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ORIGINAL RESEARCH REPORT

Warming Up With a Dynamic Moment of Inertia Bat Can Increase Bat Swing Speed in Competitive Baseball Players

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Introduction: While most baseball players' warm-up with a weighted bat/donut, there is evidence to suggest the swing speed decreases after the warm-up even though the bat feels lighter. Warming up with a dynamic moment of inertia bat may not decrease the swing speed and therefore improve the performance of baseball players. The hypothesis is that a dynamic moment of inertia bat will negate the effect of the kinesthetic illusion observed with a weighted bat. ***Objective:*** To measure the difference in bat swing speed between warming up with the dynamic moment of inertia bat compared with a weighted bat. ***Methods:*** Thirty-nine competitive baseball players participated in the study. All players were randomly assigned a warm-up tool that could be either a dynamic moment of inertia bat or a weighted bat. After the players' warm-up, they swung their normal bat, and the bat swing speed was measured using a high-speed camera. We used motion analysis software to calculate the swing speed which measured the linear displacement during the last 15 frames before ball contact. The process was then repeated so that each player had the chance to try both warm-up bats. ***Results:*** The post warm-up swing speeds using the dynamic moment of inertia bat were significantly faster compared with a weighted bat warm-up. There was a 0.56 (0.78) m/s (1.26 [1.74] mph) increase in swing speed when using the dynamic moment of inertia bat ($P = .0001$), which is an average increase of 2.10% compared with a weighted bat warm-up. ***Conclusions:*** Our findings suggest that using a dynamic moment of inertia bat before an at-bat can increase swing speed compared with a weighted warm-up. Future studies are needed to determine if using a dynamic moment of inertia bat as part of rehabilitation can facilitate returning to competition after injury by focusing on swing speed.

Keywords: baseball, physiology, biomechanics, strength

Baseball is a popular sport, and most athletes are using a warm-up method that may not be beneficial to their bat swing speed. According to Statista and the World Baseball Softball Confederation, there are 15 million baseball players in the United States and an estimation of 65 million worldwide. In 2016, Baseball Canada reported that 120,000 Canadians played baseball across the country, and the numbers are increasing every year. All of these baseball players use their own method of on-deck warm-up. Players may choose to go with lighter bats, heavier bats, or any other warm-up tool that aims at increasing the swing resistance to make the players feel ready once they take their own normal bat.[1–4] Donuts were invented in 1955[5] and provide a heavier feeling during the swing so that when the weight is removed, the bat feels lighter. However, a weighted bat has more resistance and a slower swing speed during the warm-up compared with a normal bat.[6,7] Furthermore, the evidences suggest that after warming up with a weighted bat; the resulting bat swing speed decreases.[8–10] The weighted device has a positive mental effect (feeling lighter) but has a negative effect on the swing speed of the normal bat; this phenomenon is called the "kinesthetic illusion" or "kinesthetic aftereffect."[9–11] The kinesthetic illusion is most noticeable after warming up or preparing for an at-bat. Many players of all levels of sport commonly use the weighted donut to warm-up. A weighted donut is potentially slowing down their bat swing speed.[8–11]Therefore, a better option is needed.

Identifying a training tool in baseball that could improve swing speed could have significant effects on rehabilitation and performance. In the late stages of rehabilitation, when clinicians are targeting more sports-specific exercises using a dynamic moment of inertia bat could be beneficial in reacquiring bat swing speed. Since it is the goal of the rehabilitation professional to help the patients learn the successful execution of movements,[12] we believe that using a dynamic moment of inertia during a sport-specific phase of the rehabilitation instead of a heavy bat can be better to improve swing speed and return to sport.

There is some preliminary evidence to suggest that a variable moment of inertia bat may not decrease swing speed as compared with the weighted donut[13,14] and does not change the biomechanics of the player's swing.[14] A direct relationship exists between the increase in bat swing speed and the decrease in bat mass.[15] Recently a company created a bat which can make the weight move during a swing. We believe that the prototype bat could help baseball players increase their swing speed.

