Impact of the Variable Weighted MOI Baseball Bat on Swing Velocity Enhancement

by

Luke A. Chapman

Submitted to the Department of Mechanical Engineering
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ABSTRACT

The sport of baseball is ubiquitous in American culture and has observed global prominence. Since its creation in the 1800s, individuals have sought to improve batting performance which is evident by the plethora of scientific literature that exists on the topic through today. Bat velocity is one key aspect of a successful baseball swing because as bat velocity improves, key components such as decision time, swing mechanics and batted-ball velocity also improve. As such, a prototype bat design is proposed in this study through a brief validation protocol of identified literature that speaks to core physical principles (i.e. moment of inertia and center of mass) combined with market research validation. This prototype model is adjustable for different age groups to allow for development at a young age. Although this prototype requires further validation, the potential for superior batting performance is promising.

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I am profoundly grateful to all those who have supported and encouraged me throughout my time at MIT. Your belief in my abilities has been a constant source of inspiration.

Contents

List of Figures

List of Tables

Chapter 1
Introduction

Baseball has been central in American sports culture since its inception in the early 1800s, with over 16 million people in the U.S. having played at least once in 2023 alone [1]. Arguably, one of the hardest skills to perform in all of sports is hitting a baseball at the professional level which requires elite hand-eye coordination and timing [2]. As a result of baseball's popularity combined with the highly technical aspects involved, there is no shortage of literature regarding baseball technique, especially when it comes to batting [2]. However, due to the exorbitant amount of information on this topic, it can be challenging to accurately identify and determine the common themes in the literature for what constitutes a "correct" batting technique as well as training plan to optimize successful baseball batting. As an example, two of the most famous batting coaches of all time, Ted Williams and Charlie Lau (1984-1986), stressed the importance of different aspects of a baseball swing; Williams focused on the importance of rotation in hitting while Lau focused on the linearity of hitting and weight shift [3,4]. This shows that there are many factors that impact a successful baseball swing and that many different coaching perspectives exist. Specifically, regarding young athletes, adolescence is a crucial period to "build a sufficiently diverse motor repertoire" as proper coaching at this age is important [5]. The Long-Term Athlete Development (LTAD) Model shows this by breaking down the physical development of athletes into nine stages, with a focus on how training, competition and recovery can be optimized for different age groups to reach full athletic potential [6]. Stage 3, the "Learning to Train" stage, occurs at ages 9-12 and 8-11 for males and females, respectively. For both males and females, this stage is a crucial stage for training motor learning [6].

The rationale for this work is derived from a 2016 paper where Noorbhai et al. designed a coaching cricket training bat to help youth players develop an optimal backlift, i.e. the motion in which the batter lifts the bat in preparation for the delivery [7]. Noorbhai conducted biomechanical analysis of over 100 cricket players from youth to elite levels. At the junior level, players were often taught a straight batting backlift technique (SBBT), where the batter would lift the bat up directly over the stumps with the face of the bat directed towards the wickets. However, Noorbhai noticed that although nearly 75% of young cricket players use the SBBT, at the professional level that number declines to 25% [8]. Instead, 75% of professional players employ the more natural lateral batting backlift technique (LBBT) where the batter lifts the bat towards the slips (45-80 degrees of the stumps) with the face of the bat pointing towards the off-side. As a result of this observation, Noorbhai et al. designed a coaching cricket bat that biomechanically allowed young cricket players to develop a LBBT (without formal coaching) by altering the weight, moment of inertia (MOI) and angular momentum of the cricket bat [7].

The popularity of baseball as a sport and the plethora of different literature on the mechanics of the baseball swing were both key motivating factors in the preparation of this study. As such, the purpose of this study was to isolate an aspect of batting that is universally considered to be integral to batting success, i.e. bat velocity. To develop this aspect of bat velocity, a prototype training bat or other product that addresses this aspect with special emphasis on athletes from childhood to young adulthood (7-25 years) was subsequently designed.

Applying a similar approach for a baseball training bat design, stance analysis of successful Major League Baseball (MLB) batters (n = 14) and young athletes in the Little League World Series ranging from 10 to 12 years old (n = 7) was conducted and both hand and bat positions were characterized at the pre-pitch, mid-pitch, and ball-contact time frames as further detailed in **Section 3.1**. Secondly, a literature review and training bat ecosystem evaluation was conducted to further understand the work that had previously been completed. Finally, swing velocity was chosen as the variable of interest and a novel prototype design was proposed. To hit home runs, a batter must exert immense power to hit the ball out of the baseball park. Hill's Muscle Model (described in **Section 2.2**) provides a relationship between force output and velocity which are both proportional to power. By increasing swing velocity and strength, the batter will be able to maximize their power exertion.

