ABSTRACT

MATTA, PHILIP A. Is Youth Baseball Safe? A Computational and Experimental Examination into Reducing Youth Baseball Injury Potential. (Under the direction of Gregory S. Sawicki, Joseph B. Myers, and Richard Goldberg).

While there is concern that the number of overuse arm injuries in youth baseball is rising, the number of impact injuries remains higher for youth baseball than in high school or college. Reducing the weight or hardness of a standard baseball has been espoused by some as a method to reduce these injuries and was investigated. Reducing the weight of the standard ball to four ounces increase the batted ball exit velocity (BBEV) by approximately 10% and subsequently increases batted ball range. Despite the increase in BBEV, there is an overall decrease in impact momentum at a ball-player collision due to the decreased ball mass. Unfortunately, the increase in BBEV leaves position players and pitchers with less time to defend themselves. Reducing the weight of a standard baseball from five-ounces to four, leads to less than a 5% increase in impact probability for position players (typically first and third baseman). However, the impact probability for pitchers can increase by up to 36%. Pitchers may require almost two times the amount of time a position player requires to avoid a struck baseball. A four-ounce ball with reduced coefficient of restitution may be the optimal adjustment, as this ball can exhibit the same BBEV as a standard ball while further reducing the impact momentum and only the reducing the batted ball range, in standard impact conditions, by 5% or less.

Is Youth Baseball Safe? A Computational and Experimental Examination into Reducing
Youth Baseball Injury Potential

by
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ACKNOWLEDGMENTS

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CHAPTER 1 INTRODUCTION

Young children and adults alike have enjoyed baseball in America for over a century and it has been recognized by some as 'The Great American Pastime'. Its popularity has increased over the years and now well over 5 million youths play in competitive baseball leagues every summer [1]. Baseball is often perceived as a tactical game where skill and execution are inherent and physical play an afterthought. Although the pace of play is slower than most sports and contact between players is rare, injuries are unavoidable. Many injuries are no worse than simple bruises and skinned-knees from sliding and diving around the field, however, two-types of injuries continue to plague baseball leagues and endanger America's youth [2].

The first type of injury is known as an acute ball-player impact and these come in many forms and with varying consequences. These injuries occur when a baseball is thrown or hit and then collides with another player. Examples include when a player is hit by a pitched baseball or a groundball takes a bad hop and strikes a defender. Injuries like this vary greatly in terms of severity but often cause dental damage or damage around the eye with facial injuries accounting for just over 33% of all injuries in players under the age of 18 [3]. Many youth leagues have responded by introducing facemasks to batting helmets in an effort to reduce the number of injuries to batters, but little has been done to protect defensive players [4]. A growing number of leagues have been pushing for softer balls in an effort to reduce the severity of the injury should the impacts occur and the preliminary data looks encouraging but changing the composition of the ball may have side-effects yet to be investigated [5].

The second type of injury prevalent in baseball, and alarmingly so in youth baseball, is chronic overuse arm injury [2]. The mechanism for injury has been studied in great detail and overuse arm injuries are believed to occur due to repetitive stress on the arm that cause cumulative microtrauma to the soft tissue surrounding the elbow and shoulder [6]. The types of chronic overuse arm injuries range from problems like minor pain and soreness in the elbow and shoulder, to more severe injuries like slap lesions, tears of the rotator cuff or labrum, and ulnar collateral ligament damage. These injuries have been, and continue to be commonplace in the ranks of college and professional baseball but have become more common in youth baseball leagues in the recent years [7]. Most youth leagues have responded to the rise in these injuries by placing pitch count restrictions for youth pitchers and required days of rest but little can be done to regulate the pitch count of players who play and pitch in multiple leagues. Some promising research was conducted by Fleisig et al. in 2006 as they were able to show that you can reduce force and torque in the elbow and shoulder by reducing the mass of the baseball [8]. This outcome is promising for youth as it may help to reduce chronic arm injuries in youth players but the effect of changing the weight of a baseball on the rest of the game, and particularly the number of acute ball-player injuries, is unclear.

What is clear is that youth baseball players are at a higher risk for acute ball-player impact injuries and recent injury trends indicate that youths are also at risk for chronic arm injuries as well [2,7]. Batting helmets with facemasks can help to protect batters from facial injuries but what about pitcher and fielders? Pitch count restrictions have been enacted in

many youth leagues to stem chronic arm injuries but how do we protect kids who play in multiple leagues and throw far too many pitches because of it?

In the work that follows we addressed a method to potentially reduce the severity of ball-player impact injuries and the number of chronic arm injuries simply by modifying the characteristics of the youth baseball. The paper introduces a modeling framework that allowed us to adjust the physical properties of the ball and investigate various parameters of interest. The results of this experiment spawned a second study to investigate the factors that influence avoidance ability in a baseball environment. The results of these studies hope to inform those overseeing youth baseball leagues and increase the overall safety of 'The Great American Pastime'.

CHAPTER 2: MODELING SIMULATION

CHAPTER 2.1 INTRODUCTION

Although youth baseball fields are smaller than their adult counterparts, most youth baseball leagues continue to use the same ball used by professional players. Youth sports often use modified equipment and field sizes compared to their adult counterparts to effectively scale down the sport for younger populations. Previous studies have justified modified equipment by citing that it allows youth players to learn and practice proper mechanics by using equipment that is scaled down to better match the strength of the player while reducing the risk of injury to pre-adolescent athletes [1, 2, 9]. Taking advantage of these benefits, youth football, soccer, and basketball leagues use smaller and lighter balls. Moreover, junior hockey leagues have also started to use lightweight pucks to make the game

safe and fun for youth players. In addition, these four sports also utilize smaller field dimensions in an effort to scale down the sport for younger populations.

Youth baseball is in step with these sports with regards to scaling down the playing field from professional baseball field dimensions. Typical youth fields have a shorter distance from home plate to outfield fences, a shorter base-to-base distance, and a shorter home plate to pitching mound distance than professional fields. However, while a small number of youth baseball leagues use baseballs that are "softer" than standard balls, the majority of youth leagues (9-12 years of age) use balls that are identical in size and weight to those used by their high school, college and professional peers. This standard ball may be putting youth players at an increased risk for injury [8,11]. In youth baseball, this injury risk comes in the form of overuse arm injuries and ball-player impact injuries [1-3].

It is estimated that more than 5 million children play in organized baseball leagues and another 13 million play in unorganized leagues every year; approximately 2.2 million are between the ages of 9 and 12 [1]. Lyman et al have shown that one half of all youth pitchers will experience joint pain in the elbow or shoulder in a season [6]. Overuse arm injuries are believed to occur due to cumulative microtrauma to soft tissues [6]. This microtrauma has many proposed mechanisms including high elbow varus torque, shoulder internal rotation torque, elbow flexion torque, shoulder proximal force, and elbow proximal force [12-15].

One promising idea to help decrease overuse arm injuries is to decrease the ball mass for youth players. Decreasing ball mass has been shown to reduce elbow varus torque and shoulder internal rotation torque in youth pitchers, thus leading to the belief that reducing baseball mass may be effective in reducing overuse arm injuries [8]. However, decreasing

ball mass also leads to an increase in pitched ball velocity and if introduced into youth leagues, a lightweight ball could potentially cause an increase in batted ball velocities and subsequently an increase in the frequency and severity of batted ball-player impact injuries [8, 11].

While overuse injuries are associated with repeated use of the overhand throwing motion, acute injuries are associated with a number of factors, such as collisions between a player and a ball, bat or base. Over a 13-year period, from 1994-2006, there were an estimated 598,706 baseball related injuries to children between the ages of 9-12 treated in US hospital emergency departments [3].

A small number of youth leagues have instituted a modified or reduced impact ball (a 'softer' ball) in an effort to reduce the severity of ball-player collision injuries. A USA Baseball three-year equipment research study showed that reduced impact balls were effective in decreasing the risk of ball-related injuries by an average of 29% [16]. Although a reduced impact ball seems promising for reducing impact injuries, this modification fails to address overuse arm injuries.

A potential solution to address both overuse arm injuries and ball-player impact injuries is to reduce the mass and modulus of the ball. Previous research by Crisco et al, showed that a lower modulus and reduced mass baseball reduces the impact force to a simulated face and chest model [11]. However, the performance (batted ball exit velocity, batted ball range, etc.) of a ball with these properties has not been investigated. Previous research by Sawicki et al. has provided a reliable and robust modeling framework to predict

the effects of altering ball mass and ball properties on specific outcomes like batted ball exit velocity (BBEV) and batted ball range (BBR) [17].

The collision model developed by Sawicki et al. and used in this study utilizes the impulse-momentum principle for collisions of relatively rigid bodies and uses the coefficient of restitution to account for the energy lost during impact. Although there have been improvements to impact models for relatively rigid bodies, such as the inclusion of factors that account for deformation, these models have only been studied at low impact speeds (>=10m/s) that are not representative of collision speeds for little league baseball and thus have not been incorporated into this model [18]. Additionally, recent studies have shown that balls do not roll when they bounce, as assumed by the Sawicki model, but rather grip during the bounce which can change the post impact rotational velocity of the ball depending on the tangential compliance or elasticity of the colliding surfaces [19]. This tangential compliance has been modeled and experimentally studied for collisions between baseballs and bats at very low impact speeds (>=6ms). This study indicates that the rotational velocity of the ball after impact may be slightly less than the Sawicki model predicts for low impact speeds [20]. Although this experiment was performed at impact speeds that are far less than those seen in little league baseball, the result implies that baseballs may not travel as far as the Sawicki model suggests due to a reduced Magnus force. Although batted ball distance is considered in this experiment, the primary concern of this study is the batted ball flight time for balls that are hit towards the pitcher and in these situations, small changes in the Magnus force will have little if any effect on this outcome.

