

Back arm joint kinematic differences between skilled and less-skilled collegiate softball players

NOOR AZILA AZREEN¹, RAJA NURUL JANNAT RAJA HUSSAIN², MUHAMAD NOOR MOHAMED³,
MUHAMAD SAFIQ SAIFUL ANNUR⁴, MAISARAH SHARI⁵, HOSNI HASAN⁶

^{1,5,6} Faculty of Sports Science and Recreation, Universiti Teknologi MARA, Shah Alam Campus, Selangor,
MALAYSIA

^{2,3,4} Faculty of Sports Science and Recreation, Universiti Teknologi MARA, Seremban 3 Campus, Negeri
Sembilan, MALAYSIA

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Abstract:

Softball is a globally popular sport that reached the Olympic level for women only. However, research on softball, particularly among female players, remains at its infancy stage. Softball is played by two teams of nine players, with each side striving to score more runs via batting than the other. This is accomplished when the team is playing offence and batting the ball. A great batting performance is essential to enhance the likelihood of scoring a run. Batting is one of the hardest sports skill to learn, if not the hardest. Thus, this study examines selected arm kinematics that improve batting performance in skilled and less skilled female collegiate softball players during bat-ball contact. Using 3D motion analysis, five skilled and five less skilled female collegiate softball players use their dominant hand to hit a stationary ball off a tee placed in the middle of their individual striking zone. From a stationary tee, participants executed eight swings with maximum effort. The kinematics of shoulder abduction, shoulder flexion, elbow flexion and wrist flexion are calculated using the Visual3D software. The data from eight maximal effort swings for each kinematic variable during bat-ball contact are averaged and analysed using an Independent T-test. The results reveal that the shoulder flexion and elbow flexion angles display statistically significant differences between skilled and less-skilled batters. During bat-ball contact, skilled batters hold their hands further out from their bodies, as evidenced by a larger elbow extension ($139.19 \pm 18.95^\circ$), compared to less skilled players ($87.3 \pm 8.3^\circ$). Additionally, skilled players are reported to have less shoulder flexion than less-skilled players. This research suggests that less-skilled players bend their shoulders more when striking the ball with the bat in contrast to skilled players whose shoulders are somewhat more extended during bat-ball contact (by 6.05°). This study revealed that skilled players are able to adjust the degree to which their arm bends during ball contact. The adjustment maximises the surface area of the bat that makes contact with the ball, hence increasing a batter's probability of successfully striking the ball. As demonstrated by the skilled female softball players during bat-ball contact, keeping an extended arm position may assist batters in creating higher bat velocity.

Keywords: Softball, batting, arm kinematics, skill level, collegiate, Visual-3D

Introduction

The popularity of softball has considerably increased over the last 15 years, with an estimated 65 million individuals in over 140 countries playing softball or baseball (World Baseball Softball Confederation, 2017). With players of all ages competitively participating (Makorohim & Syaputra, 2019), softball has become one of the most popular female sports in the United States (Smith et al., 2015; Stergiou & Decker, 2011). Its popularity is likely to increase after its reintroduction as an Olympic sport in 2021. Despite the popularity of softball and the importance of batting in the sport, scientific studies concerning softball remain scarce as compared to baseball, especially among female players (Athanasakis et al., 2021; Milanovich & Nesbit, 2014).

The outcome of a softball game is determined by each team's offensive output (Dermawan et al., 2021). A team must hit the ball and move its runners around the bases without getting out. In order to win, they must score more runs while on offense than their opponent (Nakashima, Horiuchi, & Sakurai, 2020). Thus, a solid batting performance is the primary requirement for raising the odds of scoring (Athanasakis et al., 2021). Consequently, batting is not only the most essential aspect of softball, but it is also a crucial aspect of offensive skill (Carboch et al., 2022; Dermawan et al., 2021). Batting is widely regarded as one of the most challenging and demanding skill in sports (Ae, Koike, & Kawamura, 2020; Kuo, Cheng, & Lee, 2020; Washington & Oliver, 2020). During a fast pitch, a batter has less than 0.5 seconds to react and swing the bat during bat-ball contact from the pitcher's pitch (Carboch et al., 2022; Athanasakis et al., 2021; Takamido, Yokoyama, & Yamamoto, 2019; Lim & Kwon, 2016).