Bat swing speed is important, and there is more attention on bat swing speed lately in baseball. Increasing swing speed is a very common goal for being considered a good hitter in baseball.[16,17] Some have suggested that the most important variable for Hall of Fame induction is the number of home runs hit.[18,19] A positive relationship exists between batted ball speed, swing speed, and distance traveled by the ball.[20–22] A swing speed increase of only 1 m/s (1.6 mph) can cause the batted ball to travel nearly 5 m (16 ft) further.[23] By increasing the swing speed and the distance travelled by the ball, a player can improve the chances of home runs.

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Therefore, the purpose of our study was to determine if warming up with a dynamic moment of inertia bat can improve the swing speed compared with warming up with a weighted bat.

Methods

Participants

This study was approved by the university ethics committee (institutional review board number 30010037). The participants were informed of the risks and benefits of the investigation prior to signing the institutionally approved informed consent document to participate in the study. Thirty-nine subjects (age = 19.5 [3.3] y, height = 1.82 [0.05] m, weight = 83.03 [12.30] kg, arm length = 0.72 [0.03] m) were recruited from a university baseball team and from a local baseball academy. Our inclusion criteria included all males, over 18 years old and with more than 5 years of competitive baseball experience. In addition, all participants were healthy and suffered from no current injuries, which was defined as causing a player to miss at least one practice in the last week. All the participants were male because the baseball team had no female players; in addition, studies have indicated that female players' bat swing speeds are slower, which would increase the variability of measuring swing speeds before and after a warm-up. Our exclusion criteria included players who were injured before the beginning of the study or during the study, and if the player had already been training with a bat swing device including a dynamic moment of inertia bat. Finally, any other physical or mental conditions that would affect the baseball swing would also lead to the exclusion of a participant.

The Moment of Inertia Bat

Figure 1 shows the dynamic moment of inertia prototype used in this study. The dynamic moment of inertia bat weights are interchangeable. This bat allows the players to adjust the weight of the dynamic moment of inertia bat to weight as much as their normal bat. The ability to change the weight of the prototype allows us to avoid creating a kinesthetic illusion by having a heavier bat. The weight can freely move along the shaft of the bat during the swing. Because the weight is attached to the grip by elastics, the dynamic moment of inertia bat forces the players to swing as fast as possible each time. If the player does not swing fast enough, the weight will not move. The goal of the player is to synchronize the timing of the swing with the weight reaching the end of the bat. The weight should hit the end of the bat at the same time as the player would like to hit the ball during a swing. If for some reason the player slows his swing, the resistance bands prevent the weight from hitting the end of the bat and therefore lets the player know that his current swing is not fast enough. The strength of the resistance is adjustable by changing the elastic bands.

Swing Speed Measure—High-Speed Camera

We used 2 methods to calculate swing speed to get accurate results. The first method that we used was a high-speed camera filming at 600 frames per second. We used the CASIO EXILIM Pro EX-F1 (Casio Computer Co, Ltd). The camera was positioned over their head; where we could see the distance markers on the floor, their baseball bat and ball (Figure 2). This method was widely used in past research and has given similar results compared with a motion caption system.[24]

The intraclass correlation coefficient (2, *k*) for the analysis of angles using a high-speed video analysis with the CASIO Exilim camera was reported between .803 and .986.[25] Based on the recommendations, the required frames per second for baseball was a minimum of 480.[26] We therefore used 600 frames per second for this study. After each swing, we transferred the video files to a computer. We used the Kinovea software (2019 Kinovea, version 0.8.15, Charmant) for the video footage analysis. Kinovea has previously been validated as a tool to assess time-related variables,[27] and it was a valid, precise, and reliable (both interrater and intrarater) software with an intraclass correlation coefficient (2, *k*) between .79 and .997.[28] Since the name of the slow-motion footage file was not including the name of the player, all of the calculations were done by keeping that file name. This encryption allowed the researcher who calculated the swing speed to be blinded and could not determine which group the participant was in.