1.1 Bat Anatomy and Batting Phases

Before delving into the characteristics of the bat prototype design, it is important to understand that the baseball bat comes in many different materials, lengths and weights; but they all have the same general shape and components (**Figure 1.1**). Materials include composite, aluminum alloy and wood (most commonly ash and maple) [9]. Composites are commonly made of carbon fiber and mostly used by younger players as the barrels are longer and vibration is less, whereas aluminum alloy is used by high school and college athletes as these bats are lighter which allows for faster bat velocity. Wooden bats are required to be used in the MLB to promote fairness between the pitcher and batter due to their decreased "sweet spot" size [9]. Aluminum alloy and composite bats are also able to hit a ball at an average of 4 mph (1 m/s) faster than wooden bats [9]. Many college players will practice with wood bats in the off-season as they prepare for entering the MLB as wooden bats can take considerable time to become familiarized with [10]. To establish definitions to be used in this study, a diagram of the parts of a baseball bat is shown in **Figure 1.1**.

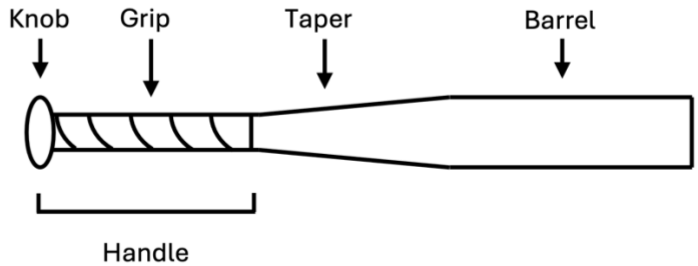


Figure 1.1: Diagram of the main parts of a baseball bat

To better understand the components of a baseball bat swing, a characterization of the full motion is needed. In a 2011 paper, titled: *The Biomechanics of a Baseball Swing*, Fortenbaugh seeks to characterize the swing in six steps as shown in **Figure 1.2**: stance, stride, coiling, swing initiation, swing acceleration and follow-through [11].

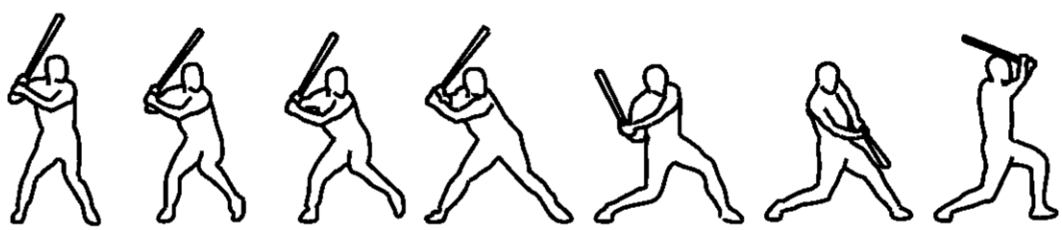


Figure 1.2: Components of a baseball swing as described by Fortenbaugh [11, 12].

Ball contact (though not a stated component) included for reference.

In Fortenbaugh's study, the movements of professional baseball players (n = 43) were tracked and analyzed [12]. The results were subsequently averaged to determine the "typical" professional batter. During the stance step, weight was concentrated on the back foot and both knees were flexed. The stride step was marked by an increase in force of the trail foot as the lead foot leaves the ground and extends in a forward motion. While this is happening, the bat elevates and wraps further around the batter's head. The coiling phase is marked by a shift of weight forward onto the lead foot as the pelvis and shoulders tilt up and the trunk counter-rotates. During swing initiation, force in the lead foot spikes as the lead knee extends as the trail upper arm drops significantly and the bat finally begins to rotate forward. In the swing acceleration phase, the lead knee continues to extend and the pelvis rotates to approximately face the pitcher. At the same time, upper trunk rotation reaches its maximum velocity as both the arms drop, the elbows extend, and the wrists flex which creates a snapping motion with the bat, accelerating the bat tremendously just before ball contact. Finally in follow-through, force is dissipated through a deceleration in the rotation of trunk and ground reaction forces decrease as well.

Initially, based on previous studies, this study motivation was to analyze the differences in swing mechanics among baseball batters that yielded varied performance outcomes between youth and professional batters. However, after a closer analysis of every phase of the baseball swing, the major variable that this study chose to focus on was bat velocity, which is mostly affected by the swing initiation and swing acceleration phases.

Chapter 2

Background

2.1 Moment of Inertia of a Baseball Bat

The moment of inertia (MOI) is an important consideration when designing any bat or racquet in sport and is thereby relevant when designing a baseball bat [13]. The essence of the MOI is linked to the distance between the distributed mass of the object and its axis of rotation, as shown in **Figure 2.1**.

