# Experimental Investigation of Youth Baseball Bat Performance

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**TOPICS:** Baseball, bats.

**Abstract:** The batted-ball performances of youth wood and nonwood bats are examined through experimental methods. The goals of the study are to build a database of performance data on youth bats using a hitting machine in a controlled laboratory environment and to examine how the lab data compare using three performance metrics including the current BPF certification metric. The performance metric that best correlates the lab data with field performance is found to be the BBS metric.

**Key words**: Youth, Baseball, Batted Ball Speed, Ball Exit Speed Ratio, Bat Performance Factor

## 1- Introduction

The use of aluminium and composite bats (also known as nonwood bats) in youth baseball is a controversial topic. Initially, aluminium bats were used to reduce team operating costs associated with replacing wooden bats, which are more prone to breaking than aluminium bats. The nonwood bats typically have a lower moment of inertia (MOI, commonly referred to as "swing weight") which allows making contact with the ball easier than with the "heavier" swing-weight wood bats. With the advent of high-performance aerospace grade aluminiums, manufacturers were able to make relatively thin-walled barrels, thereby developing the trampoline effect during the bat-ball collision, which in turn results in batted-ball speeds that can be greater than those off wood bats. For players who have trouble making contact with a wood bat, the nonwood bats provide encouragement to keep playing baseball. Composite bats introduce the potential for even greater batted-ball speeds than those off aluminium bats.

The controversy arises in the allegation that the nonwood bats exhibit batted-ball speeds which are significantly greater than wood batted-ball speeds. As a result, many towns and state legislatures have introduced bills banning the use of nonwood bats. These new laws are being considered despite the lack of scientific data to support such bans. Some laws banning nonwood bats have been rejected due to the lack of scientific data, but others have passed despite the lack of credible data. These bans could potentially lead to many youth players becoming discouraged from playing baseball if the light swing-weight nonwood bats are removed from the game. The aim of this research is to construct a database of youth baseball bat performance, which will be a credible scientific database documenting the performance of the wood and nonwood youth bats, and to use this database to investigate a potential revision of the current performance metric and the associated bat testing protocol. Such data could lead to a performance standard that can assure the nonwood bats hit the same as their wood counterparts without eliminating the light swing-weight nonwood bats from the game.

## 2- Background

The current test for youth bat performance is called BPF (Bat Performance Factor) per ASTM F1881 (2005) Standard Test Method for Measuring Baseball Bat Performance Factor. The BPF consists of a baseball being fired at a stationary bat, which is supported on a “low-mass” freely spinning turntable, impacting at the COP (Center of Percussion), and the inbound and rebound speeds of the baseball are measured. The COR (Coefficient of Restitution) of each baseball used in the test is characterized using the ASTM Standard F1887 (2002), which is performed at 26.8 m/s (60 mph). The *BBCOR* (Batted Ball Coefficient of Restitution) is calculated using the inbound and rebound speeds of the ball, the moment of inertia (MOI) and the ball mass,

$$BBCOR = (BESR - 0.5)(1 + k) + k \tag{1}$$

where,

$$k = \frac{m_{ball}(x^2)}{MOI} \tag{2}$$

where $x$ is the distance from the pivot (15.24 cm (6 in.) from the knob) to the impact location and $m_{ball}$ is the mass of the baseball used in the test.

The BPF test is performed at 26.8 m/s (60 mph). The *BPF* is calculated as,

$$BPF = \frac{BBCOR}{COR} \tag{3}$$

Another bat-performance test commonly used is the BESR (Ball Exit Speed Ratio) test. The BESR test is performed by firing a baseball at a stationary bat, which is supported on a “low-mass” freely spinning turntable. The bat is impacted at multiple locations along the barrel of the bat until a “sweet spot” has been isolated. The “sweet spot” is the location on the bat that results in the highest BESR value. The calculation of the *BESR* is,

$$BESR = \frac{V_{reb}}{V_{inb}} + 0.5 \tag{4}$$

where $V_{reb}$ is the speed of the ball after impacting the bat and $V_{inb}$ is the initial velocity of the ball.