The batter's batting skills are defined by bat speed and contact accuracy during the batting motion, both of which affect the ball's trajectory and distance (Ae et al., 2020; Hussain et al., 2019). Bat speed has been proven to be a significant predictor of a batter's performance when attempting to make contact with a ball. A range of areas designed to optimise batting performance in terms of bat speed have been explored in the scientific literature. Another important aspect of batting performance is the angle of the bat as the player approaches contact with the ball (Williams et al., 2020). While approaching the ball with the optimal bat angle, a greater surface area of the bat is exposed for contact, hence boosting the possibility of a faster ball. This may result in a greater chance of success during an at-bat (Williams et al., 2020). Research on the kinematics of the hitting motion has been conducted to better understand the factors that lead to higher bat speeds.

Despite the vast amount of research to date, most studies had either focused on bat swing kinematics and kinetics (Katsumata et al., 2017; Dowling & Fleisig, 2016; Ae & Koike, 2015) or the properties and performances of the bat (Milanovich & Nesbit, 2014). The batters' body kinematic analysis was ignored. Although kinematic parameters linked to bat velocity have been examined, little is known about how an individual's body mechanics contribute to the optimal bat angle for improved batting performance. Baseball and softball players' batting mechanics previously examined revealed that the most common swing-related body kinematics involve the lower extremities, pelvis and torso (Washington & Oliver, 2018; 2020; Iino, Fukushima, & Kojima, 2014; Chang et al., 2011).

Washington and Oliver (2018) investigated the kinematic differences between hitting from a tee and hitting off a front toss among collegiate softball players. In this study, the tee condition showed greater trunk lateral flexion to the back side at foot contact, greater trunk rotation toward the lead side at follow through and greater pelvic rotation towards the lead side at follow through. Katsumata et al. (2017) claimed that the success or failure of the ball-bat impact is directly related to the organisation of body movements in such a way that a working point moves towards the impact area. The study emphasised that the rotating movements of the batter's trunk and arms are the key elements of a batting motion. This study focuses on the kinematics of the trunk and the leading arm. Dowling and Fleisig (2016) suggested that batters can generate increased bat velocity by extending their back elbow and abducting their back shoulders during ball contact. In baseball, the speed and launch angle of the ball are both affected by the position of the bat's back arm, as stated by Larson (2021). Based on this background, the present study solely focuses on the back arm kinematics during softball batting due to its key role in directing the batter's hands to the ball. The aim is to fill the research gap regarding this body mechanics.

Previous studies have shown that hitting kinematics vary according to the skill level and age of players (Inkster et al., 2010; Escamilla et al., 2009). Relatively little has been done to compare the biomechanics of hitting between batters of different skill levels despite the availability of several works that examined the kinetic and kinematics of the bat swing (Ae et al., 2020; Katsumata et al., 2017; Tago et al., 2016; Fleisig & Kwon, 2014; Inkster et al., 2011; Escamilla et al., 2009b). There is a significant knowledge gap in understanding the differences between competition levels since most research had only focused on professional athletes (Dowling & Fleisig, 2016; Inkster et al., 2011; Escamilla et al., 2009a). Additionally, previous research that had examined the kinematics of batting at different competition levels did not account for body mechanics. To better understand how to teach excellent hitting kinematics to players of all ages and skill levels, researchers have discovered that examining hitting kinematics at different ages, abilities and levels is helpful (Misaki et al., 2016). Coaches may benefit from more tailored lesson plans if they have a better understanding of the kinematic disparities between players of varying levels of ability. Assuming proper mechanics reduce the risk of injury. Comparing kinematics across skill levels may shed light on what causes injuries (Zheng et al., 2008). For this reason, the kinematic differences in the back arm of skilled and unskilled softball players are compared in this research.

One of the first studies to analyse swing kinematics between players of two levels was Escamilla et al. (2009a). They compared 12 young hitters with 12 adult batters. The bat's linear velocity and the lead elbow's peak angular velocity at bat-to-ball contact identified batters of different ages and skill levels. Inkster et al. (2011) analysed baseball batting using 3D motion capture to assess the differences in swing kinematics between high-calibre and low-calibre batters. The maximum bat swing velocity was significantly different between high- and low-calibre batters ($p < 0.05$), with high-calibre batters swinging at a faster rate (36.8 m/sj1) than low-calibre batters (33.8 m/sj1). The maximum angular velocity of the lead elbow was found to be significantly greater (35.7%) among reasonably high-calibre batters. A more recent study by Ae and Koike (2015) had compared elite college and amateur baseball players during the batting motion and found substantial differences in the sequence of angular velocities displayed by the pelvis, trunk and bat. Although the researchers did compare batting kinematics according to the levels of players, they ignored body mechanics which affect the bat angle during ball contact. The bat angle helps athletes make better contact and improve their batting success.