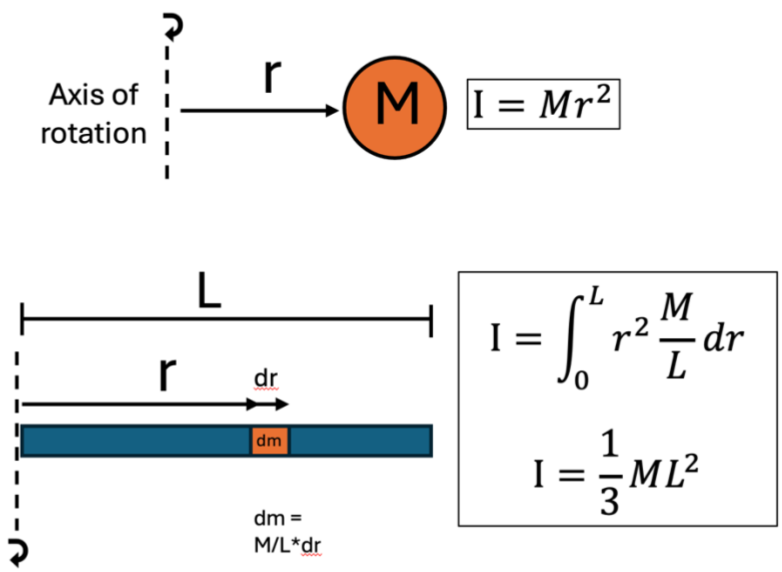


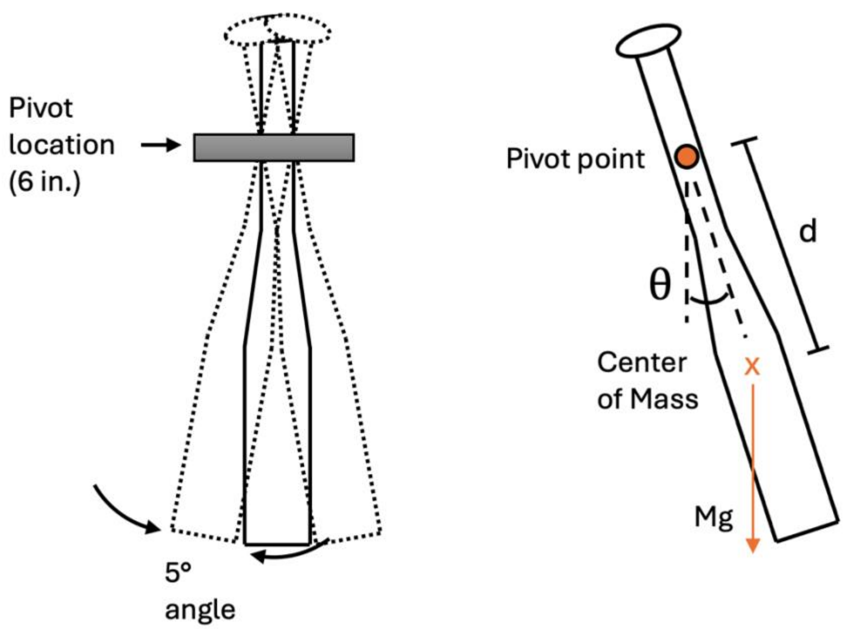
Figure 2.1: Equations for the moment of inertia (MOI) of both a point mass about an axis of rotation and a rod rotating about its end (an approximation of a batter swinging a baseball bat) with diagrams [14]. The equations for the MOI of both objects are shown. *I* is the MOI, *L* is the length of the rod, *r* is the distance from the axis of rotation to the mass elements, *M* is the mass of the entire object, *dm* is the mass of the mass element for the integral (defined in the figure), and *dr* is the length of the mass element.

The rod rotating about its end in **Figure 2.1** is used as a first-order approximation for a baseball bat being swung by a batter. In reality, swinging a baseball bat would have a higher MOI than swinging a rod as more of the bat's mass is located further from its axis of rotation [14].

The MOI of a baseball bat is important to the batter because if the MOI is less, the bat is relatively easier to swing and control [13]. To decrease the MOI of a baseball bat, the bat may either weigh less (*M* is decreased) or the weight may be brought closer to its axis of rotation (*r* is decreased). Whereas the mass of the bat, *M*, is only linearly proportionate to MOI, bringing more weight closer to the axis of rotation would be especially effective as MOI is proportional to the square of *r*, the distance of the mass from its axis of rotation.

Although decreasing the bat's MOI increases ease of swing and control, if the mass of the bat is decreased by reducing the barrel size, it would become more difficult for the batter to accurately hit the ball in the "sweet spot". The sweet spot is the ideal location on the bat to allow for maximum batted-ball distance, usually around 5-7 inches from the barrel tip depending on the bat [15]. Alternatively, if the size of the barrel is increased then the "sweet spot" is easier for the batter to hit with the ball but the MOI is increased which makes the bat more unwieldy. As a result, the compromise between these two factors is key.

Modeling the MOI of a baseball bat by integrating along its length is complicated due to its geometry. As a result, bat manufacturers have developed a way to experimentally measure it, described in **Figure 2.2**.



$$I = \frac{T^2 Mgd}{4\pi^2}$$

Figure 2.2: Baseball bat MOI experiment with key variables labeled [16]. The pivot point is defined as six inches from the knob-end of the bat. *I* is the moment of inertia, *T* is the period or time it takes for one oscillation to occur in the setup shown on the left-hand side, *M* is the

mass of the bat, *g* is the gravitational force, and *d* is the distance between the pivot point and the center of mass of the bat.

Similar to the simple rod approximation, this equation shows that MOI is decreased by distributing the weight closer to the knob-end of the bat, as this would decrease both *d* and *T*.

