THE IMPACT OF VIDEO ASSISTANT REFEREE (VAR) ON THE ENGLISH PREMIER LEAGUE

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ABSTRACT

The Impact of Video Assistant Referee (VAR) on the English Premier League

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The aim of this study is to examine how the introduction of the Video Assisted Referee (VAR) system influenced the English Premier League (EPL). Since its implementation in 2019, VAR has been a constant source of debate and controversy in the English Premier League. Many studies have been done on the immediate impact of VAR on other elite professional soccer leagues, but the scope of results is very limited and due to be updated. The data for the ensuing analysis consists of 3800 matches played in the English Premier League during the five seasons before (14/15, 15/16, 16/17, 17/18, and 18/19) and five seasons after (19/20, 20/21, 21/22, 22/23, 23/24) the implementation of VAR. The following variables were recorded for each match: goals, fouls committed, penalty kicks awarded, penalty kicks scored, shots, offsides, red cards, yellow cards, tackles, and interceptions. Match statistics were web scraped from FBref.com using software packages in R. Welch's T-tests, Mann-Whitney U-tests, and generalized linear models were used at an unadjusted 0.05 significance level to compare average total match statistics in the English Premier League for seasons before and after the implementation of the VAR, across three different time periods used for comparison: (i) 1 year before and after VAR, (ii) 3 years before and after VAR, and (iii) 5 years before and after VAR. In the 1 year comparison, we found a statistically significant increase in the number of average total match fouls, and statistically significant decreases in the number of average total match offsides, tackles, and interceptions. In the 3 year comparison, we found a statistically significant increase in the number of average total match tackles, and statistically significant decreases in the number of average total match offsides and interceptions. In the 5 year comparison, we found statistically significant increases in the number of average total match goals, penalty kicks awarded, penalty kicks scored, yellow cards, and tackles, and statistically significant decreases in the number of average total match offsides and interceptions. However, we discuss several other notable rule changes since the implementation of VAR in the English Premier League that could have also affected these results. Although we did observe multiple statistically significant differences in certain match statistics, it would be statistically inappropriate to conclude that VAR has caused these changes. Further, due to the large sample size, these results are likely statistically significant, but not as practically significant in the real world. In conclusion, VAR does not seem to drastically affect gameplay overall in the English Premier League.

Keywords: VAR, Video Assistant Referee or Video Assistant Refereeing

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Chapter 1

INTRODUCTION

1.1 Motivation

The English Premier League is widely considered the best and most competitive soccer league in the world. In fact, the English Premier League has been ranked first in UEFA's league coefficient rankings over the past five seasons, which is based on the league's teams' performances in European competitions (UEFA, 2024). On top of success abroad, the English Premier League has some of the toughest domestic competition of any league in the world, making it one of the most entertaining and highest-grossing sports competitions in the world. To be precise, in 2023, the EPL was the most-watched soccer league in the US (Portada, 2024), and across the world (Moore, 2024; Adegbola, 2023), with a potential TV audience of 4.7 billion people. As such, introducing a major change to the league's refereeing system was never going to go untalked about.

1.2 Definition of VAR

According to the English Premier League, a Video Assistant Referee is "a qualified referee who remotely watches the match via a number of screens and can view slow-motion replays, enabling them to advise the on-field referee" with decision-making (Premier League, 2020a). As further clarified by the International Football Association Board, a Video Assistant Referee "may assist the referee only in the event of a 'clear and obvious error' or 'serious missed incident' in relation to:

1. Goals (or fouls leading up to goals like handballs or offsides)
2. Penalty kicks
3. Direct red cards (not second yellow cards/cautions)
4. Mistaken identity (when the referee cautions or sends off the wrong player of the offending team) (IFAB, 2024a)

To clarify, a designated Video Assistant Referee assigned to each game actively watches along in a remote location and automatically checks camera footage for every potential or actual goal, penalty, direct red card decision/incident, or case of mistaken identity, using different camera angles and replay speeds (IFAB, 2024a). The Video Assistant Referee can then communicate with the on-field referee via headset communication and recommend a review if needed. The review can either be a “VAR-only review”, used for objective decisions like offsides, in which the on-field referee acts solely upon the advice audibly received from the VAR via headset, or an “on-field review”, used for subjective decisions like red cards, in which the on-field referee walks over to a pitch-side monitor to view the replay footage himself. The English Premier League, and all other competitions that use VAR, average 8 reviews per match, with almost all of them being VAR-only reviews. VAR-only reviews are much more ideal due to their efficiency, with an average length of 35 seconds, whereas on-field reviews take an average of 68 seconds (Plavšić , 2023). For future reference, a ‘VAR intervention’ refers to scenarios when the on-field decision is overturned.

