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The Effect of Different Warm-up Procedures on Bat Speed in Baseball

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ABSTRACT

The purpose of this study was to compare the effect of a new warm-up condition, overloaded arm weights (721 g each arm, [OA]), on the bat speed during warm-up and immediately after warm-up with traditional warm-up conditions such as no-extra mass warm-up (control condition, [CO]) and overloaded bat warm-up (885 g donut on a bat, [OB]) conditions. Twenty male subjects who had competitive baseball experience participated in this study. Electromagnetic motion capture system was used to capture body segment motions. Results indicated that the OB showed significantly slower bat speed than the CO and OA did during warm-up ($p<.05$) and the bat speeds of OA and OB were similar. There was no main effect of different types of warm-up condition on the bat speed at post-warm-up swings. However, the first trial immediately after the OA and OB showed significant slower than the later trials ($p<.05$). Conclusively, the overloaded arm weights and overloaded bat did not show statistical superiority than the standard warm-up conditions in the deck circle and recovery time more than 3 minutes after loaded warm-up is recommended.

Keywords : Bat speed, Warm-up, Baseball

I. Introduction

In baseball games, many players utilize an overloaded bat during warm-up routine in the on-deck circle. However, any reason of using the overloaded bat has not been well reported in previous studies. Previous baseball studies demonstrated inconsistent results on the effect of an overloaded bat warm-up.

DeRenne and his colleagues have studied the effects of short-term warm-up or long-term training for differently weighted bats (DeRenne, 1982; DeRenne & Branco, 1986; DeRenne, Buxton, Hetzler, & Ho, 1995; DeRenne, Ho, Hetzler, & Chai, 1992; DeRenne & Okasaki, 1983). They concluded that warm-up implementation with only °æ10% extra weight of a game bat was the best choice for the on-deck circle to bring an improvement of bat speed during a real game. They mentioned that the °Ækinesthetic illusion', a feeling of faster bat speed immediately after a weighted bat warm-up, was responsible for the common mistakes of using a donut at the waiting deck-circle (Nakamoto, Ishii, Ikudome, & Ohta, 2012).

However, some studies showed different results (Kim & Hinrichs, 2005; Otsuji, Abe, & Kinoshita, 2002; Southard & Groomer, 2003; Szymanski et al., 2012). Otsuji et al. found no significant difference on averaged bat speed between pre- and post-warm-up swings but a significant decrease in bat speed (3.3%) at the first trial immediately after the overloaded bat warm-up (1.72 kg). They also suggested that the warm-up with an overloaded bat induced only a psychological benefit (i.e., a significant faster feeling of game bat speed) to players due to the lingering effect of the sensory experiences of batting. Southard and Groomer (2003) found a significant decrease in averaged bat speed and an altered movement pattern immediately following the overloaded bat warm-up (1.59 kg). Kim and Hinrichs (2005) found an improved bat speed immediately after the overloaded bat warm-up (1.45 kg) but no group difference between the standard-bat and the overloaded bat warm-up because the improvement was detected after standard bat warm-up as well. Szymanski et al. (2012) recommended female intercollegiate softball players not to use a commercial weighted donut because it produced the slowest bat speed after warm-up in comparison with diverse warm-up devices. Partially inconsistent results of previous studies came from experimental conditions (e.g., ball contact vs. no ball contact, diverse resting periods after warm-up, and

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diverse measuring devices such as a simple photo-sensor, high-speed cameras).

Biomechanically the mechanism of bat swing was well known as an example of open kinetic chain principle, indicating sequential rotations from the proximal segment to the distal segments (Putnam, 1993). In the fast arm-swing motion of the horizontal plane, it is well known that the most proximal segment (i.e., the trunk) mostly contributed to the hand speed than other distal segments (Kim, Hinrichs, & Dounskaia, 2009). Similarly, it was assumed that the stimulation of the proximal segment motion with added mass would be more efficient than that of the distal segment motion with added mass in baseball batting task.

In addition, a transient effect of bat speed immediately after weighted warm-up were detected only at Otsuji et al. (2002) and a recent study of Wilson et al. (2012). This transient deterioration and improvement of performance decent time after warm-up trials or acute conditionings has been interpreted as the evidence of post-activation potentiation ([PAP]; Sale, 2002, 2004; Robbins, 2005). PAP is the transient increase in muscle isometric twitch and low frequency tetanic force due to conditioning activity. When this neuromuscular activity overcame the impaired excitation-contraction coupling caused by fatigue, the performance was improved after warm-up. However, this PAP effect was not tested by the different locations of weight on the system.