We used the Kinovea software to analyze the high-speed footage. In order to use the software, we placed distance markers on the floor and on the baseball tee to calculate the linear

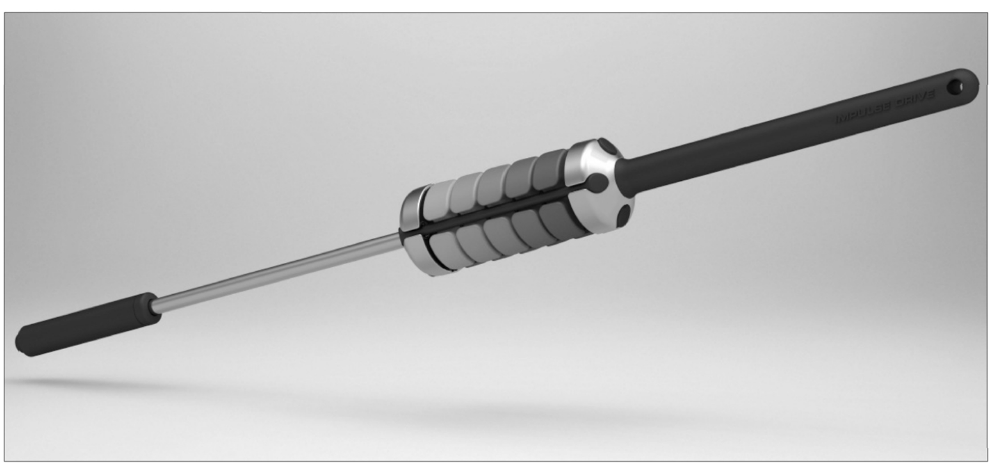

Figure 1 — This is a sketch of the prototype that is defined as the dynamic moment of inertia bat. The handle can be seen on the right-hand side, the removable weights are the disks, and the elastics are the black tubes next to the removable weights.

Figure 2 — A picture of the data measurement setup. We can see distance markers on the floor to facilitate the calibration of the Kinovea software. We can see a participant holding his own bat just before he swings toward a ball on a tee. In a ladder, I was filming using a high-speed camera the swing of the participant. Extra lights had to be added to compensate for the darkness of the indoor field to allow use to see something on the high-speed footage. The ball is batted into a net as a safety measure.

displacement and calibrate the software. To be consistent, we used the last frame before the bat contacted the ball as the end of the displacement for each swing. The 15 frames that preceded the last frame were used to calculate the swing speed. This method has been used in previous studies measuring bat swing speed.[20,29] The Kinovea software has a function that allows for object's displacement tracking. We used this function to track the "sweet spot" on the bat. The sweet spot was 6 in away from the end of the bat, which was also consistent for what is needed to be accurate with the BLAST sensors. Once the total linear displacement of the sweet spot was determined through 15 frames, we were able to calculate the swing speed of each swing with the formula below:

$$\text{Linear swing speed (mph)} = \frac{\text{Distance traveled by the sweet} - \text{spot (miles)}}{\text{frame duration (h)}}.$$

Once the swing speed was calculated, we averaged the results per warm-up tool from all recorded swings.

Swing Speed Measure—Inertial Sensors

To confirm our speed calculations with the high-speed camera, we used the BLAST® (Blast Motion, Inc.) inertial sensors. Inertial

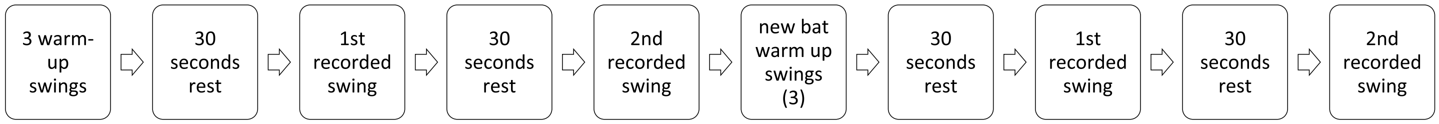

Figure 3 — Order of testing for every player.

sensors were widely used in past studies because of the ease and quickness of use. Recently, the BLAST sensor was suggested to be the most accurate device on the market to measure swing speed in baseball.[30] When comparing the results from the motion analysis system to the BLAST sensor, the BLAST sensor had the lowest error margin from all of the models compared. The relative error was 5% compared with the motion capture.[30] The blast sensor was also used to quickly exclude bad swings when the participants were in front of the camera.