The purpose of this study was to investigate the effect a lighter ball would have on youth baseball. The parameters of interest included BBEV, impact momentum at a ball-player collision, and BBR. Additionally, we also investigated the effect of reducing the coefficient of restitution (COR) for a lighter ball. Previous research has shown that the COR between two elasto-plastic spheres can be predictably altered by modifying the elastic modulus; thus, a reduced COR correlates to a reduced modulus as long as the yield strength is held constant [21]. We examined four hypotheses.

First, we expected that the BBEV of a lightweight ball would be greater than a standard ball if struck in the same manner. Second, we tested the hypothesis that decreased ball mass would result in decreased impact momentum at ball-player collisions, supporting the results of previous research [11]. Third, we expected that a lightweight ball would travel farther than a standard ball due to an expected increase in BBEV. Finally, we hypothesized that by adjusting the COR of a lightweight ball, it would be possible to alter BBEV and range of the ball keeping performance similar to a standard baseball.

CHAPTER 2.1 METHODS

We modified the simulation model presented by Sawicki et al. to accommodate baseballs of varying mass and coefficient of restitution (COR). A schematic of the instantaneous collision between the ball and bat is shown in Figure 2.1. Model parameters (Table 2.1) were assigned default values that were used for all experiments except where specifically noted otherwise.
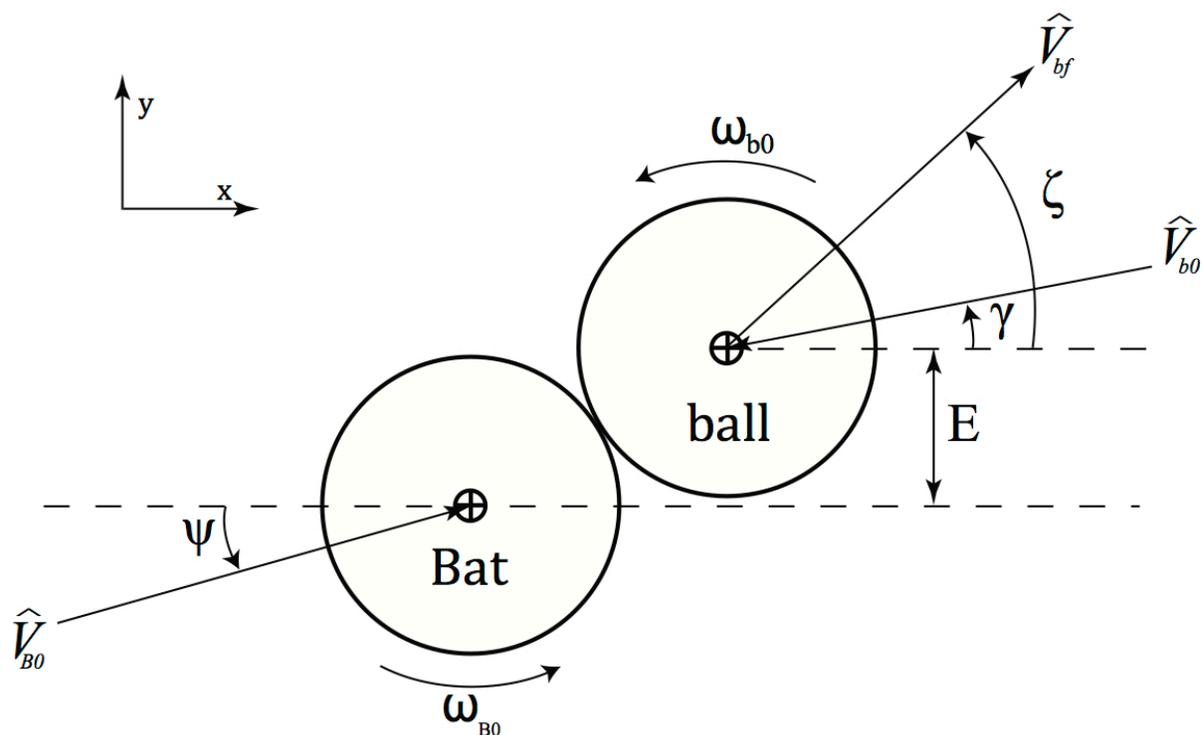
Figure 2.1 Two-dimensional impact schematic adapted from Sawicki et al. Impact occurs with horizontal, vertical and rotational bat and ball velocities. Post-impact variables that control trajectory include $\hat{V}_{bf}$, ω_{bf}, and ζ.

The simulation model was composed of three distinct phases: (1) the pre-impact phase, (2) the instantaneous collision phase between the bat and ball, and (3) the post-impact flight phase. The pre-impact phase simulated a pitched baseball and required assigned conditions for the initial linear ($\hat{V}_{b0}$) and rotational velocity (ω_b) of the ball. In the defined coordinate system the initial linear velocity of the ball was always negative, but the sign for the initial rotational velocity was dependent on the type of pitch thrown. Only pure topspin and backspin were considered. If the pitched ball was a fastball, the ball had backspin and a negative rotational velocity; however, if the pitched ball was a curveball, the ball had topspin and a positive rotational velocity. Only fastballs were considered for this study and the initial

rotational velocity was always negative. The initial conditions for ball velocity were specified at the pitcher's mound, 46 feet from bat-ball impact. The initial linear velocity of the ball was purely in the x-direction; however, the ball is subject to drag, Magnus, and gravitational forces that cause $\hat{V}_{b0}$ to have components in both the y and x direction at impact.

Table 2.1 Model parameters. The subscripts 'b', 'B', '0', and 'f'' refer to baseball, bat, initial, and final, respectively

Symbol	Description	Value
$\hat{V}_{b0}$	Initial ball velocity	28 m/s
ω_{b0}	Initial ball rotational velocity	-130 rad/s
γ	Pitched ball angle from horizontal	-
$\hat{V}_{B0}$	Initial bat velocity	25 m/s
ω_{B0}	Initial bat rotational velocity	0 rad/s
ψ	Bat swing angle	0
E	Undercut Distance	0.009 m
$\hat{V}_{bf}$	Post-impact initial velocity	-
ω_{bf}	Post-impact rotational velocity	-
ζ	Post-impact launch angle	-
COR	Coefficient of restitution	0.525
COR_R	Reduced COR for an equivalent lightweight ball	-

The initial conditions defined for the bat in the pre-impact phase included the bat linear velocity ($\hat{V}_{B0}$), rotational velocity (ω_B), swing angle (ψ), and undercut distance (E). The bat linear velocity was always positive and Sawicki et al. showed that wrist-roll (rotational velocity) has limited effects on BBEV so ω_B was set to zero [17]. For an upward oriented swing (i.e. uppercut), ψ was positive, for a downward oriented swing, ψ was negative. The undercut distance was taken as the difference in meters between the center of mass (COM) of the ball to the COM of the bat. The undercut distance was positive if the COM of the ball was above the bat.

The initial conditions of the bat and ball in the pre-impact phase determined the initial conditions at impact and ultimately the post-impact initial flight conditions as well. From the instantaneous collision phase between the bat and ball, initial conditions that determined the range of the ball were obtained. In addition to drag, Magnus, and gravitational forces, the range calculation also takes into account environmental factors such as wind, temperature, and elevation. For all simulations the wind velocity was zero, the temperature was 75 degrees Fahrenheit, and the elevation was set to zero (sea level). For a more complete description of the simulation model, refer to Sawicki et al. 2003 [17].

Sawicki et al. employed the model in an optimization framework to find values for the undercut distance (E) and swing angle (ψ) that optimized batted ball distance. We modified this model to determine parameters relevant to our study and address our hypotheses.

The first experiment was designed to determine the effect of ball mass on BBEV. The National Operating Committee on Standards for Athletic Equipment (NOCSAE) requires baseballs to weigh between 5 and 5 ¼ ounces; thus, a baseball weighing 5 ⅛ ounces was considered standard for this study. We varied ball mass from 5 ¼ to 4 ounces in ¼ ounce increments and BBEV and flight time to the pitcher (FTTP) was recorded.

The second experiment characterized impact momentum with respect to ball mass. Impact momentum provides insight to the potential severity of ball-player collisions regardless of impact location. We assumed that the player with the highest risk of batted-ball injuries was the player closest to the batter (the pitcher), as the available time to react is minimized. Additionally, upon delivering the ball to home plate pitchers are often in a

compromised state of balance due to the follow-through of the pitching motion potentially increasing their risk of batted ball-player collision injuries. Thus, our concern in this experiment was with pitchers positioned 46 feet from home plate.