1.3 Development of VAR

The idea of VAR was conceived during The Royal Netherlands Football Association’s (KNVB) Refereeing 2.0 project which aimed to reinvent and improve refereeing via the use of technology. The KNVB ran trials using video replay technology to assist refereeing in the Dutch Eredivisie beginning in the 2012-2013 season. After early success, the Royal Netherlands Football Association petitioned to the International Football Association Board to modify the official Laws of the Game to allow video replay technology to be used by referees (Farrell, 2019).

The International Football Association Board (IFAB) is an independent governing body responsible for amending, clarifying, and authorizing the official ‘Laws of the Game’ on an annual basis. IFAB is structured in a way that the four British football associations for England, Scotland, Wales, and Northern Ireland (The FA, Scottish FA, FA Wales, and Irish FA, respectively) get one vote each, and the Fédération Internationale de Football Association (FIFA), representing the other 207 football associations around the world, gets four votes. This structure aims to ensure

that the Laws of the Game are preserved in a way that respects the game's traditions as well as its "international reality" (IFAB, 2024b).

Nevertheless, ex-FIFA president Sepp Blatter was against the idea of VAR, so the concept gained very little traction until his resignation in 2015. Unlike his predecessor, current FIFA president Gianni Infantino held very favorable views of VAR upon his appointment. In 2016, Infantino approved several leagues across the world to conduct VAR trial runs, including during the 2017/18 German Bundesliga and Italian Serie A seasons. After these successful trials, the IFAB voted on March 3, 2018, to officially allow the use of Video Assistant Referees in all upcoming competitions, including the 2018 FIFA World Cup. The IFAB developed the official VAR protocol to be included in the Laws of the Game for league competitions for the first time beginning in the 2018/19 season.

The IFAB transferred the responsibility of VAR to FIFA in July 2020, although the two entities continue to work closely, especially in terms of VAR protocol (Premier League, 2020b). In order to support competition organizers, like the English Premier League, with the implementation of VAR technology, the IFAB and FIFA developed the Implementation Assistance and Approval Programme (IAAP). IAAP helps to ensure that the same standards are applied when introducing VAR systems to new competition, by overseeing the implementation of the technology and providing training programs for those using it (InsideFIFA, 2024). Four out of the "top 5" European leagues, the Spanish La Liga, German Bundesliga, Italian Serie A, and French Ligue 1, officially implemented VAR right away, beginning the 2018/19 season.

Table 1. Europe's "top 5" soccer leagues and their first season using VAR

Country	League	First Season using VAR
Germany	Bundesliga	2017/18*
Italy	Serie A	2017/18*
Spain	La Liga	2018/19
France	Ligue 1	2018/19
England	Premier League	2019/20

*The German Bundesliga and Italian Serie A used VAR in the 2017/18 season as an approved FIFA trial and continued using VAR for the 2018/19 season following its official inclusion in the Laws of the Game.

While the implementation of VAR can slightly vary from competition to competition, its general protocol is the same: the VAR has the power to intervene and suggest the overturning of a decision made by the on-field referee concerning incidents involving goals, penalties, red cards, and mistaken identity. However, not every competition was able to smoothly implement VAR into their referring system. While competitions such as the FIFA World Cup, German Bundesliga, and Italian Serie A, for example, were able to implement VAR with relatively little controversy or backlash, the English Premier League's implementation has not been as smooth (Garratt-Stanley, 2023).