2.2 Bat Velocity and Hill's Muscle Model

Bat velocity is the single biggest factor in achieving exceptional batting performance [13]. By improving bat velocity, the batter is able to improve batting performance through increased decision time, decreased swing time and increased batted-ball velocity. However, velocity comes at a cost. According to Hill's Muscle Model, for an element of muscle, the velocity a muscle can achieve is inversely proportional to the force it is able to output [17]. Hill's Muscle Model seeks to characterize muscle contraction through a combination of a contractile element and two non-linear springs, one in series and one in parallel (shown in **Figure 2.3**). Although the intricacies of this model are beyond the scope of this study, the general finding of velocity's relationship with force output and their influence on peak power are immensely relevant.

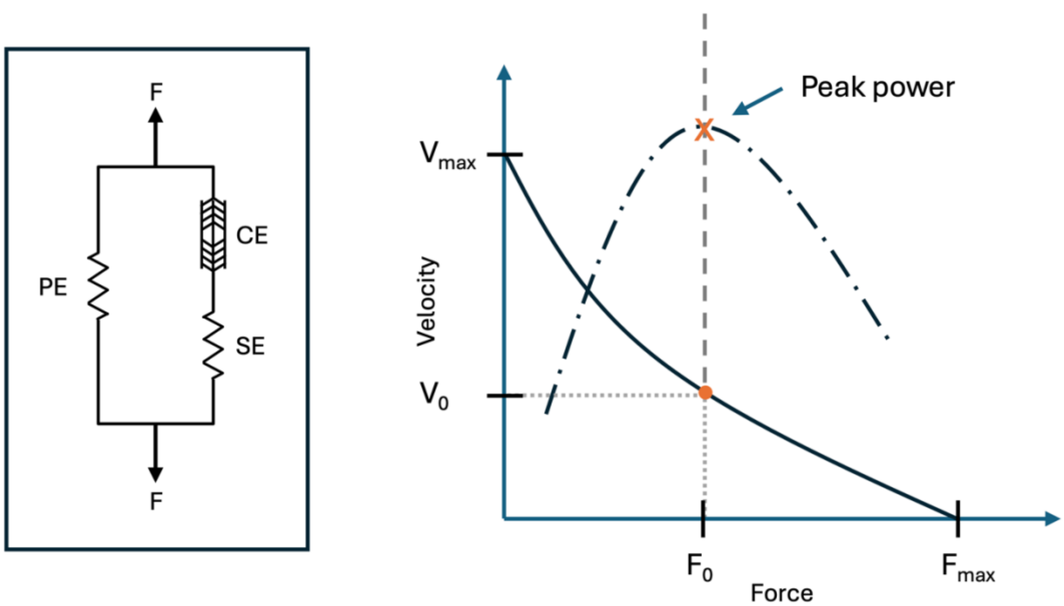


Figure 2.3: Hill's Muscle Model and supporting Velocity-Force graph [17]. F_{max} represents peak force output of a muscle which occurs at zero velocity. V_{max} represents maximum velocity that a muscle can reach which occurs when the muscle is under no force. F_0 and V_0 show the ideal force output and velocity to maximize power. Power is defined as $P = FV$, so a maximum power is able to be plotted on the graph in the figure above.

This understanding of muscle function reveals the need for training at both high force and high velocity for explosive movements such at baseball batting. By increasing both F_0 and V_0 through training, peak power is also increased which greatly improves a batter's performance.

Chapter 3

Methods

3.1 Batting Analysis

Following Noorbhai et al. and their cricket bat design process, this study first examined the stance phase of a baseball bat swing and its differences between youth and professional batters in an attempt to uncover a potential to distinguish between various batting stance types. The stances of 14 of the current best batters in the MLB according to the MLB's 2023 regular season power hitting rankings were studied (detailed in **Table 3.1**) alongside young athletes (n = 7) that competed in the Little League World Series (LLWS), a tournament held in the US that brings together some of the best teams of young athletes (aged 10-12) to compete against one another.

Table 3.1: 2023 batting statistics of 14 of the top MLB batters according to the MLB's 2023 regular season power hitting rankings, ranked from highest to lowest.

	HR	RBI	BA	R	GP
Ronald Acuña Jr.	41	106	.337	149	159
Mookie Betts	39	107	.307	126	152
Matt Olson	54	139	.283	127	162
Freddie Freeman	29	102	.331	211	161
Corey Seager	33	96	.327	88	119
Juan Soto	35	109	.275	97	162
Yordan Alvarez	31	97	.293	77	114
Yandy Diaz	22	78	.330	95	137
Aaron Judge	37	75	.267	79	106
Julio Rodriguez	32	103	.275	102	155
Luis Arraez	10	69	.354	71	147
Jose Altuve	17	51	.311	76	90
Shohei Ohtani	44	95	.304	102	135
Mike Trout	18	44	.263	54	82

HR = Home Runs; RBI = Runs Batted In; BA = Batting Average; R = Runs Scored; GP = Games Played
(All stats from the 2023 Regular Season)

Bat position and hand position were noted at pre-pitch (stance, stride, coiling), mid-pitch (swing initiation, swing acceleration), and ball contact for all 21 batters. The pre-pitch results are shown in **Table 3.2** as this included stance, which is the phase of interest.

