

[Orthopaedic Surgery]

Factors Influencing Ball-Player Impact Probability in Youth Baseball

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Background: Altering the weight of baseballs for youth play has been studied out of concern for player safety. Research has shown that decreasing the weight of baseballs may limit the severity of both chronic arm and collision injuries. Unfortunately, reducing the weight of the ball also increases its exit velocity, leaving pitchers and nonpitchers with less time to defend themselves. The purpose of this study was to examine impact probability for pitchers and nonpitchers.

Hypothesis: Reducing the available time to respond by 10% (expected from reducing ball weight from 142 g to 113 g) would increase impact probability for pitchers and nonpitchers, and players' mean simple response times would be a primary predictor of impact probability for all participants.

Study Design: Nineteen subjects between the ages of 9 and 13 years performed 3 experiments in a controlled laboratory setting: a simple response time test, an avoidance response time test, and a pitching response time test.

Methods: Each subject performed these tests in order. The simple reaction time test tested the subjects' mean simple response times, the avoidance reaction time test tested the subjects' abilities to avoid a simulated batted ball as a fielder, and the pitching reaction time test tested the subjects' abilities to avoid a simulated batted ball as a pitcher.

Results: Reducing the weight of a standard baseball from 142 g to 113 g led to a less than 5% increase in impact probability for nonpitchers. However, the results indicate that the impact probability for pitchers could increase by more than 25%.

Conclusion: Pitching may greatly increase the amount of time needed to react and defend oneself from a batted ball.

Clinical Relevance: Impact injuries to youth baseball players may increase if a 113-g ball is used.

Keywords: baseball; reaction time; response time; impact injury; youth

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.⁷ 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.⁵ Baseball injuries can typically be classified into 2 groups: acute and chronic. While numerous interventions such as break-away bases,⁵ batting helmets,⁵ face shields,⁵ and rubber-molded cleats⁵ have been adopted by many youth leagues to curb the rise in acute injuries, intervention to stem chronic arm injuries is more difficult. A 2006 study by Fleisig et al showed that reducing the mass of a baseball from 142 g to 113 g reduces elbow varus and shoulder internal rotation torque in youth pitchers, thus leading to the belief that reducing baseball mass may be effective in

reducing chronic overuse injuries to the arm.⁴ Although this seems promising to reduce chronic arm injuries, the effect a lighter ball would have on acute injuries is unknown. A lighter ball may travel faster, leaving players with less time to respond and potentially causing ball-player impact injuries to increase.

Previous research from Mueller et al showed that 52% to 62% of baseball-related injuries occur from ball-player impact, with the majority affecting defensive or fielding players.¹¹ 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- to 14-year-old children in the United States.^{5,8} 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

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of cardiac abnormality). A study into the deaths of 23 pitchers from 1973 to 1983 concluded that commotio cordis was the cause in 35% of the cases, while another study showed that it causes 2 to 4 deaths per year in baseball.^{5,15}

Fundamental changes to the ball and bat have been suggested to reduce the number of injuries (both acute and chronic). 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.⁸ Both baseball stiffness and weight have been identified as important contributors to the magnitude and severity of head and chest injuries.^{1,16,18} Previous research indicates that either reducing the weight of the baseball or its stiffness could result in a decrease in injuries or injury severity.¹ However, the effect of reducing ball weight on batted-ball exit velocity has not been explored directly.

Previous work by Nathan¹² and Sawicki et al¹⁴ provided a robust framework for evaluating the exit velocity of a bat-ball collision. The work by Sawicki et al showed that the exit velocity of a batted ball is a function of the velocity of the ball prior to impact, ball mass, and the final impulse of the collision (appendix, Equation 1).

If the velocity of the ball prior to impact is held constant, the exit velocity of the ball is solely a function of the inverse of the ball mass and the final impulse (also a function of ball mass). Calculations in previous work from Matta et al showed that reducing the ball weight from 142 g to 113 g increased batted-ball exit velocity and reduced the available time to respond for a pitcher standing 46 feet from home plate by approximately 10%.¹⁰ Although a reduced ball weight 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 for pitchers and fielders as they have less time to respond.

