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Effects of Anaerobic Fatigue on Biomechanical Variable Changes in Softball Batting Techniques

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Abstract

Softball is a sport that requires a good coordination between physical and technical aspects. Anaerobic fatigue can be a factor affecting the execution of softball batting techniques. However, an in-depth understanding of the impact of anaerobic fatigue on biomechanical variables in the batting technique context is still under-explored. This study aimed to identify and analyze the effect of anaerobic fatigue on changes in biomechanical variables in softball batting techniques. The purpose of this study was to evaluate how anaerobic fatigue affects key biomechanical variables in softball batting techniques. This information is expected to provide additional insight into the importance of anaerobic fitness in improving the performance of softball athletes. This study used experimental method with a pretest-posttest design. The subjects were experienced softball players selected using purposive sampling. Anaerobic fatigue was induced using a high-intensity training protocol. The biomechanical variables measured included bat swing speed, swing angle, and shot precision. Measurements were taken before and after the training. Data were analyzed using a paired t-test to examine significant changes. The study showed that anaerobic fatigue had a significant effect on key biomechanical variables in softball batting techniques. There was a significant decrease in bat swing speed and batting precision after anaerobic fatigue. The average bat swing speed before fatigue was 3.60 m/s, which decreased to 2.14 m/s after fatigue. In addition, the swing angle and batting precision also showed significant changes, with a lower left knee angle approaching the ground in the pre-fatigue group. This study found empirical evidence supporting the effect of anaerobic fatigue on biomechanical variables in softball batting technique. These results provide an important contribution to the general understanding of the relationship between anaerobic fatigue and technical performance in softball. Therefore, athlete trainings and preparations need to pay attention to anaerobic fitness aspects to maintain optimal performance during the game.

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INTRODUCTION

Softball is a sport that requires high levels of technical skill and coordination between players and equipment (Matt & Moore, 2020). In the context of softball batting, biomechanics plays a crucial role in the success of each hit (Flyger et al., 2006). Understanding key biomechanical factors, like bat swing speed and the angle of the hit, are essential for improving a softball player's performance (Milanovich & Nesbit, 2014). However, there hasn't been much research on how anaerobic fatigue affects these biomechanical aspects of softball batting. Therefore, it is important to investigate how anaerobic fatigue might cause changes in these biomechanical variables. This study aimed to provide stronger knowledge to help improve training and preparation for softball players.

Anaerobic fatigue, which is related to the body's capacity to perform high-intensity activities in a short period of time, has a significant impact on athlete performance (Bateni et al., 2013). In softball, where players require bursts of energy in short periods, anaerobic fatigue can be a key factor influencing overall performance (Río-Rodríguez et al., 2016). Although many studies have examined the effects of anaerobic fatigue in various sports, few have focused on the relationship between anaerobic fatigue and biomechanics in softball batting techniques. Therefore, this study aims to bridge this knowledge gap by focusing on the relationship between anaerobic fatigue and changes in key biomechanical variables in batting technique.

Anaerobic fatigue occurs when muscles can no longer generate enough energy in a short time, often caused by lactic acid buildup and reduced muscle capacity to work at high intensity (Hultman & Greenhaff, 1991). In sports like softball, which involves high-intensity, short-duration physical activities such as sprinting, hitting, and throwing, anaerobic fatigue can quickly affect players' performance (Woo-kwang et al., 2020). When muscles experience this fatigue, changes in movement patterns and biomechanics will be evident, particularly in batting techniques, where swing accuracy and speed heavily depend on muscle strength and body stability (Erickson et al., 2016).

In softball, the batting technique is a critical element influencing player performance (Mohammad, 2023; Saraya, 2018). Biomechanical variables, such as bat swing speed and angle of the hit, play an important role in determining the quality of a softball player's hit (Horiuchi & Nakashima, 2022). Although many studies have explored these factors, a deeper understanding is still needed on how changes in biomechanical variables can affect the overall batting technique. Studies exploring fatigue show that it changes the contribution of lower limb joints during stretch-shortening cycle tasks, reduces jump height, knee and ankle control, and joint stiffness (Sun et al., 2019). Additionally, running-induced fatigue alters lower limb kinematics and kinetics during countermovement jumps, particularly during the landing and final push-off phases, which could potentially increase the risk of injury (Yu et al., 2020). In this context, exploring the impact of anaerobic fatigue on biomechanics is essential to improving athlete performance (Aquino et al., 2022). This study aimed to provide richer insights into softball biomechanics and identify knowledge gaps that have not been extensively explored, particularly in softball.

