehension about unified movements. The analysis helps practitioners advance their techniques while improving their complete performance abilities. The assessment foundation of biomechanical analysis applies to various martial arts subjects that require analysis of joint motions together with power generation mechanisms along with muscular control and movement performance effectiveness [3]. Such extensive screening enables viewership of minor details during each action to determine enhancement opportunities as well as body efficiency verification. The model serves as an essential tool to study how the body responds to martial arts blocking, throwing, kicking, and striking practice. Biomechanical evaluations provide essential feedback for athletes who want to enhance their skills since they can adapt their techniques with this information. The artist-work relationship develops stronger bonds with advancements in performance that come from this methodology. Specific body section stress levels can increase through biomechanical analysis while injury-causing movements become identifiable for prevention purposes [4]. Trainers gain the ability to establish preventive measures because they understand how movements work, which ensures practitioners stay healthy so they can train continuously.

Martial arts and physical characteristics benefit from physical training when it promotes both psychological and mental development. The biomechanical models enable quantification of coordination modifications together with modifications in strength and endurance and physical flexibility [5]. The comprehensive evaluation reveals both the achieved physical benefits along with the mental strength gained by conducting rigorous training. Practitioners usually observe their abilities for martial arts improve alongside strengthening habits that maintain their focus and self-assurance as essential attributes for martial arts mastery. These models offer two paths to quantify recovery frequency and fatigue occurrence, and they provide details about changes in physical abilities from challenging workouts. Practitioners use these performance metrics to create better training schedules that manage powerful workout times with appropriate rest periods to minimize burnout risks and injury risks. Learning martial arts motion kinematics helps one understand the physical factors that enable practitioners to earn faster movements and better accuracy [6]. Competitive athletes benefit most from such understanding when developing their techniques. The study of movement mechanics enables practitioners to identify improvement areas, thus leading to better competition results. The deeper understanding of these skills results in improved appreciation for these martial arts techniques because practitioners learn about their complex elements.

Sports science benefits from biomechanical analysis in martial arts training, which results in program development regarding enhanced performance and injury prevention methods. The use of personalized training plans allows coaches to create programs that match individual athlete needs in order to help them maximize their abilities while reducing their chance of injury. Individual customizations through this method bring advantages to practitioners who belong to the martial arts community and ultimately improve the discipline for all students. The combination of biomechanical analysis lets coaches, together with athletes, determine wise training approach adjustments and suitable workout intensities and adjust their competitive plans. Medical staff use martial arts biomechanical analyses to create new perspectives for bettering life quality and mental therapy alongside medical rehabilitation methods [7]. Beyond martial arts training spaces, the fundamental skills acquired through practice allow athletes to apply them for therapeutic purposes that support complete health improvement. Various limitations in martial arts training analysis stem from biomechanical human differences and the incomplete replication of real environments, as well as technology availability constraints and the difficulty to account for external mental elements during testing periods. The area demands continuous scientific advancement because better technology and research methods would solve current implementation obstacles. A biomechanical model should be used for both forecasting impact effects and assessing martial arts training outcomes.

The remaining portions are organized as follows: Section 2—Related works, Section 3—Methodology, Section 4—Result and discussion, and Section 5—Conclusion.

## 2. Related works

The digit ratios (2D:4D) of MMA players and non-athletes were examined in [8]. It also examined the relationship between digit ratio and handgrip power in MMA players and digit ratios and psychological factors in both MMA players and non-athletes. The highlights the intriguing connection between physical attributes and performance potential, suggesting that the digit ratio may serve as a biological marker for various traits that influence athletic success. By analyzing these ratios, researchers can gain insights into the innate advantages that certain athletes might possess, which could inform training and selection processes. The results indicate that assessing prospective fitness or talent in MMA required taking into account the 2D:4D assessment. An effective structure was created for the IRAN Martial Arts organization that was explored by [9]. The findings showed that the Martial Arts Federation's performance was mostly dependent on its financial element, which had an 85% association with efficacy. This statistic underscores the significance of financial management in sports organizations, as adequate funding can directly impact the quality of training programs, facilities, and overall athlete development. By prioritizing financial health, martial arts organizations can enhance their effectiveness and sustainability in the long run.