A number of studies have estimated the amount of time it takes for a batted ball to reach a pitcher at the college or professional level, which provides insight into the likelihood of a batted-ball-player collision. Lipps et al suggested that a pitcher has a minimum of 406 ms to respond to a batted ball.⁹ However, we were unable to find estimates for the time to respond to a batted ball at the youth level. Previous work by Matta et al suggested that youth pitchers standing 46 feet from home plate had approximately 440 ms to respond before being struck if a standard ball is used and as little as 400 ms if a lightweight 113-g ball is used.¹⁰

Although difficult to assess, a few studies have addressed sport-protective responses. Research by Lipps et al showed that healthy male adults exhibit significantly faster response times during a sport-protective blocking maneuver than female adults while also showing a reduction in total response time under high-difficulty scenarios.⁹ In addition, work by DeGeode et al showed that age, sex, and perceived threat significantly affected movement times to intercept an approaching object.² Owings et al tested the reaction and movement times of boys and girls ranging from 8 to 16 years by projecting baseballs at

the subjects while they stood behind a protective safety net.¹³ The results showed that the 8- and 9-year-old subjects had sufficient time to respond, with a mean exit velocity of 26.8 m/s; the 16-year-old group had a mean exit velocity of 33.5 m/s. However, the accuracy of both responses was negatively affected by ball velocity.¹³ Finally, a study by Eckner et al revealed that a clinical test of simple visuomotor reaction time was predictive of a functional sport-related head protective response in healthy adults.³

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 considered included the available time to respond (TTR), mean simple response time (mSRT), and primary position for each subject. We examined 2 hypotheses. First, we hypothesized that reducing the available TTR by 10% (expected from reducing ball weight from 142 g to 113 g) would yield an increase in impact probability for both pitchers and nonpitchers. Second, we expected the subjects' mSRT to be a primary predictor of impact probability for both pitchers and nonpitchers.

MATERIALS AND METHODS

Nineteen male youth players (mean age, 11 ± 1.45 years; mean height, 1.56 ± 0.11 m; mean mass, $47.53 \text{ kg} \pm 12.64 \text{ kg}$) were recruited from local youth baseball organizations. For all subjects, university institutional review board approval, parental consent, and a brief medical history were obtained. Each subject, with the assistance of his parent(s), 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.

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

Simple Response Time

The SRT test is a standard visual response time test for healthy populations in which there is only 1 stimulus and 1 response.¹⁷ Automated Neuropsychological Assessment Metrics (ANAM,⁴ Vital LifeSciences, Parker, Colorado) software was used to administer the SRT test from a laptop computer. Response time is composed of 2 components: reaction time and movement time.¹³ In this experiment, reaction time can be characterized as the time elapsed between the stimulus onset of finger movement while movement time is the time elapsed between the onset of finger movement and a complete button click. The individual components of response time were not captured in this study. Each subject sat in front of a computer screen and was given the same set of verbal and written instructions. Each subject had a practice round of 5 stimuli/responses. Upon initiation of the test, the computer screen was solid blue. Every few seconds, a large white star would appear against the blue

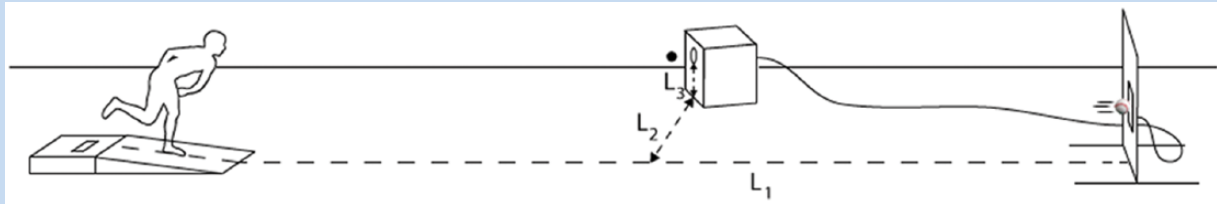


Figure 1. Laboratory setup for the pitching response time test. The participant pitches from the mound and throws a ball into the pitching backstop, where the attached microphone sends a signal to the microcontroller to shoot a NERF ball at the pitcher. L1 is the distance between the pitching rubber and the backstop (46 feet), L2 is the perpendicular distance from the box to the center line that runs from middle of the rubber to the middle of home plate (2.5 ft), and L3 is the vertical distance from the floor to where the ball is fired from the paintball gun within the box (3.5 ft).

background and the subject would click the mouse with their preferred hand to cause the star to disappear.¹⁷ This constituted 1 stimuli/response. After finishing the practice round of 5 stimuli/responses, each subject was free to ask questions if doubt still remained regarding how to complete the test. The final test consisted of 40 stimuli/responses, with mSRT being the primary outcome of interest.