The NCAA developed a variation of the BESR test to certify bats that are to be used at the high school and college levels in the United States. The *NCAA BESR* is given by,

$$NCAA\ BESR = \frac{V_{out} - \delta v}{V_{in} + \delta v} + 0.5 \tag{5}$$

where $V_{in}$ is the initial ball speed coming into the collision, $V_{out}$ is the rebound speed of the baseball and,

$$\delta v = V_{in} - V_{contact} \tag{6}$$

with,

$$V_{contact} = V_{swing}\left(\frac{L - 15.24 - z}{L - 30.48}\right) + V_{pitch} \tag{7}$$

where $V_{swing}$ is the bat swing speed as measured 15.24 cm (6 in.) from the tip of the barrel and $V_{pitch}$ is the pitch speed. The sum of $V_{swing}$ and $V_{pitch}$ is the value of $V_{in}$ used in Equation (6). The lengths $L$ and $z$ are measured in cm for Equation (7).

It is often useful to calculate the projected field speed of the ball after impacting a moving bat. This parameter is called *BBS*, and can be calculated as,

$$BBS = v\,(BESR - 0.5) + V(BESR + 0.5) \tag{8}$$

where, *BBS* is the batted-ball speed, $v$ is the speed of the pitched ball and *V* is the speed of the bat at the impact location. For this calculation, the speed of the bat is based on a swing-speed model.

The swing-speed model used in this research is based on a batting-cage study (Greenwald *et al.* 2001) of high school, college and semi-pro baseball players. The swing-speed data were analyzed to provide a swing-speed model that adjusts swing speed according to MOI (Nathan 2003). The Nathan model is based on a standard swing for a given MOI and length, and the swing speed adjusts according to changes in these two parameters. This flexibility allows the model to be adapted to younger players, but the standard swing speed, which will need to be derived from a youth swing-speed study, is not precisely known at this time in the youth-bat research. The swing-speed model used in the current research is based on a standard bat which is 86.36-cm (34-in.) long and has an MOI of 2749 kg-cm² (15000 oz-in²) (about the knob) with a swing speed of 18 m/s (40 mph) as measured 15.24 cm (6 in.) from the tip of the barrel. Swing speed is scaled up or down according to MOI and then scaled depending on length of the bat and impact location. The nominal pitch speed assumed for a youth pitcher is 22.5 m/s (50 mph) for the current research. Thus, the speeds used in Equation (7) for the youth-bat study are $V_{swing} = 18\ m/s$ and $V_{pitch} = 22.5\ m/s$.

## 3- Results

As the relative speed between the bat and the ball increases, the probability for denting and cracking increases. To minimize the level of denting and/or cracking of the bats in the laboratory testing, the 26.8-m/s (60-mph) BPF test was performed first, and then the NCAA-type BESR test was completed at 40.2 m/s (90 mph). The 40.2-m/s (90-mph) test conditions assumed a pitch speed of 22.5 m/s (50 mph) and a nominal swing speed of 18 m/s (40 mph). BBS calculations were obtained using the data from the BESR test. Each of the investigated bat performance metrics were then plotted as a function of MOI.

The COP used in the BPF test was found from the data obtained during the MOI test. The MOI was found by placing a clamped bat on a pivot and timing the period of oscillation with light gate sensors. Some of the lightest bats were not able to be performance tested in the moving-ball stationary-bat method used in this research because of their relatively low MOIs (less than 550 kg-cm² (3000 oz-in²) as measured 15.24 cm (6 in.) in front of the knob). The ball rebound speeds from these lighter bats were too slow to pass through both sets of sensors, thus the rebound speed could not be measured. A very low MOI would usually correspond to a relatively thin barrel wall, so durability at 40.2-m/s (90-mph) test speeds was typically compromised. Thus, the NCAA-type tests at 40.2 m/s (90 mph) could yield measurable rebound speeds, but the bat was dented and/or cracked in the process.

### 3.1- BESR

For the BESR tests, an impact speed of 40.2 m/s (90 mph) was used. The 40.2-m/s (90-mph) speed was the most appropriate impact velocity with respect to average youth batters that did not compromise the durability of the bat during the test, i.e. that did not dent or crack the barrels of the bats. The results for the *NCAA BESR* were calculated according to Equation (5) and plotted against MOI. The *NCAA BESR* as a function of MOI gives a good qualitative correlation of lab test data to field performance for high school and college bats. The calculated *NCAA BESR* results for the youth wood and nonwood bats are shown in Figure 1. The testing was conducted using baseballs randomly selected from a lot (typically 144 baseballs) with a known nominal BESR value using a standard bat of known *NCAA BESR* performance.

