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Analytical Study to Determine Significant Causes of Increased No-Hitters in the 2021 Major League Baseball Season

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Honors Project

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How Common Are No-Hitters?

Major League Baseball (MLB) saw the record for no-hitters in a season broken in 2021. The previous record was set in 1884, almost 140 years ago, with eight no-hitters (Hoffman, 2021). There were nine no-hitters in 2021. In addition to the no-hitters, there were also many near no-hitters, meaning the no-hitter was taken into the seventh inning or later. No-hitters are a rare feat, and somewhat random. Below is a chart of no-hitters per MLB season since 2000.

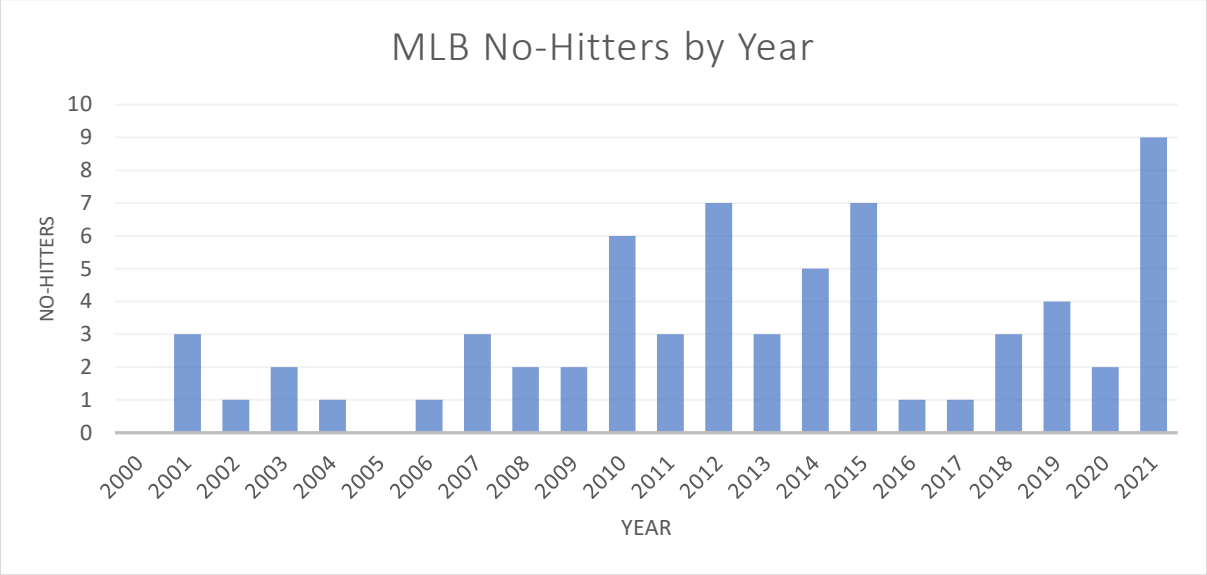

Figure 1- Number of no-hitters in each MLB season since 2000 according to baseball-reference.com

As you can see in Figure 1, there isn't much of a pattern relating to no-hitters and then there is a spike in 2021. What is even more shocking is that seven of the no-hitters in 2021 were before the All-Star break, which is about halfway through the season. Sara Sanchez, a writer for Fangraphs, wrote an article on May 12th suggesting that 2021 could be the year of the no-hitter saying, "We are barely five weeks into the 2021 season, and we've already seen four no-hitters" (Sanchez, 2021). Why so many no-hitters in 2021? And why did many of them happen so close together?

Was this random, or were there factors that led to certain pitchers dominating batters in these specific no-hit performances? Many experts have investigated why there were so many no-hitters and near no-hitters in 2021. Many of these experts have suspicions about recent changes in the game and how they have influenced offensive and pitching production among the athletes. There are currently no solid conclusions on how much changes in strategy or the properties of the baseball itself have affected the number of no-hitters that have been accomplished. It is difficult to say which changes have had more of an influence than others, especially because of the random nature of no-hitters in baseball. This analysis will specifically investigate fastball and curveball spin rates of pitchers, as well as launch angles.

What *Is* a No-Hitter?

Before diving into this investigation, it is important to define some baseball specific terms. So, what exactly is a no-hitter? Baseball Reference defines a no hitter in their "BR Bullpen" as "a game in which a pitcher, or pitchers, gives up no hits while pitching at least nine innings. A pitcher may give up a run or runs so long as he pitches nine innings or more and does not give up a hit" (baseball-reference.com). Important things to notice in this definition are that multiple pitchers can be included in the no hitter (called a "combined no-hitter"), and that no hits may be given up during nine innings. Madison Bumgardner pitched a game on April 25th where no hits were allowed, but the game was only seven innings long (baseballsavant.mlb.com), so it was not included in the no-hitter total. This leads into the next term that needs to be defined.

