Executive Summary of the Report of the Committee Studying Home Run Rates in Major League Baseball

Introduction

In 2017, in response to the increase in the home run rate, and questions raised by players, fans and members of the media regarding whether the increase in home runs was attributable to changes that were made in the baseball (*i.e.*, the "juiced" ball theory), the Commissioner assembled a diverse group of experts to examine the issue. The committee was chaired by Alan Nathan, Professor Emeritus of Physics at the University of Illinois at Urbana-Champaign. The members of the committees are listed (with a brief bio-sketch for each) at the end of this Executive Summary. The committee was broadly charged with comprehensively identifying any factor, including changes to the composition and manufacturing of the baseball, that may be causally connected to the increase in the rate of home runs in Major League Baseball ("MLB") beginning in the 2015 season. The committee set its own agenda and methodology, and both MLB and Rawlings, the manufacturer of the baseball, provided the committee with whatever data, information and resources it requested in order to complete the study.

Set forth below is an Executive Summary of the committee's findings and conclusion. The Executive Summary was prepared on behalf of the committee by Leonard Mlodinow, a theoretical physicist and author of five best-selling books on science and mathematical related topics. Dr. Mlodinow consulted with the committee during its research and analysis. The complete report of the committee is available on MLB.com.

Executive Summary

Ever since Harry Chadwick created the box score in 1859, baseball has been a game of statistics, and in the past couple years one statistic in particular has seemed to stand out: a surge in the number of home runs. A convenient measure of home run production is the percent of batted balls that result in home runs, as shown in the table below for the past ten years. Over the ten-year period, the numbers vary by more than one percentage point, but the values for 2016 and 2017 seem significantly higher than the 10-year average of 3.75%.

2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
3.6%	3.7%	3.4%	3.4%	3.8%	3.5%	3.2%	3.8%	4.4%	4.8%

To what might one attribute the rise? Yogi Berra said, "baseball is ninety percent mental. The other half is physical," and theories abound, focused on both mental and physical aspects of the game (and based on better mathematics). Some center on the balls—are they more elastic, bouncier, "juiced"? Others zero in on batter behavior—batters striving for more home runs at the expense of more strikeouts, more pull hitting, or a strategic improvement in batter's swing angles inspired by baseball's analytic revolution. A third approach is based on aerodynamics, the way the balls carry—all else equal, do balls fly farther today due to warmer air temperature, or some physical property of the ball itself?

Are the Balls Livelier?

A baseball is a complex physical system. At its center is a rubber "pill" that is coated in a tacky adhesive, then wound over by wool yarn. The yarn is conditioned for 24 hours prior to winding, and is wound in three separate layers. The circumference and weight of the ball after each layer is wound is measured to assure it is within spec. The winding is finished with a thin layer of cotton, which is given a tacky coating prior to stitching the cover, made of panels cut from top-grain leather to avoid areas with visual blemishes and wrinkling. The panels are weighed and skived to meet thickness and/or weight requirements, and prior to sewing, are soaked in cloth of controlled moisture content for 20 minutes. The 108 stitches of the covers are then hand sewn.

Multiple inspections are conducted on each ball throughout the manufacturing process. The ball manufacturing facility, in Costa Rica, has equipment to measure the "bounciness" of the finished ball, called the coefficient of restitution (COR), and each ball is also weighed and measured for circumference and other properties. Only 55% of the balls produced meet these inspection requirements for use in MLB games.

The investigative team conducted laboratory testing of 15 dozen unused Major League baseballs ("new balls") from 2013 to 2017, and 22 dozen game-used Major League baseballs ("authentication balls") from the years 2012-2017, to measure their physical characteristics, and whether the surge in home runs might have been due to a change in the manufactured balls. These tests were conducted at UMass/Lowell (UML) and the Sports Sciences Laboratory (SSL) at Washington State University.

One oft-repeated theory has been that the home run surge may be due to a "juiced ball." Since a large fraction of the impact energy is lost during ball-bat collision, small changes in energy dissipation can have a large effect on ball performance. The parameter most often associated with a "juiced ball" is its COR. To quote Yogi Berra again, "you can observe a lot just by watching," and indeed, COR can be measured by firing a ball at a rigid flat surface at 60 mph, and observing its bounce. Increasing the ball speed to 120 mph and impacting a rigid cylinder results in ball deformation that is more similar to that which occurs in a game, and is denoted CCOR. The CCOR results of new balls from UML and SSL are in good agreement, and suggest that the MLB home run surge is not due to a juiced ball.