Procedures for the Warm-Up Swinging Protocol

We welcomed every player in groups of 3 based on their position and hand dominance. The grouping of players was done to avoid having players wait for too long before doing their test after the warm-up. We measured the arm length (72.39 [2.79] cm). The arm length was the distance between the dominant side sternoclavicular joint and ipsilateral carpal bones. We used the arm length measure to calibrate the high-speed camera footage and the Kinovea software. We also noted the limb dominance for every player (16 left-handed players and 23 right-handed players). Height and weight were taken from the team's roster information. After the arm length was measured, we educated every player on how to use the dynamic moment of inertia bat. We made sure that the prototype bat weight was equal to the player's bat weight that they will be using to swing for the analysis. We filmed 2 trials per warm-up type per player. Every player was filmed 4 times total. We wanted our methods to simulate warming up in the on-deck circle before attempting an at-bat in baseball. Therefore, each player was randomly assigned to start their warm-up in the on-deck circle with either a moment of inertia bat or a weighted bat option. Every player completed the same warm-up routine: 3 swings at 75% maximum of swing speed. To avoid changing the athletes' warm-up routines or habits, we asked the athletes to replicate their usual on-deck warm-up protocol, which is swinging at 75% of their maximal swing speed. To measure the bat swing speed after the warm-up, we asked players to swing at a ball on a tee using their normal bat. The use of a baseball tee is common in baseball and has been used in previous swing speed analysis studies.[29,31] While hitting from a tee has some limitations, hitting from a tee allowed us to standardize some aspects of the swing to focus on the general swing mechanics.[31] The tee was placed one step away from the player, and the height was adapted to the waist level of every player. The participants were instructed to swing at the ball on the tee as fast as if they were attempting to hit a ball from a pitcher in a game. A good quality swing for this study was if the player was able to swing as fast as possible while still hitting the ball into a catch net. An example of a "not good" swing was if the ball was batted to the side or was only slightly touched or completely missed. A bad swing would also be the case if the sensors or the camera did not record the swing. No participant had their swing excluded in our study. Every player had 30 seconds in-between every repetition to rest and reset their position. Following their 2 measurements, they had approximately 1 minute to change their bat type and warm-up again for the next measurements. The rest periods and time required to change warm-up methods was based on the work from Baker,[22] because they indicated that a rest duration between 30 seconds and 1 minute replicated in-game conditions. Figure 3 illustrated the order of testing. The swinging protocol was based on a previous study made by Szymanski et al[4] in 2011. The warm-ups were completed with both the prototype and the heavy bat in a randomized order, but every recorded swing was with their normal bat. The total data collection time per participant was 15 minutes.

Statistical Analysis

All data were analyzed with SPSS (version 26.0) with a-priori alpha level for significance of $P \leq .05$. We compared both average swing speeds using a paired *t* test. We calculated the confidence interval for the swing speed improvement and the effect size (Cohen *d*). We estimated our power using the G*Power program (version 3.1; Universität Düsseldorf), and our sample size is similar to previous studies that have evaluated swing speeds for baseball teams with approximately 32 players.[21] The data for the prototype bat swing speed were normally distributed; however, the heavy bat swing speed data was not. The results of the Wilcoxon rank test were the same as the paired *t*-test, therefore, for the purpose of this study, we are only presenting the *t* test analysis here.

Results

There was a significant increase in swing speed (paired *t* test $P = .0001$) after warming up with the dynamic moment of inertia bat compared with warming up with the weighted bat. On average, there was an improvement of 2.10% (95% confidence interval, −2.07% to +12.27%). Our effect size (Cohen *d*) is 0.243, which is considered small.[32] The average swing velocity using the dynamic moment of inertia bat and the heavy bat is detailed in Table 1. Swing speeds of every participant are shown in Table 2.