1.4 Introduction of VAR in England

In November 2018, English Premier League clubs voted to not introduce VAR to their league until the 2019/20 season, pending preliminary testing in the English FA Cup and English Football League Cup during the 2018/19 season (Premier League, 2020b). The testing was done by Professional Game Match Officials Limited (PGMOL), the body responsible for providing the referees that officiate all matches under the English Football Association, including the English Premier League (Premier League, 2024a). PGMOL's testing deemed VAR a success, paving the way for its formal introduction to the English Premier League beginning in the 2019/20 season.

As previously mentioned, the designated Video Assistant Referee for each match is a standard qualified match official. At the beginning of every match week, PGMOL announces a team of referees appointed to each match, including the main 'on-field' referee, the two sideline 'on-field' assistant referees, the fourth official, the Video Assistant Referee and more. PGMOL referees can be assigned to any refereeing role and rotate roles each match week.

The Video Assistant Referee sits at the VAR Hub at Stockley Park, in west London, and has an appointed Assistant VAR (AVAR) and a Replay Operator (RO) on their team beside them (Premier League, 2020a). However, as clarified by the IFAB, the VAR has the same status as an on-field assistant referee and can only assist the referee, meaning the on-field referee has the sole responsibility of making the final decision (IFAB, 2024a).

In addition to the introduction of VAR, the English Premier League has introduced several notable rule changes since the 2019/20 season. Most notably are the rule changes due to the COVID-19 pandemic, as well as stricter enforcement of yellow card offenses and the deliberate increase in added time in the 2023/24 season, which leads to a general increase of all other match statistics. We must be extra considerate of this increasing effect of match statistics for any conclusions in the results section that include the 2023/24 season in its analysis.

Table 2. Notable new rules and rule changes introduced in the English Premier League since the beginning of the 2019/20 Season

2019/20 Season	1. Introduction of VAR for match officiating, allowing referees to review decisions on key incidents such as goals, penalties, and red cards. 2. Implementation of stricter handball rules, particularly focusing on instances where the ball unintentionally strikes a player's arm or hand leading to a goal or goal-scoring opportunity. **Note:** At the end of matchweek 29, English Premier League games were suspended for three months, beginning in March 2020 due to the COVID-19 pandemic. The following are temporary rules that were only used for the remainder of the 2019/20 season only under "Project Restart" 1. Teams will be allowed five (5) substitutions, instead of the usual three (3), to be made on three (3) possible in-game occasions and during the half-time break. 2. Teams can now name nine (9) players on the bench, instead of the usual seven (7)
2020/21 Season	Starting Matchweek 14 (mid-December 2020): 1. Teams can now name nine (9) players on the bench, instead of the usual seven (7) **Note:** Some Premier League clubs were allowed to host a reduced number of fans (less than 10,000) for a handful of matches depending on local government COVID restrictions, but for the most part, matches were played behind closed doors with no fans in attendance.
2021/22 Season	1. Introduction of concussion substitutes, allowing teams to make additional substitutions if a player suffers a head injury, regardless of the number of substitutions already made.
2022/23 Season	1. Permanent introduction of the five-substitution rule. Teams will be allowed five (5) substitutions, instead of the usual three (3), to be made on three (3) possible in-game occasions and during the half-time break.
2023/24 Season	1. Match officials are committed to ensuring a more accurate calculation of additional time (leading to more added time at the end of each half) 2. Stricter enforcement of yellow card offenses, especially for dissent **Note:** This increase in more added time will also lead to a general increase of all total match statistics

On average, matches in the 2023/24 season were ~3.5 minutes longer, lasting ~102 minutes, due to more accurate additional time by referees. Ball-in-play time also increased by ~3.5 minutes, averaging over 58 minutes (Premier League, 2024b).

