The Effect of Tommy John (UCL) Reconstructive Surgery on a Pitcher's Arm and Career Progression

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Abstract

Injuries have plagued professional athletes since their sports have been in existence. The examination of how teams can diminish the side effects of the injuries en route to a speedy recovery remains an evolving process and a topic of concern for all. Injury preventative tactics have been implemented by coaching staffs and various training personnel. Major League Baseball (MLB) pitchers are noticing an increase in the number of surgeries performed each year. The tearing of the ulnar collateral ligament (UCL) in the elbow has become a predominant injury among pitchers in the MLB. Reconstructive surgery, also known as Tommy John surgery, has been a necessity for any pitcher wishing to return to the mound. The goal of this research is to examine performance of players who elect to undergo Tommy John surgery. The development of a predictive model can only go so-far to include factual statistical data to determine the stress of pitchers' arms. However, the byproducts of teams acquiring this knowledge has a large impact on their decision making abilities. The research includes analytical techniques to predict future outcomes of MLB pitchers as well as an avenue to provide statistical evidence of the before and after effects on their arms.

Project Proposal Scope, Focus

In my Senior Capstone project I have worked toward expanding the knowledge that currently exists regarding pitchers performance before and after Tommy John surgery. There are multiple ways to evaluate a pitcher's performance including but not limited to pitcher sabermetrics, injury diagnostics, and how hitters react to certain pitch types thrown by certain pitchers. Currently, data exists from the American Sports Medicine Institute that includes information regarding the stress and determinant factors of how pitchers can lessen the effect of stress on their arm. I have examined data from all major league baseball pitchers to come to a conclusion on whether pitchers come back "Stronger" or "Worse off" since pre-surgery. A few questions arise such as, what does stronger entail? How will this be measured or defined. Has the pitcher undergone multiple surgeries? The research is aimed to categorize the information and give intervals as to who is considered to have a more or less successful impact post-surgery.

There are several questions that I will be addressing in regards to this topic:

- Do major league pitchers come back stronger from Tommy John Surgery?
- What is the profile or characteristics for a pitcher who needs UCL reconstructive surgery?
- What makes a major league pitcher most prone to Tommy John (UCL) surgery?
- Is there a correlation between the types of pitches thrown and their exposure to risks of Tommy John?
- Are starting pitchers more vulnerable because of number of innings pitched? Vice versa?
- Does pitching from the wind-up vs. the stretch having any impact on the stress of a pitchers arm or throwing motion?
- How does age correlate to recovery time of a pitcher who has undergone surgery?

- Does the surgeon make a difference in recovery? What are the succession rates or performance of players after surgery sorted by surgeon?

- How do players who have undergone repeated surgeries stack up against those with only one?

There are several objectives of this Senior Capstone project. The main goal is to determine whether or not pitchers comeback stronger after Tommy John Surgery. The examination of pitches thrown using the resource pitch/fx –a database of pitches thrown (see references) –will be used to dictate this outcome and remains the focus of research. The research seeks to fill the gaps when referring to the fact or myth distinction many ball clubs ask themselves of the subject matter –is it worth investing in the future of a pitcher who has undergone surgery? I will research and compare popular beliefs in the field to actual computed results resembled in historical data. I want to be able to provide useful information for leagues, team managers, coaches, trainers, and most importantly –players.

The focus of my research is an analytical project involving the analyzing of and manipulating of variables to ultimately answer the underlying question –is it statistically indicative for a pitcher comeback stronger from surgery or is it a tell-tale symbol for prospective teams to stay away? Online database research will be the preliminary source of information. Variables looked at include pitcher characteristics including but not limited to age, origin, height, weight, types of pitches thrown, velocity, and location of their home field ballpark. For example, age can be a large indicator of someone most vulnerable to a torn UCL. Additionally, the location of the park may alter a pitcher's arm. For instance, if half of their starts are in San Diego, there atmosphere is certainly different to the likes of Fenway Park in Boston. The same goes for a pitcher in Denver who will give up a fraction more homeruns per game on average due to the altitude difference. The built in advantages and disadvantages will be examined, and certain variables

must be indexed down to a level playing field –no pun intended. Pitch location and accuracy are some of the most important facets of baseball provided by Baseballsavant.com (Pitch/Fx). As mentioned earlier, this was the primary source of the raw data for pitchers; listing all pitches thrown in the MLB since the beginning of the 2008 season. Additionally, basic statistics may be incorporated such as innings pitched, velocity, pitch result, etc. Microsoft excel was the main tool utilized for the analysis.

Origin

The idea derived from my long invested interest in baseball as well as my youth career –playing in three or more seasons as long as I can remember. In addition to exposure in just about any team sport as a kid, I have I logged countless hours on the mound as a pitcher. It has always been a passion of mine to help my team by setting the pace and being in control of the game. I was not the hardest thrower on the team but from time to time, I experienced arm pain, especially in the elbow, but was more apparent after I pitched or when I felt I was overworked in both a practice and/or game setting. I never knew specifically what was responsible for the pain. As a result, I decided to look into learning more about the reasons for this. I uncovered a plethora of interesting articles and studies. Furthermore, there exist a variety of implications regarding how this can be incorporated into the business world and its practical application for executives trying to maximize efficiency while minimal costs. Subsequently, the idea evolved into a way for executives to re-evaluate players and find the true determinants behind what the risks of signing a player who has gone under the knife. The implications will be discussed below.

Literature Review

The goal of this literature review is to paint a picture for any reader to understand what baseball has been, what is currently going through, and its direct involvement in pitchers' careers. Topics discussed include the history, nature, and implications of what Tommy John surgery could signify within the realm of professional baseball pitchers' careers.

History and Controversies of Major League Baseball

Baseball remains America's past time at heart. Its roots are deeply engrained in the foundation of the nation. If the sport was a person, it has seen the seed juncture of the industrial revolution to the evolution of Boeing 757 jets –a longstanding lifespan. Its forever nostalgic atmosphere remains apparent in parks from Boston's green monster to Chicago's Ivy wall. From the times when Babe Ruth called his shot at Wrigley field to utilizing instant replay, baseball has seen many changes on all fronts. To give you an idea of where we are in time, let's run through a timeline of how the sport has evolved and changed in so many ways. There exist adaption requirements that will only benefit a team or player if done affectively. From Jackie Robinson's first steps on the field for the Dodgers, to the steroid dilemma of the 90s and 00s, to instant replay usage in baseball, the sport has endured a multitude of snags within its operations. There have been issues with stubborn major league teams only managing as they have done in the past –which is due to baseball's long-engraved culture –but that's a story for another day. That is why many teams did not support Billy Bean's sabremetric phenomenon in using big data to predict future outcomes or even why the topic of instant replay is so controversial –teams do not want to stray too far from the roots, even if they would be more successful or better off otherwise. After big data's success debut in the 2002 Oakland Athletics' comeback and playoff run, the

breakthrough has sent waves across the sport –could a team simply evaluate players based on data calculations or algorithms? It offers a plethora of other functions as well. Big data can be used to predict future outcomes which serve teams an invaluable perspective for pitchers' recovery approaches, assessing potential risks involved in resigning players, and exploiting potential in "revamped" players. Sports injuries are now the topic of concern. The 2015 Sloan Analytics Conference had a common theme among all coaches, general managers, and owners – how can we predict injuries to make better decisions? These are some of the notions I wish to address in my study. The byproducts of this knowledge have a large impact on teams' decision making abilities. The research includes analytical techniques to predict future outcomes of major league baseball pitchers as well as provide statistical evidence of before and after effects on their arms.