Table 3.2: Breakdown of professional (MLB) and youth (LLWS) batters' grip during the stance phase of a baseball bat swing.

	Pro (n=14)	Youth (n=7)
Bat Position		
Vertical	5	1
Diagonal	5	3
Horizontal	4	3
Hand Position		
Above Head	3	2
At Head	5	3
Below Head	6	2

Quantity represents the number of pro or youth batters that utilize the respective bat or hand position.

As shown in the table above, this preliminary analysis did not uncover a strong majority when it comes to bat or hand position (grip) at either the professional or youth levels nor a strong difference in bat or hand position between the two groups. Although intricacies are likely to exist, this study decided to move its focus to one key difference between these two groups: bat velocity and power.

3.2 Market Analysis

In a 2011 study of MOI's effect on bat swing, Liu et al. sought to test the ability of a "Dynamic Moment of Inertia" (DMOI) bat to influence swing velocity, batted-ball velocity, hitting distance, explosive force and grip force (shown in **Figure 3.1**) [13].

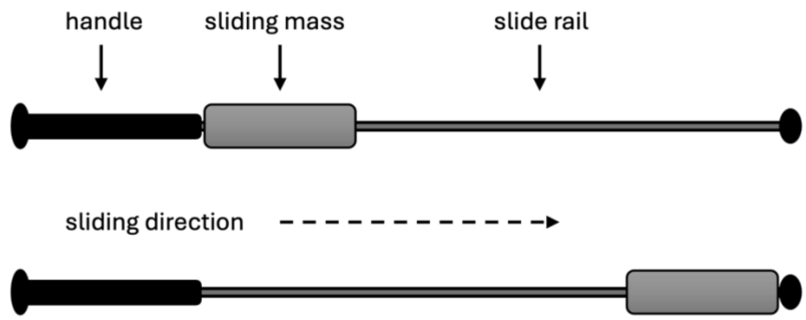


Figure 3.1: A “Dynamic Moment of Inertia” (DMOI) bat and its sliding mass mechanism [13].

The original design of a DMOI bat was first introduced by Hung et al. in 2004 in which the idea was to bring the mass of the bat closer to the axis of rotation during the initial phases of the swing to make swinging easier and more controlled (a concept more deeply described in **Section 2.1**) [18]. Thereafter, as the mass slides to the tip of the bat during swinging and reaches the end of the bat before ball-contact, the effective MOI of the bat becomes greater than a normal baseball bat, which can help increase strength and bat velocity as discussed in **Section 2.2**. Since this study was conducted, there are now DMOI bats available on the market.

As a cheaper alternative, there are also “static” MOI bats on the market that have increased mass located above the handle that does not move. These bat designs can combine the increased weight (improving bat velocity) with the smaller MOI (increasing the control and swing ease) all while decreasing the cost to under $100, which are all key factors in the prototype proposed later in this study.

Furthermore, another study measured the impact that training with various weighted bats had on bat velocity, which was of value to the prototype proposed in this study [19]. This study had collegiate baseball players (n = 60) participate in batting practice with over-weighted, under-weighted and conventional bats for regular intervals over a 12-week period in three equally sized groups, a dry-swing group, a batting practice group and a control group that only used a conventional bat. The study found that all three groups increased their bat velocity at the end of the 12 weeks, with the batting practice group, the dry swing group and the control group increasing by 10%, 6% and 1%, respectively [19]. This study shows that bat velocity can be increased more quickly by including both over-weighted and under-weighted bats in batting practice training. These findings also corroborated a similar, less in-depth study published two years earlier [20].

As both approaches of bat MOI manipulation and bat weight variation training were measured to increase bat velocity, this paper attempted to combine the impacts of both approaches through a single product, “The Variable Weighted MOI Baseball Bat”.

Chapter 4

Results and Discussion

4.1 Overview of the Prototype

Through combination of the two studies detailed in **Section 3.2**, market analysis, and Hill's Muscle Model, a prototype training bat for increasing a batter's bat velocity was proposed. "The Variable Weighted MOI Baseball Bat" is shown in **Figure 4.1** below.

Figure 4.1: Proposed prototype: "The Variable Weighted MOI Baseball Bat" [21].

a) shows an assembled view of the prototype as well as the MOI locations of the fully loaded bat (furthest right) and the fully unloaded bat (furthest left).

b) shows an expanded view of the prototype.

According to Hill's model, training a batter's maximum force and maximum velocity increases the batter's peak power [17]. According to the two papers described in **Section 3.2**, training with a heavy bat can increase bat velocity as well as power and integrating a light bat can further increase bat velocity [18, 19]. Market analysis provides context as to how the MOI of a baseball bat has been adjusted to make a heavy bat that is uniquely easy to control. Through the combination of these conclusions, the baseball training bat prototype shown above is proposed. To make the bat have a light, regular or heavy weight, aluminum rings each weighing 1 oz (28.3 g) are slid onto the bat and settle just above the handle as this location brings the MOI closer to the knob with each ring added. A 3D-printed clamp which is used to hold plates onto a barbell in weightlifting can similarly be used to hold the rings in place. The bat that the weights are slid onto has had material shed from below its barrel to bring its weight down to the minimum needed for training with a light bat. Finally, the handle is made to be detachable in order to add the rings onto the bat since the knob of the bat is larger than the inner diameter of the rings.