Avoidance Response Time

The ART test was used to determine the participant's ability to avoid a ball directed toward him. This test was designed to simulate a defensive (nonpitcher) player responding to a struck ball in a baseball game. A 2011 Azodin Blitz (Azodin LLC, Pomona, California) paintball gun was modified to shoot a NERF Ballistic Ball (Hasbro, Pawtucket, Rhode Island) at the participant. 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.

All participants were instructed to stand over a landmark in the laboratory with their hands resting on their thighs without their baseball glove. The participants were given instructions to avoid the oncoming ball. They were told that they could use any technique for avoiding the ball such as catching, dodging, or a combination of both. After the instructions were given, the participants were asked to verbally indicate that they were ready before each ball was fired. Once the participants indicated they were ready, the NERF ball was shot at the participants after a short delay. The delay was randomized between 1 and 4 seconds in an effort to prevent subjects from anticipating the ball exit. The paintball gun was aligned so that the trajectory of the ball would intersect the participants in the middle of their torso. After each ball was fired, the pitch box was randomly adjusted in an effort to mitigate the participants anticipating the location of where the ball would impact them.

Each subject had a practice round of 4 stimuli/responses followed by 4 rounds of 10 stimuli/responses, for a total of 44 stimuli. At the end of each round, the distance between the participant and the paintball gun was altered to change the time the participant had to respond to and avoid the

ball; the distance in the practice round was fixed so that all participants had 425 ms to respond, which was chosen after pilot testing indicated that this was a time over which most participants could successfully avoid the ball every time. For the subsequent 4 rounds, the available time each participant had to respond was determined by his performance on the SRT test, as measured by his mSRT. The available time at each round was as follows: (1) mSRT, (2) mSRT + 25 ms, (3) mSRT + 50 ms, and (4) mSRT + 75 ms. For example, if a participant had an mSRT of 300 ms, his avoidance trials would be conducted with an available TTR of 300, 325, 350, and 375 ms. The practice round was first for each subject, but the order of the following 4 rounds was varied so the available times for each subject were not identical.

Each participant was informed of the scoring rubric for the test. A response was scored as an "avoid" if the participant was able to avoid the ball completely or deflect/catch the ball with his hands before the ball struck his body. In this definition, catching the ball by trapping it against his body (a less-than-optimal method of catching a baseball in an actual game scenario) would be discouraged, as it would be considered a "hit." A response was scored as "hit" if the ball contacted any part of his body before his hands. The outcome of interest in this experiment was impact probability as a function of the available TTR.

Pitching Response Time

The PRT test was scored in the same manner as the ART test, with impact probability as a function of available TTR as the main outcome of interest. Unlike the ART test, where avoidance ability of a nonpitcher responding to a line drive was tested, the PRT test was designed to mimic a line drive being hit directly at a pitcher after delivering a pitch (Figure 1). Pitchers were considered separately from nonpitchers because of a perceived difference in avoidance ability between the positions in most real-game scenarios. It was assumed that when a ball is struck by a batter, defenders are often balanced, ready to respond, and anticipating a ball being hit in their direction. Conversely, pitchers are often in an unbalanced state and, in many cases, not anticipating the ball being hit in their direction.

Table 1. Breakdown of the participant population by primary position, age, and experience

	Number of Participants	mSRT (ms)	Standard Deviation
Primary position			
Pitcher	8	310	28.0
Nonpitcher	11	289	18.7
Age, y			
9	4	312	20.8
10	2	321	33.7
11	7	299	17.9
12	1	253	—
13	5	285	22.0
Seasons of experience			
0-4	10	295	25.0
5-8	9	300	24.0

mSRT, mean simple reaction time.

Practice was not allowed for this task because all subjects had already completed the ART test and it was assumed that they were familiar with the requisite avoidance task. However, there was no ball directed at them for their first and last 5 pitches. Although not presented in this study, kinematic data were collected on these pitches. The participant delivered a pitch from a custom-built mound into a backstop at a standard distance of 46 feet (see Figure 1). 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, Colorado). 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 impacted the backstop. A ball would be returned only 12 times of the 50 pitches thrown by the participant. Whether a NERF ball was fired back at the participant was controlled by a microcontroller and was unique for all participants. The paintball gun was placed 2.5 feet off-center from the pitching rubber and on the pitcher's left if he was right-handed or right if he was left-handed (see Figure 1). The distance between the pitcher and the paintball gun determined how much time the pitcher had available to respond. Of the 12 balls directed at the participant, 6 afforded 400 ms to avoid and 6 afforded 440 ms to avoid (10% difference). The order was randomized for each participant.

