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ORIGINAL

Effects of Bat Type on the Swing Motion of High School Baseball Athletes

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Objective: The purpose of this study was to investigate the factors affecting two kinds of bat swing behavior through kinematic analysis.

Method: A total of 32 high school baseball players participated in this study. The ball was placed on the tee-ball in a position where the subject could easily swing and the standard bat swing was performed as quickly and as accurately as possible using aluminum bats and wooden bats.

Results: The aluminum bat showed a rapid swing speed of about 1.79 m/sec compared to the wooden bat. The speed of the batted ball was found to be significantly greater for the aluminum bat than for the wooden bat. In addition, although the difference between the shoulder-pelvis rotation angle according to the type of bat was not indicated, there was a statistically significant difference between the aluminum bat and the wooden bat in terms of the rotational angular velocity.

Conclusion: Even though the results can explain the difference between the bat swing speed and the speed of the batted ball depending on the bat's material, it is difficult to explain the difference depending on the type of bat at the shoulder-pelvis rotation angle. However, shoulder-pelvic rotation angular velocity appears to be higher for the aluminum bat, and the differences in the type of bat is considered to be related to the batting swing factor.

Keywords: Baseball, Swing, Batting, Aluminum bat, Wood bat

INTRODUCTION

Korea is considered a powerhouse in baseball owing to its top finishes and outstanding performance in international tournaments, which has also helped increase public interest in the sport. Baseball is a sport that involves basic motions of throwing, hitting, catching, and running, and can be played anywhere with a ball, bat, and gloves (Moon, Lee, Kim, Jang & Jeong, 2013). Along with the growing popularity of baseball in Korea, the number of high school and other baseball team players, besides professional baseball players, has increased, creating a greater pool of players.

High school baseball in Korea began in 1905, with Hanseong High School being the first school to add baseball to their roster of sports. As of 2018, the number of high school baseball teams currently registered with the Korea Baseball Association (KBA) is 77, while the feverish popularity of high school baseball during the 1970s became a deciding factor that led to the establishment of a professional baseball league in Korea (Lee, 2016).

The biggest issue that has arisen with the development of high school baseball in Korea is the use of wooden bats. In April 2004, the International Baseball Federation (IBAF) banned the use of aluminum bats in international youth baseball tournaments for players 18 years or younger. Following the decision made by the IBAF, the KBA announced its own official ban on use of aluminum bats for all high school baseball teams in Korea on the premise of strengthening their competitiveness in international tournaments and KBA implemented the use of wooden bats starting from the Phoenix Baseball Tournament in August of the same year (Lee, 2015, December 21).

In baseball, the types of bats used include wooden, aluminum, and compression bats (Choi & Kim, 2012). The use of compression bats was allowed in Japan until the 1980s, but has been banned since that time, while the use of aluminum bats is banned in professional baseball (Dongascience Eds., 1999). Unlike aluminum bats, wooden bats may often break when the ball hits the handle or the end of the bat, which presents a significant cost burden. Moreover, if the ball is not batted accurately or the ball hits a part of the bat other than the center, the vibration transfers to the body of the hitter and places a greater physical burden on the batter (Lim, 2016). Hollow aluminum bats that are lightweight yet strong were introduced and accepted during the 1970s in place of wooden bats that break easily for cost effectiveness, and since then, they have been used in all amateur competitions, from little league to college baseball. In 1974, the National Collegiate Athletic

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Association (NCAA) in the US approved the use of aluminum bats. Consequently, the batters were able to swing the bat faster, which resulted in the batted ball traveling farther and at a higher velocity, whereby the number of homeruns (HRs) increased by almost 2-fold as compared to when wooden bats were used (Choi, 2015). Accordingly, the NCAA began to review guidelines for limiting the performance of baseball bats during the mid-1980s and the issue of regulating baseball bats continued to be a controversial issue. With the introduction of aluminum bats in Korea in 1976, some pitches that were not hit squarely flew to the outfield, which significantly enhanced the performance of many players, including the number of HRs hit. According to a study by Choi (2009), HR, batting average (BA), runs-batted-in (RBI), and slugging percentage (SLG) records increased from using aluminum bats, as compared to wooden bats. However, despite a broad consensus among players and coaches about the improved performance of metal bats, there have been very few scientific studies that have actually documented such performance differences (Crisco, Greenwald, Blume & Penna, 2002).