A "near no-hitter" is a somewhat ambiguous term and does not have a specific definition in the baseball world. For the purposes of this study, a "near no-hitter" will be defined as a game

that was a no-hitter until the seventh inning or later when broken, or a game in which no hits were allowed, but the game did not last a complete nine innings. In 2021, there were two games that were no-hitters through seven innings, but the games were only scheduled to be seven innings long due to double headers (Lammers, 2021). These will be classified as near no hitters because there were no hits allowed but did not meet the nine-inning requirement.

Another crucial term that needs defining is “spin rate”. According to mlb.com, spin rate “represents the rate of spin on a baseball after it is released and is measured in revolutions per minute” (mlb.com). This may seem very simple, but it can have huge effects on a pitcher’s overall performance. Pitches thrown at equal velocities, but with different spin rates will move differently and makes the pitch either easier or harder to hit for the batter. The movement created by high spin rates is what makes fastballs and curveballs effective. It is much more difficult to hit a baseball hard when it is moving so much. Spin rate is one of the major focuses of this investigation that will be explored later.

“Launch angle” is “the vertical angle at which the ball leaves a player’s bat after being struck” (mlb.com). Launch angle is another focus of this investigation. Increasing launch angle has been a recent strategy among batters to improve performance. Launch angle can also be applied to pitchers, showing if they give up more ground balls or fly balls. Typically, pitchers who give up more fly balls and have higher launch angles against them, the poorer their performance. When looking at balls hit in the field of play, it is more likely for a ball hit in the air to result in a hit than a ball that was hit on the ground. Devan Fink writes in a data driven FanGraphs post that, “In 2021, batters reached base on a fly ball about 27% of the time” (Fink, 2021). Tom Verducci, a baseball writer for Sports Illustrated, also mentions data comparing batting averages and slugging percentages of ground balls and fly balls in one of his articles.

According to his data, the league wide batting average on ground balls in 2021 was only 0.241, or about 24% (Verducci, 2022). A batting average of 0.270 is way better than 0.241. Over 500 at bats, it equates to a 14.5-hit difference. Going beyond just a hit or an out, fly balls that result in hits are more devastating to pitchers than ground balls that go for hits. Slugging percentage on ground balls is only 0.266 compared to slugging percentages of 0.692 for fly balls and pop-ups, and 0.905 for line drives last year (Verducci, 2022). To simplify this data, higher launch angles lead to more hits, and specifically extra-base hits. More ground balls are better for pitchers because they are less likely to result in a hit. Plus, with a runner or runners on base, a ground ball has a better chance to turn into a double play, helping a pitcher out even more.

How Has Baseball Been Changing?

Baseball, America's pastime, is an ever-changing sport. It has grown and advanced over more than a century. There have been both physical changes like the composition of the ball, as well as strategical changes. These strategical changes have been spurred on by technological advancements in studying the game in order to optimize performance. Some examples of strategical changes in the past decade include an increase in bullpen usage, focus on launch angle, an emphasis on pitchers' spin rate, and even making extreme defensive shifts. Teams are spending a lot of resources to find new ways to gain an edge against competition. In addition to teams changing their strategies in how to train players to get the most out of their abilities and performances, MLB has also been making changes to the game to appeal to more fans and keep the game of baseball relevant and interesting for viewers.

Do Bullpens Help or Hurt No-Hitter Totals?

Over the years, MLB teams have started to rely more and more on relief pitchers. Starting pitchers are getting taken out sooner and more often, leading to less complete games. The bullpen is now used in almost every MLB game.