As far as the authors are aware, Dowling and Fleisig (2016) are the only researchers who used body mechanics to analyse batting kinematics across multiple levels of competition (youth, high school, college and professional athletes) while factoring in the role of the back arm. At the time of ball contact, professional baseball batters were seen to have their shoulders and elbows further stretched than amateurs. It can be assumed

that the skill level of a player influences the batting mechanics of that player. Aside from this one study, previous biomechanical analyses of softball and baseball batting have primarily focused on the lower limbs, pelvis and torso, without examining the back arm kinematics or comparing the skill levels.

Due to the similarity between baseball and softball, a certain amount of knowledge can be gleaned from baseball research. However, certain properties, such as the swing plane, may vary (Iino et al., 2014). To adequately evaluate the batting performance during softball, a comprehensive description of the softball swing mechanics is necessary. The ability to identify swing kinematics is crucial for enhanced performance. The fundamental component of good coaching is improving players through feedback and lessons. Therefore, it is vital to expand the limited understanding of softball batting. The purpose of this study is to compare the batting arm kinematics of skilled and less-skilled softball players during bat-ball contact. Our research can assist coaches in identifying the elements that require improvement in an athlete's swing, such as optimising the arm angle during ball contact to flatten the bat and enhance the surface area for making contact with a baseball.

Material & Methods

Participants

Five skilled softball players who underwent formal training throughout the years with at least four years of experience in playing competitive football were recruited from a collegiate softball team. These players have an average age of 20.8 ± 0.84 years, a height of 160.0 ± 2.15 m and a weight of 59.8 ± 4.86 kg. The five less-skilled collegiate softball players have an average age of 20.2 ± 1.33 years, a height of 156.7 ± 3.53 m and a weight of 53.12 ± 3.78 kg. They had never played softball at a competitive level and only possess a limited amount of experience playing the game at a recreational level (Hasan et al., 2016). This study only included female participants due to two reasons: there is little research on the fundamental mechanics of the female softball swing and softball is only played by women in the Olympics (Athanasakis et al., 2021; Milanovich & Nesbit, 2014). All participants were examined in a controlled environment within a laboratory setting (Biomechanic Lab, Universiti Teknologi MARA, Seremban Campus). Participants are all right-handed and were injury-free at the time of data collection. Participants were informed in advance regarding all protocols. Their participation in the experiment was fully voluntary and informed consent was obtained. This study was approved by the Ethics Committee of Universiti Teknologi MARA.

Procedure

In accordance with the upper body Plug-in-Gait model, each participant was fitted with 27 reflective markers (14 mm) at the following anatomical landmarks: left/right front head, left/right back head, right scapula (acts as an anti-symmetry marker), xiphoid process of sternum, jugular notch (in between right and left clavicle), C7 spinous process, T10 spinous process, left/right tips acromion, left/right upper arm, left/right elbow (lateral epicondyle), left/right middle forearm, left/right wrist (1st finger and 5th finger), left/right posterior superior iliac spines and left/right anterior superior iliac spine (Molina, Bott, & Stodden, 2019).

Each marker was attached with hypoallergenic skin adhesive double-sided tape and an adhesive overlay. Twelve circular reflective stickers with 16 mm diameter were adhered to the ball's surface. Each circular reflective sticker was affixed in order for the camera to recognise it as a different marking (Fig. 1). To determine bat-ball contact, eight extra round reflective stickers (10 mm) were affixed to the distal and proximal ends of the bat at four positions (Kidokoro & Morishita, 2021). After securing all reflective markers, each participant was given as much time as necessary to conduct their preferred warm-up regimen.