Therefore, the first purpose was to investigate whether the warm-up with the proximal added mass (overloaded arm weights) would induce different results during warm-up and after warm-up, compared with the traditional warm-up conditions (overloaded bat and no-extra mass conditions) in baseball batting task. The second purpose of this study was to investigate whether different transient changes in bat speed within post-warm-up trials would exist as a result of different warm-up conditions. It was hypothesized that there would be a main effect for different types of warm-up condition on the bat swing speed during warm-up and after warm-up. The second hypothesis was that the overloaded arm condition would produce better bat speed immediately after warm-up than the other conditions. Finally, it was hypothesized that there would be different changes in transient bat speed within post-warm-up swings according to different warm-up procedures.

II. Methods

1. Participants

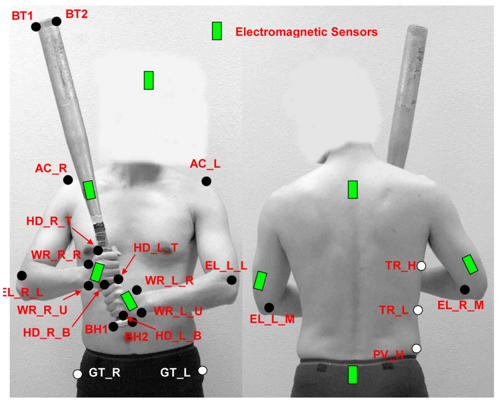
Twenty male subjects (M±*SD,* height, 180.0±5.5 cm; body mass, 84.1±10.9 kg; age, 23.2±4.23 years) who had competitive baseball experience in high school or college participated in this study. Twenty-six subjects were recommended as a result of power analysis from the pilot data (Overall & Doyle, 1994). But only 20 subjects participated in this study due to the difficulty of recruiting subjects. They signed a consent form before data collection according to Institutional Review Board regulations.

2. Instrumentation and Procedure

1) Instrumentation

The Advanced Motion Measurement-3D system (AMM-3D, Phoenix, AZ), consisting of twelve electromagnetic sensors (Liberty® 2.0, Polhemus system, Colchester, VT, USA) and data collection software, was used to collect linear and angular positions of the full body motions with the

(a)



(b)

Figure 1. Experimental set-up: (a) the wired AMM-3D system and the batting tee and (b) locations of electromagnetic sensors and registration points in the upper body to calculate the local coordinate system of each segment. Note: bat mid-hand points (BM1 and BM2) were not presented but they were located in the midpoint of two hands. Registration points and electromagnetic sensors in lower bodies were not included in this figure.

(a) (b)

Figure 2. (a) arm weights and (b) a donut weight on the bat

sampling rate of 240 Hz and to calculate angular and linear velocities. Each sensor provided three-dimensional position vectors and three-dimensional segment angles with respect to the global reference frame (a 4" by 4" transmitter). Twelve sensors were placed on bat, head, upper body (T3), pelvis (S2), right upper arm, right hand, left upper arm, left hand, right shank, right foot, left shank, and left foot(Figure 1).

In order to create the body fixed reference frame and joint centers, major anatomical points of the body and the bat were registered: bat handles (BH1 and BH2), bat tips (BT1 and BT2), bat mid-hand (BM1 and BM2), right and left acromial processes (AC_R and AC_L), medial and lateral elbow of the right arm (EL_R_M and EL_R_L), medial and lateral elbow of the left arm (EL_R_M and EL_R_L), radial and ulnar styloid processes of the right arm (WR_R_R and WR_R_U), radial and ulnar styloid processes of left arm (WR_L_R and WR_L_U), 2nd and 5th metacarpal joints of the right hand (HD_R_T and HD_R_B), 2nd and 5th metacarpal joints of the left hand (HD_L_T and HD_L_B), high and low points of the trunk (TR_H and TR_L), high pelvis point (PV_H), right and left greater trochanters (GT_R and GT_L), medial and lateral knee, medial and lateral malleolus, heels, toes, and fifth metatarsal joints(Figure 1(b)). A batting tee and a standard baseball were used as a target. The ball was placed on the top of a batting tee and its height was adjusted by the subject for his convenient swings(Figure 1(a)).