Wood youth bats typically have a barrel diameter of 5.72 cm (2.25 in.), and the nonwood youth bats are made in two barrel sizes. One nonwood size is comparable to the wood bats with a 5.72-cm (2.25-in.) diameter barrel, and the other size, known as big-barrel bats, has a barrel diameter of 6.99 cm (2.75 in.). It can be seen in Figure 1 that the big barrel bats generally have a higher BESR value than the wood bats of the same MOI, while the 5.72-cm (2.25-in.) barrel-diameter nonwood bats are shown to have a lower BESR value than the wood bats of the same MOI. Youth baseball players are known to prefer nonwood bats over wood bats as the players hit further using nonwood bats than with wood bats. The data shown in Figure 1 do not support what is observed in the field. Thus, Figure 1 implies the *NCAA BESR* is not a good metric for relating lab measurements to field performance for these youth bats.

College and high school bats are required to fall within limited ranges for length, weight and MOI. The minimum difference between the weight measured in ounces and the length measured in inches has to be greater than or equal to -3. For example, a 34-in. (86.36 cm) long bat cannot weigh any less than 31 oz. (880.7 g). These limited ranges of length, weight and MOI allow the possible *NCAA BESR* values for college and high school bats to correlate well with projected field batted-ball speeds. The same good correlation is not true for the youth bats.

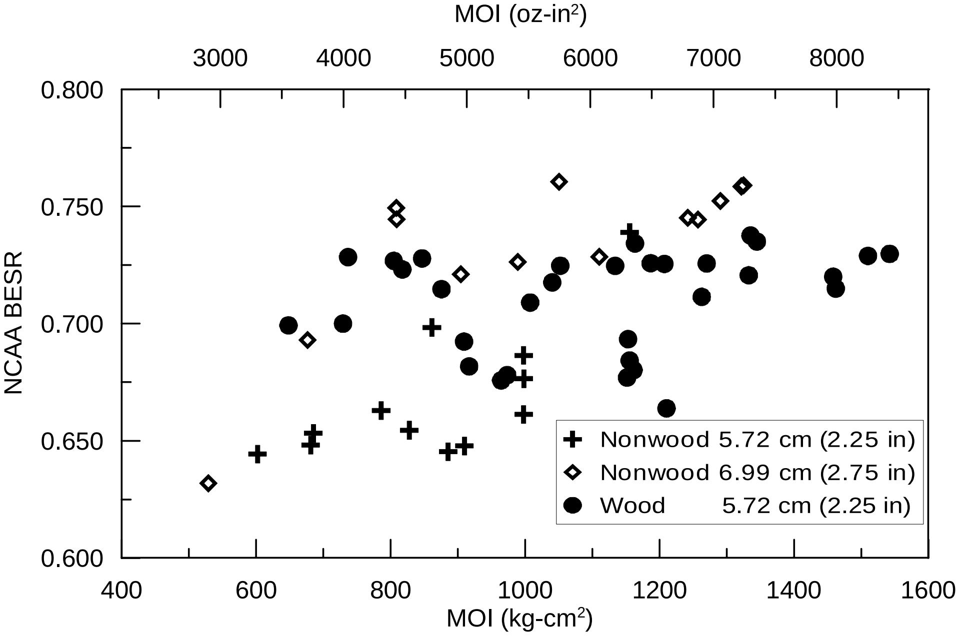

**Figure 1: NCAA Ball Exit Speed Ratio vs. Moment of Inertia**

Youth bats can exhibit a length (in inches) to weight (in ounces) difference as much as 14.5 units and can span a wider range of allowable MOIs and lengths than do the college and high school bats. As a result, there are many combinations of lengths and weights for youth bats that can exhibit the same MOI. Because of the multiple combinations of weight and length, the *NCAA BESR* value is not a good metric for comparing the relative performance of youth bats. A 5.72-cm (2.25-in.) barrel nonwood bat and a 5.72-cm (2.25-in.) barrel wood bat can have the same MOI but can differ in length by up to 10.16 cm (4 in.). Even if the two bats have the exact same *NCAA BESR* in addition to identical MOI, they can differ in batted-ball speed by several kilometers per hour. The reason for the disparity in batted-ball speed is the difference between the lengths of the bats. The longer nonwood bat shares a similar sweet spot (in this case defined by the location of the maximum BBS measured from the tip of the barrel), but ends up several cm further away from the hands due to the extra length of the bat, yielding a higher bat speed at the point of impact. This behavior can be observed in the data which are summarized in Table 1.