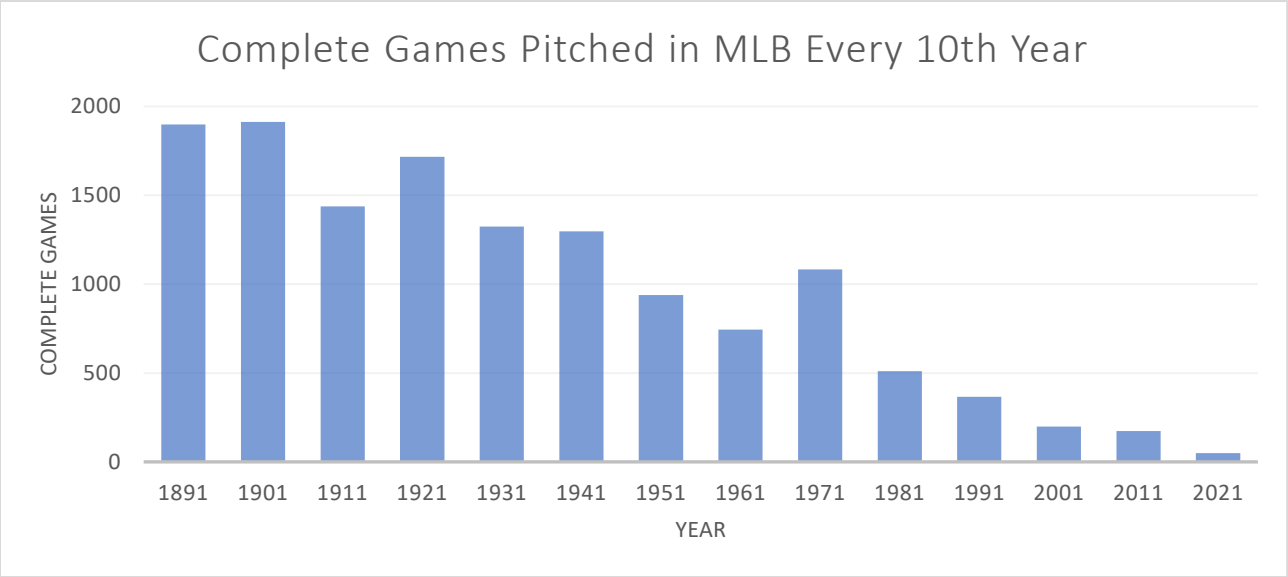

Figure 2- Number of complete games pitched every 10th season in MLB starting in 1891 according to baseball-reference.com

There is a very clear and significant decline in the number of complete games pitched in MLB. This shows how the culture of baseball has been changing with a much greater reliance on relief pitchers. There were only 50 complete games during the MLB season last year, while there were 199 just 20 years ago. Over 1000 complete games were thrown in 1971. Why is this happening? Possibly to prevent injury and overuse of a single pitcher during a long and strenuous season. Another possibility is the growing idea that a relief pitcher will simply perform better than the tired starting pitcher late in the game. In a study by Philippa Swartz and others that was published in *The American Statistician* in 2017, evidence is given to support that "the best

pitching tends to occur roughly between the 20th and the 70th pitches. Pitching performance tends to deteriorate beyond the 70th pitch, and even more quickly beyond the 100th pitch" (Swartz, et. al). This explains a lot of things like how there are many more near no-hitters than complete no-hitters. Pitchers become fatigued later in the game and make less quality pitches, giving batters more of an edge. As a pitchers' performance starts to fade there are better opportunities for batters to break up a no-hitter if they haven't already. Even when a starting pitcher is relieved for at an advantageous time, the pitcher coming out of the bullpen typically is not throwing high quality pitches to their first few batters. Many pitchers have been taken out of the game allowing no hits, just for a relief pitcher to blow the no-hit bid. A relief pitcher gave up the first hit to an opponent in the seventh inning or later 10 times in 2021, while only two times the bullpen completed the no-hitter (Lammers, 2021). It also explains why managers go to the bullpen sooner in games and more frequently.

In today's game of baseball, more than one other pitcher comes into the game to finish it out. There has been an increase in the amount of relief pitchers used per game, which shows how much strategy has been implemented into baseball tactics of pitching.

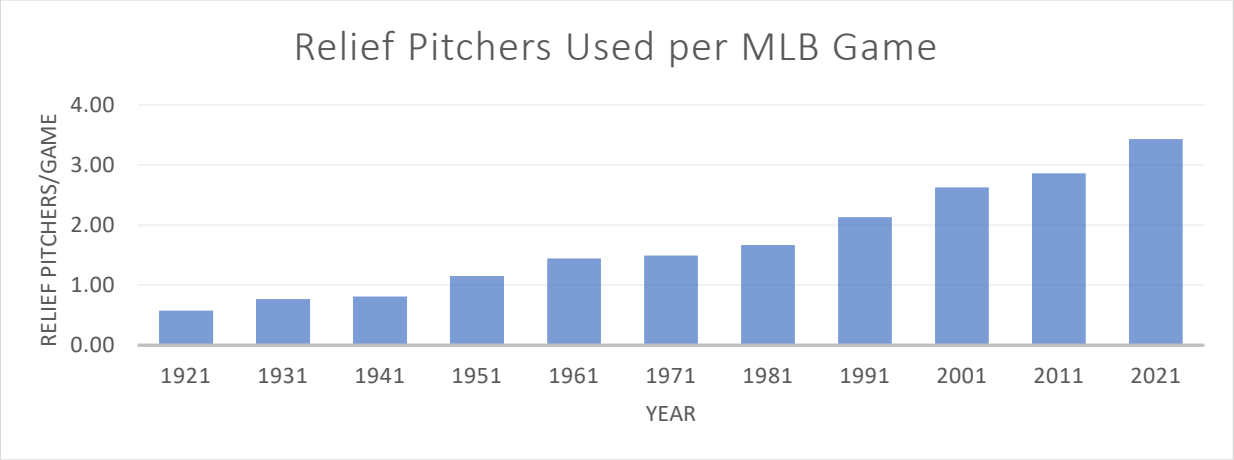

Figure 3- Average number of relief pitchers used by each team per MLB game every 10th year starting in 1921 according to baseball-reference.com

Many games now see 4 to 5 different pitchers including the starter to pitch just 9 innings. It used to be very uncommon to see 2 different players come out of the bullpen in a single game for a team. Bullpen usage has been one of the most influential trends in MLB strategy that has been growing over the years.