Three different conditions of altered segmental mass in warm-up sessions were defined as follows: 1) no additional loading on the limbs and the bat (i.e., standard bat or control condition, CO), 2) extra masses on upper arms only (i.e., the overloaded arm, OA), and 3) extra mass on the bat only (i.e., the overloaded bat, OB). For the OA condition, two arm weights (721 g each, Veleo arm weights, USA) were placed on each upper arm around the circumference of the upper arm CM and tightly secured with Velcro®. The mass amount of the arm weights was determined according to Kim's study (2008). A fixed mass of 721 g was equal to about 35% of the upper arm mass (with respect to the mean body mass of subjects; [Figure 2(a)]). For the OB condition, a 20 oz. commercial donut ring (567 g) was added on the standard bat (885 g; [Figure 2(b)]). Thus the total mass added to a subject was 885 g (i.e., only a standard bat), 2,327 g (i.e., a standard bat plus two arm weights), and 1,452 g (i.e., a standard bat plus a donut ring) for the CO, OA, and OB conditions, respectively (Table 1).

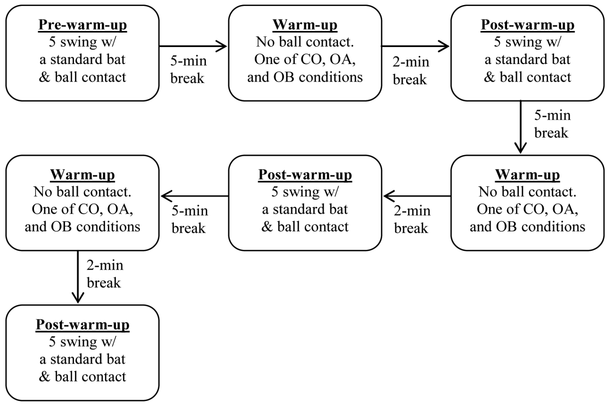


Figure 3. Flowchart of the experimental protocol: OA = overloaded arm (additional mass on upper arms), OB = overloaded bat (an additional mass on the bat), and CO = no additional mass on upper limbs and the bat (control condition). All swing trials were performed as fast as possible 'w/' indicated 'with'

2) Procedure

When subjects came to the laboratory, they were requested to stretch and warm up their body until they felt comfortable swings. Then the electromagnetic sensors were attached on major body segments and the major anatomical points were registered by the digitizing pen in an attempt to create the local coordinate system of each segment. The static trial with anatomical standing posture was collected to calculate static joint angles (Euler angles).

After static trial, each subject was asked to perform seven sets of bat swing, consisting of five swings per set. At the

Table 1. Description of warm-up conditions

Name	Description	Mass
CO	Standard bat (Control)	885 g bat only
OA	Overloaded Arm	a bat + 2 arm weights =2,327 g
OB	Overloaded Bat	a bat + 567 g donut =1,452 g

first set defined as the pre-warm up swing, each subject swung a standard bat as fast and accurate as possible with a ball contact. There was a 30-s time interval between each trials. A 5-min rest after pre-warm-up swing was given before a first warm-up set. The order of warm-up conditions was determined by the counterbalanced design among CO, OA, and OB conditions according to the coming order of subjects to the laboratory. The warm-up swing was defined as no ball contact but with a maximum bat speed. After the first warm-up set, there was a 2-min rest before post-warm-up swings. The post-warm-up swing was the ball contact swing as same as the pre-warm-up swing. Then a 5-min rest was given to subjects before the second warm-up condition. The subsequent procedure followed same routine of the second and third sets of the bat swing(Figure 3).

3. Data Analysis

The built-in program in AMM-3D system produced the resultant linear velocity at the tip of the bat (i.e., the bat swing speed) and segmental angular velocities of pelvis, trunk, upper arms, forearms, and bat with respect to the global reference frame. From a profile of the resultant linear velocity at the tip of the bat, the peak value was considered as the bat swing speed of each trial. Since there was a ball contact, the bat speed at the moment of ball contact was very clear (i.e., a large glitch sign in velocity profiles). During warm-up swings, there was no ball contact. Thus, the swing speed was determined by the maximum bat tip speed in the middle of swing. The peak swing speed occurred immediately before or after the imaginary target. To test the second hypothesis, the change in bat speed was defined as the percentage difference between post- and pre-warm-up swings.