Using an eight-camera Optitrack motion capture system (PrimeX 13W: OptiTrack, United States), 14-millimeter-diameter marker data was captured at 240 frames per second to capture accurate kinematics data, as recommended by previous research (Langdown, Bridge, & Li, 2013; Wagner, Pfusterschmied, Klous, Duvillard, & Müller, 2012). Motive motion capture software, which is included with Optitrack cameras, was utilised to obtain the 3D marker data. To optimise the recording and capture all reflecting markers during the swing, tripod-mounted cameras were set around the batting area facing the capture area. A standard stationary tee was then set up in the middle of the capture volume (Dowling & Fleisig, 2016). Since each participant's strike zone depends on the height and batting stance, the batting tee was adjusted according to height (Yang et al., 2021; Washington & Oliver, 2018; Szymanski et al., 2007).

The stationary tee was positioned midway between the knee and hip and at a distance from the body to simulate a pitch thrown above the centre of the strike zone. The ball is set at the midpoint of the high ball (the upper strike zone boundary) and low ball (the lower strike zone boundary) (Washington & Oliver, 2018; Dowling & Fleisig, 2016). Once the system was properly calibrated, a static trial was conducted for capturing and labelling marker data using motion capture software. Each participant then spent two minutes simulating what they would do prior to an at-bat situation before the actual trial occurred. Following the warm-up session, participants were required to complete a set of eight batting trials from a stationary tee with a 20-second interval of rest between each trial and a 10-minute interval of rest after every 15 trials until a total of eight successful swing trials was accomplished (Williams et al., 2020).

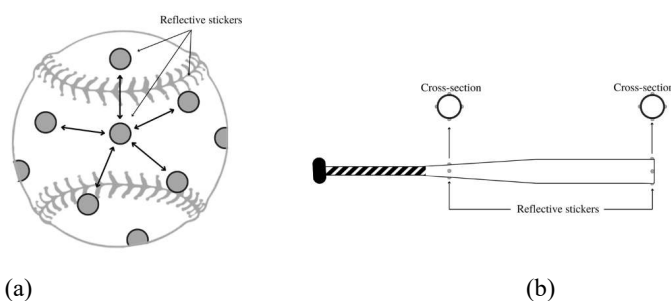


Figure 1. Location of reflective stickers on: (a) ball and (b) bat

Assessment Protocol of Anthropometric Characteristics

The anthropometric measurements include: standing height (m), weight (kg), lower strike zone boundary (cm), high strike zone boundary (cm), shoulder offset (m), elbow width (m), wrist width (m) and hand thickness (m). Participants' height and weight were measured to the nearest 0.05 m and 0.5 kg using SECA 763 electronic weighing and measuring system. For the low and high strike zones, measurements were taken with a roll-up measuring tape (SECA 206) while the batters were in their normal batting position. This measurement was used to determine the midpoint of the strike zone. Each participant's shoulder offset, elbow width, wrist width and hand thickness were measured to build a Visual 3D model template (C-Motion, Inc., Germantown, MD). Other than the shoulder offset, which was measured with SECA 206 roll-up measuring tape, all measurements were taken with a Harpenden Skinfold Calliper.

Data Processing

Using the Visual 3D software (C-motion, Inc., Germantown, MD), shoulder abduction, shoulder flexion, elbow flexion and wrist flexion kinematics were computed. The study's raw three-dimensional coordinate data were smoothed using a zero-lag, fourth-order, low-pass Butterworth filter with a 12 Hz cut-off frequency. The selected digital filter is considered ideal for data smoothing (Escamilla et al., 2009a). Every trial's data was normalised to 100 data points using the Visual 3D software. In this research, shoulder abduction angle is defined as the angle between the distal direction of the upper arm and the line between two shoulders in respect to the frontal plane (identified as 0°) when the arm is positioned straight down to the side (Fig. 2a). Shoulder flexion angles are the angles that determine the longitudinal axes of the proximal and distal segments (Fig. 2b). Elbow flexion is defined as the angle between the forearm and upper arm. The elbow flexion angle is 0° at full extension (Fig. 2c). The angle between the vectors from the wrist marker to the hand marker and the elbow marker was used to compute wrist flexion (Fig. 2d) (Katsumata et al., 2017; Dowling & Fleisig, 2016; Tago et al., 2016). At bat-ball impact, the desired kinematic data was extracted. Immediately after the bat hits the ball, the ball's position abruptly changes. Therefore, the frame prior to this modification was considered as the moment of bat-ball contact (Katsumata et al., 2017).