In Table 1, the three bats have nearly equal BESR values. The only variations among the bats are the MOIs, lengths and locations of the sweet spots. These differences are large enough to cause significant differences among the swing speeds at the sweet spots and therefore a noticeable difference in the respective batted-ball speeds. The difference in BBS would not be obvious if looking at a plot of *NCAA BESR* vs. MOI where Bat IDs JJ022 and JJ044 would essentially overlap.

| Bat ID | Length cm (in.) | Weight g (oz.) | MOI kg-cm² (oz-in²) | Sweet Spot Location cm (in.) | Calculated Swing Speed km/h (mph) | BESR | BBS km/h (mph) | Type | Barrel Diameter cm (in.) |
|---|---|---|---|---|---|---|---|---|---|
| JJ044 | 80.963<br>(31.875) | 513.3<br>(18.105) | 910<br>(4975) | 17.8<br>(7.0) | 67.6<br>(42.0) | 0.678 | 93.2<br>(57.9) | nonwood | 5.72<br>(2.25) |
| JJ022 | 73.500<br>(28.938 ) | 606.7<br>(21.400) | 917<br>(5013) | 15.2<br>(6.0) | 61.0<br>(37.9) | 0.679 | 86.4<br>(53.7) | wood | 5.72<br>(2.25) |
| JJ054 | 78.740<br>(31.000 ) | 633.5<br>(22.345) | 1152<br>(6297) | 16.5<br>(6.5) | 63.1<br>(39.2) | 0.677 | 90.3<br>(56.1) | wood | 5.72<br>(2.25) |

**Table 1: Comparison of wood and nonwood bats having similar Moments of Inertia and Ball Exit Speed Ratios**

### 3.2- BPF

The BPF test was performed on the youth bats according to ASTM Standard F1881 (2005). This test is performed at 26.8 m/s (60 mph). The *COR*, as measured per ASTM Standard F1887 (2002), is found for a single ball. This one baseball is impacted onto the bat at the center of percussion for six valid hits. The BPF test measures the *BBCOR* and normalizes the *BBCOR* by dividing the *BBCOR* by the ball *COR*.

The current BPF limit for 5.72-cm (2.25-in.) barrel youth bats is 1.15, and there is no BPF limit for the 6.99-cm (2.75-in.) barrel youth bats. The BPF values for the youth bats tested in this research were plotted against MOI and are shown in Figure 2. According to these BPF data, four of the 5.72-cm (2.25-in.) nonwood bats that were tested in the current study performed at or below the 1.15 BPF limit, and two of the bats had BPF values just above the 1.15 limit. Figure 2 shows no correlation between BPF and MOI. The wood bats have a relatively uniform BPF values between 1.05 and 1.10 regardless of the MOI of the bat. This relatively uniform BPF value is because the barrel of a wood bat is relatively rigid in comparison to the hollow-barrel nonwood bats. As a result of the “rigid” barrel, the wood bats do not exhibit any trampoline effect, and the *BBCOR* is essentially the same for all wood bats. The BPF data given in Table 2 show no correlation to field projected BBS. All of the bats have essentially the same BPF value, but the bats exhibit a wide range of field projected BBS values. This lack of correlation is also true when comparing BPF to other physical properties of the bat such as length and weight.