$$\text{Change in bat speed}(\%) = \frac{(\text{mean of post warmup} - \text{mean of pre warmup})}{\text{mean of pre warmup}} \times 100$$

Similarly, the bat speed difference in the third hypothesis testing was defined as follows:

$$\text{Bat speed difference}(\%) = \frac{\text{each of post warmup} - \text{mean of pre warmup}}{\text{mean of pre warmup}} \times 100$$

1) Statistical Analysis

A one-way repeated measures ANOVA was performed through SPSS software (SPSS Inc., Chicago, Illinois). A statistical significance level for ANOVA was .05. In an attempt to control Type I error (i.e., false positive) and Type 2 error (i.e., false negative), The Bonferroni adjustment was used for multiple comparisons. Significance level of each

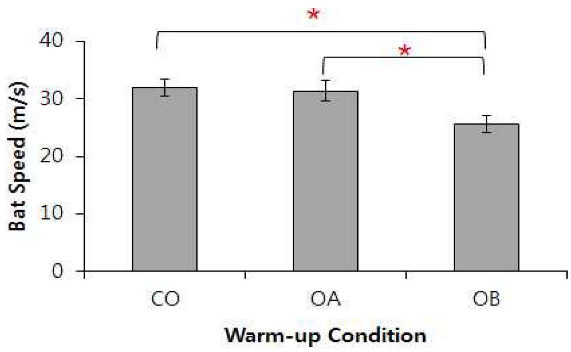


Figure 4. Bat speed during warm-up swings: CO = standard bat, OA = overloaded arms, and OB = overloaded bat. *Significant difference between each group was found (p <.0169)

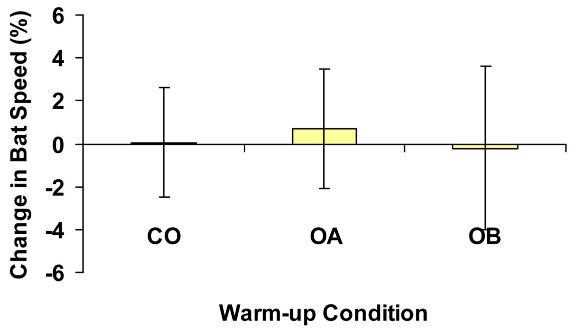


Figure 5. Change in bat speed after warm-up: CO = standard bat, OA = overloaded arm, and OB = overloaded bat

comparison was chosen at .01 and thus the experiment-wise significance level for 3 comparisons (i.e., 3 levels for a factor) was chosen at .017 ($1[10.05]^{1/3}$=.0169; Stevens, 1990). When sphericity was violated, Huyuh-Feldt adjustment was applied to the significance.

III. Results

1. Bat Swing Speed During Warm-up

Regarding the bat speed during different warm-ups, a significant main effect of different types of warm-up was detected by a one-way repeated measures ANOVA (F [38, 2]=351.2, p<.001). Bonferroni comparison indicated that the CO swing (31.95±1.50 m/s) and the OA swing (31.35°æ1.82 m/s) were significantly faster than the OB swing (25.55±1.43 m/s; [Figure 4]). There was no difference on the bat speed between the CO swing and OA swing. Thus the first hypothesis was supported.

2. Effect of Warm-up Conditions on the Post-Warm-up Swings

For the second hypothesis, the dependent measure was a

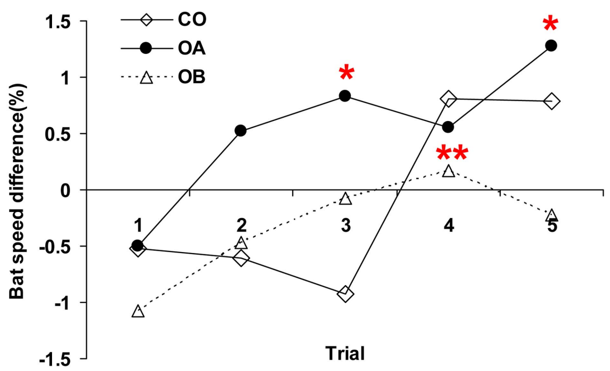


Figure 6. Bat speed difference (compared with pre-warm-up swings) according to trial during post-warm-up swings. *The third and the fifth trials after the OA warm-up were significantly higher than the first trial (p<.05). **The forth trial after the OB warm-up was significantly higher than the first trial (p<.05)