What Does Launch Angle Have to Do with No-Hitters?

Launch angle is a recent trend in strategy that is taking the baseball world by storm. Statistics have revealed that increasing the launch angle of a batted ball tends to lead to better results; more extra base hits and scoring more runs, which leads to winning more games. In an article written only about a month into the start of the 2021 season, Chris Clegg notes large increases in average launch angle in a few specific players. One of the mentioned players is Shohei Ohtani, whose “average launch angle of 18.2 degrees is nine degrees higher than last season” (Clegg, 2021). Shohei Ohtani ended up winning the American League MVP award and a Silver Slugger award last year with 103 runs, 100 RBIs, 46 home runs, and a 158 OPS+. He also led all of baseball with 9.1 Wins Above Replacement and a 5.1 Win Probability Added (baseball-reference.com). And this is just one extreme example. Increasing launch angles is a league wide phenomenon. Below is a graph of this trend.

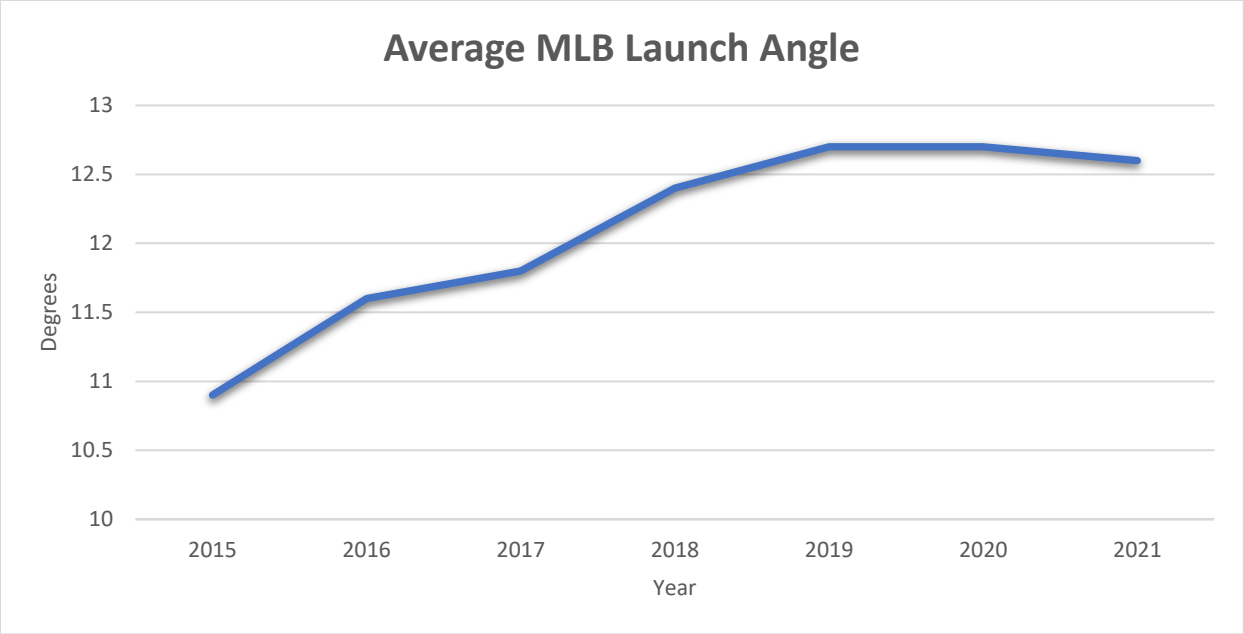

Figure 4- Average MLB launch angle by season starting in 2015 according to baseballsavant.mlb.com

Data on launch angles was not collected before the 2015 season, and since then the trend can be clearly seen. Since 2019 this trend has plateaued at about 12.7 degrees. This is probably because there is a suggested range that launch angle is said to be most productive. In a study on the "home run surge" in 2019, scientists investigated launch angle among other factors. Alan Nathan, a physicist from Illinois who helped with the study claims, "To hit a home run, it turns out, the optimum launch angle for piercing through the air is in the 25-to-30-degree range," (Arvil, 2020). Players know that hitting the ball straight up at greater launch angles is not a perfect answer. There is a balance between hitting the ball at an angle to maximize distance and hitting a pop fly for an easy out. So, the fact that the average launch angle across the MLB has settled around 12.7 degrees is not surprising. Batters do not want to hit the ball too high, so the league wide average launch angle has stopped increasing year over year. Later, this investigation will look at whether launch angle has had any effects on the number of no-hitters thrown.