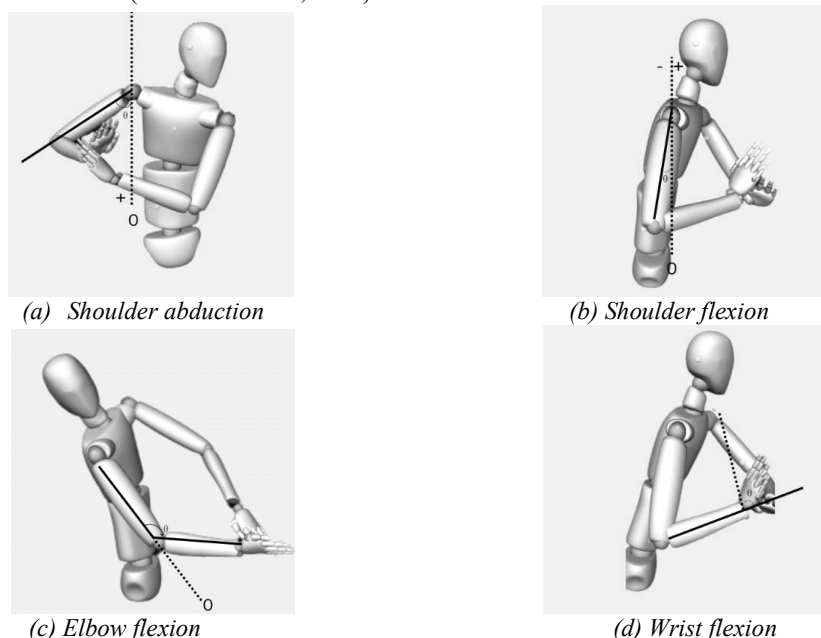


Figure 2. Definition of kinematic variables: (a) shoulder abduction, (b) shoulder flexion, (c) elbow flexion and (d) wrist flexion

Statistical Analysis

All descriptive statistics were computed and displayed as the mean standard deviation. For each participant's eight swings, the mean of all kinematics variables was determined. Using the Independent T-test, differences between skilled and less-skilled players were analysed. At the $p < 0.05$ level, the two groups were reported to be significantly different. The analysis was performed using the Statistical Package for Social Science, version 25.

Results

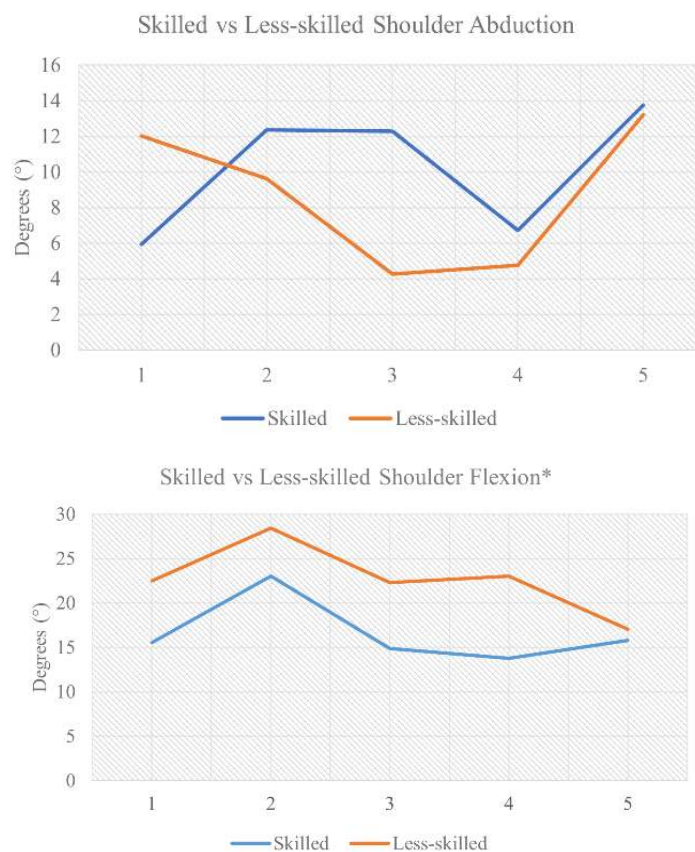
Differences in back arm kinematics were observed at bat-ball contact (Table 1). The Independent T-test revealed a statistically significant difference regarding shoulder flexion between skilled (mean $\pm$ SD = 16.61 ± 3.66 , $p = 0.038$) and less skilled batters (mean $\pm$ SD = 22.66 ± 4.03 , $p = 0.038$).