We again varied ball mass from 5 ¼ to 4 ounces in ¼ ounce increments. Once the ball traveled 46 feet in the positive x-direction (the distance from home plate to the mound), the height of the ball was evaluated. If the height of the ball, relative to the ground, was between 3 and 5 ½ feet, the instantaneous velocity of the ball was recorded and used to determine impact momentum. If the height of the ball was outside of these bounds, the undercut distance (E) was adjusted incrementally until the height of the batted ball was between 3 and 5 ½ feet. This ensures that all reported values for impact momentum represent conditions that could actually lead to a batted-ball player collision.

The third experiment investigated the relationship between ball mass and batted-ball distance. For this simulation, the swing angle (ψ), undercut distance (E), and ball mass were varied and the distance traveled by the ball (in the x direction only) was recorded. We varied the swing angle from -45 to 45 degrees, undercut distance from 0.00 to 0.06 meters, and ball mass from 5 ¼ ounces to 4 ounces. The wide-ranging values for swing angle and undercut distance were to account for all possible swing strategies and impact combinations that could cause the ball flight to have an initial positive velocity in the x and y direction, creating a fly ball in fair territory.

The fourth experiment was designed to determine what COR value would cause a four-ounce ball to have the same BBEV as a standard ball. A four-ounce ball was chosen for optimization as previous research has shown that a four-ounce ball can lower kinetic

parameters at the elbow and shoulder linked to overuse injury [8]. The standard defined by NOCSAE states that baseballs must have a COR between 0.50 and 0.55 at 60 mph. The COR for the four-ounce ball started at 0.525 and was reduced by 0.001 until the BBEV was within 1% of a standard ball. This COR was recorded and called the reduced coefficient of restitution (COR_R). Experiments 1-3 were then repeated using a four-ounce ball with a COR_R.

CHAPTER 2.3 RESULTS

The relationship between ball mass and BBEV is shown in Figure 2.2. The BBEV of a four-ounce ball was 10% greater (7 mph) than a standard ball. As a result of the increased velocity, the FTTP is reduced by 10%, 416 ms compared to 464 ms. At bat and ball speeds of 35-65 mph, the reduction in FTTP for a four-ounce ball varies between 8-12% (386-666 ms for a four-ounce ball and 419-674 ms for a standard ball) and the BBEV varies between 10-13% (50-83 mph for a four-ounce ball and 49-76 mph for a standard ball).
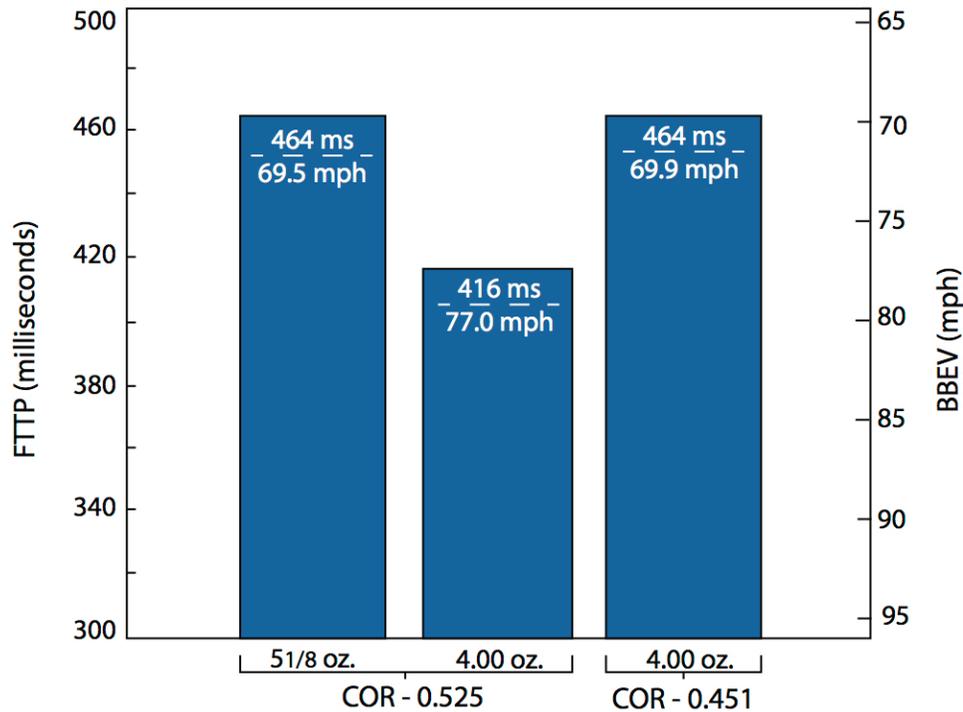
Figure 2.2 Relationship between ball mass, COR, FTTP, and BBEV. A four-ounce ball will reach the pitcher 48 ms faster than a standard ball while a four-ounce ball with a reduced COR will reach the pitcher in same amount of time.

Although a reduction in ball mass results in higher BBEVs, the impact momentum is reduced within the range of ball masses tested Figure 2.3. Reducing the mass of the ball by four ounces, a 22% reduction in mass, reduces the impact momentum by 11.6%.

A contour plot of batted ball range based on the pre-impact conditions E and Ψ for a standard ball is shown in Figure 2.4. Based on the default initial conditions for bat and ball speeds, the maximum distance a standard ball can travel is 241 feet. If struck in the same manner, a four-ounce ball will travel 275 feet, a 14% increase over the standard ball.
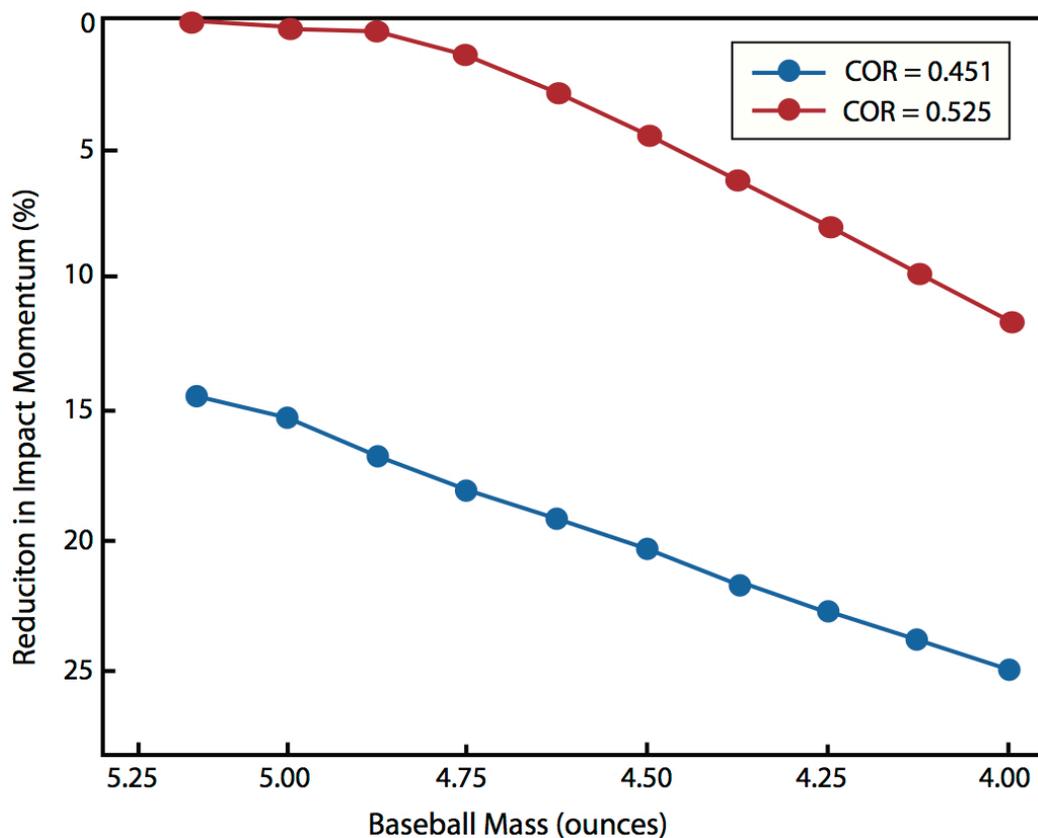
Figure 2.3 The reduction in impact momentum compared to a $5\,^1/_8$ ounce ball with a COR of 0.525. A four-ounce ball sees a 15% reduction in impact momentum while a four-ounce ball with reduced COR sees a 25% reduction in impact momentum.