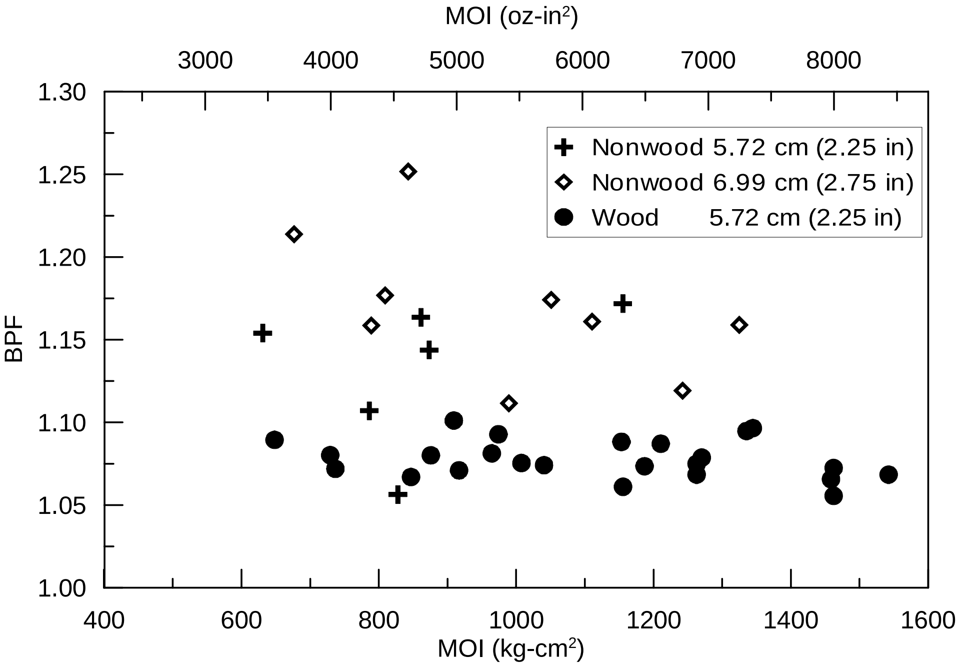

**Figure 2: Bat Performance Factor vs. Moment of Inertia**

| Bat ID | Length cm (in.) | Weight g (oz.) | MOI kg-cm² (oz-in²) | Location cm (in.) | BESR | BBS km/h (mph) | BPF | Type | Diameter cm (in.) |
|---|---|---|---|---|---|---|---|---|---|
| JJ063 | 73.820<br>(29.063) | 465.9<br>(16.4) | 631<br>(3449) | 12.40<br>(4.88) | 0.605 | 88.2<br>(54.8) | 1.nwood | | 5.72<br>(2.25) |
| JJ010 | 71.120<br>(28.000) | 618.0<br>(21.8) | 789<br>(4314) | 12.37<br>(4.87) | 0.701 | 92.9<br>(57.7) | 1.nwood | | 6.99<br>(2.75) |
| JJ025 | 78.740<br>(31.000) | 612.3<br>(21.6) | 1111<br>(6072) | 14.48<br>(5.70) | 0.729 | 97.7<br>(60.7) | 1.nwood | | 6.67<br>(2.63) |
| JJ007 | 81.280<br>(32.063) | 686.1<br>(24.2) | 1325<br>(7243) | 15.29<br>(6.02) | 0.764 | 101.2<br>(62.9) | 1.nwood | | 6.99<br>(2.75) |
| JJ005 | 81.123<br>(31.938) | 683.2<br>(24.1) | 1242<br>(6791) | 15.75<br>(6.20) | 0.756 | 100.4<br>(62.4) | 1.nwood | | 6.67<br>(2.63) |

**Table 2: Comparison of Bat Performance Factor results**

In Table 2 the first four bats have nearly identical BPF values. The projected BBS shows no correlation to the BPF measured for these bats. Because the first four bats are ~1.16, it would be expected that a bat having a lower BPF should produce a slower batted-ball speed. However, Bat ID JJ005 has a lower BPF than the rest of the bats in Table 2 but has a projected BBS greater than all but one bat. Because it is possible for a bat to meet the BPF criterion of 1.15 or less but have a higher BBS than a bat that fails to meet the 1.15-BPF criterion, BPF is a poor metric for measuring bat performance. As mentioned previously, the big barrel nonwood bats are not required to perform at or below a BPF of 1.15.

### 3.3- BBS

The batted-ball speeds were calculated using Equation (8) and used the swing-speed model by Nathan. The BBS calculation requires the use of a swing-speed model to account for variations in bat swing speed as function of MOI.

A relatively slow swing-speed input must be used because of durability issues. The test was conducted at 40.2 m/s (90 mph). The assumed pitch speed was 22.5 m/s (50 mph), so the resulting swing-speed used in Equation (8) had to be 18 m/s (40 mph). Typical impact speeds may be higher or lower, so future research should be completed to support or to correct the pitch and swing speeds used to evaluate youth bats in this study. Because it is most accurate to match the relative bat/ball speed used in the BBS calculation to the relative bat/ball speed used during testing, and the standard youth swing model has yet to be established, the magnitude of the predicted BBS for the current study may only be approximate. The BBS method is very useful at a minimum for qualitatively ordering the relative performance of the bats to each other.