Do Higher Spin Rates Influence No-Hitters?

The last MLB trend that will be looked at for this project is spin rate. The definition of spin rate was covered earlier, but what makes it such a big deal? Why has looking at pitchers' spin rates been such a big trend? Driveline Baseball, a player development organization, has done many studies on spin rate. In the conclusions of a 2019 study by Dan Aucoin and others, they state, "Spin rate is important to understand, because it can affect the movement of the pitch, which helps determines the number of whiffs and types batted ball outcomes a pitcher gives up" (Aucoin, et al, 2019). Another way to say this is that whether a pitcher gives up more ground balls or fly balls to hitters, and how many swings and misses the pitcher can create, can all be traced back to that pitchers' spin rate. This has huge implications because a pitcher who can generate more swings and misses and limit line drives and hard-hit balls will be much more successful over the course of a season. The focus here is specifically on spin rates for fastballs and curveballs because they are pitches that are typically more successful with higher spin rates. However, high spin rates are not beneficial for every type of pitch. Ryan Dailey notes in a blog post on baseball spin rates that, "Unlike fastballs and curveballs however, [changeups] are often thrown intentionally to have less spin and speed in order to deceive a hitter" (Dailey, 2018). Corbin Burnes, the 2021 NL Cy Young Award winner, was in the 100th percentile in fastball spin rate, and the 92nd percentile in curveball spin rate last season (baseballsavant.mlb.com). Burnes also had a big part in breaking the record of no-hitters thrown in a single MLB season, pitching eight innings of the 9th no-hitter in 2021. Josh Hader pitched the final inning of the game (baseball-almanac.com). With all the data about high spin rates on fastballs and curveballs improving pitchers' performances over a season, it is easy to jump to the conclusion that better spin rates are a major influencer of throwing a no-hitter. But this is not the case. Not all the

pitchers who had a part in breaking the record were in the top 10 percent of the league in spin rate. Tyler Gilbert, who threw a complete game no-hitter, was only in the 34th percentile in fastball spin rate, and the 42nd percentile in curveball spin rate (baseballsavant.mlb.com). So, is spin rate an important factor in throwing a no-hitter? Sort of. Spin rate does impact a pitchers' overall performance throughout a season, as seen with the example of Corbin Burnes. However, there is not a spin rate threshold pitchers have to meet to throw a no-hitter. Pitching performance for a single game is so much more than just spin rate. There are an almost infinite number of other variables to consider during a single games' pitching performance. Any pitcher, regardless of their average spin rate, is just one bad pitch or one small mistake away from not throwing a no-hitter. Even when a mistake is not made, a hitter may get a lucky hit on a poorly hit ball. There is far too much randomness in a game of baseball to say that spin rate alone contributes to no-hitters.

Is 2021 Really an Outlier?

Before continuing this investigation, it is important to check if 2021 is truly an outlier compared to other years. Yes, the record was broken for no-hitters in a season, but the record was not shattered by unbelievable proportions. Maybe it was an extra lucky year for pitchers and does not hold much significance.

Below is a simple box and whisker plot created in R Studio from data of MLB no-hitters since 1920. The y-axis is the number of no-hitters in a season. As you can see, the median number of no-hitters is two, with the fourth quartile ending at six no-hitters. Any number of no-

hitters in a season greater than six is statistically considered an outlier, making nine no-hitters in a single season an extreme outlier.

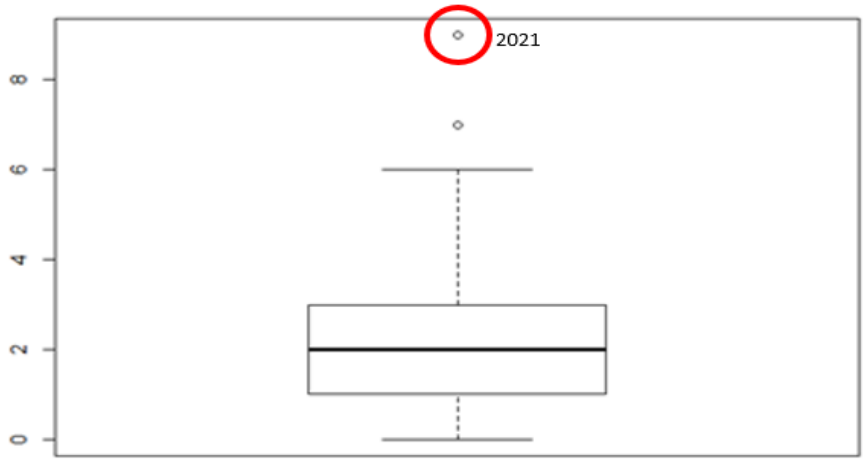

Figure 5- Box and whisker plot of no-hitters from 1920 to 2021 created in R Studio. Data from baseball-almanac.com.