The relationship between FTTP, BBEV and COR for a four-ounce ball is shown in Figure 2.5. If the COR of a four-ounce ball is reduced from 0.525 to 0.451 (COR_R), the BBEV and FTTP will be nearly identical to a standard baseball (Figure 2.2).
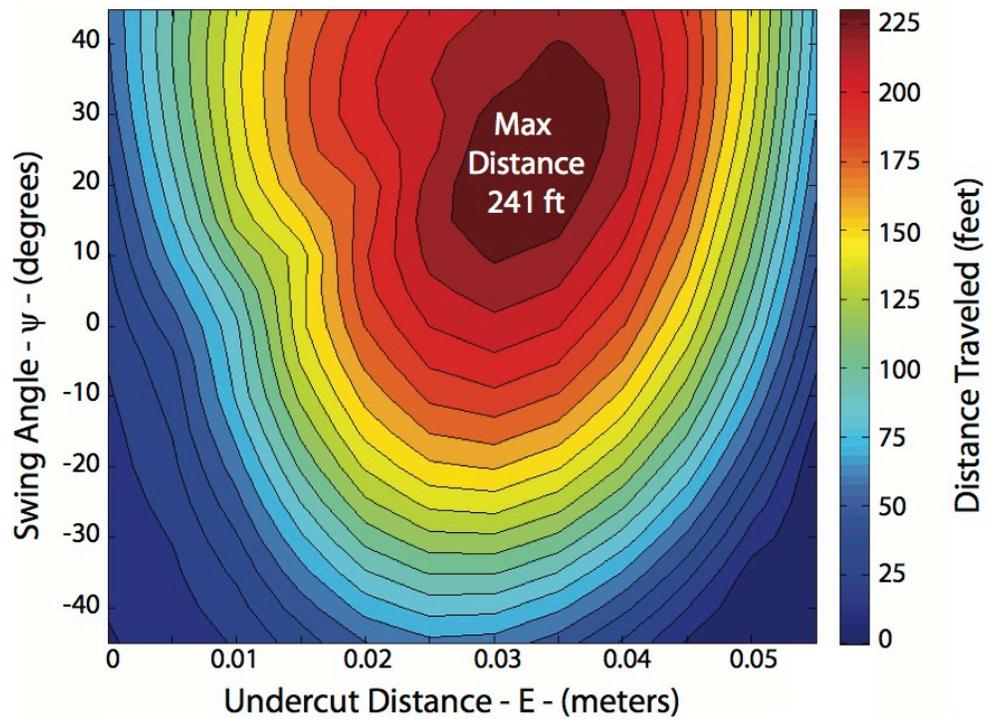
Figure 2.4 A contour plot of batted ball range for a standard ball under varying unique swing conditions. The maximum range for a standard ball is 241 feet.

The impact momentum of a lightweight ball with COR_R is less than both the lightweight ball and standard ball (Figure 2.3). A four-ounce ball with a COR_R has 25% less momentum at impact than a standard ball and 14% less momentum than a lightweight ball.
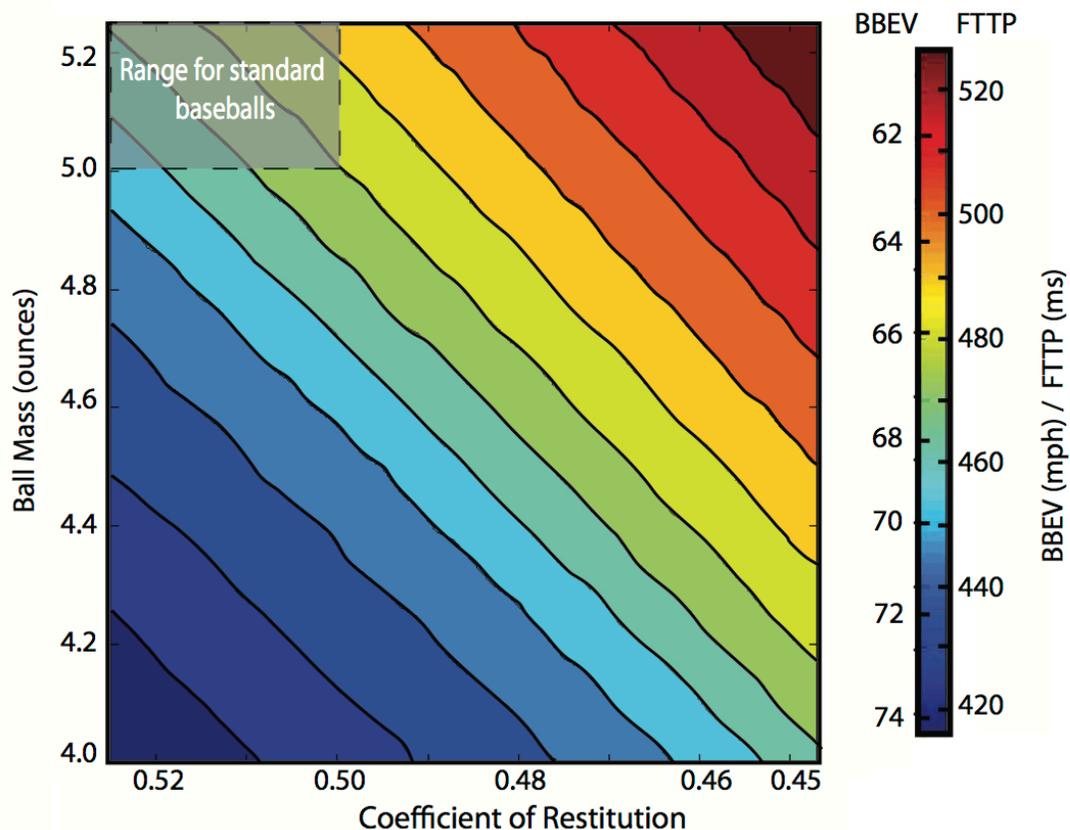
Figure 2.5 A contour plot of BBEV and FTTP for balls of varying mass and COR. As ball mass and COR are reduced, FTTP and BBEV can be consistent with a standard ball.

With the default initial conditions for bat and ball speeds, the maximum distance a four-ounce ball with a COR_R can travel is 229 feet; a decrease of 5% compared to the standard ball.

CHAPTER 2.4 DISCUSSION

Youth baseball currently faces two main injury risks: batted ball injuries and overuse arm injuries. Although a lightweight ball may potentially reduce overuse arm injuries it is

unclear how the reduction in mass would affect the frequency of batted ball injuries. At the default speeds selected for $\hat{V}_{b0}$ and $\hat{V}_{B0}$, the BBEV and FTTP for a four-ounce ball increased and decreased by 10%, respectively. Our first hypothesis was that a decrease in ball mass would increase BBEV and these results support that hypothesis. Youth pitchers standing 46 feet from home plate would have 48 fewer milliseconds to react to a batted ball if it weighed 4 ounces instead of the standard 5 ⅛ ounces. Using only this information, it is difficult to project whether or not a four-ounce ball would lead to an increase in batted ball player collision injuries. If we make the assumption that the relationship between the FTTP and the frequency of ball player collisions are inversely related, than the frequency of collisions would increase with a four-ounce ball.

Previous research has shown that youth tennis and table tennis players (both male and female) between the ages of 10-14 have an average reaction time of 430-460 milliseconds for a visual simple reaction time (SRT) test [22]. Although research needs to be done on the relationship between SRT tests and the ability to avoid a struck ball, this suggests that both a four-ounce and standard baseball may place youth players in situations where they simply do not have enough time to react to and avoid a batted ball.

Although the number of impact injuries may increase, the impact momentum at a pitcher batted ball collision is decreased with a four-ounce ball. This result supports our second hypothesis and is consistent with the results from Crisco et al. [11]. The impact momentum of a four-ounce ball is 11.6% less than a standard ball; however, the implications of this result are not completely clear. The impact response is dependent upon both the location of impact and the impact variable of interest. For example, Crisco et al. showed that

a lower mass ball would decrease peak sternal displacement but not decrease peak sternal velocity [11]. Although a four-ounce ball appears as if it may be safer and reduce the severity of impact injuries, the degree to which the severity is reduced is unknown.

The third experiment was primarily concerned with how a lighter ball would affect the competitive landscape of the youth game. Youth sports have been able to integrate equipment changes into their games because these changes do not adversely affect competition. One problem facing the introduction of a four-ounce ball is an increase in the batted ball distance, giving offenses a competitive advantage. The results from this experiment supported our hypothesis that a lightweight ball (four-ounce) would travel farther than a standard ball.

However, simply considering the maximum range of a batted ball does not fully address the affect this four-ounce ball would have on the competitive landscape of youth baseball. Typical youth baseball fields have outfield fences that are placed 185-200 feet from home plate. In this case, a ball that travels 241 feet is no better than a ball that travels 275 feet as they both result in a home run. Instead, a better metric would be to look at the difference in the number of home runs produced given the array of different swing strategies from experiment three. We will define a home run as any ball traveling in excess of 200 feet. In total, there were 228 unique swing combinations tested for the standard and four-ounce ball, respectively. Of those 228 unique swings, 42 produced balls that traveled in excess of 200 feet for the standard ball, while 66 swings produced balls that traveled in excess of 200 feet for the four-ounce ball. A four-ounce ball resulted in a 57% increase in batted balls over 200 feet. Although this calculation is simplistic, it demonstrates that without rule changes

and/or changes in field dimensions, a four-ounce ball would produce a gross advantage to hitters when contact is made between the bat and ball.

A four-ounce ball, although potentially beneficial in reducing overuse arm injuries, may increase the frequency of batted ball player collisions and may jeopardize the integrity of the youth game by providing an unfair advantage to hitters. A four-ounce ball with a COR_R could be the optimal solution as it may reduce both overuse arm injuries and the severity of ball player collision injuries. The results from the fourth experiment, shown in Figure 2.5, support our final hypothesis and show that if the COR of a four-ounce ball was reduced to 0.451, the FTTP and BBEV would be nearly equivalent to a standard ball (within 1%). If the FTTP is the primary determining factor in the frequency of batted ball player collisions, this result suggests that a four-ounce ball with a COR_R will not increase the frequency of collisions. In addition, Figure 2.3 shows the impact momentum from a four-ounce ball with a COR_R is further reduced from that of a standard ball (a 25% reduction in impact momentum). Crisco et al. suggested that a ball with a reduced elastic modulus (reduced COR) and reduced mass would aid in reducing impact injuries and our results support the idea that one particular solution to that problem is a baseball with a mass of four-ounces and a COR of 0.451 [11].