As detailed above, the prototype consists of three major components: the bat geometry, the rings, and the handle attachability. Components were designed to be manufactured simply so that an initial prototype may be created with readily available tools and materials. Each of these components is described in detail in the sections that follow, including more detailed drawings of each component.

4.2 Prototype Bat Geometry

Three important characteristics that a baseball bat is defined by are length, weight, and material. All three of these are chosen largely based on age, height, and weight. The dimensions of the bat shown in **Figure 4.1** were chosen with high-level high school and college athletes in mind, but the dimensions can easily be adjusted for younger athletes as shown in **Table 4.1**, located at the end of **Chapter 4**. The specific model used in this initial design is the Rawlings "Big Stick Elite" 243 Maple Wood Bat which has a 33-inch (83.8 cm) length and 30-oz (850 g) weight. This model was chosen for two reasons: its weight and its material. Firstly, the weight of 30 oz was chosen as it is standard for athletes at the college level [19]. The material of wood (maple specifically) was chosen over aluminum alloy or composite since wooden bats are solid and, are therefore, most easily manipulated into the shape needed for this design through use of a lathe, whereas metal bats are hollow. The dimensions of the manipulated bat are shown in **Figure 4.2** below.

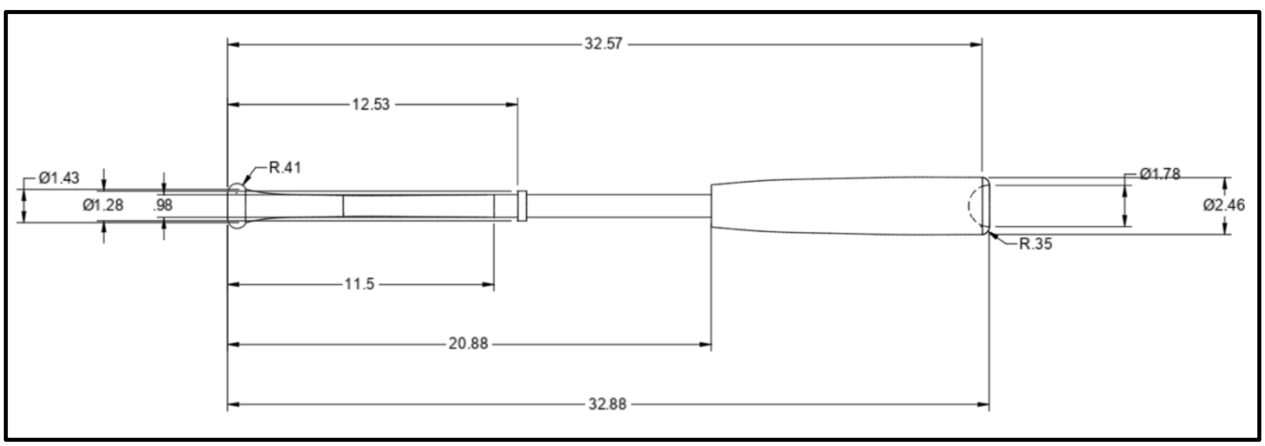


Figure 4.2: Dimensions of prototype bat (2D)

The two main features of this part of the prototype are the material removal along the taper and the ring stopper near the midpoint of the bat. The material removal was necessary both to decrease the weight of the bat and to allow for the seven uniform rings to be stacked. The lightest bat used in the study on alternating bat weight was a 27 oz bat (765 g), so 3 oz (85 g) of material needed to be removed from this 30 oz bat for it to weigh 27 oz with no rings attached [19].

Maple wood has a density of ρ_{maple} = 578.04 oz/in^3 (1000 g/cm^3) therefore, 7.53 in^3 (123.4 cm^3) of material needed to be removed from the bat. To do this, a hollow cylindrical extrusion with an inner diameter of 0.976 inches (2.479 cm) was performed, beginning 20.877 inches (53.028 cm) above the knob-end and terminating 5.0 inches (12.7 cm) above the knob-end.

To ensure that the rings do not increase the MOI of the bat by sliding further down the bat than intended, a ring stopper was added (shown in **Figure 4.3**). The two halves of the maple-wood ring stopper were placed around the 0.976-inch diameter portion of the bat with its bottom face lining up at 12.525 inches (31.814 cm) from the knob-end. This placement allows surface area for the batter's hands, seven rings, and one ring clamp. With an outer diameter of 1.282 inches (3.256 cm) and height of 0.375 inches (0.953 cm), once the permanent ring stopper is placed, a bat weight of 27.00 oz is achieved.

Figure 4.3: Ring stopper placement before and after attachment.