The rationale for choosing 440 and 400 ms of available TTR was based on previous research by Matta et al,¹⁰ who showed that there is approximately a 10% difference in the available TTR

between a standard 142-g ball (440 ms) and a lightweight 113-g ball (400 ms). With a standard ball, the available TTR could be as little as 440 ms with a pitcher who throws with high velocity and a hitter who swings with a high velocity, but 400 ms is highly unlikely. With a lightweight ball, the same pitcher-batter scenario would leave a player with only 400 ms to respond. In this way, the balls that we directed back at the pitcher leaving 440 ms to respond represented a likely worst case scenario for a standard ball, but the balls that left the pitcher with only 400 ms to respond represented a worst case scenario for a ball lighter than 142 g.

Statistical Analysis

All statistics presented were computed using SPSS version 17 (IBM, Armonk, New York). All regressions presented are from the raw binary outcome data, not aggregated data, for each subject. In addition, practice data from the ART test were included in the model. For the ART and PRT tests, a binary logistic regression was performed on the binary outcome variable of interest (impact probability).

RESULTS

The mSRT for all 19 participants was 298 ± 24 ms (Table 1). There was not a significant difference ($P = 0.13$) in the mSRT between nonpitchers and pitchers using 95% confidence intervals (CIs). Catchers tended to have faster mSRTs than all other positions, with an mSRT of 274 ± 27 ms, while pitchers tended to be slowest, with an mSRT of $310 \text{ ms} \pm 28$ ms. There was also no significant difference in mSRT between age groups ($P = 0.09$),

Table 2. Significance levels for logistic regression factors in the binary logistic regression equations for response time

Factors	ART/Best Case	PRT (exposures 1 and 2)/Worst Case
Time to respond	0.00*	0.18
SRT	0.76	—
Pitcher/nonpitcher	0.00*	0.02*

ART, avoidance response time; PRT, pitching response time; SRT, simple reaction time.
Note: Only significant factors were included in the regression equations.

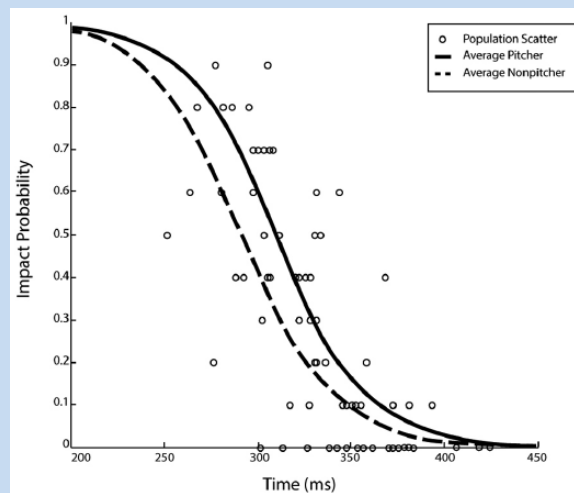


Figure 2. Scatter plot of the results from the avoidance response time test. Each open circle represents the outcome of 1 round (mean of 10 stimuli/responses). The solid black line is a plot of equation 2 (see the appendix) for the average pitcher, and the dotted black line represents the average nonpitcher.

although it tended to decrease with increasing age, in line with previous work.⁶ Although primary position was not a significant factor in the SRT test, it was significant, as was available TTR, in predicting performance in the ART test (Table 2).

Figure 2 shows a scatter plot of the results from the ART test for all individuals as well as the binary logistic regression for pitchers and nonpitchers (appendix, Equation 2). Nonpitchers slightly outperformed pitchers in this task (see Figure 2). The results from the ART test also serve as the best case scenario for impact probability in the PRT test analysis for pitchers.