Discussion

Increasing the swing speed is a common goal for competitive baseball players because of the positive significant relationship between batted ball speed, swing speed, and distance traveled by the ball after being hit.[21,22] The goal of hitting the baseball far became one of the most attractive characteristic in Major League Baseball.[33] Since the number of home runs hit is the most important variable for Hall of Fame induction, it proves the attractiveness of the home runs production.[18,19]

Our results suggest that using a dynamic moment of inertia bat dynamic moment of inertia bat as a warm-up tool can significantly increase bat swing speed in competitive baseball players. Our average swing speed values were in accordance with past studies looking at athletes with a similar baseball experience or

Table 1 Summary Table Describing the Average Swing Speed With the 2 Different Warm-Up Methods and the SDs in Meters per Second of the 39 Baseball Players

Average swing speed after warm-up with the prototype	SD	Average swing speed change after warm-up with the heavy bat	SD	Effect size (Cohen *d*)
29.02 m/s	2.23 m/s	28.45 m/s	2.40 m/s	0.243

Note: The effect size is also displayed.

Table 2 Summary Table Describing the Average Swing Speed With the 2 Different Warm-Up Methods and the Swing Speed Percentage Change for the 39 Baseball Players

No.	Prototype swing speed, m/s	Heavy swing speed, m/s	%Change
1	29.17	28.25	3.24
2	24.81	25.12	−1.25
3	27.02	27.20	−0.66
4	26.82	26.35	1.78
5	28.05	27.47	2.12
6	30.38	29.64	2.49
7	30.06	29.79	0.90
8	28.05	26.42	6.18
9	28.30	27.36	3.43
10	30.26	30.31	−0.15
11	29.48	28.21	4.52
12	28.57	29.06	−1.69
13	29.95	29.37	1.98
14	23.98	22.80	5.20
15	29.62	29.73	−0.38
16	22.91	20.41	12.27
17	31.45	30.87	1.88
18	32.28	29.57	9.15
19	29.06	28.57	1.72
20	29.19	29.57	−1.28
21	27.74	27.38	1.31
22	25.73	25.50	0.88
23	26.89	26.60	1.09
24	28.86	28.45	1.41
25	29.03	29.24	−0.72
26	33.28	32.79	1.50
27	29.70	29.26	1.53
28	30.59	28.89	5.90
29	30.48	29.04	4.95
30	30.33	29.62	2.42
31	29.10	29.30	−0.69
32	29.57	29.62	−0.15
33	27.24	25.80	5.58
34	32.25	32.45	−0.62
35	30.17	29.62	1.89
36	30.80	29.53	4.31
37	32.14	32.48	−1.03
38	27.63	28.21	−2.06
39	30.64	29.82	2.77

competition level. Past studies had swing speed of baseball athletes between 50 and 80 mph depending on their level of play.[4,22,34,35] To be more precise, Welch et al[36] reported average swing speeds for pro baseball players with wooden bats of 31 m/s with a SD of 2 m/s (69.34 [4.47] mph). When we know that in baseball miles per hour translate into feet for the batted ball, even the slightest increase in swing speed could make the difference between a home run and a ball that falls short. It is for that reason that even if our effect size is considered small, our results were still statistically and clinically significant. As suggested by previous authors, even a small increase in the batted ball speed could be the difference between a ground ball out and an in-field hit, or deep fly ball compared with a home run.[37]

In a previous study using a dynamic moment of inertia baseball bat, the participants trained with the device for a long training period. In our study, we examined the immediate effect of a warm-up with a dynamic moment of inertia bat, which was an increase in bat swing speed, differentiating us from other studies. When we compare our results, the swing speeds improved by 6.20% after an 8-week training program.[14] The percentage of improvement was greater than our results, but we did not allow the participants to train with the prototype. All they were allowed to do was to warm-up with the prototype. Our sample size was also bigger (N = 39) compared with a previous training study (n = 9 for the training group and n = 8 for the control group).[14] Therefore, future studies are needed to determine if training with a moment of inertia bat can further increase bat swing speed.