Finally, the range of the four-ounce ball with a COR_R was also tested. Given the default conditions, the maximum distance this ball can travel is 229 feet (a 5% decrease from the standard ball). The reduction in distance traveled is due the lower inertia of the four-ounce ball. If we consider all 228 unique swings, 33 balls travel in excess of 200 feet. This is a decrease of 21% when compared to the standard ball. This presents a trade-off for a four-

ounce ball with a COR$_R$ as it may reduce overuse arm injuries and the severity of batted ball injuries but may decrease the offensive output of little league teams.

CHAPTER 2.5 CONCLUSION

The purpose of this study was to investigate the effect a lighter ball would have on youth baseball. The implementation of a four-ounce ball in youth baseball would result in an increase in BBEV, leaving pitchers with less time to react and avoid batted ball collisions. Although this may increase the frequency of ball player collisions, impact momentum is reduced in these collisions, potentially reducing the severity of the injury. The distance traveled by a four-ounce ball is markedly increased over a standard ball and may result in a gross competitive advantage for hitters when contact is made. Implementing a four-ounce ball with a reduced COR may be the optimal adjustment to the game as it reduces the loads on the upper extremity of the pitcher, does not increase the exit velocity of the ball, and decreases the impact momentum at a potential batted ball-pitcher collision.

CHAPTER 3: DETERMINIG IMPACT PROBABILITY

CHAPTER 3.1 INTRODUCTION

Baseball is one of the most popular youth sports in the United States with estimates nearing 6 million US children playing in organized baseball leagues and as many as 13 million more playing in unorganized leagues [5]. Although baseball is the most popular youth sport by participation, it ranks third behind basketball and football in the number of annual injuries sustained by youth participants [23]. Baseball injuries can typically be

classified in two groups: acute and chronic. Numerous interventions, such as break-away bases, batting helmets, face shields and rubber molded cleats have been adopted by many youth leagues to curb the rise in acute injuries [23]. Although these interventions have helped in reducing the overall injury rate, there remain a large number of acute injuries from ball-player impacts in youth baseball [1].

Previous research from Mueller et al. showed that 52-62% of baseball related injuries occur from ball-player impacts with the majority of these injuries occurring to defensive or fielding players [24]. Although many of these injuries can be classified as minor, ball-player collisions that occur at the head and chest can be dangerous and sometimes fatal. Costly dental injuries make up 10% of baseball injuries to youth players and baseball is also the leading cause of sports-related eye injuries in 5-14 year old children in the US [23, 25]. Impact to the chest can be the most dangerous of all ball-player impact types due to the risk of commotio cordis (death from blunt trauma force in the absence of cardiac abnormality). A study into the death of 23 pitchers from 1973-1983 concluded that commotio cordis was the cause of death in 35% of the cases while another study showed that it is the cause of 2-4 deaths per year in baseball [23,26].

Fundamental changes to the ball and bat have been suggested in order to reduce the number of injuries (both acute and chronic) in the game. Sweeping changes to most youth, high school and collegiate bats have resulted in adjusted bat-ball coefficient of restitution (BBCOR) standards with the aim of reducing the speed with which balls leave the bat. In addition, the US Consumer Protection and Safety Commission proposed softer balls for youth leagues to help prevent and/or reduce the severity of head, neck and facial injuries that

occur every year [25].   Both baseball stiffness and mass have been identified as important contributors to the magnitude and severity of head and chest injuries [27-28,11].   A 2006 study by Fleisig et al. showed that reducing the mass of a baseball from five ounces to four also reduces elbow varus torque and shoulder internal rotation torque in youth pitchers, thus leading to the belief that reducing baseball mass may be effective in reducing overuse arm injuries [8].   Previous research indicates that either reducing the mass of the baseball or reducing its stiffness could result in a decrease in the number of injuries or injury severity.

A previous study by Matta et al. showed that reducing the mass of a baseball from five ounces to four, reduced the time available to react for a youth pitcher standing 46 feet from home plate by approximately 10% [29].   So although a reduced mass ball may be attractive for limiting the severity of ball-player impact injuries or chronic arm injuries in youth players, it may actually increase the incidence of ball-player collisions.   No study to date has examined how reaction time or available time to react influence impact probability in youth players.

Psychologists have identified three different types of reaction time tests but likely the most relevant or applicable test for baseball avoidance is the simple reaction time test [30, 31].   In a simple reaction time experiment there is only one stimulus and one response with no distraction or choice involved in the experiment.   This is similar in construct to a player reacting to and trying to avoid a struck baseball.   The only stimulus is the oncoming baseball and there is likely little distraction or choice involved but rather just an instinctive reaction. If these two tasks are indeed similar, it is possible that knowing a player's mean simple reaction time (mSRT) would give you an indication of a player's ability to avoid a baseball.

That would then open the door to testing each youth player's reaction time in order to determine their likelihood or danger level for batted ball injuries. Knowing each players mSRT could be used to inform coaches on which players should play where. If a player has a slow mSRT, a coach could then decide to put that player in the outfield or middle infield rather than have him pitch or be a corner infielder where the risk of injury is perceived to be greater.

The primary aim of this study was to determine the factors that influence a youth player's ability to avoid a struck baseball in a game scenario. The factors we considered included the available time to react, mean reaction time, age, primary position, and experience for each subject. We examined two hypotheses.

First we expected that reducing the available time to react by 10% (expected from reducing ball mass from five ounces to four) would yield a significant increase in impact probability for pitchers and players alike. Second, we expected that mean reaction time would be a primary predictor of impact probability.

CHAPTER 3.2 METHODS

Nineteen male youth players, age 11 ± 1.45 years, height 1.56 ± 0.11 m, and mass 47.53 kg ± 12.64 kg, were recruited from local city teams in the Raleigh, Durham and Chapel Hill, NC area. For all subjects, parental consent and a brief medical history were obtained. In addition, each subject, with the assistance of their parents, completed a questionnaire that detailed previous baseball experience, primary position, and number of sports played. Subjects with previous arm injuries caused by baseball activity were excluded from this

study. The Institutional Review Board at the University of North Carolina – Chapel Hill approved this study.

The study was organized into three separate experiments: a (1) simple reaction time (SRT) test, an (2) avoidance reaction time (ART) test, and a (3) pitching reaction time (PRT) test. Each subject completed each test in the order presented above.

The SRT test is a standard visual reaction time test for healthy populations in which there is only one stimulus and one response [30]. ANAM[4] (Vital LifeSciences, Parker, CO) software was used to administer the SRT test from a laptop computer. In this test, each subject sat in front of the computer screen and was given the same set of verbal and written instruction. Each subject had a practice round of five stimuli/responses. Upon beginning the test, the computer screen was solid blue. Every few seconds a large white star would appear against the blue background and the subject would click the mouse button with their preferred hand to cause the star to disappear [32]. This constitutes one stimuli/response. After finishing the practice round of five stimuli/responses, each subject was free to ask questions if doubt still remained of how to complete the test. The final test consisted of 40 stimuli/responses with mean simple reaction time (mSRT) being the primary outcome of interest.

After completing the SRT test, each subject began the ART test. The ART test was used to determine the participant's ability to avoid a ball that is directed towards them. This test was designed to simulate a defensive (non-pitcher) player reacting to a struck ball in a baseball game. A 2011 Azodin Blitz (Azodin LLC, Pomona, CA) paintball gun was modified in order to shoot a NERF Ballistic Ball (Hasboro, Pawtucket, RI) at the

participants. The paintball gun was secured in a wooden box in an effort to reduce the noise and increase the precision and repeatability of each fire. The exit velocity of the NERF ball was fixed at 32.7 ± 0.6 mph.

Each participant was instructed to stand over a landmark in the lab with their hands resting on their thighs. The participant was given instructions to avoid the oncoming ball. They were told that they could use any technique for avoiding the ball such as catching the ball, dodging the ball, or a combination of both strategies. After the instructions were given, the participant was asked to verbally indicate that they were ready before each ball was fired. Once the participant indicated they were ready, a button was pushed that caused the paintball gun to shoot a NERF ball at the participant after a short delay. The delay between the button push and the ball being shot was randomized between one and four seconds in an effort to prevent subjects from anticipating or learning the timing between the button push and ball exit. The paintball gun was aimed so that the trajectory of the ball would intersect the participant in the middle of their torso. After each ball was fired, the pitch of the gun inside the box was randomly adjusted in an effort to mitigate the participant anticipating the location of where the fired NERF ball would impact them.

Each subject had a practice round of four stimuli/responses followed by four rounds of 10 stimuli/responses for a total of 44. At the end of each round, the distance between the participant and the paintball gun was altered in order to change the time the participant had to react to and avoid the ball. The distance between the paintball gun and the player in the practice round was fixed so that all participants had 425 ms to react. This time was chosen after pilot testing indicated that this was a time most, if not all participants could successfully

avoid each and every time. For the subsequent four rounds, the available time each participant had to react was determined by their performance on the SRT test as measured by their mSRT. The available time at each round was as follows: mSRT, mSRT + 25 ms, mSRT + 50 ms, mSRT + 75 ms.