Injury Significance

Overall, injuries have plagued professional athletes at what seems to be an even greater level than before, so there are a variety of sources on how big data affects sports. There remains a fair amount of literature in the field today on the topic at hand –Tommy John Surgery. There exist examination techniques of how teams can diminish the side effects of the injuries en route to a speedy recovery. Injury preventative tactics have been enforced by coaching staffs and various training personnel but there are other factors that must be considered before making a conclusion. The tearing of the ulnar collateral ligament (UCL) in the elbow has become a predominant injury (Tommy John) among pitchers in major league baseball. Reconstructive surgery has been a necessity for any pitcher wishing to return. This surgery is intended to repair torn ligaments in the elbow while using a few different types of surgeries. Major League Baseball pitchers are seeing an increase in the number of surgeries performed each year –up

from four major league pitchers in 1999 to over thirty in 2013 (Erikson, 539). The American Sports Medicine Institute, which includes renown doctors who have studied sports medicine published a multitude of studies on both little league baseball and professional baseball players – in addition to those mixed in between (high school and college). This research is the best available and actually used to create regulations and mandated rest periods for younger pitchers advocated on their *Pitch Smart* campaign website. They are credible because they give great medical insight, which has proven to be accurate over the course of decades (not covered as in-depth in my own methodology of research). Despite this trustworthy research, Tommy John Surgery still remains an evolving process and a topic of concern for all pitchers wishing to comeback and perform at an equal or greater level. A definitive answer on how to predict injuries and affectively address the issues involved in tearing of the UCL ligament has yet to be fully uncovered. The underlying questions that remain up in the air have been introduced in the Scope section of this paper. Some of these questions are partly addressed, however there are others are that I have brought to the discussion –which I have looked to answer and/or verify as a direct result of my research study.

Applications

The research from current databases in conjunction with my research study is especially relevant to the future use of professionals and the analysis will give groundwork for owners, executive managers, and decision makers the wherewithal to make more accurate decisions when running their business. Risk of injury is the overarching measurable piece for a player's worth on the field, whether it be in a promotional business sense (i.e. goodwill and character–Derek Jeter) or a player's dominance representing the driver for the team's overall performance. The in-depth analysis has the ability to provide major league ball clubs information needed to avoid certain

free agents or reassess old, traditional intuitive thoughts surrounding prospective players. Moreover, injuries don't just cost wins, they cost money. "Major League Baseball spent $665 million last year on the salaries of banged-up guys and their replacements [the most of any major American sports league]." (Kamenetsky). "How can we prevent and/or avoid injury overall? How can my club [or team] get to a championship for the fewest dollars spent?" Baseball has a history of using predictive analytics and sabermetrics for the future benefit of the organization; the phenomenon we all know as predictive analytics. My research will not provide a means for teams to evaluate injury prevention, but rather, give baseball an answer as to whether the "Tommy John List" pitchers are something clubs should take a chance on. This project is a worthwhile study that will contribute to what research has already been compiled in this area of baseball.

Understanding Tommy John Surgery

There exist a plethora of facets to consider before analyzing the data out there. In order to refine the search to a manageable dataset, I have compiled relevant data and analysis (seen in the methodology section). While there are not many publications on the analysis of the data, there are analyses on how to prevent injuries and why they are occurring in the first place. Before delving into the review of sources that have been examined, there are a few key terms and techniques that are to be discussed in order to gain a full understanding of the topic. The UCL tendon is repaired with a graft tendon, which is a piece of living tissue that is surgically transplanted into one's elbow. There are multiple types of grafts used but the most common technique used in research studies is the Palmaris longus ligament –a weak flexor tendon from the forearm (also used in a lot of wrist reconstructions due to its flexibility and size). Another predominant term to be familiar with is the Modified Jobe surgical technique pioneered by Dr.

Frank Jobe during the first ever UCL reconstruction surgery –his reported results were published in a landmark article in 1986. "The Modified Jobe Technique for UCL reconstruction/repair uses a series of tunnels in the ulna and humerus to pass the graft in a figure-8 fashion and secure it to itself and surrounding soft tissue (see figure 1, right). Repair of the original UCL is added for greater stabilization. The Modified Jobe can be performed using the Anthrex Elbow UCL reconstruction instrument set. FiberWire and FiberLoop may be used to stitch the graft ends and for final fixation." (Anthrex). The surgery takes approximately 12 months to heal and properly rehabilitate for a pitcher to return to competitive play. Dr. James Andrews has since modified the technique by elevating the flexor-pronator muscle mass without detachment and subcutaneous rather than sub muscular ulnar nerve transposition. The evolved procedure closer to the skin is known to offer a reduced risk in a rupturing or further tissue tearing. On to more baseball related terms, two major positions for a pitcher's delivery are *Cocking* and *Acceleration* –both of which are post-windup. *Cocking* involves the potential energy build-up from the legs to one's core (see figure 2). This motion is considered to be in effect from the breaking of the hands to their full extension. Subsequently, the *acceleration* phase is a pitcher's downward motion toward home plate. It involves the rotating of the torso and whip of the arm. This phase is most responsible for injuries occurred due to one's want to increase velocity in an effort to make it more difficult for the batter to hit

Figure 1

the ball. Velocity is derived from the motion, which is why one's arm can be abused. Even with perfect mechanics, a pitcher's arm remains very vulnerable due to the unnatural motion of throwing a baseball. At the 90 degree frame of the arm in the acceleration phase, the elbow ligaments are said to have over five bowling bowls of weight hanging on a string on the throwing hand –that is about 60 pounds or 100 newton meters of torque on the elbow ligaments (see figure 3). The elbow is not meant to have that much strain put on it. Unlike an underhand softball pitch, the throwing motion that starting pitchers repeat for over 100 times each game is considered an "unnatural" motion in which the human body is not meant to perform. As a result, ligaments and other tendons that are in use become vulnerable to tearing if not kept an eye on. The familiarity of these notions are important to grasp in an effort to understand the niceties associated with a pitcher's workload.

Trends

As competition has increased, the need to standout has followed in the same fashion. The need to become *better, faster, and stronger* have emerged into the psyche of any athlete –more specifically, pitchers whose arms endure a greater amount of stress. As the amount of winter leagues, prospect camps, information technology arises, so does the competition as it becomes easier for clubs to scout prospects via web. Simultaneously, a great amount of information has come to surface regarding injuries in baseball. As a result, preventative tactics have seen a steady effort to counterbalance these two conflicting forces –the fierce competition and the desire to stay healthy in the process of career progression. There exists a pitcher's dilemma, defined as exhausting their arm for immediate success. The minor league competition increases their risk to UCL tearing because it has an effect on how these pitchers go about advancing their career. "If I throw at 90 percent to save my arm, and Larry throws at 100 percent, who do you think the team

will notice first? There's an incentive for me and everyone else to throw at max effort." (Carleton).