mean value across five trials. The three levels were CO, OA, and OB conditions. The result showed no main effect of different types of warm-up statistically (F[38, 2]=1.303, *p*=.283; [Figure 5]). The observed power was small(.265) and effect size was .07. The change in bat speed after the OA warm-up was 0.659±2.79%, after the CO warm-up was 0.049°æ2.54%, and after OB warm-up was −0.203±3.83%. Thus, the second hypothesis was not statistically supported. The negative mean after the OB indicated a reduced bat swing speed after warm-up.

3. The Transient Bat Speed Within Post-Warm-Up Swings

Even though there was no significant main effect on the mean change of bat speed between pre-warm-up and post-warm-up, statistical significances were detected in within post-warm-up swings for the OA and OB conditions. After the OA warm-up, the bat speed change measure at the third (0.549±3.39%) and the fifth trials (1.28±3.27%) were significantly higher than the first trial (−0.499±3.21%; *p*<.05). After the OB warm-up, the bat swing speed on the forth trial (0.173±3.95%) was significantly higher than the first trial (−1.07±3.21%; *p*<.05; [Figure 6]).

IV. Discussion

1. Bat swing speed of the Overloaded Arm

This study investigated the bat swing speed during different types of warm-up. As authors expected results, the OB swing induced a significant drop of bat swing speed due to increased mass in the swing system. The main causes of speed drop would be explained by the increase in moment of inertia (MOI). Since the MOI is proportional to the product of mass and squared distance from the axis of rotation, the extra donut placed far from the trunk axial axis might work as additional rotational resistance to subjects (McGinnis, 2005).

However, the extra mass (1,441 g) on the upper arm, even higher amount of mass than a donut, did produce similar bat speed (31.35±1.82 m/s) to the no-extra mass bat swing (31.95±1.50 m/s). This implied that the increased mass close to the axis of rotation would not affect the rotational resistance of the system. Namely, the high MOI of core section (i.e., trunk) had a certain tolerance on the increased MOI without losing performance in an attempt to maximize bat speed. Practically this result would be beneficial to post-warm-up swings because no significant changes in bat speed during warm-up would not deteriorate intersegmental kinematics of multi-joint segments in post-warm-up swings. Southard and Groomer (2003) revealed the deteriorated bat speed immediately after OB swings was attributed to changes in temporal leg in sequential rotations from proximal to distal segments.

The amount of the extra mass (35% of upper arm) in this study might not be optimal for bat speed improvement. This amount was determined by unpublished study (Kim, 2008) which was based on a three-segment model. However, the substantial baseball bat swing seemed a four-segment model including the trunk, upper arms, forearms, and a bat. Thus further study with diverse amounts of mass should be attempted to get an optimal bat swing performance. People involved in open kinetic chain motions (e.g., kicking, swinging, striking, and throwing) are recommended to consider the effect of the increased MOI in implementing extra devices for training.

2. After-Effect of Overloaded Arm Warm-up

This study also investigated the immediate after-effect of different types of warm-up condition. Regarding the after-effects of warm-up, the inconsistency of results in previous studies partially resulted from inconsistent experimental set-ups (DeRenne, 1982; DeRenne & Okasaki 1983; DeRenne & Branco, 1986; DeRenne, Ho, et al., 1992; DeRenne, Buxton, et al., 1995; Otsuji et al., 2002; Southard & Groomer, 2003; Kim & Hinrichs, 2005). This study applied a ball contact swing and measured the swing speed at the fixed point of the bat. Thus results of the current study would be more object than previous results.

The post-warm-up swing after different types of warm-up showed no support for Southard and Groomer (2003)'s finding statistically. The overloaded warm-up deteriorated the bat swing speed (−0.203±3.83%) like Southard and Groomer' finding, but it was not significant statistically. The OA warm-up showed increased mean value (0.659±2.79%)