For example, if a participant had a mSRT of 300 ms, than their avoidance trials would be conducted with an available time to react of: 300, 325, 350, and 375 ms. The ART test for this participant would be a practice round of four stimuli/responses at 425 ms and 10 stimuli/responses at 300, 325, 350, and 375 ms, respectively, for a total of 44 stimuli/responses. The practice round was first for each subject but the order of the following four rounds were varied so the available times for each subject, although set by the method described above, was not identical for each subject.

As previously mentioned, each subject was instructed to 'avoid' the oncoming ball. We also instructed each participant of the rubric for scoring the test to alleviate any lingering confusion. A response was scored as an 'avoid' if the participant was able avoid the ball completely or deflect/catch the ball with their hands before the ball struck their body. In this definition, catching the ball by trapping it against their body (a less than optimal method to catch a baseball in an actual game scenario) would be discouraged, as it would be considered a 'hit'. A response was scored as a 'hit' if the ball contacted any part of their body before their hands. The outcome of interest in this experiment was impact probability as a function of the available time to react.

The third and final experiment was the pitching reaction time (PRT) test. The PRT test was scored in the same manner as the ART test and also used impact probability as a

function of available time to react as the main outcome of interest. In the ART test we tested the avoidance ability of a non-pitcher position player reacting to a line drive but in the PRT test we tried to mimic the scenario of a line drive being hit directly at a pitcher after delivering a pitch (Figure 3.1). We considered pitchers separately from position players because of a perceived difference in avoidance ability between the positions in most scenarios. When a ball is struck by a batter we believed that a defender is often balanced, ready to react, and anticipating a ball being hit in their direction where as a pitcher is often in an unbalanced state and, in many cases, not anticipating the ball being hit towards them.
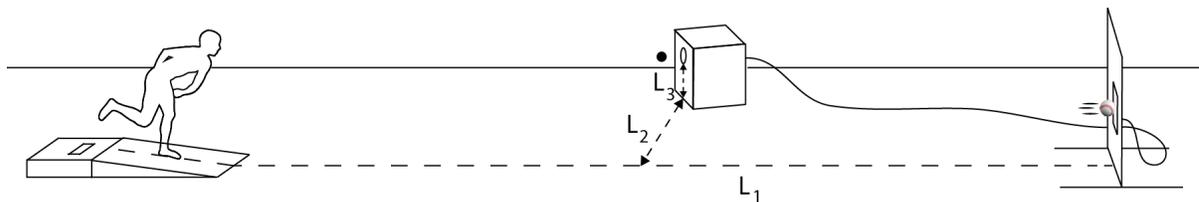

Figure 3.1 Sketch of lab set-up for the pitching reaction time (PRT) test. The participant pitches from the mound and throws a ball into the pitching backstop where the attached microphone sends a signal to the microcontroller to shoot a NERF ball at the pitcher. L_1 is the distance between the pitching rubber and the pitching backstop (46 feet), L_2 is the perpendicular distance from the center line that runs from the center of the rubber to the center of home plate (2.5 feet), and L_3 is the vertical distance from the floor to where the ball is fired from the paintball gun within the box (3.5 feet)

Practice was not allowed for this task because each subject had already completed the ART test and it was assumed that they were familiar with the avoidance task being asked of them. However, there was no chance of a ball being directed at them for their first five or their last five pitches. Kinematic data was collected, although not presented in this study, and the first five pitches and last five were used for this analysis when the participants were not under the threat of a ball being returned.

In the PRT test the participant delivered a pitch from a custom built mound into a backstop a standard distance of 46 feet. In order to simulate the situation where a batter strikes a ball back at the pitcher, the pitching backstop was fitted with an ADMP401 MEMS Microphone (Sparkfun Electronics, Boulder, CO). The microphone detected the impact of a pitched ball into the pitching backstop and fed this signal into a microcontroller (PIC18F4520) to trigger the firing of a NERF ball from the paintball gun. However, the paintball gun did not fire every time the ball impacts the backstop. A ball would only be returned 12 times out of the 50 pitches thrown by the participant. Whether or not a NERF ball was fired back at the participant was controlled by a microcontroller and was unique for all participants. Of the 12 balls directed at the participant, six afforded 400 ms to avoid and six afforded 440 ms to avoid (10% difference). The order was randomized for each participant. The paintball gun was placed 2.5 feet off-center from the pitching rubber: on the pitchers left-hand side if he was right handed, and the right-hand side if he was left handed (Figure 3.1). The distance between the pitcher and the paintball gun determined how much time they had available to react.

The rationale for choosing 440 and 400 ms of available reaction time for the PRT test was based on previous research by Matta et al. [29]. They showed that there is approximately a 10% difference in the available time to react between a standard five ounce ball (440 ms) and a lightweight four ounce ball (400 ms). They showed that with a standard ball, the available time to react could be as little as 440 ms with a pitcher who throws with high velocity and a hitter swings with a high velocity but 400 ms is highly unlikely for little league players using a standard ball. However, the same pitcher-batter scenario that

generated an available time of 440 ms for a standard ball would leave a player with approximately only 400 ms to react if the mass of the ball was four ounces. In this way, the six balls that we directed back at the pitcher with 440 ms to react represent a standard ball and lightweight ball under certain scenarios but the balls that leave the pitcher with only 400 ms to react are likely only possible in the youth game with a ball lighter than five ounces.

All statistics presented were computed using IBM SPSS Statistics version 17 (IBM, Armonk, NY). All regressions presented are from the raw binary outcome data and not aggregated data for each subject. Additionally, practice round data from the ART test was included in the model and presented in Figure 3.2 and Table 3.2. For the ART and PRT tests, we performed a binary logistic regression on our binary outcome variable of interest, impact probability. The models were initially designed with all of factors of interest included (available time to react, mSRT, age, primary position, and experience) but if the model lacked significance than the factors were systematically reduced and the model recreated using a reduced set of factors of interest.

Table 3.1 Breakdown of the participant population by primary position, age, and experience.

	Number of Participants	Mean Reaction Time – mSRT (ms)	Standard Deviation
Primary Position			
Pitcher	8	310	28.0
Infielder	7	294	11.4
Outfielder	1	298	-
Catcher	3	274	27.0
Age			
9	4	312	20.8
10	2	321	33.7
11	7	299	17.9
12	1	253	-
13	5	285	22
Seasons of Experience			
2	2	320	32.3
3	7	290	29.8
4	1	281	-
5	5	300	10.5
6	2	303	6.08
7	-	-	-
8	2	301	44.95

CHAPTER 3.3 RESULTS

The results of the simple reaction time (SRT) test are shown Table 3.1. The mSRT for all 19 participants was 298 ms. There was no significant difference in the mSRT between positions using 95% confidence intervals (CI). Catchers tended to have faster mSRTs than all other positions with an average of 274 ms, while pitchers tended to be slowest with an average of 310 ms. There was also no significant difference in mean reaction time between age groups, although mean reaction time tended to decrease with increasing age, which agrees with previous work [33].

Although age and primary position were not significant factors in the SRT test, they were significant, as was available time to react, in predicting performance in the avoidance

reaction time (ART) test (Table 3.2).   Figure 3.2 shows a scatter plot of the results from the

ART test for all individuals as well as the binary logistic regression that best fit the data. The

results from the ART test (Eq. 3.1.) also serves as the 'best case scenario' for impact

probability for pitchers which will be examined further in the *Discussion* section.   The

regression equation is

$$IP_{ART} = \frac{1}{1+e^{-(18.457-0.049*ATR-2.084*C-0.383*IF-0.742*OF-0.266*Age-0.001*Exp)}} \qquad (3.1)$$

where IP_{ART} is the impact probability during the ART test, *ATR* is the available time to react,

C is a catcher, *IF* is an infielder, *OF* is an outfielder, *Age* is the age of the player, and *Exp* is

the experience of the player measured by seasons.   A subject could have one year of

experience but multiple seasons of experience if he played in a spring, summer and fall

league – three seasons total.