Previous research has discussed various aspects of softball batting techniques, but there is a lack of knowledge regarding the interaction between anaerobic fatigue and biomechanical changes in these techniques. Many studies focus more on individual variables, such as bat swing speed or angle of the hit, without considering the impact of anaerobic fatigue as a key variable (Dowling & Fleisig, 2016; Horiuchi & Nakashima, 2022; Messier & Owen, 1984; Tago et al., 2005, 2006; Washington & Oliver, 2018; Werner et al., 2005). This research gap creates the need for further exploration of how anaerobic fatigue affects key biomechanics in softball batting techniques.

The findings from this research have significant practical implications for softball coaches and athletes. By understanding how anaerobic fatigue influences biomechanics in batting techniques, coaches can develop more specific and focused training programs on fatigue management. For instance, training that includes strength and conditioning exercises to increase the body's tolerance to anaerobic activity can help maintain batting technique stability even under fatigued conditions. Furthermore, this understanding can assist in game strategy management, such as player substitutions or better rest management.

Previous studies have not explicitly evaluated the complex interaction between anaerobic fatigue and biomechanical variables, which may reduce a comprehensive understanding of how fatigue modifies technique execution. Therefore, this study seeks to complement and expand this understanding by detailing the impact of anaerobic fatigue on key biomechanical variables, creating a more holistic insight into improving softball players' hitting quality. Thus, this research is expected to make a significant contribution to enhancing the quality of softball players' batting techniques and provide a foundation for developing more effective training strategies.

METHODS

This research employed an experimental method, as this approach allowed the researcher to identify the causal relationship between anaerobic fatigue and biomechanical changes. The experimental approach was chosen because the involved variables can be manipulated and measured directly under controlled conditions. This provided strong internal validity, which was essential for measuring the effect of high-intensity training interventions on biomechanical performance. The experimental approach was used because it enabled the researcher to quantitatively analyze the biomechanical changes that occur due to fatigue. Moreover, this method was suitable for answering research questions focused on cause-and-effect relationships, which could not be achieved with observational or descriptive methods.

Participants

The participants in this study consisted of 15 softball players who were purposively selected from the Bumi Asri club. The sample size of 15 players was chosen based on purposive sampling criteria, considering that this study used experienced subjects with similar characteristics in batting biomechanics. Although this sample size is relatively small, experimental studies often use smaller sample sizes to obtain more in-depth data from each subject. The selection focused on batting specialists or batters who possessed specific experience and skills in softball batting techniques. The participants had an average age of 20 ± 0.6 years, forming a relatively homogeneous group in terms of age. In addition, the participants' heights ranged from 1.71 ± 1.2 meters, with an average body weight of 59 ± 3.7 kilograms. This careful sample selection was expected to provide representative and relevant data to illustrate the effect of anaerobic fatigue on biomechanical changes in softball batting techniques.

Instruments

This research utilized several tools to ensure accurate and detailed data collection related to biomechanical variables and anaerobic fatigue parameters. High-speed action cameras (GoPro Hero 11, USA) were used to capture high-resolution movements, a tool widely used in biomechanical research (Balsalobre-Fernández et al., 2015). Manual markers and a set of three-dimensional calibrations were used to ensure accuracy in measuring angles and body positions during movement, which have been validated in various studies on three-dimensional motion (Jun et al., 2013). The motion analysis software (Kinovea, Spain) was also used to analyze biomechanical variables such as movement speed and angles, which has been proven valid and reliable in sports research (Puig-Diví et al., 2017). The subjects' heart rates were monitored using the Polar H10 (Finland), which has been extensively validated and shown to be highly accurate in measuring heart rates as an indicator of anaerobic fatigue (Gilgen-Ammann et al., 2019). Additionally, a Bushnell 101922 speed radar (Germany) was used to measure swing speed, and it has been proven accurate in various studies related to athletic performance (Haugen et al., 2012).