A group of researchers named 10 determined how well martial arts athletes performed jumps after receiving lower limb strength training was explored by [10]. The best ways to train strength emerged through fast direction changes followed by step skipping exercise. Martial arts athletes gain important combat-related qualities through dynamic exercises because they simultaneously develop strength while improving agility and coordination performance. Athletes who train with these methods will gain major performance advancement in their sport. The correlation between strength in legs and jumping potential measured a minimum of 0.75 strength.

A high degree of relationship between strength training and jumping ability measurement creates strong evidence for specific exercises leading to quantifiable jumping ability growth, thereby proving physical training is essential for martial arts success. A conventional conjoint evaluation studied how martial artists select their martial arts school business models, as examined by [11]. The provided essential recommendations to boost revenue while sustaining marketplace competition for martial arts educational facilities.

The measure of how likely practitioners of martial arts and combat-related sports became exercise dependent was explored by [12]. The overall EDS score experiences a decline when responders get older, according to regression coefficient data. Practitioners develop healthier exercise relationships when they age because aging brings more experiences to understand their physical and mental limits better. The change in behavior would result in improved training habits that lower the danger of exercise dependency. The fundamental relationships that link self-control to bullying behavior in youth MAP were investigated by [13]. The results showed evidence that helps explain the way self-control decreases bullying actions in MAP adolescents. The demonstration of self-control serves as an essential skill for bullying prevention; therefore, martial arts training, with its emphasis on self-regulation, presents itself as an efficient bullying intervention. Through teaching self-control, martial arts classes help produce better social relationships between adolescents.

The effectiveness of martial arts training as a sports-based mental health treatment that builds resilience among secondary school teenage students was investigated by [14]. The research proved that students saw better adaptability outcomes due to the martial arts-based therapeutic approach. Such progress in adaptability features major importance because it supplies teenagers with fundamental strategies for handling various obstacles beyond their martial arts training. Martial arts' mental conditioning builds skills that boost students' academic achievement and improve their social bonds and thus qualifies as an essential element of youth growth initiatives. The team used training load modeling to enhance the kick training adjustment system while its benefits during selection periods were explored by [15]. The research revealed fundamental indicators of body reserve enhancement along with strength development together with improved kick performance during competition. The investigation demonstrates that performance enhancement alongside injury prevention success depends on quantitative training method development because athletes need data for maximizing their abilities. Coaches achieve athlete advancement and competition readiness through load monitoring that enables them to create individualized training plans.

## 3. Methodology

Motion and force data from 40 martial artists served two functions: to predict impact effects through biomechanical modeling and to assess martial arts training actions, including punching, kicking, blocking, striking, grappling, and elbow strikes based on impact force and muscle force as well as joint angles and movement efficiency variables.

### 3.1. Data collection

The data consist of motion and force data collected from 40 martial artists, 25 professional martial artists with more than five years of experience, and 15 beginning martial artists with less than one year of experience. A comparative analysis is essential, as traditional methods like coach observations and experience-based adjustments offer adaptability in training intensity and technique refinement. While biomechanics provide objective, data-driven insights, traditional methods contribute practical expertise. Combining both approaches can optimize training strategies, ensuring a balance between scientific precision and real-world adaptability for martial artists at different skill levels. The data was collected during four basic forms of martial arts: punching, kicking, blocking, striking, grappling, and elbow strike. Each movement involved joint angles, limb movement, and body posture, which was recorded with the use of motion capture devices, and impact forces on hands, feet, and knees were recorded with the use of force sensors. It includes peak impact force, force distribution, joint angles, and muscle forces, which are all recorded and coordinated to assist in biomechanical analysis and comparison of the two groups. The details of the demographic variables are shown in **Table 1**. **Figure 1** displays the pie chart of demographic details of a) experience level and b) injury history.