Verducci Effect

There remain a variety of sources that offer opinions in determining where the arm pain stems from. All of which offer reasonable justifications behind why. One of the main forward indicators to an overused arm is innings pitched. Many sources are hooked on this idea of the verducci effect –also known as the year after effect. According to Greenhouse (2010), the concept is defined as Rule of thumb among executives and pitching coaches that young pitchers' workload should not exceed a 25-30 inning increase from year to year. Gassko (2006) states that the research suggests the opposite Injuries occur if pitch limits are exceeded on a game by game basis and the specific increase from year to year does not have as large of an impact on one's throwing arm. Nonetheless, there remains this argument within the realm of pitching of what actually contributes to stress on arms. Greenhouse (2010) states that velocity peaks in a pitcher's mid-twenties and that young pitchers, classified as 25 and younger have on average a 0.5 mile per hour (mph) advantage over all other pitchers. In the study, 340 pitchers were sampled in the MLB. 140 were classified as the verducci effect sample (VE) and 200 as the non-verducci effect group (NVE). Overall, these 340 pitchers were found to have favorable results, experiencing increasing strikeout trends and decreasing walk trends. Over a three-year period, the verducci effected group saw a higher percentage on the disabled list from their second to third years in the majors (9.35 percent increase). On the contrary, the 240 pitchers experienced a 1.46 percent increase in joining the disabled list from their second to third years on the mound. This illustrates that pitchers are more likely to experience injury as their careers progress if they are in the verducci group (25-30 inning increase year to year) compared to those who are not (null).

Moreover, these same pitchers experience a decrease in velocity –about 0.3 mph less than the rest, who actually gain the same amount behind each pitch they throw. Furthermore, it was determined that the fastball from the prior year has five times more predictable capability than that of two years prior, meaning that the naïve model of the year prior stands true (more recent data has a greater significance than years further in history). This study shows that young gunslingers such as Josh Johnson and "King" Felix Hernandez are at risk and must be monitored carefully. To sum up the findings, the workload and age help predict production, velocity, and injuries but the overall conclusion does not show significant results as to whether the verducci effect helps explain injury and risk further than what one would expect. Although this research shows many obvious trends, it serves a great omen to the current state of where baseball players stand in the leagues current norms and conditions.

According to the Baseball Prospectus sports writer, Russell Carleton (2013), the verducci affect is not actually true. He took data from 2011 pitchers to construct a logit regression model for what variables were associated with a pitcher suffering an elbow injury as well as other pertinent arm injuries. The results showed that homerun rates, number of batters, change in innings from year to year, and ERA were the largest contributors to elbow injuries. How big is the risk? 27.4 percent of those who had an elbow injury this year have had a similar injury the year prior and only 2 percent did not have an injury. This means that the chance of hurting your arm the following year after an injury is 25.4 percent more likely. The same was done with two year gap which showed a decreased spread to 13.4 percent (15.2 – 1.8) meaning that the longer you go without the injury reoccurring, the less likely you are to have it happen again. Thus the conclusion is the older you get and if you have been exposed to an injury before has a very large impact on how likely you are to get injured again. "Once a pitcher is damaged, he's damaged

goods. And it's not like you can tell a pitcher not to throw another pitch; that's what pitchers do. And sometimes they get hurt. That's life." (Carleton, 2013).

Pitch Limits & Mandated Rest

Coaches and player restraints during a young age's impact potential and progression; even before the major leagues. The According to Carleton (2014), various rules for different states may impact the consistency of performance in the long run –more specifically in high school pitchers. Not all states have mandated rest or regulations on pitch limits. Mandated rest is classified as the mandatory calendar day rest for pitchers after appearing in a game. Under this rule, if a pitcher is on the mound on Monday, he is not allowed to appear in another game until Tuesday, Wednesday, or Thursday (depending on the state's rules). This precaution allows for pitchers to rest their arms in an effort to lessen the acute effects of stress on their arms. The mandated rest is meant to act as a preventative measure for arm injuries. More specifically, elbow injuries account for 10.1 percent of pitchers compared to 11.9 percent for mandated rest states and non-mandated rest states, respectively. Of these percentages, 2.0 and 3.2 percent respectively underwent Tommy John surgery meaning that those who pitch in states without regulated states have a greater chance tearing their UCL on average. The second pre-caution are the pitch limits which is simply what it implies –a limit to the amount of pitches that are thrown in a game before having to be "Pulled". From 2002-2012, starters with elbow injuries from states with regulatory pitch limits accounted for 10.3 and 16.8 percent in regulated and non-regulated states, respectively. From these number, 2.8 and 3.7 percent underwent Tommy John Surgery. Therefore, those from states without regulations had a lower Tommy John surgery rate. There is a clear connection between states with regulations and/or mandated rest versus those who do not. The states with preventative measures are proven to do better in preventing elbow injuries. When comparing the

mandated rest days to the pitch limits, pitch limits contribute more to amount of elbow injuries showing 16.8 percent of pitchers in non-regulated states versus the 11.9 percent for mandated rest. Moreover, "States with more lax regulations produced pitchers who were more likely to go on the disabled list and to have elbow injuries" (Carleton, 2014). Pitchers from unregulated states are 63 percent more likely to have an elbow injury and 32 percent more likely to undergo TJ surgery in any given year compared to those who are not regulated.

A large problem is that the ASMI guidelines for rest and pitch limits can only go so far to stop pitchers from heaving in front of scouts or state championship adrenaline that pushes a pitcher past the ideal standards–not to mention the coaching incentive of leaving a more dominant pitcher in the game. The culture of baseball is aligned to go against ASMI recommendations. This disconnect has laid a platform for less and less pitchers making it to the *bigs*. Furthermore, even if it was corrected and the league kept everyone's arm healthy, that just means more competition, and the cycle goes on. Until the league expands to the point where mediocre players are accepted, there will always be this dilemma. As mentioned earlier, competition and emotion take precedence in prioritizing pride and health. For example, a high school pitcher in Washington threw 194 pitches in 14 innings; an extremely high amount of pitchers compared to 90 pitch average over 7 innings. Dylan Fosnacht (May 14,2014) said quote, "People might criticize me for throwing 14 innings, but I'm going to do whatever it takes to win". The "Win at any cost" mentality is seen as a note of concern for preventative measures. It should be noted that there is not pitch limit in Washington State.

Noteworthy Research, ASMI

As mentioned previously, many studies are conducted by the American Sports Medicine Institute. The two main names that jump out on the list of credible experts in the field are Dr.

James Andrews and Dr. Glenn Fleisig. Andrews performs has experience in performing other surgeries including Robert Griffin III for anterior cruciate ligament –more commonly known as ACL. "Doctor James R. Andrews is a co- founder [alongside Glenn Fleisig and others] of the American Sports Medicine Institute (ASMI) a non-profit institute dedicated to injury prevention, education and research in orthopedic and sports medicine…Doctor Andrews is internationally known and recognized for his skills as an orthopedic surgeon as well as his scientific and clinic research contributions in knee, shoulder and elbow injury prevention and treatment." (Andrewssportsmedicine.com) He has also mentored over 300 orthopedic surgeons. Flesig –a co-director of the ASMI –has been a spokesman promoting the organization's research and appeared as a presenter at the nationally recognized MIT Sloan Analytics Conference. The two, alongside other doctors who perform research and expertise on the subject are usually among the first to receive a phone call from professional organization to a schedule reconstructive surgery for the intended athlete. Their surgeries and analysis of research has given way to breakthroughs in dissecting the cause and effects on major league baseball pitchers. However, because they are among the few trusted sources, it makes it difficult to access the true outcomes. The injury dilemma exists to give insight into how big an epidemic has come about and what it means for pitchers.