To further show that 2021 is statistically significant, I ran a 90% confidence interval in R Studio for the no-hitter data. We can assume the data is normally distributed by the Central Limit Theorem because there are more than 30 observations. Akhilesh Ganti breaks down the Central Limit Theorem simply by stating, "The central limit theorem (CLT) states that the distribution of sample means approximates a normal distribution as the sample size gets larger, regardless of the population's distribution. Sample sizes equal to or greater than 30 are often considered sufficient for the CLT to hold" (Ganti, 2022). Because the data is normally distributed with a 90% confidence interval, each tail of the confidence interval contains 5%. However, we can ignore the lower bound because our focus is on a record high number of no-hitters. The upper bound of the confidence interval is 8.74. So, we can say that in any given year, we can be 95% confident that there will not be nine or more no-hitters in the MLB season.

```
> confint(slr, level = 0.90)
                    5 %       95 %
(Intercept) 1949.737740 1963.48894
NH             3.962931    8.74056
```

Figure 6- Confidence interval output coded in R Studio for no-hitters in any given MLB season. Data from baseball-almanac.com.

So, the answer is yes, the 2021 MLB season is an extreme outlier in terms of no-hitters. This allows us to continue the investigation to figure out why this outlier has occurred.

What Variables Influenced No-Hitters?

Data analyst experts have developed a method to determine the expected batting average (xBA) of a batted ball based on measurements including launch angle, exit velocity, and more. Basically, expected batting average tells us the odds of any particular batted ball resulting in either a hit or an out. It would make sense that the odds of throwing a no-hitter would increase as the opponents' odds of getting a hit on a batted ball decrease. League wide batting average for the 2021 season was .244 (baseball-reference.com). Batters' xBA against pitchers in the nine no-hit games in 2021 was .238, only .006 lower than the season average. This suggests extremely good defense behind the pitcher who threw the no-hitter, a lot of luck with hard hit balls directed right at a fielder, or a combination of both. I decided to take a deeper look into what factors influence xBA to see what other factors might be impacting batters not hitting the ball well. I ran a multiple linear regression model with explanatory variables exit velocity, launch angle, distance, pitch velocity and spin rate, with expected batting average as the response variable. Below is the output of the multiple regression model run in R Studio.

```
Call:
lm(formula = xBA ~ ExitVelo + LA + Dist + PitchVelo + SpinRate,
    data = LaunchAngle)

Residuals:
     Min       1Q   Median       3Q      Max
-0.31013 -0.14148 -0.03486  0.15039  0.50862

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) -3.365e-01  3.025e-01  -1.112  0.26785
ExitVelo     7.692e-03  1.358e-03   5.664 7.68e-08 ***
LA          -2.614e-03  7.790e-04  -3.355  0.00101 **
Dist         5.203e-04  1.799e-04   2.893  0.00441 **
PitchVelo   -4.019e-03  3.316e-03  -1.212  0.22746
SpinRate     9.193e-05  4.664e-05   1.971  0.05063 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.192 on 145 degrees of freedom
  (6 observations deleted due to missingness)
Multiple R-squared:  0.3011,    Adjusted R-squared:  0.277
F-statistic: 12.49 on 5 and 145 DF,  p-value: 4.345e-10
```

Figure 7- Multiple linear regression output coded in R Studio for predicting expected batting average. Data from baseballsavant.mlb.com.

The adjusted R-squared value is only 0.277, so these variables together do not create a strongly correlated model for predicting xBA. I tried different combinations of these variables, but this was the highest adjusted R-squared value. The variables exit velocity, launch angle, and distance are all significant at alpha level 0.01. It would make sense that the odds of throwing a no-hitter would increase as the opponents' odds of getting a hit on a batted ball decrease, so I decided to look more into these variables. However, pitchers cannot control the exit velocity of the batted ball. That is dependent on the batters' swing, not the pitch. This goes the same for distance. The distance the ball travels has more to do with the batters' ability to hit the ball than the pitcher's ability to perform well. That leaves launch angle.

The league wide average launch angle in 2021 was 12.6 degrees, compared to the average launch angle of batters on the no-hit side of the no-hitters in 2021 that was just 10.28 degrees

(baseballsavant.mlb.com). That is over a two-degree difference! This suggests that keeping batters launch angle lower can increase a pitchers' odds of throwing a no-hitter. This makes sense because this is the same reason why batters have been increasing their launch angles; to improve offensive performance. Pitchers want to decrease launch angles to improve their own performance. But this is not a perfect conclusion. I decided to run a linear regression model on xBA with launch angle as the explanatory variable. Below are the results.

```
Call:
lm(formula = xBA ~ LA, data = LaunchAngle)

Residuals:
     Min       1Q   Median       3Q      Max
-0.22543 -0.18521 -0.08776  0.12252  0.63257

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept)  0.2445936  0.0190434  12.844   <2e-16 ***
LA          -0.0006512  0.0006230  -1.045    0.298
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.2251 on 150 degrees of freedom
  (5 observations deleted due to missingness)
Multiple R-squared:  0.00723,   Adjusted R-squared:  0.0006114
F-statistic: 1.092 on 1 and 150 DF,  p-value: 0.2976
```

Figure 8- Simple linear regression output coded in R Studio for predicting expected batting average using launch angle as the explanatory variable. Data from baseballsavant.mlb.com.