While many scientists have performed analyses on the mechanics of baseball batting motion (Escamilla et al., 2009; Inksteret, Murphy, Bower & Watsford, 2011; Mcintyre & Pfautsch, 1982; Race, 1961; Szymanski et al., 2007; Welch, Banks, Cook & Draovitch, 1995), there is only a limited number of experimental studies on baseball bat performance. A study by Bryant et al. (1977) reported that the velocity of balls struck by aluminums bat was higher than that of wooden bats, while studies by Bahill & Karnavas (1989, 1991) and Bahill & Freitas (1995) reported that each player has an ideal bat weight. Moreover, a study by Greenwald, Panna & Crisco (2001) also reported that the velocity of balls struck by aluminum bats was significantly higher than that of wooden bats, but the reasons for such increase in batted-ball velocity were not identified.

Baseball swings vary from player to player due to differences in the fitness and habits of each player, but a baseball swing consists of rotational motion of the bat and body segments, whereby the kinetic energy from the bat and body needs to be transferred to the ball as much as possible (Chun, 2012; Kim, 1997). Generally, bat speed is associated with batted-ball velocity (Crisco et al., 2002), where generating faster bat speed results in higher batted-ball velocity (Sawichi & Hubbard, 2003). Kirkpatrick (1963) proposed a theory on optimum bat weight, which mentioned that using a heavier bat offers the benefit of gaining power, but the bat speed slows, whereas using a lighter bat allows sharper swings, but power is lost in the batted ball (Lee, 2003).

Today, since wooden bats have been used in high school baseball games for 13 years, the use of wooden bats has been pointed out as a factor that diminishes the skills of individual players and impedes their ability to adapt to professional games (Lee, 2015, December 21). Studies by Choi (2009) and Chun & Kim (2012) reported that, with respect to differences in performance based on using aluminum versus wooden bats in collegiate baseball games, using an aluminum bat showed higher offensive capabilities than using a wooden bat, demonstrating that there are higher capacities in various offensive categories for each spot in the batting order.

However, in the environment of high school baseball in Korea, where college acceptance is of the utmost priority, there is no room to provide systematic training on batting skill. Moreover, since teams are under pressure to produce good results when they enter tournaments, some instructors focus solely on "winning baseball" (Lee, 2015, December 21). In particular, when high school baseball players who have not fully developed their swing motion yet, use wooden bats that are more difficult to handle and have relatively less bounce, they have difficulties in executing their swings and become desperate to just hit the ball. As a result, they end up playing "small baseball" with bunts and team batting with emphasis on singles rather than extra base hits (Lee, 2014, May 14). In baseball, each player has an individual ability, natural talent, and style, and thus, the goal is to accurately identify the power and talent of each player and nurture the player within the boundaries of not negatively influencing his own abilities (Johnson & Giorgis, 2006). However, wooden bats currently used in high school baseball in Korea were introduced with no consideration for the skill level of the high school baseball players, and thus, it is necessary to study methods for improving play with wooden bats, while understanding the importance of differences between types of bats, which has become a major issue.

Accordingly, the objective of the present study was to perform kinematic analysis on the effects of different types of bats (same weight and length) on the baseball swing of high school baseball players.

METHODS

1. Participants

The participants in the present study consisted of 32 baseball players from KBA-registered high schools who have at least 5 years of baseball playing experience. The physical characteristics of the participants are shown in Table 1. All players selected for the study did not suffer any injuries to the arms and legs within one year prior to the study and had no other physical limitations. Considering that the participants were all minors, the objective and method of the study were explained to the parents, director of the athletic department, and coaches. Informed consent was subsequently obtained.

Table 1. Physical characteristic of subjects (M ± SD)

n	Age (yr)	Height (cm)	Weight (kg)	Career (yr)
32	22.3±2.0	174.3±4.4	79.8±7.8	7.33±1.8

2. Measurements

In the study, an infrared 3D motion capture system (Vicon MX-T10, T40, Vicon Inc, UK) was used in analyzing the baseball swings of the participants. A total of 10 motion capture cameras were set up around the participant and the images were captured at a rate of 300 Hz.