If the players were to start warming up with the dynamic moment of inertia bat, the players could improve their chances of hitting the ball further. When we compared the results from the swing speed using the dynamic moment of inertia bat to a heavy bat, we could clearly see that the players who used the weighted bat had slower bat speeds. This phenomenon could be explained using the computational theory. The computational theory stated that the motor pattern was increased when the movement that occurs in the present mismatches the predicted movement.[38] In other words, the computation theory meant that when a baseball player warmed-up with a weighted bat, the player prepared himself to recreate the same action or speed in this case later on. The recreated action is what is referred to as a prediction. Once the player used their normal bat, their prediction from the warm-up was not accurate because the bat was lighter. The players then had to adjust to that new weight and that created a slower swing. Another hypothesis to explain the change in swing speed is that when players used a weighted bat to warm-up, their body was unable to control the motor inhibition that was required for movement correction. This correction led to a different result compared with a normal bat weight.[39,40]

The last reason why training with a dynamic moment of inertia could have improved the swing speed is because the swing in baseball requires a lot of power. The dynamic moment of inertia focuses on a higher speed of execution, therefore, improving the power of the baseball athletes. The inertia training load was advantageous for increasing power, which is a combination of mass and acceleration.[34] The inertia training is particularly important when rehabilitating athletes who require power in their sport. If a weighted bat were used as a warm-up tool to rehabilitative or sport-specific exercises, aiming at bringing back an athlete to their preinjury level of competition, the athlete would not benefit from the training with a heavy bat when transitioning to a normal bat because of the kinesthetic illusion, the computational theory, and the lack of power training. The use of a dynamic moment of inertia would be more indicated because the tool has the same weight as their normal bat, the inertial resistance can be gradually increased, and we have shown that it improves the swing speed when warming up. In addition, using a dynamic moment of inertia does not affect the athlete's swing mechanics.[14] The strong relationship between biomechanics and injury epidemiology was first described in 1996 by Winston et al.[41] Negus and Sih[42] even mention that biomechanical asymmetries may predispose one to injury. By not affecting the biomechanics, we think that the dynamic moment of inertia could prevent injuries.

The results in our study share some similarities with previous studies that demonstrated a heavier bat leads to a slower swing speed. Baseball players, therapists, and coaches should be warned about the potential decrease in swing speed that was happening to the players every at-bat when warming up with a weighted donut.

We believe that the dynamic moment of inertia bat could have helped players swing faster due to the change in resistance during the swing of the bat. First of all, the overall weight of a dynamic moment of inertia bat could be adjusted to be equal to the weight of any player's normal bat weight. Another advantage is the resistance of the moving weight can be adjusted for every player. The variable resistance bands forced the player to always maximize their speed because if the player slowed down, the elastic would have pulled on the weight and increased the resistance to the swing. Therefore, the faster the player swung, the easier the swinging became.

Practical Implication

In conclusion, the use of a dynamic moment of inertia bat was an effective tool for baseball players to warm-up instead of a weighted bat/donut. Coaches should consider the use of different warm-up tools to avoid the kinesthetic illusion and facilitate improved swing speeds. Players and coaches should pay a close attention to their swing speed to promote performance. While we can recommend the use of a dynamic moment of inertia bat for warm-up because we now know the prototype will not decrease swing speed. Future studies should look at integrating a dynamic moment of inertia bat as part of a rehabilitation protocol instead of heavy bats.

Limitations

There are some limitations with our study. As stated earlier in the methods, the first limitation is that our participants hit the baseball off a tee instead of from a live pitcher. Future studies will be needed to examine using a moment of inertia bat to warm-up prior to live pitching in a baseball setting. In addition, only healthy male baseball players participated in the study. The results are only generalizable to that population, and more studies are needed to examine the effect of using the moment of inertia bat in the female or injured population.

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