The adjusted R-squared is miniscule, and the p-value is 0.2976, showing no significance. Launch angle does not significantly impact expected batting average on its own. Expected batting average does not directly translate to a players actual batting average, hence why it's called "expected" batting average. There are just too many factors that go in to whether a ball comes off the bat as a hit or an out. After all the analysis, it seems like it simply comes down to randomness and luck.

How Many No-Hitters Can We Expect Next Season?

There is no good way to predict when a no-hitter will be thrown. When running another linear regression model of no-hitters on the year, we can see how random no-hitters really are.

```
Call:
lm(formula = Year ~ NH, data = HPData1)

Residuals:
    Min      1Q  Median      3Q     Max
-47.317 -23.539  -5.993  24.785  54.035

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 1956.613      4.141 472.459  < 2e-16 ***
NH             6.352      1.439   4.414 2.56e-05 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 27.2 on 100 degrees of freedom
Multiple R-squared:  0.1631,    Adjusted R-squared:  0.1547
F-statistic: 19.49 on 1 and 100 DF,  p-value: 2.563e-05
```

Figure 9- Simple linear regression output coded in R Studio for Simple linear regression output coded in R Studio for predicting no-hitters. Data from baseball-almanac.com.

The adjusted R-squared is a mere 0.1547, showing that there is practically no correlation between the year and the number of no-hitters thrown. The extremely low p-value shows statistical significance that there is a lot of change in the response variable (the year), when the explanatory variable changes (number of no-hitters). Simply said, the number of no-hitters each year is inconsistent and random. To drive home how random no-hitters are, I created another visualization in Tableau that can be found below.

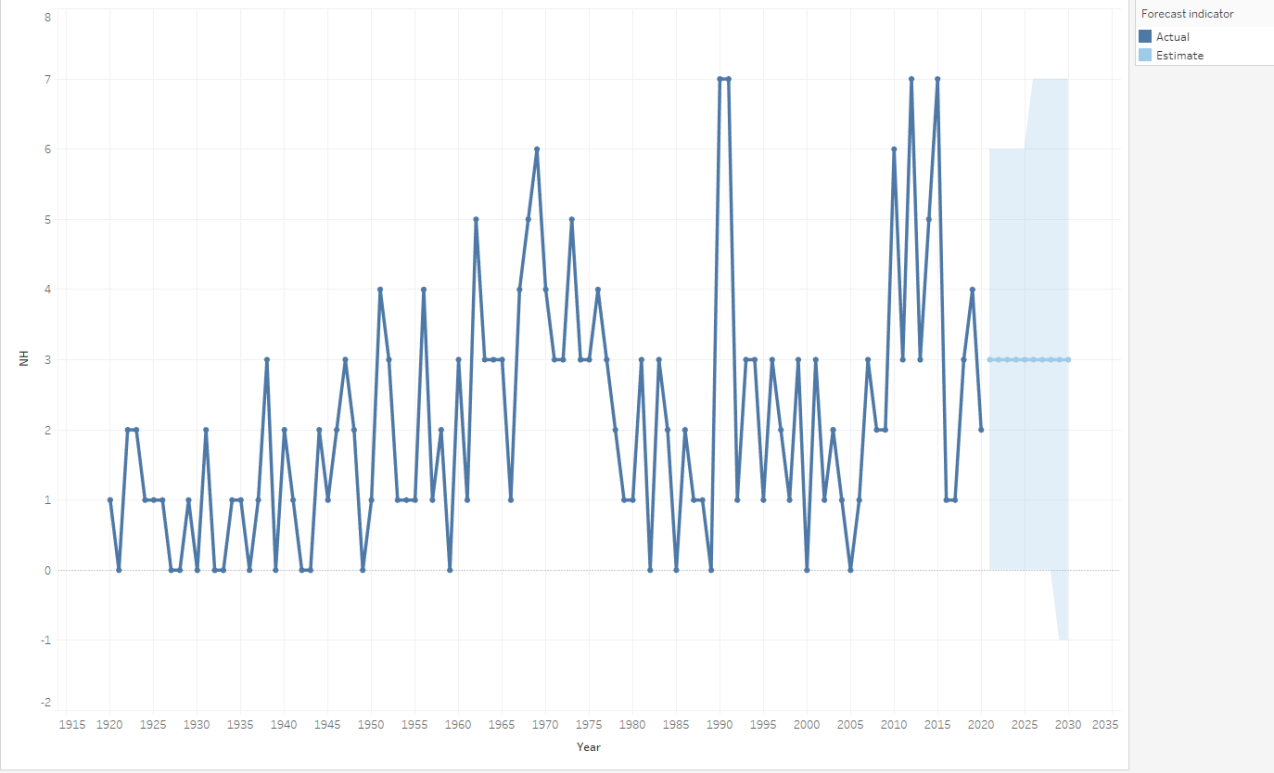

Figure 10- Graph of no-hitters with forecast for future no-hitters created in Tableau. Data from baseball-almanac.com.