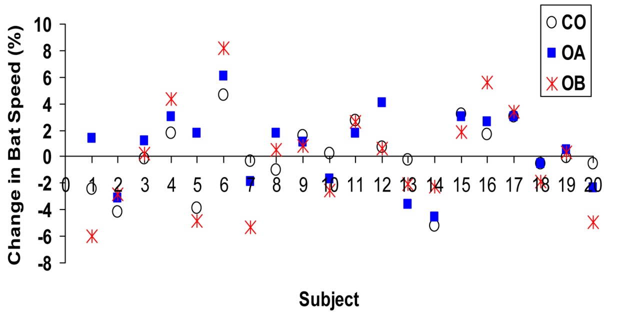


Figure 7. Scatter plot for change in bat speed after different warm-ups for each subject: CO = standard bat, OA = overloaded arms, and OB = overloaded bat

of bat speed but statistically no significance. This was due to large standard deviation of bat speed within-subject measures, which might be attributed to a baseball skill level of each subject or individual status of conditioning.

<Figure 7> revealed the scattered bat speed values across all twenty subjects. Many subjects showed large variation within-subject measures so that the slight increase of mean bat swing speed was not statistically significant. Interestingly, highly skilled level subjects (subject #1 and #5) showed the superiority of the OA warm-up for bat speed increase than other warm-up conditions. They are both current baseball athletes in college team. The large variations in data might depend on individual levels in baseball experiences or physical conditions. As well, the prolonged personal preference of a warm-up routine on a deck circle even no data collected in this study might contribute to the large variations in bat speed.

3. The Transient Bat Speed Within Post-Warm-Up Swings

The transient bat swing speed within post-warm-up swings did not fully support Otsuji et al. (2002) because the first swing immediately after the overloaded bat warm-up was not significantly lower than the mean value of pre-warm-up swings. However, the first swing immediately after the OB warm-up was significantly lower than subsequent swing (e.g., fourth trial) according to simple contrast test. This significant drop of the bat speed at the first trial was also detected immediately after the OA warm-up. Thus it was speculated that these results might be partially due to post-activation potentiation ([PAP]; Sale, 2002, 2004; Robbins, 2005). The previous activity (e.g., warm-up or training) affects the following performance because of fatigue and PAP. Fatigue tends to attenuate the performance of contractile ability, while PAP enhances it. PAP is transient increase in muscle isometric twitch and low frequency tetanic force due to conditioning activity. Sale (2002) also showed the transient interaction of fatigue and PAP. Fatigue tends to attenuate relatively quickly but PAP does relatively slow so that the maximum effect of PAP would occur later than 3 min. Thus normally increase in performance was found to be peak between 4 and 15 minutes after loaded exercises (Duthie, Young, & Aitken, 2002; Gullich & Schmidtbleicher, 1996; Jensen & Ebben, 2003; Young, Jenner, & Griffiths, 1998). Incidentally, the first trial of this study belonged to 2 min after a warm-up and the subsequent trials (3rd, 4th, and 5th trials) occurred after 3- to 4-min. This suppressed bat speed result was accorded with a recent study of Wilson et al. (2012). They showed increased peak bat speed significantly 4 minutes to 8 minutes after five differently-weighted bat warm-ups compared at 1 minute, 2 minutes, 4 minutes, and 8 minutes after warm-ups.

There were a couple of limitations in this study. The first was the maximal effort to attempt the maximal bat speed during warm-up swings. Substantially some players make submaximal efforts to prevent muscular injury during warm-up. Thus, the practical warm-up routine might be different from the present study. The second was that this study used a batting tee not a live pitching at the moment of ball contact.

Base on the current study, there was no reason to use the overloaded bat during warm-up in the on-deck circle. It would not help to improve bat swing speed. However, it might be another reason (e.g., stretching musculotendon unit) that this study could not test because most of players are following that routine. If baseball players have to use the overloaded bat for other purposes (e.g., stretching musculotendon unit), they should think about the bat speed drop immediately after the warm-up. Thus at least more than three dry swings with a 3-min rest are recommended to maximize the effect of PAP and to minimize fatigue. Rather the overloaded arm warm-up is recommended if they want to improve their bat speed immediately after warm-up.

V. Conclusion

In summary, the new approach to warm-up condition of baseball bat swing, the extra mass on the upper arms, was not beneficial to the bat swing speed statistically immediately after warm-up. This study also found the effect of PAP after loaded warm-ups. The swing speed immediately after loaded warm-up was suppressed and then recovered at subsequent trials later. Thus if baseball players have to do overloaded warm-up, they should have at least more than three dry swings with a 3-min rest to maximize the effect of PAP and to minimize the effect fatigue.

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