Table 3.2 Significance levels for variables included in the
binary logistic regressions equations

Factors	ART/Best Case	PRT (Exposure 1)/ Worst Case
Time	.000[*]	.324
Reaction Time	.948	-
Age	.011[*]	.093
Experience	.990	.023[*]
Catcher	.000[*]	-
Infielder	.079	-
Outfielder	.109	-

* 95% confidence intervals - p-value (<.05)

Figure 3.2 also includes four additional curves which show how the impact

probability changes for certain populations including: a 9 year old pitcher, a 9 year old

catcher, a 13 year old pitcher, and a 13 year old catcher each with an average of 4.3 seasons

of experience.   Both Figure 3.2 and the Eq. 3.1 show that as the age of the participant

increases, their impact probability decreases.   Additionally, it also shows that catchers are

better at this avoidance task than pitchers.
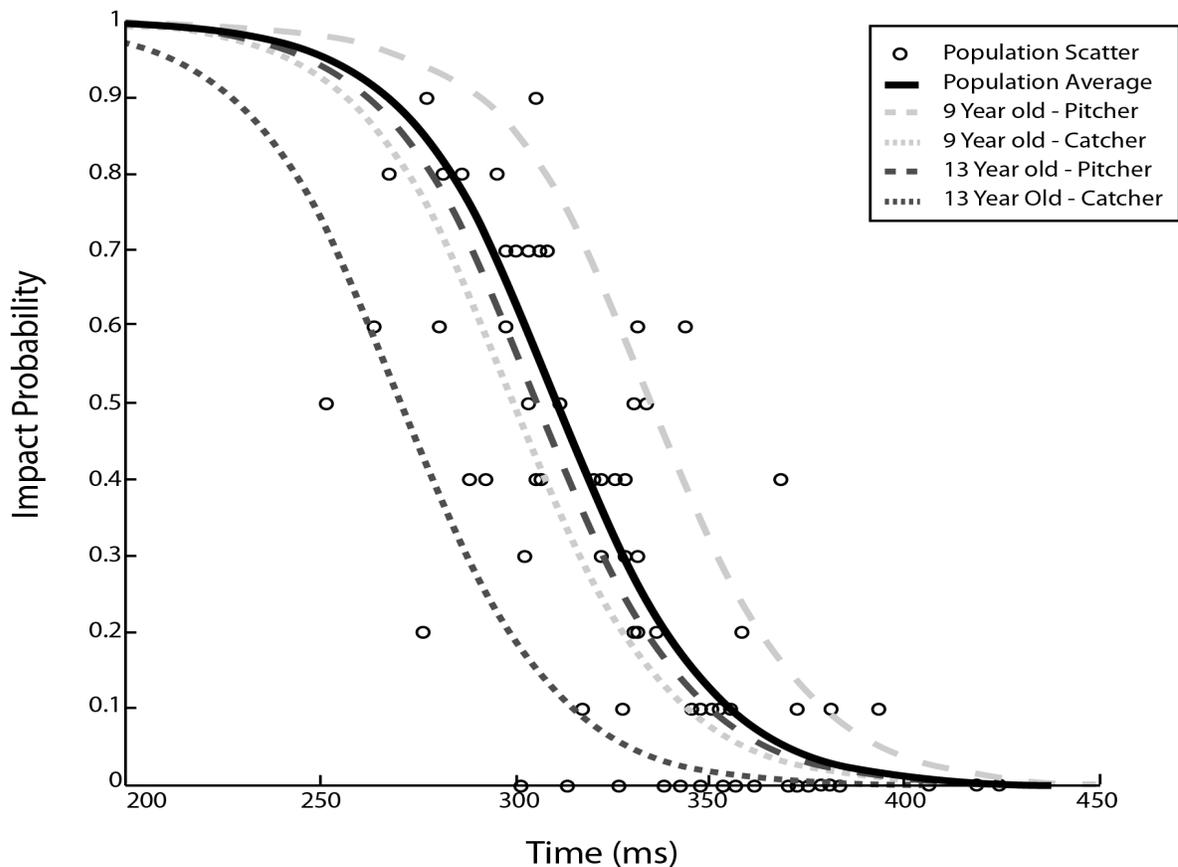
Figure 3.2 Scatterplot of the results from the avoidance reaction time (ART) test. Each open circle represents the outcome of one round or the average of 10 stimuli/responses. The solid black line is a plot of Equation 3.1 for the average participant – an 11-year-old pitcher with 4.3 seasons of experience. The grey and black dotted lines are plots of Equation 3.1 but with varying ages and primary positions.

The results from the pitching reaction time (PRT) test indicate that previous

experience (i.e. the number of seasons played) is the only significant factor in determining

impact probability after delivering a pitch (Table 3.2). The aggregated results of 19 subjects

for each exposure are shown in Figure 3.3. The first exposure the participants had with 400

ms to react resulted in a 'hit' nearly 90% of time but by the last exposure it only resulted in a

hit 16% of the time. When given 440 ms to react the first exposure resulted in a 'hit' nearly

80% of the time but the by the last exposure it only resulted in a hit 21% of the time.

Notably, for each exposure, the difference between the average number of 'hits' at 400 and

440 ms was insignificant using 95% CI.
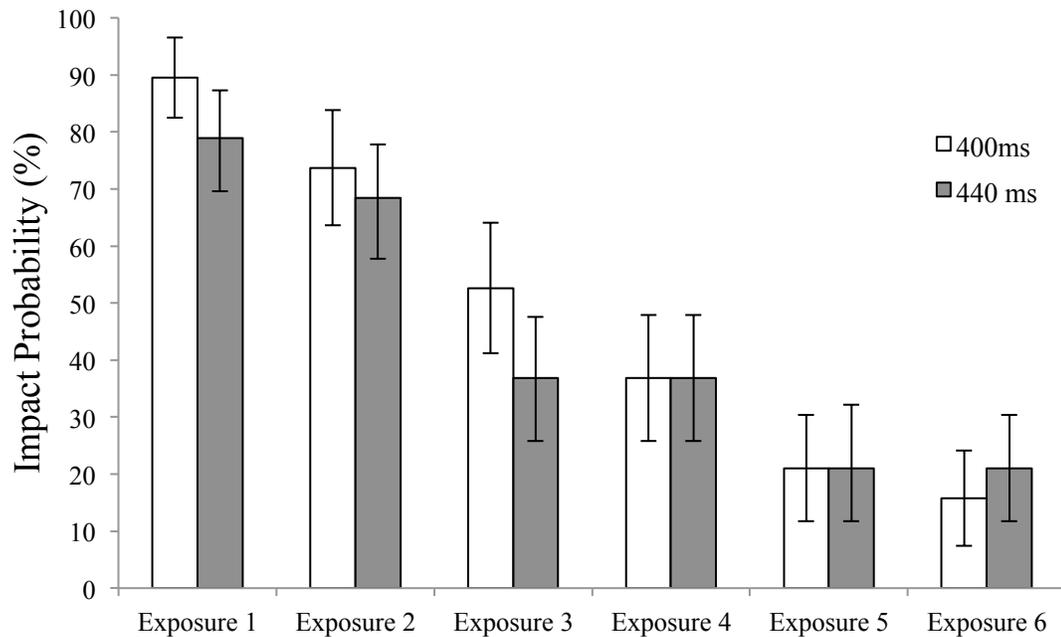
Figure 3.3 Bar-graph of aggregated impact probability data for 19 participants. Each subject had to avoid six balls with 400 ms to react and six balls with 440 ms to react. Exposure 1 represents their first attempt at both times and Exposure 6 represents their last attempt at both times.

We fit a binary logistic regression for the first exposure (reasoning examined in the

Discussion) shown by Eq. 3.2. This result (Eq. 3.2) also serves as the 'worst case scenario'

for the impact probability of pitchers. This will be further addressed in the *Discussion*

section.

$$PRT\ IP = \frac{1}{1+e^{-(7.889-0.027*ATR-0.848*Age-0.852*Exp)}}\qquad(3.2)$$

Primary position and mean reaction time were initially considered in the model but had very small coefficients and reduced the overall significance of the model so they were omitted in the final model shown by Eq. 3.2. A plot of the regression equations from the ART test (best case) and the first exposure of the PRT test (worst case) are shown in Figure 3.4 and examined in the *Discussion*.
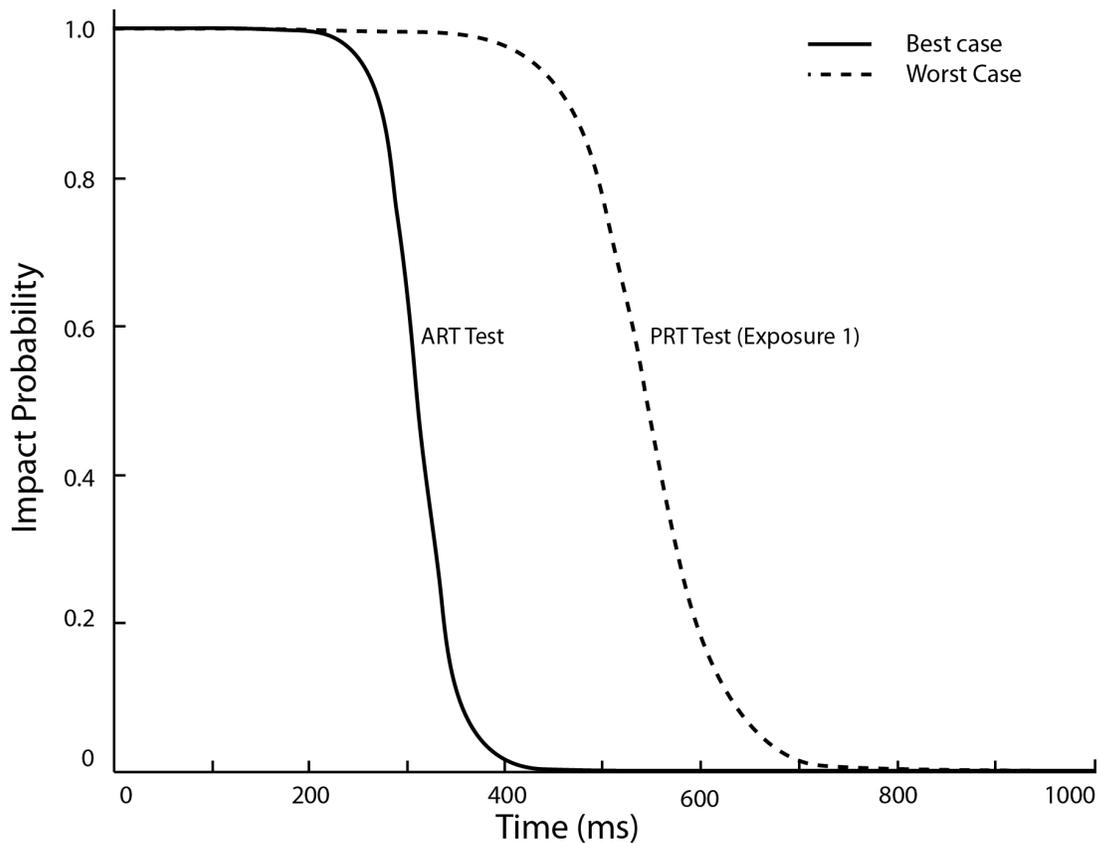

Figure 3.4 A plot of the Eqs. 3.1 & 3.2. The solid black line is the best case scenario represented by the ART test and the dotted black line is the worst case scenario represented by the Exposure 1 of the PRT test.