ASMI performed a research study on athletes who have undergone UCL reconstructive surgery of the elbow (Cain, 2010). All of the surgeries were performed by Dr. James Andrews. The institute followed up with 1281 athletes over a 19 year period with a telephone questionnaire (two-year minimum). Of the total participants in the study, most said they returned to equal or level play (75.5 %). They found 85 percent of the total 1281 athletes were baseball pitchers, broken down into those who threw over the top (44%), three-quarters (52%), and sidearm (4%).

96 percent of these pitchers complained of arm pain in the cocking and acceleration phases, while 47 percent complained of more specific acute pain in the elbow. The most successful pitchers threw with the over the top motion, seeing an 83 percent return to equal or better play. The AMSI recommends the surgery participants should have at least 3 months before considering to see if your elbow pain heals and complete rest from any exercises. On average, from surgery to the initiation of throwing a baseball was 4.4 months, while it took another 7.2 months to get to full competition. However, sometimes it took as long as three full years to return to the mound in a few instances and other only three months. The study broke down the operative findings in high school, college, minor league, and major league levels, and depicted that from this study, 25 of the 1281 athletes were major leagues who completely tore their UCL as opposed to a partial tear. The study also shed light on the fact that this sample involves athletes whom grew up the 1990s, a time when sound youth competitive baseball leagues were becoming more and more prevalent. Four seasons of baseball was not uncommon to see, even in the northeast where AAU indoor leagues were popping up from region to region. This notion could play a large factor as to why the amount of surgeries have increased overall.

Rehabilitation

An interview was conducted with Bryant University's baseball trainer Cameron Siciliano in order to gain a full understanding of the effects of Tommy John surgery on players. Forearm strength and grip are focused on in preliminary stages of rehabilitation along with range of motion exercises such as pronation and supination. These exercises help strengthen the forearms in an effort to regain one's range of motion and flexibility to offset the risk of re-injury. A pitcher's core is very important to take into consideration when rehabilitating post-surgery. These exercises are healthy advocated for all pitchers, but especially those who have undergone

Tommy John as taking the pressure off the elbow ligament (at least initially) will aid further development of a pitcher's accuracy and velocity. A pitcher's mechanics should be very closely watched when working their way back to competitive play. Cutting back on the number of breaking pitches thrown is something that should be considered in terms of precautionary measures involved will alleviating stress. The snapping motion of these pitches which are not "Over the top" can be detrimental to positive progress. Overall, a major league baseball pitcher undergoes much more stress on their arms during the acute stages of their motion toward the home plate than a positional player would endure. For this reason, a pitcher's time table for return is usually 4-5 months longer than that of a positional player. (James Grant with Cameron Siciliano, Bryant University Assistant Athletic Trainer, March 24, 2016).

Preliminary Field Conclusions

Overall, the research thus far shows the best predictor of needing TJ is having a previous elbow injury. There are contradicting notions in that regulations are good to preserve arms and that people should ignore UCL injury risk (minimal) because it will not make a difference and the effect is not large enough to quantify altering current approach. "The [TJ] success rate is in the 80 percent range" (Carleton, 2014), meaning that the pitchers return and stay for at least a year in the major leagues. Despite the success rate, this disconnect goes against all professional ASMI guidelines and recommendations and deserves attention.

Study Overview

Using the data mined from baseballsavant.com (pitch/fx, see figure 3), I have worked backwards to examine the performance of major league baseball pitchers. Columns downloaded include the player's name pitch type and result, at bat result, velocity, pitch and break angles, rotation,

zones, batter count, inning number, etc. This data can be specified within the query on the website before it exports the output onto an excel sheet. Specifications include pitch types (17), pitch results (19), game dates, home vs. road games, regular vs. post-season games, yeaar/season as well as where the games were played. Included in my research study are assigned values to columns/fields for accuracy measurements in pitches in addition to if statements, logical operators, etc. All are vital throughout the data cleansing process for ease of data manipulation and organization. Additionally, there were many graphs explored throughout the process, courtesy of baseballsavant.com. Because I am completing my Capstone project in the applied analytics field, I have designed a project that will incorporate various analytical methods. An event t-test has been used to compare before and after results for velocity –the details are outlined in the methodology section.

Data Sources Used

In my research I have utilize a few types of sources. Many of my sources come from online journals. These will give me reliable information and results from important research studies that have already been done. I am looking for sources that offer studies to compare my research to, however my research will be unique and pull together many facets of arm stress. Additionally, online articles and blogs on the topic represent popular opinions and information about the subject matter and help illustrate an accurate picture of what research already exists as well as its significance to my project. Publications from these sports sources offer great insight into what makes a pitcher's arm stressed.

First and foremost, as mentioned earlier, the main data used were baseball pitches from 2008 to 2015 via baseballsavant.com. The data was downloaded from this website and formatted as discussed in further detail within the methodology section of this study. Additionally, I have used

an excel workbook (Roegele) compiled by Jon Roegele, a baseball sabermatician as a means of selecting the players to test whom have undergone Tommy John surgery. I have adopted various sheets from this workbook and configured a personal database of players who have received Tommy John, renamed as "TJ List". The workbook has aided my study by presenting a list of players including but not limited to facts such as the date of the player's surgery, position, team, surgeon, and pre/post games played after returning to the field for competitive play. Other tabs within the workbook showed players who have had Tommy John surgery two times in their professional career as well as their surgeons, surgery succession-revision rates. Additionally, recovery time averages are given for various age groups from 12 years of age to a 36-50 interval. Of the major league players, the most were performed in the 28-29 years old age group (84). (TJ list, "Recovery Time").

Using the "TJ list", I created a tab for climate tab to reference where the players are from with which the player's high school and/or origin were used (referenced from the "TJ list" tab in the workbook). Furthermore, I created to compile a list to categorize the players' origins as "US, warm climate, cool climate, or Non-US". These identifications can be seen on the tab "Climate HS" (figure 3). Each state is represented as being a hot or cold climate state, as well as whether these states have mandatory regulations or mandated rest (a binary code was used, 1=yes, 0=no). I used the "countif" excel function to summarize the data for the amount of players within each category (see figure 3). These categories were helpful in exploring the data on a holistic level and aided in understanding how the players may have been impacted from their adolescent starting stages toward a professional career in baseball.

A third workbook titled "Player comparison & Analysis – Final" was used to in consolidating the sampled players data together and served as the main platform for analysis, discussed further in the methodology section.

Hypothesis

Thus far, the research in the field has indicated that players who undergo Tommy John surgery perform worse after Tommy John. These pitchers are perceived as "damaged goods" and will have trouble maintaining successful careers post-surgery due to elbow fatigue and other byproducts of failed rehabilitation efforts. As mentioned in the literature review, if players are to remain healthy for longer durations or gaps during their careers post-injury, they are less likely to experience the same injury, thus they are not hindered by the niceties associated with surgery (all other things equal). All things considered, my hypothesis is as follows: Tommy John Surgery will prolong a pitcher's career, but those who undergo the surgery will experience negative effects as it relates to their long-term career performance.