From the executives of the English Premier League's point of view, the main goal of introducing VAR is to improve the accuracy of refereeing decisions, while, like any other rule, having minimal impact on the players, managers, fans, and gameplay itself. Now, with three separate levels of refereeing (the main on-field referee, the assistant sideline on-field referees, and the video assistant referee) there is almost no excuse for refereeing error. Despite this, since the introduction of VAR in the English Premier League, PGMOL has issued 13 official apologies to clubs for instances in which VAR was used incorrectly against them or failed to intervene to correct the on-field decision (Dabbs, 2023). Interestingly enough, there were no mistakes to be apologized for during the first two seasons after the implementation of VAR, as all 13 official PGMOL apologies have come during the 2021/22 season or later. Implementing VAR requires referees to adapt to the new technology and be informed on its proper use, which seems to be a problem in the English Premier League specifically. Currently, there is a total lack of transparency of VAR to the fans, players, and coaches, as none of them are aware of what transpires between the on-field referee and the VAR during checks. The English Premier League has released a handful of videos of the communication via headset between the on-field referees, the VAR, the AVAR, and others during VAR checks and it's often chaotic with everyone just talking over each other.

Despite the blatant mistakes and messy process, the English Premier League's decision to implement VAR has undeniably achieved its goal of improving the accuracy of refereeing decisions overall. Before VAR was introduced, only 82% of the decisions made by referees in the English Premier League were deemed to be factually correct. However, through match week 23 of the 2023/24 season, 96% of refereeing decisions have been correct, with VAR correctly intervening on 57 occasions (Premier League, 2024c).

In general, most studies indicate that VAR can significantly improve the accuracy of referees' decisions, as well as positively impact the outcome of the match (da Silva et al., 2023). With such claims, it would be hard to deny that the introduction of VAR has achieved its goal of increasing refereeing accuracy. However, it would be even harder to deny that the VAR system

has still not been perfected in the English Premier League, or that it hasn't impacted the league in other ways.

1.5 Latest News

On April 11, 2024, it was announced that the English Premier League will use a semi-automated offside technology (SAOT) as a part of the VAR protocol in the upcoming 2024/25 season, which was used in the 2022 Men's FIFA World Cup in Qatar. SAOT utilizes 10 bespoke cameras that track 29 data points on the limbs and extremities of all 22 players on the pitch, so the system always knows the exact position of every player, at all times. This data is processed by AI in real-time, and automatically notifies the VAR when an offsides play has been detected (Johnson, 2024a). PGMOL Chief Refereeing Officer, Howard Webb confidently claims this will speed up the VAR check process (Premier League, 2024d). This will also drastically reduce the impact of the actual Video Assistant Referee for offside calls. Further, on April 30, 2024, Howard Webb also announced that English Premier League referees could soon announce to the stadium and television broadcast why a decision was changed after visiting the VAR monitor for an on-field review (Johnson, 2024b). This would greatly help to improve the transparency between VAR and the fans, players, and coaches.

However, it was shockingly announced on May 15, 2024, that the English Premier League club Wolverhampton Wanderers started the process to abolish the VAR system. Wolverhampton's official statement read, "After five seasons of VAR in the Premier League, it is time for a constructive and critical debate about its future. Our position is that the price we are paying for a small increase in accuracy is contrary to the spirit of our game and should therefore be removed from the 2024/25 season onwards." There is a meeting tentatively scheduled for June 6, 2024, in which English Premier League clubs will vote on whether to keep or scrap the use of VAR for English Premier League matches starting with the 2024/25 season. At least two-thirds of clubs, which is 14 out of 20, must vote in support of the idea for the VAR abolishment process to be officially approved. However, there seems to be an agreement among several clubs that VAR is more good than bad, and they would prefer to improve it rather than scrap it

(Sky Sports, 2024). This controversial decision to abolish the use of VAR would follow in the footsteps of the Swedish Football Association, who in July 2023 chose to reject the use of VAR in the Swedish Allsvenskan league based on a vote by the clubs. Currently, the Swedish Allsvenskan league is the first and only league among Europe's top 30 soccer leagues to reject VAR (FP Sports, 2024).

Chapter 2

LITERATURE REVIEW

As stated in the introduction, lots of research and analysis about the effect of VAR on other elite soccer competitions has already been performed, using a wide variety of different approaches to analysis. Most of the existing analysis involves competitions other than the English Premier League and uses simple summary statistics to compare just one or two years after the respective implementation of VAR. Nevertheless, the following literature review aims to highlight the results of some of the most interesting and prominent conclusions made about the impact of VAR in other elite soccer competitions so far, which we will aim to improve upon in our analysis.