The BBS values calculated from the youth bat data are plotted as a function MOI in Figure 3. The BBS data for each class of bats (wood, 5.72-cm (2.25-in.) nonwood and 6.99-cm (2.75-in.) nonwood) exhibit an essentially linear correlation with MOI. The 6.99-cm (2.75-in.) diameter bats are typically hitting 1.8 to 2.6 m/s (4 to 6 mph) faster than the wood bats, and the 5.72-cm (2.25-in.) diameter bats are outperforming the wood bats by approximately 0.9 to 2.6 m/s (2 to 6 mph). The BBS values plotted in Figure 3 are a consequence of the swing-speed model, so these values should not necessarily be taken as representative of batted-ball speeds in the field. However, the data do imply a measurable difference among the classes of bats. The BBS data explain why youth players can hit further with the nonwood bats than the wood bats. Such a conclusion could not be made using the BPF and NCAA BESR metrics.

The BBS metric looks to be the best measure for relating lab measurements of bat performance to projected field performance for youth bats. The BBS vs. MOI data for the wood bats could be used as a benchmark for the conclusion of an upper bound on youth bat BBS values as a function of MOI. To improve the accuracy and credibility of the method, a swing-speed model developed from youth batters should be used in the BBS calculations. Further research and sample size will be needed to determine to what extent the nonwood bats outperform the wood bats.

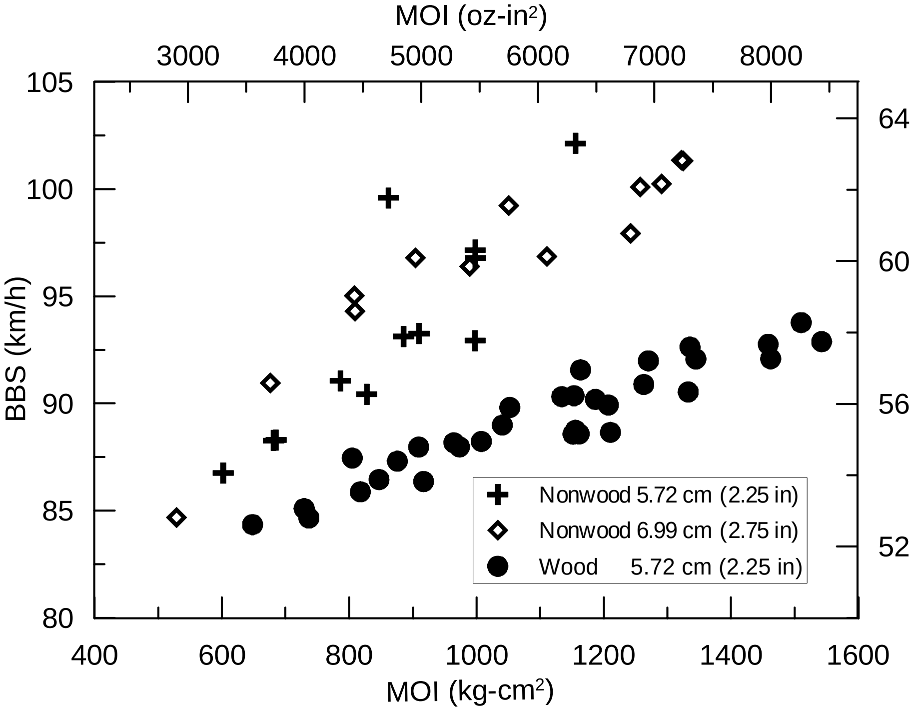

**Figure 3: Batted-Ball Speed vs. Moment of Inertia**

## 4- Conclusion

The performance of youth bats can be characterized a number of ways, but some metrics yield misleading results and may not be a good measure for governing performance. BBS has been shown to be a practical metric for projecting field performance provided a credible swing-speed model is available. Using the BBS metric to relate lab measurements to projected field performance supports qualitative field observations and shows that youth nonwood bats typically outperform wood bats. Further research and sample size will be needed to determine to what extent the nonwood bats outperform the wood bats, including a swing-speed study.

## 5- References

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