Methodology

Using pitch/fx data baseball pitches thrown in from the range of 2008 to 2015, I took a sample of pitches from a year before the player underwent surgery as well as one after for each respective candidate. Samples players were determined at random using the "TJ List" excel workbook. However, constraints such as innings pitched and years of available data were noted and adjusted accordingly. More complexities are explained further in the validity section of this study. I decided to assess performance using three measures –accuracy, velocity, and stamina (with the assumption that an increase in each is evaluated as a positive result).

As mentioned previously, the selection of the sample players was determined randomly from the TJ list workbook and referenced to the platform workbook for a further dissection of comparative analysis (see figure 4). This selection included with constraints including the amount of innings pitched, years of data available, among other variables. Once the players were selected, I chose the sample year that I would look at for each of the players before and after surgery (see figure 5, left). The pitch data for both test years of these players were then pulled into excel. The pitch type, velocity, and pitch result were some of the main variables when determining the accuracy and velocity analysis for each pitcher (see figure 6).

Before TJ Season

Name	Surgery Date	Test season (YR)	Age
Matt Harvey	10/22/2013	2013	24
Neftali Feliz	8/1/2012	2010	24
Joba Chamberlain	6/16/2011	2010	25
Daisuke Matsuzaka	6/10/2011	2010	30
Adam Wainwright	2/28/2011	2010	29
Stephen Strasburg	9/3/2010	2010	21
Joe Nathan *	3/26/2010	2008	35

After TJ Season

Name	Surgery Date	Test season (YR)	Age
Matt Harvey	10/22/2013	2015	26
Neftali Feliz	8/1/2012	2014	28
Joba Chamberlain	6/16/2011	2013	28
Daisuke Matsuzaka	6/10/2011	2013	33
Adam Wainwright	2/28/2011	2013	32
Stephen Strasburg	9/3/2010	2013	24
Joe Nathan *	3/26/2010	2013	40

After running "countif" functions to sort the data by pitch type, an average velocity per pitch type was determined (see figure 7). The same was done for the post-surgery sample year. The pre vs. post-surgery comparison tab shows the variations of each of the types of pitches (see figure 8). Furthermore, a t-test was performed to determine the significance of the mean velocity for all of the player's pitches before and after surgery. This was done through the data analysis tab by selecting "t-test: Two-Sample Assuming Unequal Variances", which is a safer and more conservative approach than an equal variance test. A t-stat was determined (see figure 15). For example, Matt Harvey had a 6.0 t-stat, which when compared to the critical two-tail 1.96 interval is far apart in terms of standard value, thus it is significant. So since t-stat is outside of that range

(-1.96<X<1.96), we reject the null hypothesis and conclude that the mean difference in before/after velocity is convincing enough to say that the average velocity of Matt Harvey's pitches differs before and after Tommy John Surgery. This was the case for all of the players sampled and will be discussed in further detail in the findings section of the study.

To test for accuracy improvements (or lack thereof), a comparative analysis labeled "Pre vs. Post Comparison" for each respective player was done. Using the pitch result variable, a ball vs. strike comparison was performed to obtain a percentage of pitches thrown as strikes (see figure 9). Statistics such as hits and runs allowed were incorporated as totals for each respective tested year and indexed with innings pitched (IP) to adjust for the differing amount of innings each pitcher threw (see figure 10).

Findings/Results

Figure 11 shows the results for each player. Overall, the averages of hits and runs allowed per inning pitched increased for these seven players tested (+.02 hits/IP, +.01 runs/IP), which is a bad result but does not significantly differ from pre-surgery. After reviewing the literature and performing the study, the most significant discovery I have made is that there are many ways to evaluate what how a pitchers perform as well as how these injury play into their career moving forward. It remains very difficult to find one reason as to why the pitcher got Tommy John. While it has not been determined to have significant results and differing correlations for players, a definitive cause or result has yet to be identified. However, the research has outlined the difficulty in holding an elbow injury responsible for positive or negative impacts. There are many variables in which player's careers are affected including but not limited to mental state, team needs at the time, rehabilitation, surgeons, coaches, weather, etc. that may impact the player's progression or lack thereof moving forward in their careers. For example, Matt Harvey

of the New York Mets, has increased velocity after in his four-seam and two-seam fastballs, change-up, and slider. His accuracy increased 2.45 percent –defined as strikes divided by total pitches. However, his hits and runs allowed per innings pitched increased 0.07. Moreover, in 2015, the National League East competitors had a worse record in terms of wins (284) than in 2013 (317). This does not make sense that Matt Harvey performed worse statistically in 2015 when his NL East opponents were considered "easier" in retrospect.

Another example is Daisuke Matsusaka (Dice-K), the man who is arguable responsible for the Red Sox success in winning the 2007 World Series, tallying 18 wins and 3 losses. However, he has logged many pitches on the mound in his lifetime. Japanese leagues tend to leave pitchers in for much longer than what is recommended in the MLB. The following quote is about Matsusaka pitching performance in the 1998 Koshien Tournament while in high school: "In the quarterfinals, [Matsusaka] pitched a 250-pitch, 17-inning game at age 17 for the victory." (BaseballReference.com). Because his surgery was in 2011, the 2010 season was used as the test season before surgery, and followed with 2013 as the sample season post-surgery. Dice-K posted decreasing velocities all of his pitches from 2010 to 2013 (see figure 12). However, he experienced increasing accuracy of 1.45 percent –a modest increase. Moreover, Dice-K's hits allowed per inning pitched dropped from 0.89 in 2010 to 0.84 in 2013 –a positive result. We found that his pitches all were decreasing velocity, increasing accuracy, and positive statistical results. All things equal, this would mean that velocity is less important than accuracy. Unfortunately, all things are never held equal in baseball. Many factors support this claim including his switch from the American League to the National League during that span. In the AL, a DH is substituted each pitcher in the batting lineup. National League pitchers are at an

advantage of having a "guaranteed out" when pitchers bat, whereas American League pitchers have to face the likes of homerun hitters David Ortiz, Jose Bautista, or Chris Davis.

All other pitchers including Neftali Feliz, Joba Chamberlain, Adam Wainwright, Stephen Strasburg, and Joe Nathan were analyzed the same way using average velocity, strike percentage, and compared with statistics. Joe Nathan has had surgery twice in his career. There was not a sufficient amount of change for further analysis. Reliever Neftali Feliz decreased velocity on three of his four pitches. However, his slider increase a drastic 4.21 mph. He may have decided to throw this pitch with less break, resulting in less stress on the elbow from the contortion involved (see figure 13). He also saw a 26 percent decrease in the amount of runs allowed between his test years of 2010 and 2014, going from 0.30 runs allowed per inning to 0.22, respectively. The consensus was that these players have do not show significant evidence that pitchers perform better post-surgery. The surgery does prolong a pitcher's professional career as indicated in figure 14. The average return percentage for MLB pitchers is 76 percent. However, there is no guarantee that these players will perform better. There have been players who do well and some not so well, but they are accounted for in the multitude of other variables. Whether a player performs better or worse after Tommy John reconstructive surgery remains a very difficult predicament and one that cannot be confidently said with certainty. It is a very situational decision in which the player's performance cannot be pinned to the elbow injury. Age batter skill, league, player condition, weather, etc. have an effect on the outcome.

