# COMPARISON OF LINEAR AND ANGULAR SWING VELOCITIES WITH DIFFERENTLY WEIGHTED WARM-UP BATS IN SOFTBALL PLAYERS

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Swing velocity has been considered as one of the essential factors of bat swing biomechanics, and traditionally coaches and players think it can be altered by using a differently weighted bat for warm-up before an at bat. The purpose of this study was to examine the effects of 3 differently weighted warm-up bats on 3D linear and angular kinematics. Ten female varsity softball players were recruited and bat swing kinematics with normal (NW), heavy (HW), and light (LW) weighted warm-up bats were collected. Both linear and angular kinematic variables were compared between different bat weights using RMANOVA. Only 1 velocity variable difference between LW and NW, and 4 temporal differences between HW and NW were found. It is suggested that in general, swing kinematics is not altered by differently weighted bats warm-up prior maximal swing.

**KEY WORDS:** kinematics, computer modelling, baseball, softball

**INTRODUCTION:** Swing velocity has been considered as one of the key factors for a successful batting in baseball and softball. Therefore, coaches and players display a constant interest in methods to increase bat velocity for competition. A typical method to increase bat velocity is utilizing differently weighted warm-up bats prior to maximal performance (Montoya et al., 2009; Reyes & Dolny, 2009; Szymanski et al., 2012). These warm-up bats may be lighter or heavier than a regular weighted bat used in a game situation. However, studies have shown mixed results. Montoya et al., (2009) found that using normal weighted warm-up bat displayed the fastest swing velocity, but other studies show that heavier weighted bats resulted in the fastest swing velocity (Southard & Groomer 2003). Szymanski et al., (2012) found that there were no differences between differently weighted warm-up bats. Thus, there is no agreement and coaches and players still practice based on their own experience or beliefs.

One major issue for this controversy is because no published study has measured bat velocity in three dimensional (3D) techniques. To date, all of these works only focus on anterior-posterior component and ignore possible alternations on the other 2 directions. Further, angular swing kinematics have not been reported in the literature. Therefore, the purposes of this study were 1) to examine the 3D linear kinematics of maximum swing with 3 differently weighted warm-up bats, and 2) to propose a novel and simple model to analyze angular swing kinematics.

**METHODS:** The study was a 1-way repeated measures design using differently weighted warm-up bats as the within subject factor. Ten female varsity collegiate softball players volunteered and completed the study (age: 20.1 $\pm$ 1.1 yrs; mass: 76.4 $\pm$ 21.3 kg; height: 165.7 $\pm$ 8.4 cm). All participants provided informed consent.

Data collection was conducted in a typical biomechanics laboratory. Three weighted bats (normal weighted, NW, 29 oz.; heavy weighted, HW, 45 oz.; light weighted, LW, 13 oz.) were used in the study and order was randomized. Seven reflective markers were placed on the bat (1 top marker on the center of the bat top, and 6 on the barrel) and marker trajectories were recorded by a seven-camera motion analysis system (Vicon, CA, USA) at 100 Hz. For each bat condition, participants performed a self-selected warm-up protocol (instructed to simulate their on-deck routine) using designated weighted bat. Next, participants performed five maximal swings (instructed to simulate real bating in a competition) using normal bat and marker trajectories were recorded by Vicon Nexus software for subsequent analyses. There was three minutes of rest between each condition. The best trial of each condition was selected for later analysis. Data was filtered with 4th order Butterworth filter at 6 Hz cut-off prior subsequent analysis.

Data analysis was conducted by self-developed Matlab programs (Mathworks, Inc, Natick, MA, USA). Any marker drop was first reconstructed using least squares algorithm (Veldpasu et al., 1988). The interval of interest was manually defined from the beginning of loading phase to the end of the follow through phase. Linear bat swing velocities of all directions were obtained by differentiation of the top marker on the bat using generalized cross-validatory spline (GCVSPL) (Woltring, 1986).