To set the events within a baseball swing motion, a ground reaction force (GRF) measurement system (OR6-7, AMTI, USA) was used with a measurement rate of 1,800 Hz. To investigate the differences on the type of baseball bat used, an aluminum bat (B9, Easton Baseball Bats, USA) and a wooden bat (K1M, BMC, USA), both 33 in (83.8 cm) in

length and 30 oz (850 g) in weight, were used. The balls used in the study were official KBO game balls. Moreover, a baseball tee was used to allow the participant to set the ball height to a level where the baseball swings can be performed comfortably.

To analyze the baseball swing motion, a total of 44 markers were attached to major joints and body segments (Figure 1), and as shown in Figure 2. Once marker was attached to the baseball and three markers each were attached to the aluminum and wooden bats used: on the end cap, on the knob, and 28 cm away from the knob.

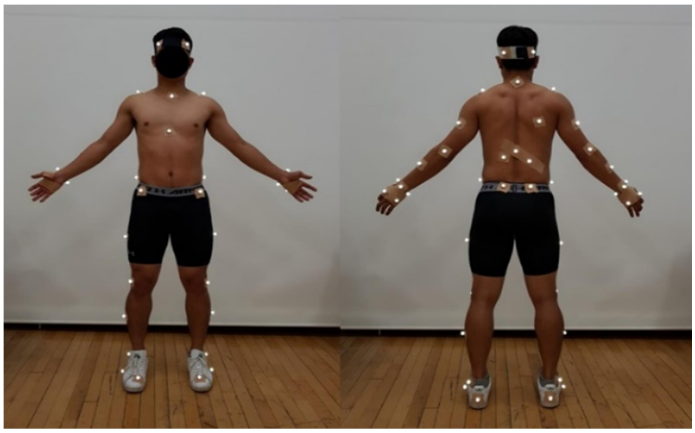

Figure 1. Placement of reflective markers

(A) (B) (C)

Figure 2. (A) Ball marker, (B) Bat marker, (C) Baseball tee

3. Data processing

Prior to the actual baseball swings, the participants performed regular warm-up exercises to loosen up, after which, they took practice swings to adjust where their front foot would land after the swing on the GRF measurement system. Moreover, once the participants adjusted the height of the ball on the baseball tee to levels that would allow them to swing the bat comfortably, they began hitting the ball off the tee. The participants performed standard baseball swings to contact the ball as quickly and accurately as possible. The participants randomly selected which bat to use and in which order in performing the baseball swings.

Baseball swings using one type of bat were measured 5 or more times, with 10 s of rest in between each swing. Measurement data from three successful swings were selected and the mean was calculated for use in statistical analysis. To control other factors, such as fatigue, 10 min of rest was given when switching from one type of bat to the other type.

1) Events

Baseball swing motion was divided into a total of three events (Figure 3).

- Foot off (FO): the point of the front foot lifting off the ground
- Impact: the point of impact between the bat and ball
- Follow: the point where the swing has been completed after impact, where the linear velocity of the bat knob instantaneously stops

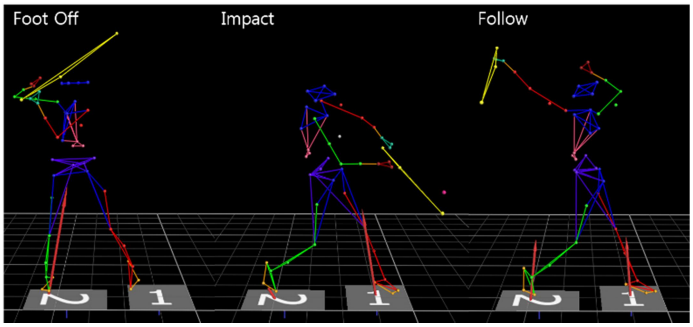

Figure 3. Event

2) Analysis variable of bat swing

The joint coordinate system was used for the joint angles used in the study, where the directions of axial rotations were defined by the right-hand rule: X-axis representing left-right direction (flexion/extension); Y-axis representing front/back direction (adduction/abduction); and Z-axis representing up/down direction (Cole, Nigg, Ronsky & Yeadon, 1993). The methods used to calculate the major variables were as follows:

The maximum bat speed and maximum batted-ball velocity were calculated as variables that represented the coordinate values of markers attached to the tip of the bat and the ball over time. A first-order differential equation was applied to the variables to display the results as linear composite speed indicating percentage of displacement over time.