4.3 Prototype Ring

The weighted ring component (shown in **Figure 4.4**) of this prototype is the key aspect that harnesses the benefits of lowering the MOI and varying the weight on bat velocity. The alternating bat weight study used bats weighing in the range of 27 to 34 oz (765 to 964 g) with the weight of the bats going up and down by 1 oz (28.3 g) every three weeks [19]. Therefore, space for seven 1 oz (28.3 g) rings is necessary to allow this bat prototype's weight to be in the same range of 27 to 34 oz (765 to 964 g) with 1 oz (28.3 g) increments.

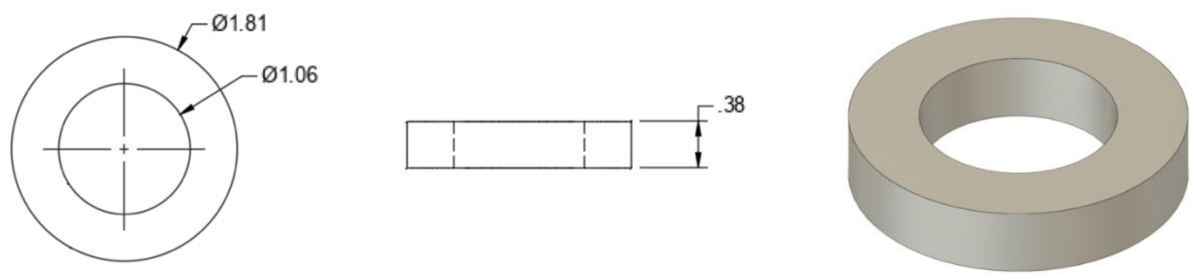


Figure 4.4: Weighted aluminum ring weighing 1.0 oz.

The four main variables in designing the ring were the material, inner diameter, outer diameter, and height. Aluminum was selected as the material as it is cheap, available, easy to machine, and also light with a common density of ρ_{Al} = 1.6 oz/in^3 (2.7g/cm^3). The inner diameter was selected to be 1.055 inches (2.680 g), as this is equal to the diameter of the bat plus a gap of 0.039 inches (1 mm) around the entire ring. The height was selected as 0.375 inches (0.953 cm) to minimize the length of the bat that the rings occupy. By minimizing the ring's height, the MOI can be most decreased by concentrating the weight while leaving room for the batter's hands. Lastly, the outer diameter is a free variable that is constrained by the ring weight of 1 oz (28.3 g). To find the value of the outer diameter that creates a ring of 1 oz, **Equation 1** was used.

$$d_o = 2\sqrt{\frac{\rho_{Al} \cdot m}{\pi \cdot h} + \frac{d_i^2}{4}} \tag{1}$$

Equation 1 above shows how the outer diameter, d_o, of the ring was determined, where ρ_{Al} = 1.6 oz/in^3 (2.7g/cm^3) is the common density of aluminum, m = 1 oz (28.3 g) is the required weight of the ring, h = 0.375 inches (0.953 cm) is the height of the ring, and d_i = 1.055 inches (2.680 g) is the inner diameter. This equation provides the outer diameter of the ring to be 1.81 inches (4.60 cm). Using these values, with a 0.05mm fillet on all edges of the ring, an aluminum ring of 1.00 oz (28.3 g) is achieved.

Lastly, a component that can hold the rings firm in their place on the bat while still allowing for them to be detachable was needed so that the rings do not slide down the bat or shift during use. For the purposes of this initial prototype, a 3D-printable barbell collar used in weightlifting was selected and is shown in **Figure 4.5** below. It would be recommended to include a rubber insole inside the clamp as to prevent slippage and decrease vibration for the batter.

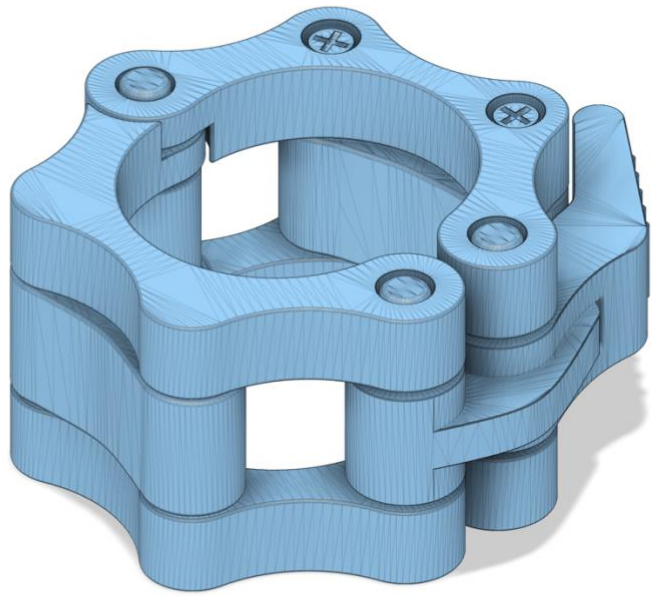


Figure 4.5: Example of a 3D-printable collar with an inner diameter of 0.976 inches (2.479 cm) used to hold the rings in place [22].