A significant difference in elbow flexion was also noted between skilled (mean $\pm$ SD = 139.19 ± 18.95 , $p = 0.02$) and less-skilled batters (mean $\pm$ SD = 87.3 ± 13.62 , $p = 0.02$). However, shoulder abduction and wrist flexion did not display a statistically significant difference between the two groups ($p > 0.05$).

Table 1. Comparison of skilled and less-skilled batters for each arm kinematics variable (mean $\pm$ SD)

	Shoulder Flexion (SD)*	Shoulder Abduction (SD)	Elbow Flexion (SD)*	Wrist Flexion (SD)
Skilled	16.61(3.66)	10.22(3.60)	139.19(18.95)	23.90(15.02)
Less skilled	22.66(4.03)	8.78(4.11)	87.3(8.2)	25.18(13.62)

(Note: (*)) significant differences between group ($p < 0.05$)



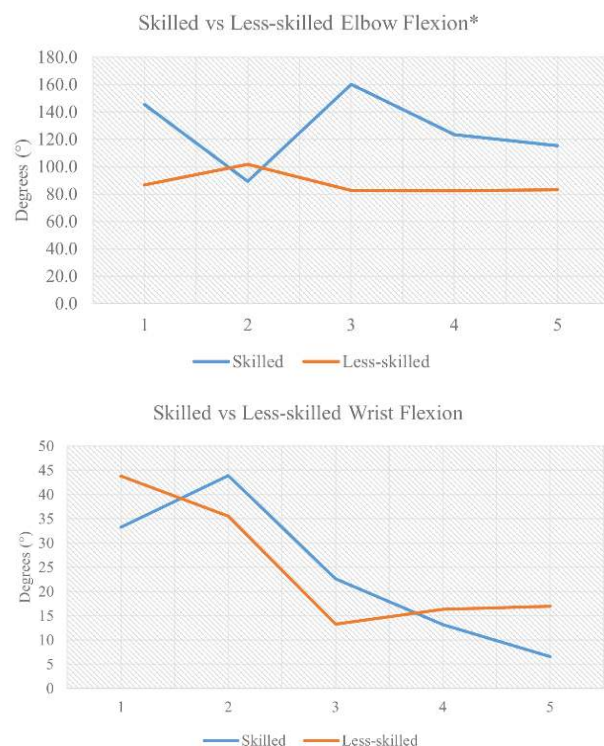


Figure 3. Comparison of skilled and less-skilled players for each kinematics variable. (*) Statistically significant, $p < 0.05$

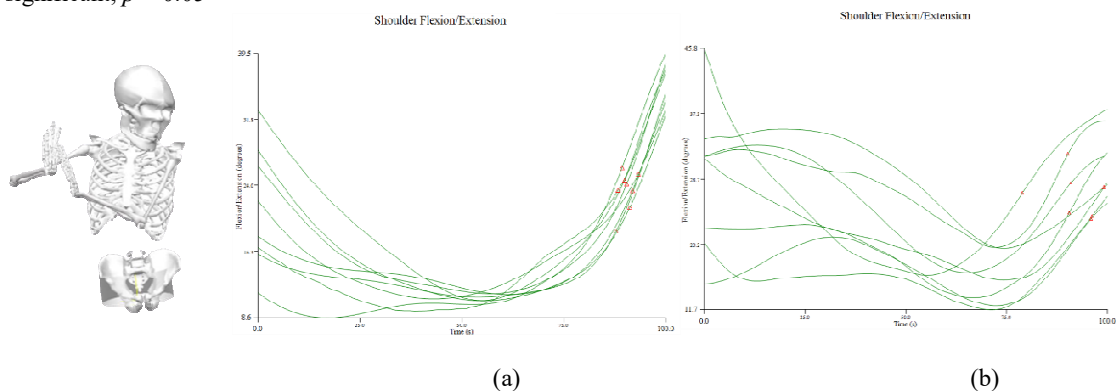


Figure 4. Example of shoulder flexion for (a) skilled and (b) less-skilled participants