For shoulder-pelvis rotational angle and angular velocity, 4 coordinates were used: right shoulder (A), left shoulder (B), right pelvis (C), and left pelvis (D) coordinates. After using the coordinates to derive $\overrightarrow{AB}$ and $\overrightarrow{CD}$, the inner product of $\overrightarrow{AB}$ and $\overrightarrow{CD}$ was calculated to derive the difference in shoulder-pelvis rotational angles. The angular velocity of shoulder-pelvis rotation was derived by applying first-order differential on the rotational angle. For the shoulder-pelvis rotational angle and angular velocity, the maximum values during the swing phase were used in the analysis.

Table 2. T-test results for bat swing maximum speed, batted maximum speed (M ± SD)

	n	AB	WB	*t*	*p* value
BSMS (m/sec)	34	36.23±1.77	34.44±1.85	9.017	.000***
BBMS (m/sec)	34	37.15±2.54	34.62±3.01	4.584	.000***

***$p<.001$, BSMS: Bat Swing Max Speed, BBMS: Batted Ball Max Speed, AB: Aluminium Bat, WB: Wood Bat

Table 3. T-test results for should-pelvis rotation max angle, angular velocity (M ± SD)

	n	AB	WB	*t*	*p* value
SPRMA (deg.)	34	41.34±9.08	41.16±7.60	.366	.717
SPRMV (deg./sec)	34	264.68±87.86	249.32±81.89	2.148	.041*

*$p<.05$, SPRMA: Should-Pelvis Rotation Max Angle, SPRMV: Should-Pelvis Rotation Max Angular Velocity, AB: Aluminium Bat, WB: Wood Bat

4. Data processing and statistical analysis

Nexus (Vicon inc, UK), a motion analysis software, was used to transform the 2D marker data acquired from the cameras to 3D spatial data by non-linear transformation (NLT). To remove noise in the transformed data, Butterworth 4th order low-pass filter was used for smoothing with the cut-off frequency set to 14 Hz. The kinematic variables used in the analysis were calculated using Visual 3D (C-motion Inc, USA).

For statistical analysis on the differences in kinematic variables of baseball swing motion, the present study derived the mean and standard deviation of each measured variable data, which were tested by a paired *t*-test using SPSS 23.0 (IBM, USA). In the analysis, the significance level was set to $p=.05$.

RESULTS

The maximum linear composite speed during the swing phase was used for the bat speed of high school baseball players. The results indicated that aluminum bat showed a bat speed of 36.23±1.77 m/sec, which was statistically significantly higher than 34.44±1.85 m/sec shown by the wooden bat ($p<.000$). Moreover, the maximum linear composite speed after impact was used as the batted-ball velocity. The results indicated that aluminum bat showed a maximum batted-ball velocity of 37.15±2.54 m/sec, which was statistically significantly higher than 34.62±3.01 m/sec shown by wooden bat ($p<.000$, Table 2).

Table 3 shows the differences in the maximum values of shoulder-pelvis rotational angles during baseball swing motions. Aluminum and wooden bats showed maximum shoulder-pelvis rotational angle of 41.34±9.08° and 41.16±7.60°, respectively, where the difference was not statistically significant ($p>.05$). However, aluminum and wooden bats showed maximum shoulder-pelvis rotation angular velocity of 264.68 ±87.86°/sec and 249.32±81.89°, respectively, where the difference was statistically significant ($p<.05$).

DISCUSSION

The objective of the present study was to conduct a kinematic analysis using two different types of bats (same length and weight) to identify the factors that influence the baseball swings of high school baseball players. In baseball, quick bat speed is an important element in that it enables the player to the hit the ball harder and perform more accurate batting by allowing enough response time to adjust to how the ball changes in flight. A study by Hubbard & Seng (1954) reported that quicker bat speed allowed the batter to have more time to study the ball thrown by the pitcher; hit the ball more accurately; and increase the consistency of swing. In the present study, the difference in bat speed between aluminum and wooden bats was 1.79 m/sec, confirming that quicker bat speed can be generated from using an aluminum bat than a wooden bat. Studies by Greenwald et al. (2001) and Crisco et al. (2002) on baseball bat speed using wooden and aluminum bats reported that bat speed was faster by approximately 1.4 m/sec when an aluminum bat was used, which is similar to the findings in the present study. In a study by Smith, Broker & Nathan (2003) that compared the bat speed of 10 bats with uniform weight and 10 bats with uniform moment of inertia, bat speed was closely correlated with moment of inertia, but the weight of the bat had very little impact on bat speed. Therefore, a wooden bat that has the same weight as an aluminum bat has the center of mass closer to the end of the bat, which means that it has a higher moment of inertia, and because higher moment of inertia is affected more by rotational resistance, swinging a wooden bat would result in decreased bat speed (Crisco et al., 2002; Kim, 2013). Moreover, when different bats with the same length and weight are compared, using an aluminum bat instead of a wooden bat that is difficult to handle in high school baseball games, would allow the batter to have more time to make decisions about the pitch thrown, resulting in improved batting ability during the game.