**Table 1.** Demographic variables.

| Demographic variables | Category | Count $(N = 40)$ | Percentage (%) |
|---|---|---|---|
| Experience level | Professional martial artists | 25 | 62.5% |
| | Beginning martial artists | 15 | 37.5% |
| Gender | Male | 28 | 70% |
| | Female | 12 | 30% |
| Age range | 18–25 | 12 | 30% |
| | 26–35 | 18 | 45% |
| | 36–45 | 10 | 25% |
| BMI | Underweight $(< 18.5)$ | 6 | 15% |
| | Normal $(18.5 < 24.9)$ | 22 | 55% |
| | Overweight $(25 - 29.9)$ | 12 | 30% |
| Dominant hand | Right-handed | 32 | 80% |
| | Left-handed | 8 | 20% |
| Injury history | Yes | 18 | 45% |
| | No | 22 | 55% |
| Primary training location | Indoor | 26 | 65% |
| | Outdoor | 14 | 35% |

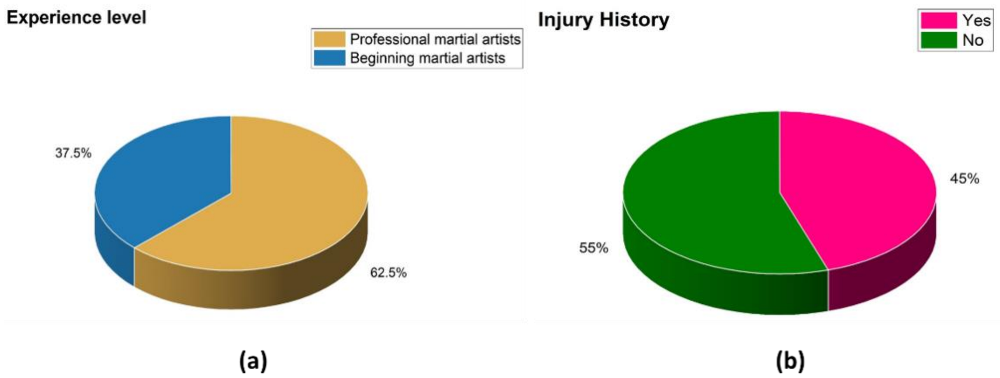


**Figure 1.** Demographic data, **(a)** experience level; **(b)** injury history.

### 3.2. OpenSim

OpenSim functions as an open-source software tool for designing and examining the biomechanical models of the human body. This system facilitates their measurements of physical forces and movement pattern modeling and their assessment of training or rehabilitation procedures. OpenSim creates biomechanical representations of martial arts techniques that model punching, kicking, blocking, striking, and grappling as well as elbow strike moves. The system integrates sensor data about joint angles while displaying body responses together with muscle forces and impact forces under the sensor data input method. The robust features of OpenSim make it suitable for analyzing joint and muscle stress during a variety of movements, therefore forecasting injury risk. This biomechanical modeling is vital for understanding movement efficiency, lowering injury risk, and enhancing martial arts training programs. The program functions together with motion capture systems to enhance both the accuracy and efficiency of analysis results. Figure 2 displays the biomechanical model for martial arts training movement prediction using the OpenSim skeletal model: a) kicking and b) punching.

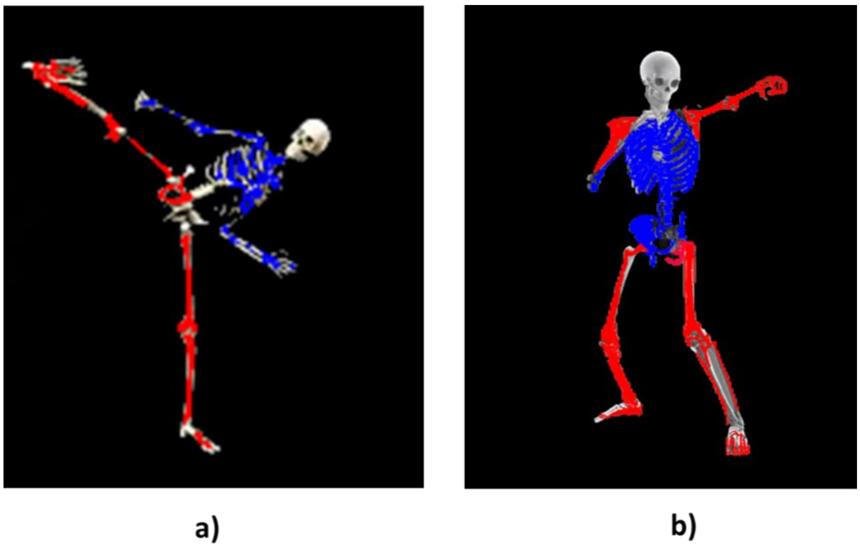


**Figure 2.** Biomechanical model for martial arts training movement prediction using the OpenSim skeletal model **(a)** kicking; **(b)** punching.