Procedures

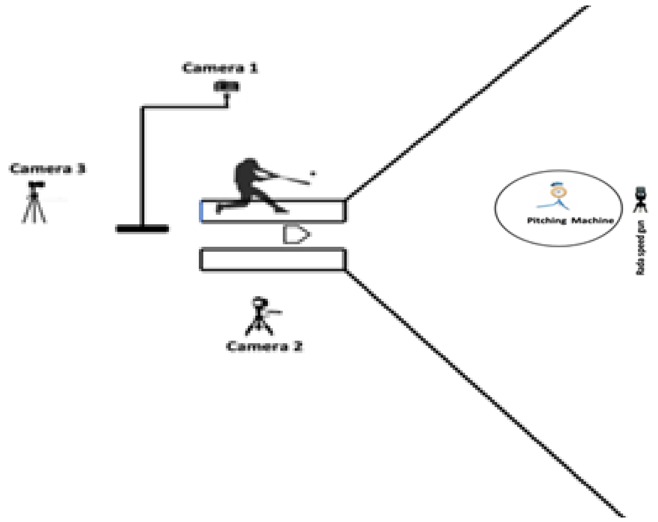

Figure 1. Batting Kinematics Data Collection Scheme

Camera 1 was placed perpendicularly above the subject area at a distance of 5 meters to record shoulder and hip joint movements during softball batting. Camera 2 was placed on the right side of the subject area, while the third was positioned perpendicularly behind to obtain a comprehensive view of the entire upper body joint movements. The participants were instructed to warm up for 15 minutes. After a 3-minute rest period, they were asked to hit the ball as fast as possible, following the scheme shown in figure 1. The ball speed was measured using a Bushnell 101922 radar, manufactured in Germany. The average value from six hits was calculated, and ball speed was measured in km/h.

Data Analysis

Data were analyzed using SPSS version 21.0 for Windows by conducting descriptive statistics to determine the mean ± SD. A paired sample t-test was applied to identify differences between pre-fatigue and post-fatigue conditions in terms of the maximum ball speed during softball batting at a 95% confidence level. This statistical analysis was used to compare the pre-test and post-test values of biomechanical variables. This test was chosen as it is suitable for experimental designs with repeated measurements within the same group and can identify significant changes due to intervention. The paired t-test is deemed adequate to detect significant changes in a small group, provided the normality assumption is met. This sample size is also consistent with previous studies in the same field, which showed significant results with a similar number of subjects. Time-position data were filtered using a fourth-order low-pass Butterworth filter with a cutoff frequency of 13.5 Hz.

Kinematic Parameters

These parameters were used to determine the characteristics of the softball batting mechanism, a model relevant to the principles of movement anatomy. The parameters selected to describe the softball hitting motion were based on biomechanical data. Kinematics and kinetics were calculated using two-dimensional information generated during the test. Reflective markers determining general kinematics, including displacement and speed for linear measurements, were used to define the characteristics of the softball batting mechanism, relevant to the principles of movement anatomy.

RESULT

This research collected data through video recordings of batting techniques in softball. The collected data was analyzed using statistical methods via IBM SPSS v.26. The analyzed data was obtained from samples consisting of players from the UPI softball student activity unit and Indonesian national softball players. Before data collection, the sample participants were individually measured, and the results are shown in Table 1.

Table 1. Anthropometry

No	Item	Average	St. dev
1	Age (years)	20	0.60
2	Height (cm)	171	1.62
3	Weight (kg)	59	3.70
4	BMI (kg/m²)	22	1.45
5	V02max (ml/kg/min)	50	2.12

Table 1 shows five items forming the subtest. The average age is 20 years, height 171 cm, weight 59 kg, BMI 22 kg/m², and VO2 Max 50 ml/kg/min. These results align with the aerobic capacity standards required in softball, as players engage in high-intensity activities (Artikel et al., 2016). A higher VO2 Max correlates with better performance, as players with higher aerobic capacity can perform closer to their maximum effort (Girard et al., 2015). Thus, players with a good level of aerobic capacity, as indicated by increased VO2 Max, have a better ability to perform batting in softball, as this action is repeated multiple times during a game. There is also a relationship between greater arm strength and improved hitting accuracy, as well as grip strength and hitting precision (Septianingrum et al., 2018).

Table 2. Approach Phase – Contact Phase

No	Variable	Before Fatigue		After Fatigue	
		Average	St. dev	Average	St. dev
1	Approach Time (seconds)	1.13	0.28	1.24	0.45
2	Total Approach Distance (cm)	54.04	2.45	38.88	3.48
3	Contact Time Between Bat and Ball (seconds)	0.71	0.07	0.53	0.26

The descriptive data from the approach phase to the contact phase is presented in Table 2. Total approach distance affects the final batting result, as one of the determinants of batting success is the initial batting position. In the pre-fatigue group, the average score was 54.04 cm, significantly higher than 38.88 cm in the post-fatigue group. These results show a significant difference between the two groups, affecting the final ball speed when launched from the bat during the final phase of batting.

The descriptive data from the accuracy of each batting step and the follow-through phase is presented in Table 3. Table 3 shows that pre-fatigue players had higher batting speed, a more optimal left knee angle, faster bat speed, and shorter ball release time compared to post-fatigue players. This demonstrates superior technique and physical performance in the batting phase through the follow-through phase before fatigue sets in.