CHAPTER 3.4 DISCUSSION

The results from this study partially support the first hypothesis that a 10% reduction in the available time to react will significantly increase impact probability for both players and pitchers. Considering position players first, the results from the ART test (Figure 3.2 & Table 3.2) show that the available time to react does play a significant role in determining impact probability. However, Figure 3.2 shows that impact probability is only sensitive to available times to react from 225-440ms. At these times a 10% reduction in the time available to react can increase impact probability anywhere from 5-36%. Our results do not directly support or reject our hypothesis for position players but rather show that there is a certain range of times where a 10% decrease in the available time to react can dramatically increase impact probability, even if that range of times is quite small.

It should be noted that previous work by Matta et al. showed that even in very high collision speeds between a bat and a five-ounce baseball, it would likely take more than 400 ms to travel 46 feet [29]. The closest defenders to the batter, not including the pitcher, are typically the first and third baseman and they are often positioned 55 feet away or more. Thus, the results from the ART test show that in situations that are typical in the game of youth baseball, a 10% reduction in the available time to react will not greatly affect impact probability for position players.

To consider pitcher's impact probability we can reexamine Table 3.2 and Figures 3.3 and 3.4. The PRT test was designed to have a ball directed towards the pitcher only 12 times out of the 50 pitches thrown in an effort to keep the participants from anticipating a ball being returned. However, the results clearly show some learning or anticipation affect from

the first few times they attempted to avoid a ball (Exposures 1 and 2 in Figure 3.3) to the last few times (Exposures 5 and 6 in Figure 3.3).

We observed that during Exposures 1 and 2, most participants were relaxed, focused on pitching, and rather unconcerned with a ball potentially being fired at them. After each pitch, most participants would slightly fall off to one side of the mound. After the first few exposures, their mechanics started to change slightly. Instead of falling off to one side of the mound, most participants finished in a fairly balanced state. Instead of tucking their glove tight to their chest, they often finished with their glove out in front of their body and open, ready to catch a returned ball.

The learning or increased anticipation from each exposure presents a challenge in determining which exposure is representative of an real game scenario. Many methods could be employed but we adopted the strategy of creating a best-case-worst-case scenario. The worst-case scenario for a pitcher may be adequately represented by the first exposure. At this exposure, most participants seemed completely unconcerned with avoiding a ball and were only worried about throwing strikes. Although the best-case scenario for a pitcher could be represented by Exposure 6, we felt it would be more logically estimated by the results in the ART test. The ART test represented a scenario where the player knew that a ball was coming and they were balanced and prepared to avoid the ball. From a real game perspective, this is likely the most we could ever expect out of any defensive player or pitcher.

If we take this approach, it is possible to create an upper and lower bound for our expectations of the impact probability for a pitcher (Figure 3.4). The best-case in Figure 3.4 represents a scenario where the pitcher is anticipating having a ball hit back at them. This

scenario could occur when a physically imposing hitter is up to bat so the pitcher may be expecting a hard hit ball or maybe it's a late-game situation and the hitter who is up has already hit two balls back up the middle so the pitcher is anticipating another. Conversely, the worst-case scenario could occur when a diminutive hitter is up to bat or the hitter has a three ball and no strike count so the pitcher does not expect the hitter to swing on the next pitch he delivers.

Figure 3.4 indicates the impact probability for a pitcher is sensitive over a range of available times to react from 224-600 ms. Consequently, our results suggest that the only times in which a 10% reduction in the available time to react will not significantly increase impact probability is when the exit of the velocity of the batted ball is high enough to only leave the pitcher with less than 225 ms or low enough to leave him more than 650 ms to react. Times between 225 and 650 ms could substantially increase the impact probability, anywhere from 5-36%.

Interestingly, the factors that predict impact probability for position players and pitchers do not agree (Table 3.2). Age, available time to react, and position influence impact probability for position players but when attempting to avoid a ball after delivering a pitch only experience influences impact probability. Finally, our hypothesis that mean simple reaction time (mSRT) would be a significant factor in determining impact probability was not supported by our results (Table 3.2). The significant role that playing experience has in ball avoidance as a pitcher may not be all that surprising. Injury literature has showed us that these batted ball injuries become less common as players get older and it is clear to see that playing experience and age have a positive correlation [1]. Age was a significant factor for

impact probability in the ART test and was close to being significant in the PRT impact probability model (Table 3.2) and may have been with additional subjects. The results from this test, as well as past injury evidence show us that playing experience and age are vital in determining risk of an acute batted ball injury. Interestingly, it may actually be a combination of a lack of playing experience and age that is most dangerous to player safety rather than equipment. Lastly, increased caution and concern for player safety seems to be warranted during the first few years of a baseball player's development.

This study has limitations. The paintball gun used to fire balls at the participants was only accurate over a distance of some 30 feet. For this reason, balls were not fired from 46 feet and in line with home plate as would be preferred to better represent a struck ball in a real-game scenario. In pilot testing the location of the paintball gun was offset to the right, offset to the left, and in line with the pitcher but lower on the ground in order to determine the optimal location. Ultimately, we decided to put it on the side opposite of the players throwing arm because participants noted that it was easier to 'see the ball' from this side.

Additionally, the NERF ball used was 0.044 m in diameter, 0.029 m smaller than a baseball. This potentially could have made the ball more difficult to see for participants than a standard baseball and artificially increased the impact probabilities reported.

CHAPTER 3.5 CONCLUSIONS

The purpose of this study was to investigate whether reducing ball mass from five to four ounces for youth baseball would influence the incidence of acute batted ball impact injuries. Although previous research showed that a four-ounce ball would reduce the

available time to react by 10%, the effect of this reduction had not been previously investigated or quantified. Our results indicate that a 10% reduction in the available time to react would not significantly increase batted ball impact injuries to position players. This result is a consequence of position players having more than enough time to avoid batted balls, whether standard or lightweight, in typical defensive alignments where they are 50 or more feet from home plate. Pitchers, however, are only 46 feet from the batter and are often unbalanced after delivering a pitch. Our results indicate that delivering a pitch increases the amount of time required for a player to avoid a batted ball. Transitioning to a four-ounce ball in youth baseball could, in some cases, increase the batted ball impact probability of pitchers by over 30%.

CHAPTER 4 CONCLUSIONS AND FUTURE DIRECTIONS

As one of the oldest organized youth sports in America, the future of youth baseball continues to be bright. However, the increasing number of chronic arm injuries in players no older than 10 or 11 years old is alarming and acute ball-player collisions result in thousands of emergency room visits each year, with only youth football and basketball causing more visits.

The goal of this work was to show that both and chronic arm injuries and acute batted ball injuries could be reduced through the manipulation of baseball characteristics. It was already known that a reduction in baseball mass would decrease the likelihood of chronic arm injuries but side effects were unknown [8]. We were able to show that reducing ball mass by 20%, from five ounces to four, would leave a pitcher with 10% less available time to react and increase batted ball distance giving a competitive advantage to offenses if

implemented in the game today. We were also able to show that a 10% reduction in the available time to react would not likely increase the incidence of batted ball-player collisions for infield defenders like the third and first basemen, but could potentially raise the impact probability for a pitcher by up to 36% compared to a typical five-ounce ball.

If, however, we not only decrease the mass of the baseball but the coefficient of restitution (COR) as well, we can create a baseball that plays nearly equivalent to a standard five-ounce ball with additional benefits. This baseball would reduce the momentum at a ball player collision by 25%, likely reducing the severity of ball-player collision injuries. Additionally, because of the lower COR, the ball would allow both pitchers and position players the same amount of time to react as a standard ball, keeping the incidence of batted ball collisions the same. Lastly, the reduction in mass would likely also decrease the incidence of chronic arm injuries in youth players.

With little downside, a four ounce ball with a reduced COR appears to be a strong candidate to making 'The Great American Pastime' a safer game for our youth. However, further work still needs to be done. Our work has laid out the specification for a safer baseball but experimentation still needs to be done on how best to manufacture and produce this redesigned ball. Additionally, work needs to be done to determine when youth players should transition from using a four-ounce ball to a five-ounce ball and whether or not there should be an intermediate ball mass between the two.

Although questions remain on how best to implement a new ball into the youth sport, our work has provided a strong and simple argument for how to make youth baseball safer: change the baseball.

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