This 3D-printable collar was selected as it is affordable, easily manufactured, light and can be scaled to the specific diameter needed for this application. By using this clamp, the weighted rings will be held firm while remaining detachable.

4.4 Prototype Ring Attachability

The final major component of this training bat prototype is its handle attachability. The reason this feature is required is that the inner diameter of the weighted rings is smaller than the diameter of the bat knob. Therefore, the knob needed to become removeable in order to attach the weighted rings. An alternative method explored was to make the rings able to open and close, but the hinge and clasp mechanisms required were too heavy for the 1 oz weight requirement of the ring. The handle attachability method selected is shown in **Figure 4.6** below.

Figure 4.6: Three components of the handle detachability feature [18, 23].

An assembled version is shown in ***Figure 4.1****.*

This method requires that the training bat is cut through at 5 inches (12.7 cm) above the knob-end, as this is where the bat becomes a consistent diameter of 0.976 inches (2.479 cm). A hole is then drilled in the center of both pieces of the bat at a diameter of 0.086 inches (0.218 cm) and depth of 0.623 inches (1.582 cm). This allows for a Black-Oxide Alloy Steel Socket Head Screw with 2-56 thread size and 1.25-inch (3.175 cm) length to be inserted into the bat with an interference fit between the knob-end piece and smooth side of the screw. The barrel piece is then tapped for a 2-56 thread size to allow for the handle end to be manually screwed into the barrel piece which allows for the rings to be attached and detached from the bat.

4.5 Age Sizing

This prototype can be altered for different age ranges to increase market size. An example of important factors and potential values for different ages is provided in **Table 4.1**.

Table 4.1: Potential values for key differences in prototype based on age of batter.

	Age Range	Bat Length (in.)	Weight Range (oz.)	Ring Weight/ # of Rings
High School/ College	15-22	33"	27-34	1 / 7
Middle School	10-14	30"	16-31	3 / 5
Youth	7-9	27"	14-20	1 / 6

4.6 Discussion

This design is theoretical as the prototype has not physically been made but one key conclusion drawn from this work is the prototype's manufacturability. This CAD model shows that each of the major components of the model can be easily manufactured and assembled well. The design is also shown to be effective as the CAD shows that the center of mass of the bat can be altered by over an inch (shown in **Figure 4.1**).

Also, the design is easily able to be altered for different age groups as discussed in **Table 4.1**. This aspect allows for bat velocity training at a younger age and also reaches a wider market which is valuable once the product reaches production.

4.7 Strengths & Limitations

This prototype design is influenced by multiple published studies and products already on the market. It also presents a novel concept that seeks to compound previous findings of bat velocity improvements with one another. Every piece of this initial prototype is made from readily available materials using methods that are common amongst most universities.

However, a physical prototype has yet to be produced and there may be unforeseen challenges in manufacturing. There are two identified weak points on the bat at both the handle detachment site and where material has been extruded off the taper section. It is yet to be seen if these two points can withstand the high torques created by hitting a baseball at high speeds. Also, there is no proof that combining MOI manipulation with variable bat weight training will combine each of their individual influences on bat velocity.

Chapter 5
Summary

5.1 Future Work

Due to the short timeframe given for this study, only a CAD model of the initial proposed prototype was created. To build from this, a physical version of the prototype should be machined. Testing the weak points of the bat as mentioned in **Section 4.7** and measuring the MOI of the bat depending on its weight by running the experiment described in **Section 2.1** would both be of value.

The largest component needed for proof of concept remaining is a pilot study. Providing experimental evidence that combining MOI manipulation with variable bat weight training provides a greater positive benefit to bat velocity than either of those two factors do individually is necessary for proof-of-concept. To do this, a longitudinal study similar to the one by DeRenne et al. should be conducted [19]. As in the study with DeRenne et al., future work could include collecting a group of high-school or college level baseball players to participate in a 12-week study. The group could be split into three sub-groups including a control group, a dry-swing group who swings without making ball contact, and a batting-practice group who uses the prototype during live pitch practice. Each of the three groups could perform 150 swings per day broken into 15 sets of 10 with no more than 30 seconds of rest in between. For the dry-swing and batting practice groups, every five sets the weight of the bat could be changed between light, regular and heavy. Every three weeks, the weight of the bat could increase and decrease by 1 oz (28.3 g) by adding and subtracting a ring. By following these steps similar to DeRenne et al., bat velocity impact between the two training programs could be easily compared. Once proof of concept is achieved through experimentation, a next step would be to subsequently design an aluminum alloy or composite version, as all players under the professional level use these types of bat materials instead of wood.

5.2 Conclusion

Through analysis of the DMOI bat, MOI manipulation, the variation of weighted bat training study, and Hill's Muscle Model, based on several literature sources, as well as market analysis, "The Variable Weighted MOI Baseball Bat" initial prototype was proposed. Design choices were made with manufacturability in mind and next steps were proposed to develop proof of concept before moving into further product development. By potentially adding this novel product into the everexpanding baseball market, batters across the U.S. and internationally could vastly increase their bat velocity leading to many beneficial outcomes such as increased decision time, decreased swing time, increased batted-ball velocity and ultimately – batting performance.

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