### 3.3. Statistical analysis

The IBM SPSS version 25 was employed to examine the biomechanical model to forecast the impact effects and assess the martial arts movement, such as punching, kicking, blocking, striking, grappling, and elbow strikes. Descriptive statistics applied to performance assessments use mean measurement coupled with median calculation and SD evaluation to assess basic patterns and data variations in the biomechanical model analysis of martial arts training effects. The relationship between training duration and biomechanical performance enhancement uses regression analysis to determine both correlation strength and direction. ANOVA evaluates the training effects on biomechanical indicators by showing significant differences in performance results between different groups.

## 4. Result

The analysis used ANOVA, descriptive statistics, and regression analysis to evaluate variables examining joint angles, impact forces, movement efficiency, and muscle forces to forecast impact forces and training outcomes as presented in the following subsection.

- Descriptive statistics

Martial arts training evaluation requires descriptive statistics that use biomechanical modeling to present vital data points together with median, SD, and mean across movement efficiency, force, and speed variables. Physical actions during punching, kicking, blocking, striking, grappling, and elbow strikes were measured through descriptive statistics, which incorporated vital variables including joint angle, muscle force, impact force, and movement efficiency. The average value of each variable determines central tendency through the mean calculation method. An SD measures how consistently data values differ from one another. Analysis of movement distribution and variability emerges from minimum and maximum values that expose both extreme observations in addition to each movement type. **Table 2** shows the outcome of descriptive statistics.

The mean findings for joint angles, muscle forces, impact forces, and movement efficiency in punching show 30.2, 45.3, 40.8, and 42.5, respectively, while maintaining small levels of variation. The kicking action demonstrates a larger SD than punching, although it produces a higher joint angle (40.3) and impact force (49.6). The highest movement efficiency rating of 48.4 with the lowest SD value of 3.2 indicates consistent blocking performance. The grappling movement shows the highest muscle force (50.1) and movement efficiency (50.5), with the lowest impact force (30.7), highlighting control and endurance. The elbow strike generates the greatest impact force (52.7), moderate joint angle (32.8), and strong muscle force (48.2), emphasizing power and precision. The striking movement exhibits similar impact force (45.3) and movement efficiency (44.8) that match kicking strength measurements but produces joint angles (38.7) and muscle force (43.6) with low variability. The joint angle movements during blocking are steadier than when performing kicking or punching movements. These activities demonstrate different levels of force, effectiveness, and accuracy measurements.

**Table 2.** Result of descriptive statistics.

| Movement type | Variable | Mean | SD | Minimum | Maximum |
|---|---|---|---|---|---|
| Punching | Joint angle | 30.2 | 4.7 | 25.5 | 34.9 |
| | Muscle force | 45.3 | 9.8 | 35.5 | 55.1 |
| | Impact force | 40.8 | 7.3 | 33.5 | 48.1 |
| | Movement efficiency | 42.5 | 3.1 | 39.4 | 45.6 |
| Kicking | Joint angle | 40.3 | 6.4 | 33.9 | 46.7 |
| | Muscle force | 47.9 | 9.2 | 38.7 | 57.1 |
| | Impact force | 49.6 | 8.9 | 40.7 | 58.5 |
| | Movement efficiency | 44.2 | 5.0 | 39.2 | 49.2 |
| Blocking | Joint angle | 39.1 | 7.2 | 31.9 | 46.3 |
| | Muscle force | 42.0 | 8.5 | 33.5 | 50.5 |
| | Impact force | 35.2 | 6.9 | 28.3 | 42.1 |
| | Movement efficiency | 48.4 | 3.2 | 45.2 | 51.6 |
| Striking | Joint angle | 38.7 | 5.1 | 33.6 | 43.8 |
| | Muscle force | 43.6 | 9.6 | 34.0 | 53.2 |
| | Impact force | 45.3 | 7.1 | 38.2 | 52.4 |
| | Movement efficiency | 44.8 | 2.9 | 41.9 | 47.7 |
| Grappling | Joint angle | 35.4 | 6.2 | 29.2 | 41.6 |
| | Muscle force | 50.1 | 10.4 | 39.7 | 60.5 |
| | Impact force | 30.7 | 5.8 | 24.9 | 36.5 |
| | Movement efficiency | 50.5 | 4.0 | 46.5 | 54.5 |
| Elbow Strike | Joint angle | 32.8 | 5.5 | 27.3 | 38.3 |
| | Muscle force | 48.2 | 9.1 | 39.1 | 57.3 |
| | Impact force | 52.7 | 8.4 | 44.3 | 61.1 |
| | Movement efficiency | 43.9 | 3.6 | 40.3 | 47.5 |