2.1 Playing Time

One of the main concerns of using VAR is undeniably how long the VAR checks take which may take time away from effective playing time. Total playing time is the total amount of time the clock is running, whereas effective playing time is the amount of total playing time where the play is live and in active play.

When comparing the 2015 Women's World Cup, which did not use VAR, to the 2019 Women's World Cup, which did use VAR, there was a significant increase in the total playing time during the first half, second half, and the entire game (Zhang, 2020). Further, when comparing one season before and one season after the implementation of VAR in the Italian Serie A and German Bundesliga leagues, there was an increase in the number of minutes added to the playing time in the first half and the full game, but not in the second half (Lago-Peñas et al., 2019). As VAR checks force matches to temporarily stop while on-field decisions are reviewed, it only makes sense that the matches should take longer, as more injury time is added on at the end of each half. A comprehensive review of data from the football associations in Australia, Belgium, China, Czech Republic, England, France, Germany, Italy, the Netherlands, Poland, Portugal, South Korea, and the USA found that VAR-only reviews had a median length of 15 seconds while on-field reviews had a median length of 62 seconds (Spitz et al., 2021).

However, an increase in total playing time does not necessarily mean that the effective playing time has also increased. In fact, most research on the impact of VAR across top soccer leagues observes a general reduction in effective playing time for matches after the implementation of VAR (da Silva et al., 2023). In VAR's inaugural season in the Spanish La Liga, as the number of VAR interventions increased in a match, total playing time increased while effective playing time decreased (Errekagorri et al., 2020). This means that fans are getting to see less action with the ball in play, albeit for a few minutes. Nevertheless, as stated in Table 2, we must note that the effect of VAR on playing time has surely changed beginning with the 2023/24 season, as most soccer competitions, including the English Premier League, have started to more accurately track lost effective playing time, leading to an increase in the amount of added time at each half.

2.2 Goals

When comparing the first 29 match weeks (pre-COVID) of the first English Premier League season with VAR (2019/20) to the average of the previous five seasons, the number of goals scored increased by 3.6% (SpreadEx, 2020). In VAR's inaugural season in the Spanish La Liga, as the number of interventions per game increased there was an increase in goals, most likely due to the interventions awarding penalties (Errekagorri et al., 2020). However, in most literature analyzing the number of goals in soccer competitions before and after the implementation of VAR, there was a lack of statistical evidence to conclude that the number of goals has significantly changed.

2.3 Penalty Kicks

When again comparing the first 29 match weeks (pre-COVID) of the first English Premier League season with VAR (2019/20) to the average of the previous five seasons, the penalty conversion rate increased by 1.9%. Meanwhile, the number of penalties awarded decreased by 10.1%, the number of penalties scored declined by 7.9%, and the number of red cards declined by 7.4%, although none of these results were deemed to be statistically significant (SpreadEx,

2020). However, there was a significant increase in the number of awarded penalties during the 2018 FIFA Men's World Cup, which utilized VAR, compared to the 2014 FIFA Men's World Cup, which did not use VAR. The most common and logical explanation for any increase in the number of penalties awarded after the introduction of VAR is it is due to the cameras all over the stadium with slow-motion replay functionality that can be used to identify fouls that might be overlooked during the rapid flow of the game (Kubayi et al., 2021).

Finally, an analysis of 2888 penalties awarded in top leagues in England Premier League, Spanish La Liga, German Bundesliga, Italian Serie A, Dutch Eredivisie, and the UEFA Champions League, over the course of five seasons (2015/16 - 2019/20), found that the duration between the moment a foul occurred and the moment the penalty is taken does not have an effect on the conversion probability of the penalty kick. However, whether or not VAR intervenes with the referee's penalty decision has a negative effect on the conversion probability of a penalty kick. As such, it would be wise for teams to incorporate this uncertainty into their training drills (Veldkamp and Koning, 2023).