Though there was a range in each measured parameter, in each case, both the new balls and authentication balls were consistently within specifications. In fact, for some of the tested parameters, such as weight, size, and COR, Rawlings achieved much greater precision than allowed by the MLB specifications. Any variation detected was relatively small on the practical scale, and there was no evidence that it could have produced an alteration in home run frequency on the order of the increase that has been observed. What's more, the annual trends of weight and circumference do not correlate with the home run increase.

Finally, much has been written in the media about whether the range of the ball specifications is so large as to render meaningless claims that "the ball is being made within specs." For example, with the current COR specifications, a ball at the upper limit (0.578) would have nearly 36 more feet of projected distance than a ball at the low limit (0.514). Clearly, this standard is unreasonably large. But Rawlings achieves far greater precision in COR than is communicated by that standard, and there is no evidence from the laboratory testing of baseballs—whether by Rawlings, UMass/Lowell, or the Sports Sciences Laboratory at Washington State University—that changes in the COR or CCOR of the ball has played a major contributing role in the home run surge.

Batter Behavior

Theories of the home run surge that are based on the "mental" aspects of the game posit that players have altered their batting behavior. This could be due either to economic incentives related to home run production, or in response to the new wealth of data relating the particulars of bat swing to the probability of hitting a long ball.

That new data is a result of MLB's adoption of the StatCast statistical data system in 2015. StatCast provides, for every pitch, and each batted ball, information on pitch type, exit velocity, launch angle, spray angle, spin rate, spin axis, and distance traveled. As a result, today's players know that a home run is most likely to occur at a spray angle (degree of pull) of 20 degrees from dead center field towards third base (for a right-handed batter), and that 97.5 percent of all home runs are hit in the region, dubbed the "red zone", where the launch angle lies in the interval (15, 40) degrees and the exit velocity falls above 90 mph. Are they using this information to adjust their swings?

The investigative team employed that same StatCast data to analyze whether batters (and pitchers) had indeed changed their approach. Are batters swinging the bat harder to obtain larger exit velocity? Are they swinging with an elevated plane to produce launch angles more conducive to home runs? Are they pulling the ball more to decrease the distance needed to clear the fence?

The team found that exit velocities decreased slightly from 2016 to 2017, which would tend to lead to fewer, nor more, home runs. Launch angles exhibited a small increase, but only for the players with lesser home run talents. And spray angles were quite stable over the time period of the home run surge. The team also investigated the joint distribution of launch angle and exit velocity, important because a high percentage of home runs are hit with these parameters in the red zone. That joint distribution was also consistent over the time period in question. Hence there is little evidence to support the claim that batter behavior with regard to any of these factors contributed to the increase in home run hitting.

Another possible explanation for these changes in home run rates is that particular groups of players are contributing to this home run surge. But analysis of StatCast data shows that the home run surge is "global," affecting players throughout the spectrum of home run hitting ability.

What about pitchers? Some types of pitch may be considered "high risk" in that, statistically, they are more likely to lead to a home run, while others may be considered lower risk. The research team calculated the frequency of usage of 32 categories of pitches: 8 categories of pitch types—fastball, cutter, splitter, changeup, curve, sinker, slider, and knuckle-ball—each combined with four quadrants of pitch location—up and in, up and out, down and in, and down and out. If pitching strategies had contributed to the surge, then one would expect pitchers to alter them to counter it, and one would expect to see a tendency for some "high risk" pitch categories to show declining usage frequencies and some "low risk" pitch categories to show increasing frequencies. Neither effect was present in the data, indicating that changes in pitching strategy have been insignificant. To sum up, there is no evidence that batter and pitcher behavior has changed in any manner that could account for the home run surge.

Aerodynamics

If neither of the first two classes of explanation suffice to explain the home run surge, one has no choice but to place one's hope in the third. In that class of theory, we have partial success.

There is a basic series of events that lead to a home run. First, a ball needs to be put in play. Then the batted ball must fall within the right range of launch angles, and have a high enough exit velocity, to have the potential to be a home run. Last, given the launch angle and exit velocity, the ball needs to carry far enough to clear the fence. It is that latter factor that seems to have changed in the last few years: Within batted balls in the red zone, the rate of home runs exhibited a substantial increase in 2016 and 2017.