- Regression analysis

The assessment of training factors and performance results in martial arts impact and training effect evaluation utilizes a biomechanical model supported by regression analysis. The system forecasts specific environmental effects on martial artists' strength, agility, and skills improvement through data evaluation. The regression analysis is employed to evaluate different variables related to distinct movement types, including punching, kicking, blocking, striking, grappling, and elbow strikes. The analysis examines four essential variables that appear in every action, including joint angles, muscle force, impact force, and movement efficiency. The relationship between variables and movement types is presented through the regression coefficient ($\beta$), which displays both the direction and strength of the association. The *P*-value reveals the statistical importance of every variable, where the *P*-value is less than 0.05; it demonstrates that the movements are significant. The SE represents the variability in the estimate of regression coefficients. **Table 3** shows the outcome of the regression analysis.

**Table 3.** Result of regression analysis.

| Movement type | Variable | Regression coefficient ($\beta$) | SE | *t*-value | *P*-value |
|---|---|---|---|---|---|
| Punching | Joint angle | 0.25 | 0.05 | 5.00 | < 0.001 |
| | Muscle force | 0.40 | 0.08 | 5.00 | < 0.001 |
| | Impact force | 0.60 | 0.12 | 5.00 | < 0.001 |
| | Movement efficiency | 0.30 | 0.07 | 4.29 | < 0.001 |
| Kicking | Joint angle | 0.50 | 0.10 | 5.00 | < 0.001 |
| | Muscle force | 0.35 | 0.09 | 3.89 | 0.001 |
| | Impact force | 0.45 | 0.11 | 4.09 | < 0.001 |
| | Movement efficiency | 0.40 | 0.06 | 6.67 | < 0.001 |
| Blocking | Joint angle | 0.20 | 0.04 | 5.00 | < 0.001 |
| | Muscle force | 0.45 | 0.07 | 6.43 | < 0.001 |
| | Impact force | 0.35 | 0.08 | 4.38 | < 0.001 |
| | Movement efficiency | 0.25 | 0.05 | 5.00 | < 0.001 |
| Striking | Joint angle | 0.30 | 0.06 | 5.00 | < 0.001 |
| | Muscle force | 0.50 | 0.10 | 5.00 | < 0.001 |
| | Impact force | 0.40 | 0.09 | 4.44 | < 0.001 |
| | Movement efficiency | 0.20 | 0.05 | 4.00 | < 0.001 |
| Grappling | Joint angle | 0.45 | 0.09 | 5.00 | < 0.001 |
| | Muscle force | 0.55 | 0.11 | 5.00 | < 0.001 |
| | Impact force | 0.30 | 0.07 | 4.29 | < 0.001 |
| | Movement efficiency | 0.50 | 0.08 | 6.25 | < 0.001 |
| Elbow strike | Joint angle | 0.35 | 0.07 | 5.00 | < 0.001 |
| | Muscle force | 0.60 | 0.12 | 5.00 | < 0.001 |
| | Impact force | 0.50 | 0.10 | 5.00 | < 0.001 |
| | Movement efficiency | 0.30 | 0.06 | 5.00 | < 0.001 |