2.4 Red and Yellow Cards

During VAR's first season in the Italian Serie A and German Bundesliga, there was a significant decrease in the number of yellow cards compared to the previous season (Lago-Peñas et al., 2019). Moreover, combining data from the football associations in Australia, Belgium, China, Czech Republic, England, France, Germany, Italy, The Netherlands, Poland, Portugal, South Korea, and the USA, there was a significant increase in the number of red cards after the introduction of VAR (Spitz et al., 2021). Contrastingly, when again comparing the first 29 match weeks (pre-COVID) of the first English Premier League season with VAR (2019/20) to the average of the previous five seasons, the number of red cards declined by 7.4% (SpreadEx, 2020). Overall, similar to goals, most literature assessing VAR's impact on the number of red and yellow cards has a serious lack of statistical evidence to conclude that the number of goals has significantly changed and in which direction.

2.5 Fouls

When comparing one season before and one season after the implementation of VAR in the Italian Serie A and German Bundesliga leagues, there was a significant decrease in the number of fouls (Lago-Peñas et al., 2019). Further analysis of data on all top 5 European leagues from 2017 to 2022 found that the implementation of VAR has led to an increase in "respect" among players, due to the reduction of misconducts such as verbal abuse and elbowing opponents' players since the implementation of VAR. This is likely due to players now knowing that they can no longer commit any dirty or cynical acts in the blind spot of the referees, as the VAR cameras will be able to see every act anywhere on the field. Further, there has also been an improvement in the issue of mistaken identity during card issuance, as VAR has helped point out the appropriate player who deserved the punishment. However, VAR technology is still yet to solve the problem of fair play as players continue to 'dive' (also known as simulation) for referees to award fouls to the players (Musa et al., 2022).

2.6 Offsides

When again comparing one season before and one season after VAR in the Italian Serie A and German Bundesliga leagues, there was a significant decrease in the number of offsides (Lago-Peñas et al., 2019). Moreover, there was a significant decrease in the number of offsides called during the 2018 FIFA Men's World Cup, which utilized VAR, compared to the 2014 FIFA Men's World Cup, which did not use VAR (Kubayi et al., 2021). A common explanation for this decrease in offsides is provided below in the results section of our analysis of VAR's impact on offsides in the English Premier League.

2.7 Referees

In general, the introduction of VAR has impacted referees' decision-making in the German Bundesliga and Italian Serie A overall. However, the number of VAR interventions used by referees was not found to be correlated with referees' experience levels. Further, when comparing two seasons before and after VAR in the Italian Serie A and German Bundesliga, it

was concluded that the bias favoring the home team with respect to awarded penalty kicks, red cards, and the amount of added time partially decreased after the implementation of VAR. As such, it seems as though VAR has increased fairness by slightly decreasing the referee's decision-making bias towards the home team (Holder et al., 2022).

Overall, there are lots of mixed conclusions about the impact of VAR across many different leagues. While lots of already-existing literature analyzes and reviews the short-term impact of VAR on elite soccer leagues, there is an absence of an all-encompassing review of the multifaceted impact of VAR on the English Premier League specifically. The following section describes the data collection and statistical analysis process we used to analyze the impact of VAR on the English Premier League’s gameplay.

Chapter 3

METHODS

3.1 Data Collection

There is a very limited amount of freely accessible soccer data, especially regarding statistics about VAR. However, thankfully, FBref.com releases publicly available soccer data in partnership with the highly accredited software company StatsBomb. FBref is the most complete source for men's and women's soccer data on the internet, with historic and detailed match and player statistics on nearly all professional and semi-professional soccer competitions in the world. In collaboration with Opta Sports, FBref also offers advanced analytical data such as xG, xA, progressive passing, duels, and more, for over twenty competitions, including the English Premier League.

In order to efficiently collect this data from FBref, we built a web scraper utilizing the XLM and RCurl packages in RStudio, which the reproducible code can be found in the link to the GitHub repository in Appendix A below. We obtained a wide variety of match statistics on every single match in the English Premier League, from the start of the 2014/15 season through the end of the 2023/24 season, which is 3800 matches in total (380 matches per season, for 10 seasons). Once scraping was complete, we combined the individual home and away team variables to get total match statistics. After further management and data cleaning, the final dataset contained all the variables listed in Table 4 below. However, for our statistical analysis, we selected 10 variables of interest that we felt may be most impacted by the implementation of VAR, which are listed in Table 3 below.