Angular velocity of the swing was obtained from a redefined angle trajectories ($BAT_{ang}$) from the vector of the top bat marker under lab coordinate system ($BAT_g$). To obtain the angle trajectories, a best-fitted plane function was first generated from $BAT_g$ using least squares method. $BAT_g$ were then projected onto the best-fitted plane ($BAT_{proj\text{-}g}$). Three arbitrary points were selected from $BAT_{proj\text{-}g}$ to define a local coordinate system embedded on the plane and its rotation matrix R and translation vector T. $BAT_{proj\text{-}g}$ were transferred to the local coordinate system by following equation:

$$BAT_{proj\text{-}l} = R^T\,(BAT_{prog\text{-}g} - T)$$

$BAT_{ang}$ were obtained by converting $BAT_{proj\text{-}l}$ from Cartesian to polar coordinates. Last, angular velocity of the swing was calculated by differentiation of $BAT_{ang}$ using GCVSPL. To measure the goodness of fit of the plane, root mean square value ($RMS_{fit}$) of each trial was calculated between vertical component of $BAT_g$ and $BAT_{proj\text{-}g}$ trajectories, since other 2 components are identical.

Kinematics variables included peak linear and angular velocities, time to peak velocity, and relative time to peak velocity were tested using a 1x3 (group by condition) repeated measures ANOVA. Measure of goodness of fit ($RMS_{fit}$) was also testing using same approach. Greenhouse-Geisser adjustment was applied when sphericity assumption is violated. Due to relatively small sample size of the study and to be able to detect the difference between groups, the significant level was set at $\alpha = 0.10$ for omnibus test and 0.05 for pairwise comparison to minimize familywise errors. All tests were conducted using SPSS (IBM Corp., Version 21.0. Armonk, NY).

**RESULTS:** For linear kinematics, differences were found at several variables (Table 1). The LW condition displayed slower upward velocity than the NW condition ($p = 0.043$). No differences were found in time to peak variables (ranged from 0.3 to 0.4 s). Differences were found in relative time to peak variables except for anterior-posterior direction. The HW condition displayed its peak velocity approximately 3% later than the NW condition on left-right and vertical directions ($p < 0.026$).

**Table 1**

Mean (SD) of peak linear velocity and relative to peak velocity for differently weighted warm-up protocol.

| | Peak velocity (m/s) | | | | Relative Time to Peak Velocity (%) | | | |
|---|---|---|---|---|---|---|---|---|
| Bat Weight | Ant(+)-posterior | Left(+)-Right | Up(+)-Down | Resultant | Ant(+)-posterior | Left(+)-Right | Up(+)-Down | Resultant |
| Heavy | 23.6 (5.0) | 20.3 (5.3) | 10.9 (2.3) | 25.2 (4.9) | 48.0 (13.0) | 56.3 (15.2) | 57.2 (13.5) | 51.3 (13.9) |
| Light | 22.9 (4.6) | 19.9 (5.2) | 10.1 (2.2) | 24.4 (4.6) | 46.4 (12.4) | 54.1 (14.5) | 55.0 (13.0) | 49.1 (13.3) |
| Normal | 23.2 (4.6) | 20.2 (4.9) | 10.9 (2.1) | 24.7 (4.7) | 45.5 (13.1) | 53.3 (16.7) | 54.4 (14.0) | 48.2 (13.7) |
| *p* value | 0.454 | 0.560 | **0.082** | 0.386 | 0.118 | **0.059** | **0.031** | **0.034** |

Note. *P* values are for omnibus tests. **Bold:** $p < .10$.

For angular kinematics, differences were only found at relative time to peak velocity (Table 2). The HW condition display its peak velocity approximately 5% later than the NW condition ($p$ = 0.014). No differences were found in other angular variables.

**Table 2**
Mean (SD) of peak angular velocity, time to peak velocity, and relative to peak velocity for differently weighted warm-up protocol.

| Bat Weight | Peak Velocity (°/s) | Time to Peak Velocity (s) | Relative Time to Peak Velocity (%) |
|---|---|---|---|
| Heavy | 1526.7 (334.9) | 0.36 (0.15) | 51.3 (23.7) |
| Light | 1615.5 (455.3) | 0.35 (0.16) | 50.8 (23.1) |
| Normal | 1593.2 (354.9) | 0.31 (0.15) | 46.7 (25.6) |
| *p* value | 0.213 | 0.113 | **0.058** |

Note. *P* values are for omnibus tests. **Bold:** $p < .10$.