The results from the PRT test indicate that position is a significant factor in determining impact probability, but available time (400 ms compared to with 440 ms) is not (Table 2). Unlike the ART test, pitchers slightly outperformed nonpitchers in this task (appendix, Equation 3). The first exposure with an available TTR of 400 ms resulted in a hit nearly 90% of the time, but by the last exposure, it resulted in a hit only 16% of the time. The

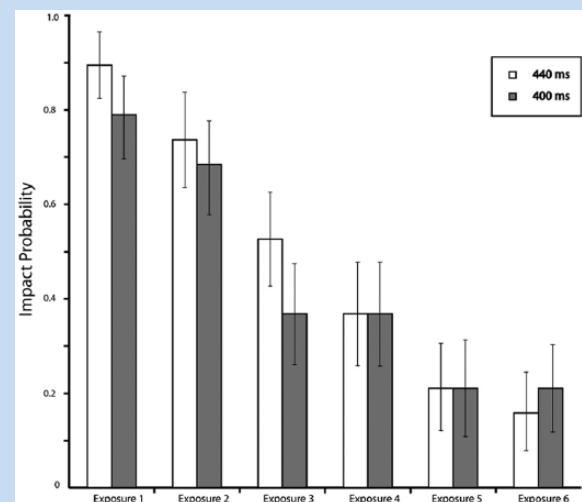


Figure 3. Bar graph of aggregated impact probability data for 19 participants from the PRT test. Each subject had to avoid 6 balls with 400 ms to respond and 6 balls with 440 ms to respond. Exposure 1 represents their first attempt at both times, and exposure 6 represents their last attempt at both times.

first exposure with an available TTR of 440 ms resulted in a hit nearly 80% of the time, but by the last exposure, it decreased to 21%. Notably, for each exposure, the difference between the mean number of hits at 400 and 440 ms was insignificant ($P = 0.18$) using 95% CI.

A binary logistic regression was fit for the first 2 exposures (appendix, Equation 3). This result also serves as the worst case scenario for the impact probability in the PRT test analysis. A plot of the regression equations comparing the best case (ART test) and worst case scenarios (the first and second exposure of the PRT test) is shown in Figure 4.

DISCUSSION

This study partially supports the first hypothesis that a 10% reduction in the available TTR would significantly increase impact probability for both pitchers and nonpitchers. Previous

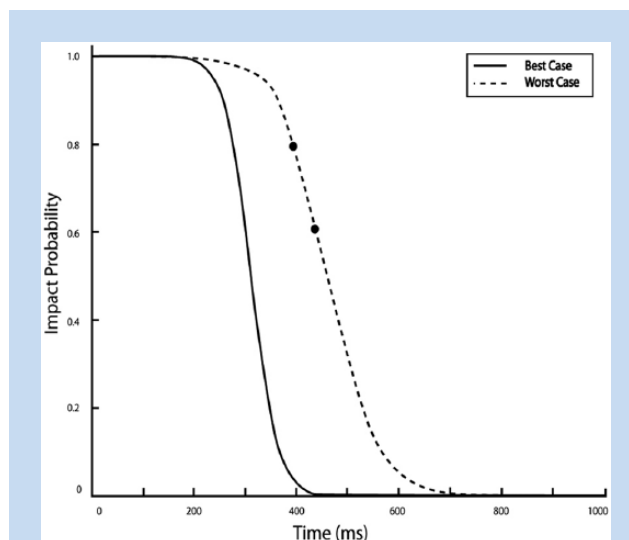


Figure 4. Binary logistic regression of best and worst case scenarios (population averages). The solid black line is the best case scenario, represented by the avoidance response time test, and the dotted black line is the worst case scenario, represented by the exposures 1 and 2 of the pitching response time test. The 2 black data points on the worst case scenario curve highlight the impact probability at 400 ms (lightweight ball) versus a standard ball at 440 ms.

work¹⁰ indicated that a 10% reduction in the available TTR would result from reducing ball weight from 142 g to 113 g. Considering nonpitchers first (all defenders not including pitchers), the results from the ART test (see Figure 2 and Table 2) show that the available TTR plays a significant role in determining impact probability. Figure 2 shows that impact probability is quite sensitive to available times to respond in the range of 255 to 390 ms. At these times, a 10% reduction in available TTR could increase impact probability anywhere from 5% to 25%. The results do not directly support or reject our hypothesis for nonpitchers but instead show that there is a certain range of times where a 10% decrease in available TTR can dramatically increase impact probability, even if that range of times is quite small.