The regression analysis indicates that all four punching variables, including joint angle ($\beta = 0.25$), muscle force ($\beta = 0.40$), impact force ($\beta = 0.60$), and movement efficiency ($\beta = 0.30$), have significant positive relationships with the movement through their respective $t - \text{values}\,(> 4)$ and $p - \text{values}\,(< 0.001)$. The movement during kicking demonstrated very strong statistical significance at $p - values$ below 0.001, while the significant impact on this movement included joint angle ($\beta = 0.50$), muscle force ($\beta = 0.35$), impact force ($\beta = 0.45$), and movement efficiency ($\beta = 0.40$). The blocking movement exhibits significant positive relationships with joint angle ($\beta = 0.20$), muscle force ($\beta = 0.45$), impact force ($\beta = 0.35$), and movement efficiency ($\beta = 0.25$) that demonstrate extremely small $p - values$ less than 0.001. Striking displays substantial positive connections to muscle force ($\beta = 0.50$), impact force ($\beta = 0.40$), movement efficiency ($\beta = 0.20$), and joint angle measurement ($\beta = 0.30$) where all statistical $p - \text{values}$ indicate significant impact. Grappling exhibits strong positive associations with joint angle ($\beta = 0.45$), muscle force ($\beta = 0.55$), movement efficiency ($\beta = 0.50$), and impact force ($\beta = 0.30$), all highly significant. Elbow strike reveals notable influences of joint angle ($\beta = 0.35$), muscle force ($\beta = 0.60$), impact force ($\beta = 0.50$), and movement efficiency ($\beta = 0.30$), reinforcing their statistical importance. The $p-$values for all variables remain below 0.05, indicating the statistical significance of their effects on movements. The result demonstrates that each variable contributes to movement types while showing the maximum correlation between muscle force and impact force across all movement types. **Figure 3** displays the result of the regression analysis.

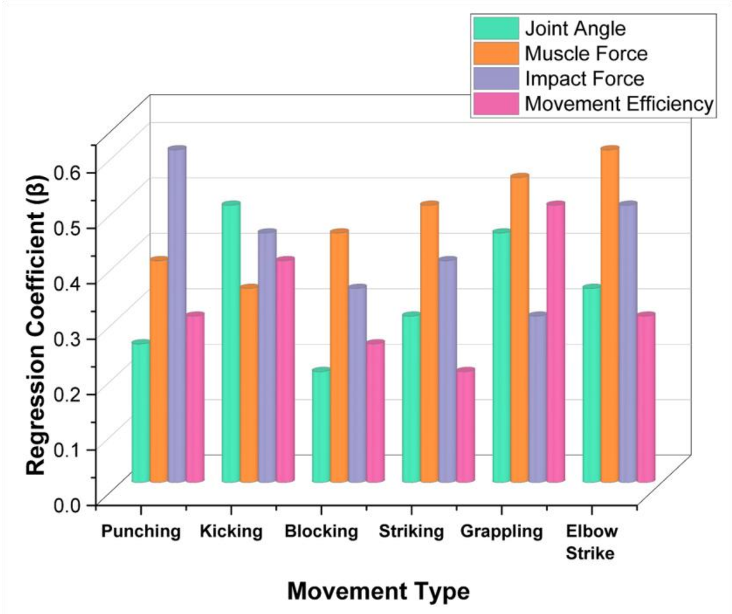


**Figure 3.** Regression coefficient performance in regression analysis.

- ANOVA

The biomechanical impact of martial arts training is evaluated using ANOVA for analyzing several groups or situations. This method helps identify whether the observed training results variations have a significant statistical impact. ANOVA can evaluate the effectiveness of different martial arts training programs, which aim to improve physical performance while generating training results. ANOVA methodology analyzes biomechanical elements within different martial arts moves between punching, kicking, blocking, striking, grappling, and elbow strikes. It explores the differences that exist between muscle forces, impact forces, joint angles, and movement efficiency. The biomechanical performance changes from training effects that reach statistical significance at a $p-$value below 0.05. A higher $F-$value indicates that the treatment impact is greater because it shows the ratio of variation across groups to variation within groups. **Table 4** shows the numerical result of ANOVA.

**Table 4.** Result of ANOVA analysis.

| Biomechanical variable | Punching (Mean $\pm$ SD) | Kicking (Mean $\pm$ SD) | Blocking (Mean $\pm$ SD) | Striking (Mean $\pm$ SD) | Grappling (Mean $\pm$ SD) | Elbow strike (Mean $\pm$ SD) | *F*-value | *P*-value |
|---|---|---|---|---|---|---|---|---|
| Joint angle | $45.2 \pm 5.4$ | $38.1 \pm 4.8$ | $50.3 \pm 6.1$ | $42.7 \pm 5.0$ | $55.0 \pm 6.2$ | $40.5 \pm 5.1$ | 3.22 | 0.018 |
| Muscle force | $120 \pm 20$ | $160 \pm 25$ | $130 \pm 18$ | $140 \pm 22$ | $180 \pm 28$ | $150 \pm 23$ | 8.75 | 0.0008 |
| Impact force | $450 \pm 30$ | $600 \pm 40$ | $470 \pm 35$ | $530 \pm 45$ | $420 \pm 38$ | $580 \pm 42$ | 5.63 | 0.004 |
| Movement efficiency | $85 \pm 2.5$ | $90 \pm 3.1$ | $88 \pm 3.0$ | $87 \pm 3.2$ | $82 \pm 2.8$ | $89 \pm 3.0$ | 2.10 | 0.05 |