Table 3. Batting Phase – Follow Through

No	Variable	Before Fatigue		After Fatigue	
		Average	St. dev	Average	St. dev
1	Batting Speed (m/s)	3.60	0.45	2.14	0.75
2	Left Knee Angle (degrees)	45.47	1.96	49.14	2.72
3	Bat Speed (m/s)	18.18	2.30	12.21	21.11
4	Total Batting Time (seconds)	1.99	0.24	1.90	0.29

DISCUSSION

Batting length has a direct relationship with the ball speed generated. In this study, the group tested before fatigue showed an average batting length of 307.60 cm, significantly higher than the post-fatigue group, which averaged only 130.81 cm. Additionally, the ball release time also revealed a significant difference between the two groups. The pre-fatigue group had an average release time of 0.36 seconds, compared to 0.67 seconds in the post-fatigue group. Higher bat speed plays a crucial role in generating greater momentum and force, both of which are directly related to the ball speed produced during batting (Bartlett, 2014). In this context, a lower left knee angle in the pre-fatigue group indicates a more optimal posture and better stability during hitting. Good stability and body posture enable a more efficient transfer of energy from the body to the ball, ultimately increasing ball speed. These findings are consistent with previous studies that show muscle fatigue can affect body mechanics and athletic performance, as noted by Nissen et al. (2009), where muscle fatigue leads to changes in body kinematics, impacting movement efficiency and the strength generated. Therefore, it is important for athletes to maintain anaerobic fitness and muscle strength to sustain optimal performance, especially in sports like softball that require a combination of strength, speed, and coordination.

Batting performance in softball is highly influenced by player's physical condition and techniques. The decline in batting performance after fatigue emphasizes the importance of physical conditioning in maintaining optimal technique throughout a game. Studies have shown that fatigue affects body mechanics, which in turn influences hitting speed and accuracy (Oliver et al., 2019). When an athlete is fatigued, they tend to experience reduced core stability and motor control, which can lead to undesirable changes in their hitting technique (Escamilla et al., 1998). Anaerobic fatigue, in particular, can cause changes in posture and weight distribution, reducing the efficiency of energy transfer from the body to the bat. This results in reduced bat speed and hitting precision, as observed in this study, where the pre-fatigue group performed better than the post-fatigue group.

Moreover, the lower left knee angle before fatigue, closer to the surface, indicates that non-fatigued athletes can maintain an optimal posture that supports hitting stability and strength. This finding is in line with the study by Zult et al. (2014), which revealed that muscle fatigue can decrease joint stability and athletic performance. Thus, to improve and maintain batting performance, athletes should focus on training that enhances anaerobic endurance and core muscle strength, as well as effective recovery strategies to mitigate the negative effects of fatigue.

Furthermore, the lower left knee angle before fatigue compared to after fatigue suggests that athletes have better control over their posture and body mechanics before fatigue sets in. This aligns with research indicating that optimal joint angles can influence hitting outcomes, with a more optimal knee angle allowing for more efficient energy transfer from the body to the ball (Inoue et al., 2013). An optimal knee angle helps athletes maintain stability and strength during hitting, maximizing the momentum and force transferred to the ball. When athletes are not fatigued, they can maintain a knee angle that supports an ideal posture, allowing them to hit with greater power and accuracy. Fatigue, on the other hand, leads to undesirable changes in body mechanics, including an increased knee angle, resulting in less stable and efficient posture.

Through proper training, athletes can be trained to maintain optimal joint angles even under fatigue, allowing their performance to remain optimal throughout the game. In this context, physical training focused on increasing muscle endurance and core stability is crucial for maintaining optimal performance throughout the game. Training programs that include core muscle strengthening and stability exercises can help athletes maintain their optimal batting technique even when fatigued (Szymanski et al., 2007). Additionally, monitoring and managing workload, along with effective recovery strategies, play an essential role in maintaining athletic performance during a long competitive season.

CONCLUSION

This study highlights the importance of adjusting batting performance factors based on biomechanical variables to improve overall performance. The study found a significant impact on the final ball speed during batting. Based on data analysis between the pre-fatigue and post-fatigue groups in the approach to contact phases, there was a significant difference in the total approach distance, which affected the final batting outcome coefficient. The pre-fatigue group had a total approach distance of 54.04 cm, significantly higher than the post-fatigue group's 38.88 cm. Several significant differences affected higher ball speed, with the pre-fatigue group achieving a batting speed of 3.60 m/s, compared to the post-fatigue group's 2.14 m/s. Additionally, one of the key differences between the two groups was the left knee angle during batting, as body position and lower center of mass concentration affected bat speed. The pre-fatigue group exhibited a lower left knee angle closer to the surface. Analysis results showed significant differences in various biomechanical aspects, contributing to the decline in batting performance when fatigue sets in. This emphasizes the importance of training focused on improving muscle endurance and core stability, as well as effective recovery strategies, to maintain optimal performance throughout the game. Therefore, proper management of physical condition and body biomechanics is crucial in maintaining and improving athletes' performance during competitions.

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CONFLICT OF INTEREST

The authors declared no conflict of interest.

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