Previous work¹⁰ showed that even at high collision speeds, it would likely take a baseball more than 400 ms to travel 46 feet. The closest defenders to the batter, not including the pitcher, are typically the first and third basemen, and they are often positioned 55 or more feet away. Thus, the results from the ART test show that in situations that are typical in youth baseball, a 10% reduction in the available TTR will not greatly affect impact probability for nonpitchers. For example, an infielder with only 475 ms of available TTR has an impact probability of 0.05%. A 10% reduction in available TTR to 425 ms only raises the impact probability to 0.58%. Nonpitchers performed better at this task than pitchers. This may be because the ART more closely mimics the response of a nonpitcher to a batted ball as opposed to a pitcher.

The PRT test was designed to have a ball directed toward the pitcher in only 12 of 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 effect from the first few times they attempted to avoid a ball (exposures 1 and 2; see Figure 3) to the last (exposures 5 and 6; see Figure 3). 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 exposures are representative of a real-game scenario. Many methods could be employed but we adopted the strategy of creating a best case (results from ART test)/worst case (exposures 1 and 2 in PRT test) scenario. The ART test represented a scenario where the players 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 bound and a lower bound for our expectations of the impact probability for a pitcher (see Figure 4). The best case in Figure 4 represents a scenario where the pitcher is anticipating having a ball hit back at him. This scenario could occur when a physically imposing hitter is up to bat or in a late-game situation where the hitter who is up has already hit 2 balls back up the middle. Conversely, the worst case scenario could occur when a diminutive hitter is up to bat or the hitter has 3 balls and 0 strikes so the pitcher does not expect the hitter to swing on the next pitch he delivers.

Our results suggest that the only circumstances in which a 10% reduction in the available TTR will not significantly increase impact probability is when the exit velocity of the batted ball is high enough to leave the pitcher with less than 225 ms or low enough to leave him with greater than 600 ms to respond (see Figure 4). Times between 255 and 600 ms could substantially increase the impact probability by more than 25%. In our worst case scenario, a pitcher with only 400 ms to react has an impact probability of 79%, whereas a pitcher with 440 ms to react has an impact probability of 61%. This worst case scenario highlights the large difference in impact probability when considering a lightweight ball that leaves a pitcher with 400 ms to respond versus a standard ball that leaves only 440 ms. This estimation is the result of an extrapolation of the data, which may not fully take into account behavior recorded by Eckner that showed that perceived threat level affects movement time and thus response time.³ It is possible that even though the available TTR is decreased, an increase in perceived threat level would

allow both pitchers and nonpitchers to have a quicker response time and limit the potential increase in impact probability.

The hypothesis that mSRT would be a significant factor in determining impact probability was not supported by the results (Table 2). Although ball avoidance may at first seem like a simple task with few if any decisions to make, much like an SRT test, our results indicate that there are many decisions a player must make before and during avoidance that increase its complexity. An SRT test may not be the best way to predict a player's ball-avoidance abilities, and further work to identify a suitable screening method should be pursued.

This study had several limitations. The paintball gun used was only accurate over a distance of 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 low to the ground to determine the optimal location. Ultimately, we decided to put it on the side opposite of the player's throwing arm because participants noted that it was easier to see the ball from this side. In addition, it is likely that defenders and pitchers may have a heightened awareness when they see a batter swing and may be better prepared to field a ball or defend themselves. With no batter present, it is possible that it took the subjects more TTR than in an actual game scenario, but additional testing would be needed to verify this. The order of the SRT, ART, and PRT tests was not randomized across subjects because of the limited number of participants, and this may have systematically affected our results in the ART and PRT tests. In addition, during the PRT test, a substantial learning curve was seen with each response (400 ms and 440 ms), and it is likely that increased learning would occur with more than 6 exposures. Also, the study included only 19 subjects, and a follow-up study with more subjects is needed to confirm these results. In addition, 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 than a standard baseball and artificially increased the impact probabilities reported.

CONCLUSION

A 10% reduction in the available time to react would not significantly increase batted-ball impact injuries to position players. However, delivering a pitch increases the amount of time required for a pitcher to avoid a batted ball. Therefore, if youth leagues transitioned to a 113 g ball, an increase of batted-ball impact injuries to youth pitchers may occur.

APPENDIX

Equation 1

$$\widehat{V}_b(p_f) = \widehat{V}_b(0) - M_b^{-1} p_f$$

Equation 2

$$IP_{ART} = \frac{1}{1 + e^{-(11.326 - 0.039 * ATR + 0.714 * P)}}$$

Equation 3

$$IP_{PRT} = \frac{1}{1 + e^{-(11.210 - 0.021 * ATR + 1.508 * P)}}$$

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