Validity

One major flaw to the study is that accuracy is not measured where the catchers set up. Thus, there could be locations where the catcher and coaches want the batter to "Chase" pitches, which would lead to wrong categorizations in accuracy levels. If these assumptions are abnormally higher in one year, it could skew the data and not accurately represent the accuracy improvement measure.

Constraints associated with the experiment start with the data available from pitch/fx. All players whom underwent surgery in 2015 were ruled out because there was no 2016 data to test as their post-surgery year comparison. Furthermore, the amount of players was limited in terms of those with sufficient innings pitched for both pre and post-surgery. A player who pitched 150 innings consistently for multiple years and the year after surgery pitched 15 innings was difficult to compare because of the significant difference in pitches thrown and not a sufficient amount of data to explain. Additionally, some players had more time to recover than others, which is something to look into for another possible study.

Lessons Learned

The research, as mentioned before includes a multitude of variables. Therefore, this process has involved compiling, formatting, and cleansing of multiple data sets, which is the most time consuming part of the process. Data Mining and cleaning takes a great amount of time. However, I have become adept with statistical analysis involved with excel, in addition to t-tests and how they can be used to determine significance. Causal and subsequent consequences of baseball correlated variables were interesting to consider throughout the process and opened up a variety of possibilities. A new perspective on how to evaluate this kind of data helped illustrate for me

that "things are not always as they seem" and to take a deeper look. Lastly, as discussed in the validity section, there were many snags during the study and roadblocks to overcome. I am glad that my passion for the sport, intellectual curiosity, and good fortune were able to guide me through dealing with some of these shortcomings.

Appendices

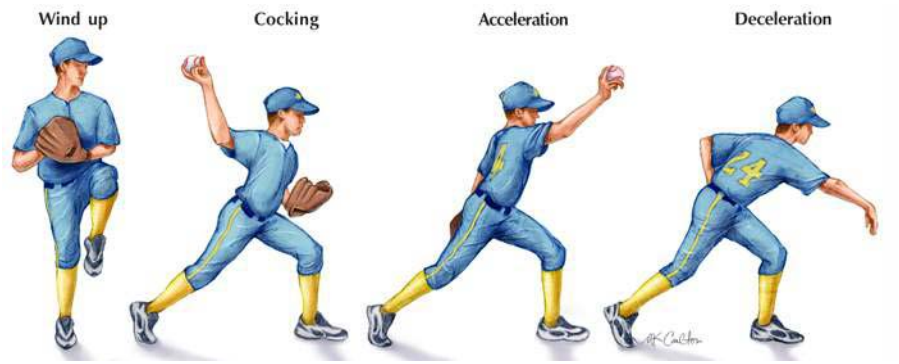

Figure 2

	A	B	C	D	E	F	G	H
1	**High School**	**TJ Surgeries**	**Average Age**		**High School**	**Climate**	**Regulations?**	**Mandated Rest?**
2	US, warm climate	443	23.8		Alabama	Hot	1	1
3	US, cool climate	418	23.8		Alaska	Cool	1	0
4	Non-US	251	23.7		Arizona	Hot	1	1
5					Arkansas	Cool	1	0
6					California	Hot	1	1
7	Total surgeries	1112			Colorado	Cool	1	0
8					Connecticut	Cool	1	0
9					Delaware	Cool	0	0
10					Florida	Hot	1	0
11					Georgia	Hot	1	0
12					Hawaii	Hot	0	0
13					Idaho	Cool	1	0
14					Illinois	Cool	1	0
15					Indiana	Cool	1	0
16					Iowa	Cool	1	1

Figure 3

Relief?	Surgery Date (1)	Surgery Date (2)	Team	Country	Age	Return Date (same level)	Recovery Time (months)	Post-TJ MLB G	Post-TJ MLB IP	Surgeon(s)
		10/22/2013	NYM	United States	24	4/9/2015	18	0	0	Dr. James Andrews
YES		8/1/2012	TEX	Dominican	24	9/1/2013	13	36	36.3	Dr. Keith Meister
YES (except 08/9)		6/16/2011	NYY	United States	25	8/1/2012	14	136	125.7	Dr. James Andrews
		6/10/2011	BOS	Japan	30	6/9/2012	12	52	167.7	Dr. Lewis Yocum
		2/28/2011	STL	United States	29	4/7/2012	13	98	667.3	Dr. George Paletta
		9/3/2010	WAS	United States	21	9/6/2011	12	97	581.3	Dr. Lewis Yocum
YES (switched)	3/26/2010	4/29/2015	MIN	United States	35	4/3/2011	12	243	231.7	Dr. David Altchek

Figure 4

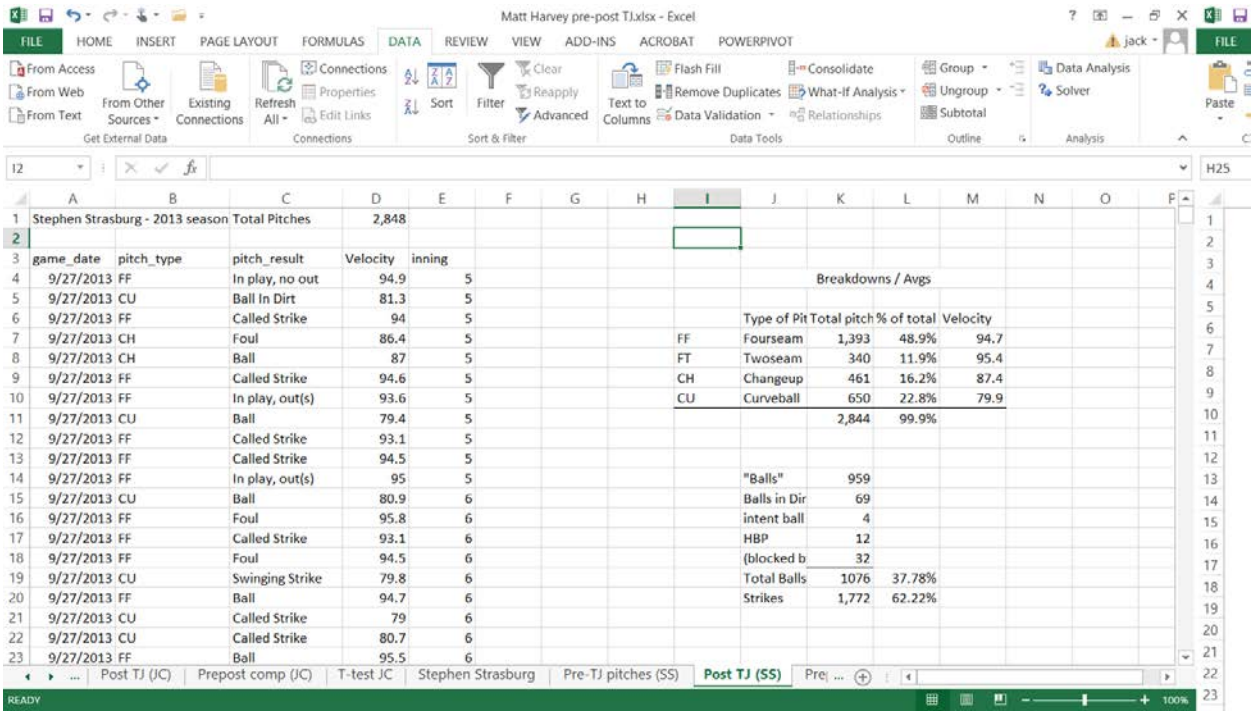

Figure 6

Type of Pitch	Total pitches	% of total pitches	Velocity
Fourseam (FF)	2,109	57.5%	94.4
Twoseam (FT)	67	1.8%	92.0
Changeup	414	11.3%	85.8
Curveball	450	12.3%	82.8
Slider	625	17.0%	88.0
	3,665	99.9%	