This is a graph of no-hitters from 1920 to 2020 (2021 was excluded as an outlier) with a forecast for the next 10 years. The estimate is three no-hitters each year for the next 10 years, but there is a very large room for error extending from zero to six for the first five years after 2020, and then zero to seven no-hitters for the next five years. There is no significant trend in no-hitters to create an accurate forecast, and there probably never will be.

Despite the extreme randomness, I created a prediction interval in R Studio for no-hitters in the 2022 season.

```
> predict(slr1, x0, interval = "prediction", level = 0.95)
       fit         lwr      upr
1 3.508639 0.009488996 7.007789
```

Figure 11- Prediction interval output with 95% confidence for no-hitters in 2022 coded in R Studio. Data from baseball-almanac.com.

At a 95% confidence level for the prediction, the model predicts about 3.5 no-hitters in 2022 with a lower bound of zero no-hitters and an upper bound of seven no-hitters. We can say with 95% confidence that there will not be nine no-hitters again in 2022. I am sure that if this same study was conducted in 2020, it would not have predicted nine no-hitters in 2021, so who knows what the next season has in store for us?

Works Cited

Aucoin, Dan, et al. “A Deeper Dive into Fastball Spin Rate.” *Driveline Baseball*, 31 Jan. 2019, https://www.drivelinebaseball.com/2019/01/deeper-dive-fastball-spin-rate/.

Avril, Tom. “The Science behind Baseball's Home Run Surge.” *Https://Www.inquirer.com*, The Philadelphia Inquirer, 23 July 2020, https://www.inquirer.com/science/home-run-launch-angle-record-strikeouts-phillies-20200723.html.

“Baseball Almanac 2022: Baseball History, Baseball Records and Baseball Research.” *Baseball Almanac*, https://www.baseball-almanac.com/.

Baseball Savant, 2022, https://baseballsavant.mlb.com/. Accessed 2022.

Baseball-Reference, 2022, https://www.baseball-reference.com/. Accessed 2022.

Clegg, Chris. “The Home of Fantasy Sports Analysis.” *FantraxHQ*, 10 May 2021, https://www.fantraxhq.com/page/13/?position=TE&order=ADP.

Dailey, Ryan P. “How Does Spin Rate Really Affect Pitches?” *Bless You Boys*, 15 May 2018, https://www.blessyouboys.com/2018/5/15/17355934/a-basic-look-at-spin-rate-and-what-it-means-for-pitches.

Fink, Devan. “There Were Fewer Homers This Year, but the Long Ball Still Reigns Supreme.” *FanGraphs*, 5 Oct. 2021, https://blogs.fangraphs.com/there-were-fewer-homers-this-year-but-the-long-ball-still-reigns-supreme/#:~:text=On%20all%20fly%20balls%20in,than%20900%20hits%20for%20outs.

Ganti, Akhilesh. “Central Limit Theorem (CLT) Definition.” Edited by Thomas Brock, *Investopedia*, 6 Mar. 2022, https://loans.jualroemah.com/terms/c/central_limit_theorem.asp.

Hoffman, Benjamin. “Brewers' Combined No-Hitter Breaks Record for the Most in a Season.” *The New York Times*, The New York Times, 19 May 2021, https://www.nytimes.com/article/no-hitters-2021-season-history.html.

Lammers, Dirk. “The Online Home for Baseball No-Hitters: Baseball No-Hitters at Nonohitters.com.” *Nonohitters*, https://www.nonohitters.com/.

Sanchez, Sara. “Could 2021 Be the Year of the No-Hitter?” *FanGraphs Baseball*, 12 May 2021, https://blogs.fangraphs.com/could-2021-be-the-year-of-the-no-hitter/.

“Statcast: Glossary.” *MLB.com*, 2022, https://www.mlb.com/glossary/statcast.

Swartz, Philippa, et al. “The Quality of Pitches in Major League Baseball.” *The American Statistician*, vol. 71, no. 2, May 2017, pp. 148–154., https://doi.org/10.1080/00031305.2016.1264313.

Verducci, Tom. “The Death of Ground Balls.” *Sports Illustrated*, Sports Illustrated, 2 Feb. 2022, https://www.si.com/mlb/2022/02/02/death-of-ground-balls.