A representative linear and angular kinematics patterns were shown in Figure 1. All participants and all condition displayed similar patterns. Only linear resultant velocity displayed a clear monomodal pattern. Linear velocity of all directions displayed multimodal patterns. Angular velocity was a distinct bimodal pattern.

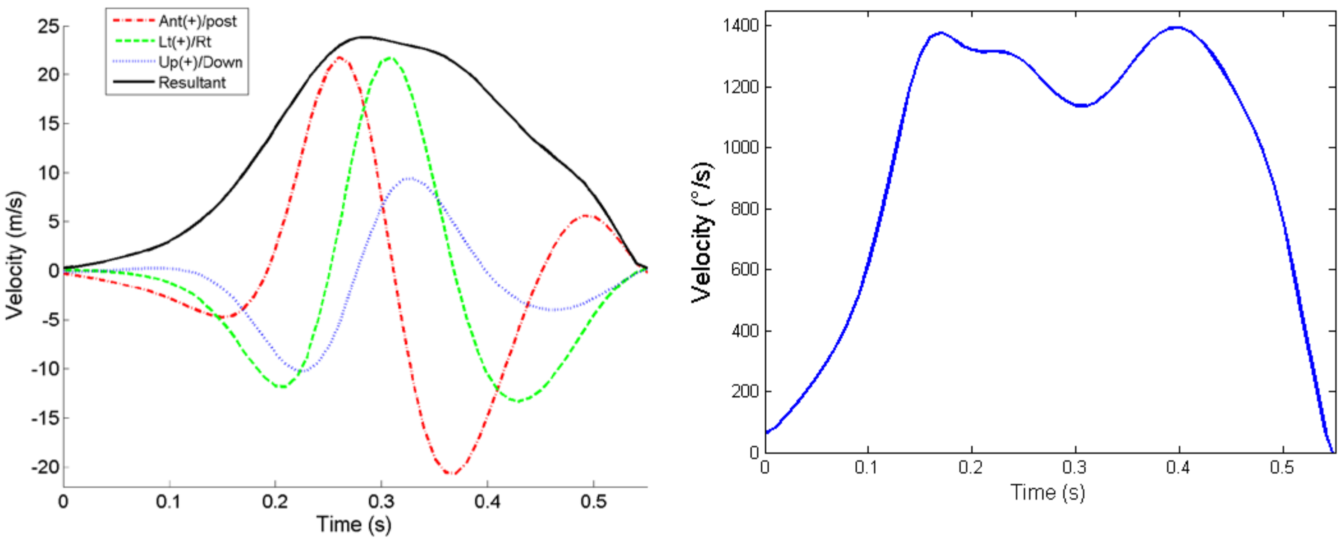


**Figure 1: Linear (left) and angular (right) kinematics patterns of normal weighted bat warm-up protocol of a representative participant. Time zero means the beginning of bat swing and end of the trial is the swing cycle.**

Although the $p$ value of the omnibus test for $RMS_{fit}$ values were low ($p$ = 0.063), no differences were found in group comparisons. The HW group (1.45 ± 0.42 m) had a tendency ($p$ = 0.060) to display lower goodness of fit than the NW group (1.22 ± 0.35 m). No difference was found between the LW group (1.30 ± 0.36 m) and NW group.