Figure 7

Breakdowns / Avgs **Before** TJ (last game 8/24/13)

Type of Pitch	Total pitches	% of total pitches	Velocity
Fourseam (FF)	2,109	57.5%	94.4
Twoseam (FT)	67	1.8%	92.0
Changeup	414	11.3%	85.8
Curveball	450	12.3%	82.8
Slider	625	17.0%	88.0
Totals	3,665	99.9%	

Surgery Date 10/22/2013
Did not play the entire following 2014 Season

Breakdowns / Avgs **After** TJ (first game back 4/9/15)

Type of Pitch	Total pitches	% of total pitches	Velocity	Difference
Fourseam (FF)	1,245	48.2%	95.7	+ 1.24
Twoseam (FT)	403	15.6%	94.1	+ 2.01
Changeup	205	7.9%	86.9	+ 1.11
Curveball	317	12.3%	82.7	- -0.04
Slider	409	15.8%	88.6	+ 0.54
Totals	2,579	99.8%		

Figure 8

2013
Balls vs. Strikes (accuracy)

"Balls"	1206	
Balls in Dirt	45	
intent ball	4	
HBP	7	
(blocked by C)	16	
Total Balls	1278	34.83%
Strikes	2,391	65.17%

2015
Balls vs. Strikes (accuracy)

Balls	774	
Balls in Dirt	39	
intent ball	6	
HBP	5	
(blocked by C)	13	
Total Balls	837	32.38%
Strikes	1,748	67.62%

\+ 2.45% Accuracy improvement

Figure 9

	Era	IP	H	R	Hits/IP	Runs/IP
2013 Year before tear	2.27	178.1	135	46	0.76	0.26
2015 Year after tear	2.71	189.1	156	62	0.82	0.33
		Difference			0.07	0.07

Figure 10

Before TJ Season

Name	Surgery Date	Test season (YR)	Age	Avg velocity	% strikes	Pitches	Hits/IP	Runs/IP
Matt Harvey	10/22/2013	2013	24	92.04	66.2%	2697	0.76	0.26
Neftali Feliz	8/1/2012	2010	24	93.52	65.1%	1072	0.62	0.30
Joba Chamberlain	6/16/2011	2010	25	91.50	63.6%	1170	1.00	0.52
Daisuke Matsuzaka	6/10/2011	2010	30	88.84	62.8%	2619	0.89	0.55
Adam Wainwright	2/28/2011	2010	29	84.58	63.3%	3356	0.81	0.30
Stephen Strasburg	9/3/2010	2010	21	92.22	65.1%	1070	0.82	0.37
Joe Nathan *	3/26/2010	2008	35	90.80	63.7%	1048	0.64	0.19
				Avgs	64.24%		0.79	0.35

After TJ Season

Name	Surgery Date	Test season (YR)	Age	Avg velocity	% strikes	Pitches	Hits/IP	Runs/IP	Velocity Diff.	Strike % Diff.
Matt Harvey	10/22/2013	2015	26	92.65	67.6%	2585	0.82	0.33	0.61	1.44%
Neftali Feliz	8/1/2012	2014	28	90.51	65.4%	482	0.64	0.22	-3.02	0.27%
Joba Chamberlain	6/16/2011	2013	28	89.92	61.2%	769	1.12	0.55	-1.58	-2.31%
Daisuke Matsuzaka	6/10/2011	2013	33	83.94	64.3%	663	0.84	0.55	-4.90	1.45%
Adam Wainwright	2/28/2011	2013	32	85.47	65.9%	3533	0.92	0.34	0.89	2.67%
Stephen Strasburg	9/3/2010	2013	24	90.56	62.2%	2848	0.74	0.39	-1.66	-2.85%
Joe Nathan *	3/26/2010	2013	40	88.92	63.6%	1021	0.56	0.16	-1.88	-0.12%
				Avgs	64.31%		0.81	0.36		

Figure 11

DICE K

Breakdowns / Avgs

	Type of Pitch	Total pitches	% of total pitches	Velocity
FF	Fourseam	1,290	49.3%	91.0
2010 FC	Cutter	308	11.8%	90.8
FT	Twoseam	296	11.3%	90.9
CH	Changeup	155	5.9%	82.0
CU	Curveball	369	14.1%	80.8
SL	Slider	169	6.5%	82.8
FS	Screwball	23	0.9%	84.8
		2,610	99.8%	

Balls vs. Strikes (accuracy)

"Balls"	934	
Balls in Di	21	
intent ball	1	
HBP	8	
(blocked b	9	
Total Balls	973	37.19%
Strikes	1,643	62.81%

	Era	IP	H	R	Hits/IP	Runs/IP
2010 Year before tear	4.69	153.67	137	84	0.89	0.55
2013 Year after tear	4.42	38.20	32	21	0.84	0.55
		Difference			-0.05	0.00

Difference

-2.59	Fourseam
-3.22	Cutter
-2.47	Twoseam
-0.91	Changeup
-5.68	Curveball
-2.46	Slider
-3.17	Screwball

Breakdowns / Avgs

	Type of Pitch	Total pitches	% of total pitches	Velocity
FF	Fourseam	281	42.4%	88.4
2013 FC	Cutter	58	8.7%	87.6
FT	Twoseam	61	9.2%	88.5
CH	Changeup	29	4.4%	81.1
CU	Curveball	194	29.3%	75.1
SL	Slider	26	3.9%	80.3
FS	Screwball	14	2.1%	81.6
		663	100.0%	

Balls vs. Strikes (accuracy)

"Balls"	224	
Balls in Di	5	
intent ball	0	
HBP	5	
(blocked b	3	
Total Balls	237	35.75%
Strikes	426	64.25%

1.45% Accuracy improvement

Figure 12

Figure 13

Tommy John Surgery Recovery Time in Months by Age				
Start Age	End Age	MLB Only		
		Average	Return%	Surgeries
12	17	N/A	N/A	0
18	19	N/A	N/A	0
20	21	18.5	88%	8
22	23	19.4	80%	35
24	25	17.2	80%	60
26	27	15.9	73%	62
28	29	16	72%	82
30	31	18.3	82%	44
32	33	16	85%	27
34	35	18.5	61%	23
36	50	14.6	79%	14
Totals / Averages		17	76%	355