With respect to the velocity of the ball batted by a baseball swing motion, the mean batted-ball velocity produced by the aluminum bat was statistically significantly higher than that of wooden bat, which was consistent with studies by Bryant et al. (1977), Greenwald et al.

(2001), and Crisco et al. (2002), which also reported that the batted-ball velocity generated by aluminum bats was higher. Using the law of conservation of momentum, assuming perfectly elastic collision between the bat and ball, where the bat and ball are assumed to be perfectly ridged bodies, the momentum (mass*velocity) after the collision remains the same as the momentum before the collision. However, because a baseball swing involves a non-elastic collision, where the momentum of the bat is transferred to the batted ball, the velocity of the ball increases. The coefficient of restitution of velocity based on this is affected only by the type of object, regardless of the relative velocity prior to the collision, and because aluminum bats are hollow and have good repulsion, they are able to produce higher batted-ball velocity than wooden bats. Therefore, as the batted-ball velocity increases, the distance traveled by the ball would also increase. Thus, using aluminum bats would lead to games with more extra base hits, rather than current high school baseball games that rely on singles due to using wooden bats, and using aluminum bats would also produce relatively good at-bats by the players to have a beneficial effect on the performance of high school baseball players.

The study did not find difference in shoulder-pelvis rotational angle based on the type of bat used. However, a statistically significant difference was found in rotation angular velocity between aluminum and wooden bats. Batting in baseball represents a process where body segments are rotated to generate momentum and this momentum is transferred to the ball through the bat (Yoon, 2013). Biomechanically, the principle behind a baseball swing is a prime example of an open kinetic chain, where rotation is generated in sequence, from the proximal to distal area. In a baseball swing, the most proximal segment is known to contribute most to bat speed than any other distal segments (Kim, Hinrichs & Dounskaia, 2009). Lee (2003) reported that the motion of winding up the upper body (shoulder and pelvis) by rotating in clockwise direction and instantaneously releasing the coiled body increases the angular velocity of the upper body and the magnitude of the angular velocity of the upper body serves as an important clue to determining the bat speed during a baseball swing. Moreover, the shoulder-pelvis rotational angle is representative of the difference in the rotational angles of the two joints, and since larger differences in such rotational angle can generate greater power, it has been reported to be highly correlated bat speed during a baseball swing (Spaniol, Bonnette, Melrose & Bohling, 2006; Spaniol et al., 2010). Moreover, because the moment of inertia is proportional to the square root of the distance and weight from the rotational axis, using an aluminum bat with a shorter momentum of inertia in the rotational axis of the upper body would allow quicker and more flexible swings than when using a wooden bat, which would not only generate quicker bat speed, but also higher batted-ball velocity.

CONCLUSION

In summary, aluminum bats showed faster bat speed and higher batted-ball velocity in the comparison between different types of bat used, but the difference in shoulder-pelvis rotation angle based on the type of bat used was difficult to explain. However, aluminum bat showed higher shoulder-pelvis rotation angular velocity. Therefore, when aluminum and wooden bats with the same length and weight are compared, wooden bats not only slowed the bat speed, but they were also unable to produce solid hits. Therefore, using wooden bats may be a factor that causes declines in the performance of high school baseball players. It is necessary to improve the current issue of using wooden bats in high school baseball games by changing wooden bats to aluminum bats. It is also believed that, based on the findings in the present study, additional future studies should examine the mechanical aspects associated with changes in the batting stance and form of players based on the material, weight, and length of the bat.

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