**DISCUSSION:** Effects on swing velocity with differently weighted warm-up bats were mixed in the literature (Montoya et al., 2009; Reyes & Dolny, 2009; Southard & Groomer 2003; Szymanski et al., 2012). The current study aimed to investigate influences of differently weighted warm-up bats by conducting a 3D linear and angular kinematic analyses. Results indicate that, in general, using differently weighted warm-up bats does not improve maximum performance.
Maximal anterior velocity in current study was lower than the published results (Montoya et al., 2009; Reyes & Dolny, 2009; Southard & Groomer 2003; Szymanski et al., 2012). This might be due to gender, sports type, and bat weight. Most studies (Montoya et al., 2009;

Reyes & Dolny, 2009; Southard & Groomer 2003) recruited male baseball players while female softball players participated in the current study, thus lower velocities were expected. In addition, the 'normal' bat weight used in current study is similar than that used in regular men baseball game. It might be still too heavy to female softball players which leads to lower velocities. However, similar linear and angular velocities of differently weighted bats reported in the study might indicate that influence of heavier bat weight is minimum.

These results imply that warm-up with differently weighted bats has limited impact on both peak linear and angular velocities, which agrees with study of Szymanski et al. (2012). It doesn't support the traditional thought of using a heavy bat for warm-up. The LW bats might influence peak velocity at the vertical direction, which is not the most impactful direction coaches and players expect. Actually using heavier bats might delay the timing when peak velocity occurs at left/right and vertical directions. This might be due to the altered rotation axis of the whole body. More studies are needed to further explore why this happen.

Linear and angular velocity patterns have several indications. The multi-modal pattern of linear velocity trajectories on each axis indicates that there are several distinct accelerate and decelerate phases across entire swing movement. The bimodal pattern of angular velocity might be helpful to coaches and players. It shows that the bat swing velocity decreases in the middle of the swing cycle, which is a critical duration for hitting. It implies that maximum performance might be improved by reducing the velocity drop. In addition, this bimodal pattern also explains the large standard deviation of temporal variables (Table 2) since global maximum might occur at either first or second apex.

The HW group displayed a tendency to have higher $RMS_{fit}$ than NW groups, and the LW group seems to have lower $RMS_{fit}$ though no significant difference to NW groups. Combined with velocity results, it might indicate that utilizing differently weighted bat in warm-up does not increase swing velocity, instead, alters the entire swing pathway. It is surmised that utilizing lighter bat will lead to a more planar swing movement in maximum performance with normal weight bat. However, evidence to explain why is not sufficient in the study.

The study is mainly limited by relatively small sample size. *Post hoc* achieved power (partial $\eta^2$) ranged from 0.066 to 0.242, which indicated that sample sizes should range from 14 to 54. Thus, it is recommended that some cautions are necessary when interpreting the results. Also, the best fitted plane approach removes some 3D information of the swing movement. A more advanced 3D analysis such as screw axis is need for further investigation.

**CONCLUSION:** In conclusion, evidence from our study suggests that differently weighted warm-up bats do not benefit maximum performance using normal weighted bat in female varsity softball players. Outcomes from this study indicate that there is a need of further investigation on whole body kinematics as well as kinetic changes of bat swing.

## REFERENCES:


Montoya, B.S., Brown, L.E., Coburn, J.W. & Zinder, S.M. (2009). Effect of warm-up with different weighted bats on normal baseball bat velocity. *Journal of Strength and Conditioning Research,* 23, 1566-1569.

Reyes, G.F. & Dolny, D. (2009). Acute effects of various weighted bat warm-up protocols on bat velocity. *Journal of Strength and Conditioning Research,* 23(7), 2114-2118.

Southard, D. & Groomer, L. (2003). Warm-up with baseball bats of varying moments of inertia: effect on bat velocity and swing pattern. *Research Quarterly for Exercise and Sport,* 74(3), 270-276.

Szymanski, D.J., Bassett, K.E., Beiser, E.J., Till, M.E., Medlin, G.L., Beam, J. & Derenne, C. (2012). Effect of various warm-up devices on bat velocity of intercollegiate softball players. *Journal of Strength and Conditioning Research*, 26(1), 199-205.

Veldpaus F.E., Woltring H.J. & Dortmans L.J. (1988). A least-squares algorithm for the equiform transformation from spatial marker co-ordinates. *Journal of Biomechanics*, 21(1):45-54.

Woltring H.J. (1986). A Fortran package for generalized cross-validatory spline smoothing and differentiation. *Advances in Engineering Software*, 8, 104-13.