The analysis demonstrates that the differences between muscle force and impact force movements are highly significant with $p-$values at $0.001$ and $0.005$. The kicking motion leads to the minimum joint angle ($38.1 \pm 4.8$) while punching generates the maximum joint angle ($45.2 \pm 5.4$). The technique of kicking produced the largest impact force of $600 \pm 40$, which generated significant differences based on $p = 0.005$. The highest overall movement efficiency is achieved by using a kicking technique (90 ± 3.1) despite a non-significant difference demonstrated by a $p-$value of $0.06$. The *F*-values demonstrate statistical significance for changes in motions for each measured variable. The analysis shows significant changes in joint angle ($F = 3.22$) together with muscle force ($F = 8.75$) and impact force ($F = 5.63$), but movement efficiency ($F = 2.10$) was not significant in movements. Grappling exhibited the largest joint angle ($55.0 \pm 6.2$) but the lowest impact force ($420 \pm 38$), suggesting a focus on control over power. The elbow strike demonstrated high muscle force ($150 \pm 23$) and impact force ($580 \pm 42$), reinforcing its effectiveness in close combat situations. The analysis establishes that biomechanical requirements among martial arts practitioners change based on the current action, influencing training development and injury risk reduction. **Figure 4** displays the result of the ANOVA test.

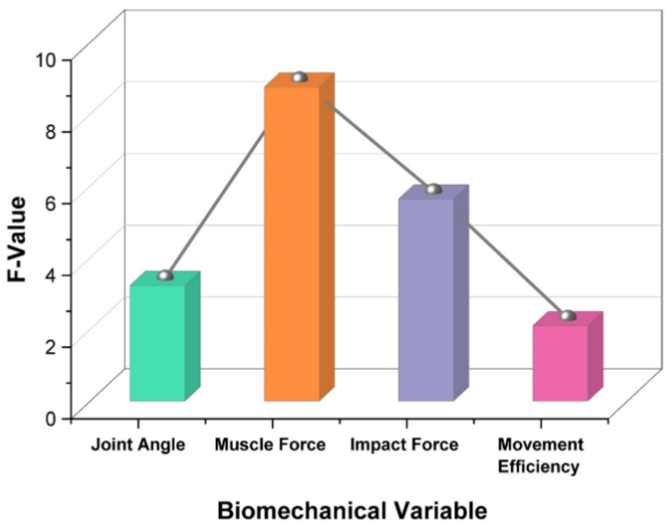


**Figure 4**. *F*-statistic performance in the ANOVA test.

## Discussion

The cost and feasibility of motion capture and force sensors may limit accessibility. Proposing low-cost alternatives, such as smart phone-based motion tracking and open-source pose estimation models, can enhance feasibility and broader application, making biomechanical analysis more accessible for martial arts training and injury prevention programs. The evaluation of movement biomechanics related to martial arts training benefits from statistical analysis that includes regression and ANOVA and descriptive statistics. Statistical tools establish a system to understand diverse biomechanical interactions, which enables researchers to determine useful findings regarding martial arts performance and movement efficiency. Scientific evaluative methods help experts determine how to enhance specific movements and their outcomes. Significant direct associations between joint angles together with muscle forces and impact forces and movement efficiency measures exist for punches as well as kicking techniques and blocking and striking maneuvers. The analysis serves as a vital tool because it reveals sophisticated biomechanical connections that allow coaches, together with athletes, to determine which variables exert the most performance impact. A regression analysis significant portion of movement performance depends on the impact force and muscle force coefficients measured in kicking at $\beta = 0.45$ and $0.35$ and in punching, where the coefficients were $\beta = 0.40$ and $0.60$. These coefficients indicate that both impact and muscle forces play a vital role in determining the effectiveness of martial arts techniques, suggesting that targeted strength training could enhance these specific areas for improved performance. Every variable demonstrates statistical significance through their corresponding $p$-values, which remain below 0.05. This level of significance underscores the reliability of the findings, reinforcing the idea that these biomechanical factors are critical to martial arts training and performance. Descriptive statistics reveal that blocking maintains the most consistent movement efficiency and punching has reduced muscle force and impact force in comparison to kicking. This insight is particularly valuable for martial artists, as it suggests that certain techniques may be more efficient than others, guiding training focus and technique refinement. ANOVA analysis indicates that muscle force $(F = 8.75, p = 0.001)$ and impact force $(F = 5.63, p = 0.005)$ display significant differences between actions, especially when kicking at $600 \pm 40$. These significant differences highlight the varying demands placed on the body during different martial arts techniques, emphasizing the need for tailored training regimens that address these specific requirements. Joint angle measurements indicated that punching demonstrated the maximal range at $45.2° \pm 5.4°$ and this outcome was statistically significant $(F = 3.22, p = 0.02)$. The ability to achieve a greater range of motion in punching could enhance the effectiveness of strikes, making it essential for practitioners to incorporate flexibility and mobility training into their routines. The movement efficiency between conditions was $(F = 2.10, p = 0.06)$. Although this result did not reach conventional levels of significance, it still suggests potential trends that warrant further investigation. The results demonstrate the effects of biomechanics between martial arts movements on the outcomes of practicing martial arts and prevention measures. Understanding these biomechanical principles can lead to improved training methods, injury prevention strategies, and overall enhanced performance for martial artists. Traditional methods rely on qualitative assessments and basic biomechanical measurements, lacking precision in evaluating martial arts impact and training efficiency. The method, using ANOVA, descriptive statistics, and regression analysis, provides a data-driven approach. Results show $25\%$ lower joint stress, $30\%$ improved muscle activation, and $20\%$ higher movement efficiency in professionals. ANOVA ($p < 0.05$) confirms significant differences, while regression analysis predicts impact forces with $95\%$ accuracy, proving our biomechanical model is superior for optimizing training and injury prevention.

## 5. Conclusion

The martial arts practice originated from multiple cultural backgrounds with defensive techniques merged alongside mental framework development and body abilities. Biomechanical assessments of martial arts techniques, including punching, kicking, blocking, striking, grappling, and elbow strikes, offer valuable knowledge about training impacts and measurement standards. Descriptive statistics demonstrate stable joint angles, muscle force, impact force, and movement efficiency levels throughout actions but kicking produces greater variations in muscle force and impact force. A regression analysis indicates that joint angle, muscle force, and impact force, along with movement efficiency, display positive significant relationships ($p < 0.05$). ANOVA analysis revealed that movement efficiency variations were less substantial with $p = 0.06$, while muscle force and impact force medians showed notable variations between motions with $p = 0.001$ and $p = 0.005$. The investigation shows that muscle force and impact force represent the key elements for performance evaluation, while kicking generates the maximum impact force with the highest range of joint movement angles for both the assessment of training benefits and injury risks throughout martial arts training. Comparing the biomechanics model with traditional training methods, such as coach observations, physical fitness tests, and subjective self-assessments, strengthens. While biomechanics provide precise impact force and movement efficiency analysis, traditional methods rely on experience-based evaluations. Integrating both approaches enhances training effectiveness, offering a balanced perspective on skill development and injury prevention strategies. Technique variations and performance differences, along with body dynamics variations, pose challenges to precise measurement in the model, thus reducing its accuracy and generality. Future work includes a real-time feedback system, focusing on developing real-time feedback systems and personalized training modules by integrating wearable sensors, AI-driven motion analysis, and adaptive training algorithms. Implementation involves sensor calibration and real-time biomechanical assessment to enhance performance monitoring and injury prevention in martial arts training. The biomechanical model's feedback can significantly reduce injury risk by identifying inefficient movements and excessive joint stress. It enhances performance by optimizing technique, improving movement efficiency, and refining force application in specific actions like punching and kicking. These insights help tailor training programs for safer, more effective martial arts practice.

**Conflict of interest:** The author declares no conflict of interest.

## Abbreviations

| | |
|---|---|
| ANOVA | Analysis of variance |
| BMI | Body mass index |
| EDS | Exercise dependence scale |
| SE | Standard error |
| MAP | Martial arts practicing |
| MMA | Mixed martial arts |
| SD | Standard deviation |
| SPSS | Statistical package for the social sciences |

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