During those seasons, there was not a substantial change in the percentage of batted balls that fell within the red zone—but there *was* a substantial increase in the rate of home runs among the balls that were hit within the zone. In other words, StatCast data show that the surge in home runs is primarily due to better "carry" for given launch conditions (exit velocity, launch angle, spray angle), as opposed to a change in launch conditions.

Thus, the home run surge is not due to a bouncier, juiced ball, or to a change in batter behavior, but to better carry, which result in longer fly ball distances, and therefore more home runs. The question now becomes, why has this happened?

One possible reason for balls carrying farther is temperature, because higher temperatures result in lower air density and therefore reduced drag, and game temperatures have risen slightly over the past few years. Closer analysis shows, however, that the better carry is not due to changes in temperature.

The other possibility is some change in the aerodynamic properties of the baseball itself. Aerodynamic performance is often described by a drag coefficient (how a ball slows along its path) and a lift coefficient (how it moves perpendicular to its path). Drag has a larger effect on hit distance than comparable changes in lift, but the irregular shape of the baseball results in relatively large variation in both lift and drag, complicating the study of aerodynamic effects.

Drag and lift measurements were performed on authentication balls as well as new balls at the Sports Sciences Laboratory at Washington State University. In addition, the committee extracted drag coefficients directly from StatCast trajectory data. In the WSU studies, lift and drag were found by measuring the change in speed and flight path of balls projected through still air. Pitching machines with spinning wheels are often used to project balls with controlled spin. The wheels can roughen the ball surface, however, and alter its aerodynamic response. As a result, in this work balls were projected using a linear accelerator in which spin was induced by supporting the ball between parallel clamps as it was accelerated.

The results of all these studies was that while changes in lift were not as apparent, the drag coefficient of Major League baseballs has decreased since 2015.

To determine whether this change could feasibly account for the increase in home runs, the investigative team used a physics model to calculate that if the change in the home run rate from 2015 to 2017 were due entirely to changes in drag, one would expect the drag coefficient to have decreased by approximately 0.012. Both procedures performed–the experimental tests at WSU and the mathematical analysis of StatCast data–indicate that the drag coefficient has changed by approximately 0.0153 since 2015, an amount sufficient to have caused the home run surge.

This supports the conclusion that the reason for the surge in home runs is reduced drag on the baseballs, leading to better carry.

Having found an aerodynamic reason for the home run surge, the question is, what change in the baseball is responsible for it? The reason this discovery is only a "partial success" is that the team has not succeeded in finding a change in any property of the balls that could have led to the reduced drag. In particular, the improved carry is not correlated with changes in the size, weight, or seam height of the baseball. With regard to seam height, a small change has been measured—the stiches are, after all, hand-sewn—but based on the average dependence of drag coefficient on seam height, the observed differences in seam height would result in a change in drag coefficient that is much smaller than the observed difference.

Further testing to isolate the reasons for the reduced drag are ongoing, centering on the ball's surface roughness, and center of gravity—if a ball has a center of gravity that is offset from its geometric center, the ball will wobble as it spins, increasing its effective surface roughness and potentially increasing its drag. As a result, manufacturing advances that result in a more spherically symmetric ball could have the unintended side effect of reducing the ball's drag.

Conclusions

In summary, the recent surge in home runs is not due to either a livelier, "juiced" ball, or any change in batter or pitcher behavior. It seems, instead, to have arisen from a decrease in the ball's drag properties, which cause it to carry further than previously, given the same set of initial conditions—exit velocity, launch and spray angle, and spin. So there is indirect evidence that the ball has changed, but we don't yet know how.

The decrease in drag coefficient is not attributable to the size, weight, seam height, or any other property of the baseball that is currently tested by Rawlings or UMass/Lowell. While it cannot be ruled out that small year-to-year variations in these properties might be a minor contributing factor to the home run surge, these changes are within normal and expected manufacturing variation. There is also no evidence that any variations in the ball occur either intentionally or through substandard quality control by Rawlings. If anything, they would be inherent to the manufacturing process, which relies on substantial "by hand" labor. Research on the cause of the drag decrease is currently focused on the ball's surface roughness, and its center of gravity. Yogi Berra, who retired in 1965 and died at age 90 just as the home run surge was beginning, said, "In baseball, you don't know nothing." But, though we don't yet have all the answers, Berra would have likely agreed that we've come a long way.