Figure 14

est: Two-Sample Assuming Unequal Variances		(safe)
Velocity of Matt Harvey's Pitches		
	Before	*After*
Mean	91.91066	92.64555
Variance	23.65491	22.10737
Observations	3668	2584
Hypothesized Mean Difference	0	
df	5674	
t Stat	**-5.99945**	
P(T<=t) one-tail	1.05E-09	
t Critical one-tail	1.645122	
P(T<=t) two-tail	2.1E-09	
t Critical two-tail	**1.960382**	

Figure 15

References

Arthur, R. (2015, September 8). Everyone's Just Guessing About Matt Harvey's Innings Limit. Retrieved from http://fivethirtyeight.com/datalab/everyones-just-guessing-about-matt-harveys-innings-limit

Arthur, R. (2015, March 27). At Least All These Tommy John Surgeries Aren't Rotator Cuff Surgeries. Retrieved from http://fivethirtyeight.com/features/at-least-all-these-tommy-john-surgeries-arent-rotator-cuff-surgeries

Baseball Reference. (2015). Daisuke Matsuzaka. Retrieved from http://www.baseball-reference.com/bullpen/Daisuke_Matsuzaka

Cain, EL, JR Andrews, Dugas JR, Wilk KE, McMichael CS, Walter II JC, Riley RS, Arthur ST (2010, October 7) " Outcome of Ulnar Collateral Ligament Reconstruction of the Elbow in 1281 Athletes" *National Center for Biotechnology Information*. U.S. National Library of Medicine. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/20929932

Carleton, R. (2014, June 17). "What High School Has to Do with Tommy John". *Baseball Prospectus*. Retrieved from http://www.baseballprospectus.com/article.php?articleid=23901

Carleton, R. (2013, February 18). "What Really Predicts Pitcher Injuries". *Baseball Prospectus*. Retrieved from http://www.baseballprospectus.com/article.php?articleid=19653

DH Petty, JR Andrews, Fleisig GS, and EL Cain (2004, May 18) " Ulnar collateral ligament reconstruction in high school baseball players: clinical results and injury risk factors." *National Center for Biotechnology Information*. U.S. National Library of Medicine. Retrieved from http://ajs.sagepub.com/content/32/5/1158

Dun, S., D. Kingsley, GS Flesig, J. Loftice, and JR Andrews. (2007, November 6) "Biomechanical Comparison of the Fastball from Wind-up and the Fastball from Stretch in Professional Baseball Pitchers." *National Center for Biotechnology Information*. U.S. National Library of Medicine. Retrieved from http://ajs.sagepub.com/content/36/1/137.short?cited-by=yes&legid=amjsports;36/1/137

Dun, S., GS Flesig, J. Loftice, D. Kingsley and JR Andrews. (2007, November 30) "A biomechanical Comparison of youth baseball pitches: is the curveball potentially harmful?" *National Center for Biotechnology Information*. U.S. National Library of Medicine. Retrieved from http://ajs.sagepub.com/content/36/4/686.short

Fleisig, GS "Q&A: Dr. Glenn Fleisig on Tommy John Surgery Prevention and Myths" (2015, September 28) *MIT Sloan Sports Analytics Conference*. Retrieved from http://www.sloansportsconference.com/?p=15206

Fleisig, GS., JR Andrews, GR Cutter, A. Webber, J. Loftice, C. McMichael, N. Hassell, and S. Lyman. (2010, November 23) "Risk of Serious Injury for Young Baseball Pitchers: A 10-year Prospective Study." *National Center for Biotechnology Information*. U.S. National Library of Medicine. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/21098816

Fleisig, GS, DS Kingsley, JW Loftice, KP Dinnen, R. Ranganathan, S. Dun, RF Escarnilla, and JR Andrews. (2005, October 31) "Kinetic Comparison among the Fastball, Curveball, Change-up, and Slider in Collegiate Baseball Pitchers." *National Center for Biotechnology Information*. U.S. National Library of Medicine. Retrieved from http://ajs.sagepub.com/content/34/3/423.short

Greenhouse, J. (2010, February 18). The Baseball Analysts: The Verducci Effect. Retrieved from http://baseballanalysts.com/archives/2010/02/verducci_effect.php

Gassko, D. (2006, November 30). The Year-After Effect. Retrieved from http://www.hardballtimes.com/the-year-after-effect/

Kamenetsky, Brian. "The Next Big Thing In Sports Data: Predicting (And Avoiding) Injuries." (2014, August 25) *Fast Company*. Retrieved from http://www.fastcompany.com/3034655/healthware/the-next-big-thing-in-sports-data-predicting-and-avoiding-injuries

Karakolis, T., S. Bhan, and RL Crotin. (2015, March 18). "Injuries to young professional baseball pitchers cannot be prevented solely by restricting number of innings pitched." Retrieved from http://www.ncbi.nlm.nih.gov/m/pubmed/25784395

Kory, M. (2015, September 15). Matt Moore Without Matt Moore's Fastball | FanGraphs Baseball. Retrieved from http://www.fangraphs.com/blogs/matt-moore-without-matt-moores-fastball

Livingston, Tim. "Tommy John Surgery: How Big Data Can Help With Epidemic Of Arm Injuries." (2015, June 8) *ThePostGame*. Retrieved from http://www.thepostgame.com/blog/eye-performance/201505/tommy-john-surgery-epidemic-cure-data-pitcher-usage-logic-innings

Lyman, S., GS Fleisig, JR Andrews, and ED Osinski. (2002, July 1) "Effect of Pitch Type, Pitch Count, and Pitching Mechanics on Risk of Elbow and Shoulder Pain in Youth Baseball Pitchers." Retrieved from http://ajs.sagepub.com/content/30/4/463.short

Makhni, Eric C., Zachary S. Morrow, Tomothy J. Luchetti, Pallavi S. Mishra-Kalyani, and A1nthony P. Gualteri. (2014, November 3) "Arm Pain in Youth Baseball Players." *The American Journal of Sports Medicine*. SAGE. Retrieved from http://ajs.sagepub.com/content/43/1/41?cited-by=yes&legid=amjsports;43/1/41

Olsen, SJ, GS Fleisig, S. Dun, J. Loftice, and JR Andrews. (2006, February 1) "Risk Factors for Shoulder and Elbow Injuries in Adolescent Baseball Pitchers." *National Center for Biotechnology Information*. U.S. National Library of Medicine. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/16452269

Paine, N. (2014, May 15). The Mystery Sabermetrics Still Can't Solve. Retrieved from http://fivethirtyeight.com/features/the-mystery-sabermetrics-still-cant-solve/

Paine, N., K. Fagan, and C. Matlin. (2015, April 7) "Hot Takedown: Duke Does It Again; Opening Day; Hedging Hockey (4/7/15)." *SoundCloud*. http://soundcloud.com/fivethirtyeight/hot-takedwon-duke-does-it-again-opening-day-hedging-hockey

Reinold, Mike. "5 Myths of Tommy John Surgery - Mike Reinold." (2014, January 27) Retrieved from http://www.mikereinold.com/2014/01/5-myths-tommy-john-surgery.html

Roegele, Jon "Tommy John Surgery List" (November 2015) Retrieved from https://docs.google.com/spreadsheets/d/1gQujXQQGOVNaiuwSN680Hq-FDVsCwvN-3AazykOBON0/edit#gid=0