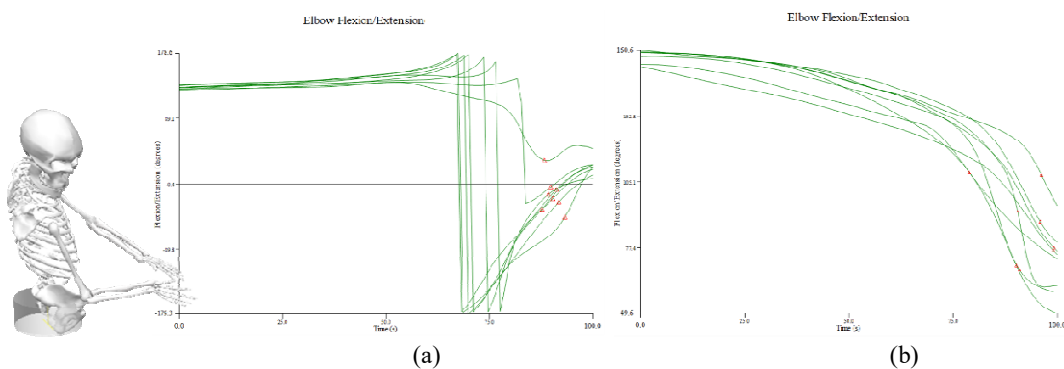


Figure 5. Example of elbow flexion for (a) skilled and (b) less-skilled participants

Discussion

The current study demonstrated a significant difference in shoulder flexion angles between skilled and less-skilled players. Skilled players reported less shoulder flexion compared to their less-skilled counterparts. This finding indicates that less-skilled players bend their shoulders more when striking the ball with the bat compared to skilled players whose shoulders are somewhat more extended during bat-ball contact (by 6.05°). In line with previous research, the current study found that skilled players make contact with their back elbows in a more extended position during bat-ball contact (Dowling & Fleisig, 2016). This was shown by the fact that their elbow angles were significantly higher ($139.19 \pm 18.95^\circ$) than those of less skilled players ($87.3 \pm 8.2^\circ$). Based on these findings, it seems that skilled players keep their hands further away from their bodies when making contact with the ball. William (2019) stated that an optimal bat angle, where the bat is flat at impact, provides the bat with more surface area to make contact with the ball. As the bat head goes through a longer arc in a given amount of time, it is hypothesised that a batter's ability to generate bat speed will increase as she maintains a more extended arm position (Healy et al., 2011). This information suggests that a player's ability to fine-tune the degree to which the elbow bends before each swing has a significant impact on where the bat is positioned when making contact with the ball (Escamilla et al., 2009b). Changing the bat's angle has been shown to improve contact which, in turn, may increase a batter's chances of hitting a home run (Williams et al., 2020).

However, the back arm abduction results found in the current study contradicts the outcomes of Dowling and Fleisig (2016) who found that professional hitters have greater amount of back arm abduction upon ball contact than batters in youth and high school leagues. William (2009) claimed that older, more experienced hitters take a different approach to a swing than younger hitters due to the significant age difference in how batting mechanics develop over time. One possible explanation for this is that after years of practice, the batter develops a more refined bat swing pattern. Therefore, it is possible that the development of professional players who participated in the study of Dowling and Fleisig (2016) may have contributed to a significant difference when compared to this study, which only recruited collegiate players as participants.

Conclusions

In conclusion, the kinematics of the back arm joint during bat-ball contact differs according to skill level. Significant variations in shoulder and elbow angles between skilled and less-skilled players suggest that skilled batters modify the location of the bat by altering the back arm angle, thus achieving an optimal bat angle for maximising the possibility of striking the ball further. Determining the proper arm angle can potentially assist batters in producing enhanced bat velocity. The study outcomes can be valuable for both athletes and sport coaches to focus on batting techniques and maximise batting performance. Additionally, the current information can be utilised to determine the ideal back arm angle for softball batting, allowing coaches and athletes to practice obtaining the perfect back arm angle. By maximising the entire surface area of the bat for ball contact, an athlete can increase the likelihood of making contact with the ball. The ability to successfully bat at any competition level will first require mastering the necessary hitting mechanics. As a result, it is beneficial for both athletes and coaches to know the differences that exist between batters with varied skill levels. This study solely focuses on arm kinematics. The results can provide valuable insight for softball training programmes. Exploring various body mechanics (e.g., trunk kinematics, pelvic kinematics and lower body) may provide additional information for improving softball batting performance. Future research is necessary to establish the kinematics of the entire body during softball batting since optimising batting kinematics can boost both bat speed and bat angle at ball contact.

Conflicts of interest: No conflicts of interest are declared by the authors.

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