Leonard Mlodinow

Committee Members

Jim Albert is Professor of Statistics at Bowling Green State University. He has written many published papers and authored four books on the interface of statistical thinking and baseball. He is active in the Section on Statistics and Sports in the American Statistical Association and is former editor of the Journal of Quantitative Analysis of Sports. He contributes regularly on the blog https://baseballwithr.wordpress.com that illustrates the use of the statistical system R in exploring baseball data.

Jay Bartroff is Professor of Mathematics and the Graduate Vice-Chair for Statistics at the University of Southern California. When he's not writing research papers and books on statistics and probability, he occasionally pontificates on sports outcomes for ESPN and its show Sports Science.

Roger Blandford grew up (with cricket!) in England and is currently Luke Blossom Professor in the School of Humanities at Stanford University. He is the co-author of a recent graduate textbook Modern Classical Physics (Princeton University Press 2017) which discusses some of the basic physical processes that are relevant to Major League Baseball.

Dan Brooks is a researcher who has long had an interest in baseball analytics. He runs the website brooksbaseball.net and is co-organizer of the highly successful summer workshop known as Saberseminar, https://www.saberseminar.com.

Josh Derenski is a statistics Ph.D. student in the USC Marshall School of Business. His research is motivated by the application of statistics to problems in various fields, particularly the field of environmental statistics. Current and past research projects include: Application of Tweedies formula to functional data, modeling water levels in lakes, and analyzing energy use in public schools.

Larry Goldstein is Professor of Mathematics at the University of Southern California in Los Angeles. He specializes in statistics and probability, with his statistical work focusing on the development of new methodology. He has served as a statistical consultant to various industries for over three decades.

Anette (Peko) Hosoi is the Neil and Jane Pappalardo Professor of Mechanical Engineering and professor of Mathematics at MIT. She is a Fellow of the American Physical Society (APS) and co-founder of the MIT Sports Lab. Her research interests include fluid mechanics and biomechanics, particularly the intersection of engineering, applied mathematics, and athletic performance.

Gary Lorden is Professor Emeritus of Mathematics at Caltech. His research specialty is statistics, and he has consulted widely as a statistician for the last forty-five years.

Alan Nathan (chair) is Professor Emeritus of Physics at the University of Illinois at Urbana-Champaign and has spent much of the past two decades doing research in various aspects of the physics of baseball. He has written numerous articles, both for academic journals and for the popular media, and runs an oft-visited website devoted to the topic (http://baseball.physics.illinois.edu).

Lloyd Smith is Professor in the School of Mechanical and Materials Engineering at Washington State University. He is Editor in Chief of the Journal of Sports Engineering and has been testing bats and balls for 20 years. His Sports Science Laboratory (https://ssl.wsu.edu) certifies bats and balls for 10 of 11 federations regulating amateur softball and baseball.

Leonard Mlodinow is a theoretical physicist and author, recognized for groundbreaking discoveries in physics, and as the author of five best-selling books. His book *The Grand Design*, co-authored with Stephen Hawking, reached #1 on the New York Times best-seller list; his book *Subliminal: How Your Unconscious Mind Rules Your Behavior*, won the 2013 PEN/E.O. Wilson award for literary science writing; and his book *The Drunkard's Walk: How Randomness Rules Our Lives* was chosen as a New York Times notable book, and short-listed for the Royal Society book award. In 2005, he returned to the Caltech faculty to teach while continuing to write books. Since 2013 he has written full-time, with his books including:

- *Elastic: Flexible Thinking in A Time of Change* (2018).
- *The Upright Thinkers: The Human Journey from Living in Trees to Understanding the Universe* (2015).
- *Subliminal: How Your Unconscious Mind Rules Your Behavior* (2012).
- *War of The Worldviews: Science vs. Spirituality* (2011), co-authored with Deepak Chopra.
- *The Grand Design* (2010), co-authored with Stephen Hawking.
- *The Drunkard's Walk: How Randomness Rules Our Lives* (2008).
- *A Briefer History of Time* (2005), co-authored with Stephen Hawking.
- *Feynman's Rainbow: A Search for Beauty in Physics and in Life* (2003).
- *Euclid's Window: The Story of Geometry from Parallel Lines to Hyperspace* (2001)