Table 3. The 10 variables of interest highlighted in this paper to analyze the differences before and after the implementation of VAR in the EPL

Variable	Code Name	Reason For Interest
Goals	totalgoals	Goals are the most important part of the game
Fouls	totalfoulscom	Has player discipline improved because of players being scared to get fouls checked by VAR?
Penalty Kicks Awarded	totalpksatt	Has VAR lead to an increase in awarded penalties now that every possible instance is double-checked using VAR slow-motion replay technology?
Penalty Kicks Scored	totalpksmade	Has the waiting time during VAR checks affect the number of penalties scored?
Shots	totalshots	Has VAR affected the attacking tendencies of the game?
Offsides	totaloff	Has VAR technology led to an increase of catching people offsides?
Red Cards	totalred	Have red cards gone down because of players scared to get fouls checked by VAR? Or, have red cards gone up because of VAR slow-motion replay technology?
Yellow Cards	totalyellow	Have yellow cards gone down because of players scared to get fouls checked by VAR?
Tackles	totaltackleswon	Have tackles gone down because of players scared to get fouls checked by VAR?
Interceptions	totalint	Have interceptions gone down because of players scared to get fouls checked by VAR?

3.2 Statistical Models and Analysis

All statistical analysis was performed in R version 4.3.3. The code for the reproducible analysis can be found in the link to the GitHub repository in Appendix A below. To begin our analysis, we checked the normality assumption and equal variance assumption which are made when using many common statistical analysis methods, like T-tests.

For the normality assumption, Shapiro-Wilk, Anderson-Darling, and Kolmogorov-Smirnov tests for normality, as well as visual inspection of histograms, confirmed that all 10 variables of interest did not strictly follow normal distribution, using a significance level of 0.05. Although one would expect normality to be met due to the large sample size and Central Limit Theorem. The resulting p-values of these three tests can be found in Appendix B below, as well as histograms for each of the 10 variables of interest. For the equal variance assumption, Breusch-Pagan and Levene's tests for equal variance confirmed only two of the 10 variables of interest, offsides and interceptions, violated the equal variance assumption, using a significance level of 0.01. The resulting p-values of the Breusch-Pagan and Levene's tests can be found in Appendix B below.

Despite the violation of normality, we still performed T-tests on the 10 variables of interest, to see how their results would compare to other analysis methods which do not assume normality. However, we used Welch's T-tests, which do not assume equal variance, to at least account for two mild violations of the equal variance assumption. Further, to be certain about the validity of our T-test analysis, we also used non-parametric Mann-Whitney U-tests, which do not make any assumptions, as well as generalized linear models (GLMs) using Negative Binomial random components, to capture the non-normal distribution of the response variables. This analysis method was inspired by Zhang et. al.'s paper in which U-tests and GLMs, among other procedures, were used to compare similar variables of interest before and after the implementation of VAR in FIFA Women's World Cups.

We utilized these three methods (T-tests, U-tests, and GLMs) hoping the resulting p-values together would provide a combined 'majority consensus' of whether there is evidence of a statistically significant difference of the 10 variables of interest after the implementation of VAR. For each response variable, we performed each of the three methods on three different subsets

of EPL match data, in an attempt to assess the immediate, intermediate, and long-term impact of VAR on the English Premier League. All tests were assessed at a significance level of 0.05. No adjustments were used to account for the family-wise error rate or false discovery rate; however, we would consider using a Bonferroni adjustment in potential future analyses.

1. **1 year comparison**: Total match statistics from 1 year before VAR (18/19) compared to total match statistics from one year after VAR (19/20)

2. **3 year comparison**: Total match statistics averaged across 3 years before VAR (16/17, 17/18, and 18/19) compared to total match statistics averaged across 3 years after VAR (19/20, 20/21, and 21/22)

3. **5 year comparison**: Total match statistics averaged across five years before VAR (14/15, 15/16, 16/17, 17/18, and 18/19) compared to total match statistics averaged across five years after VAR (19/20, 20/21, 21/22, 22/23, and 23/24)

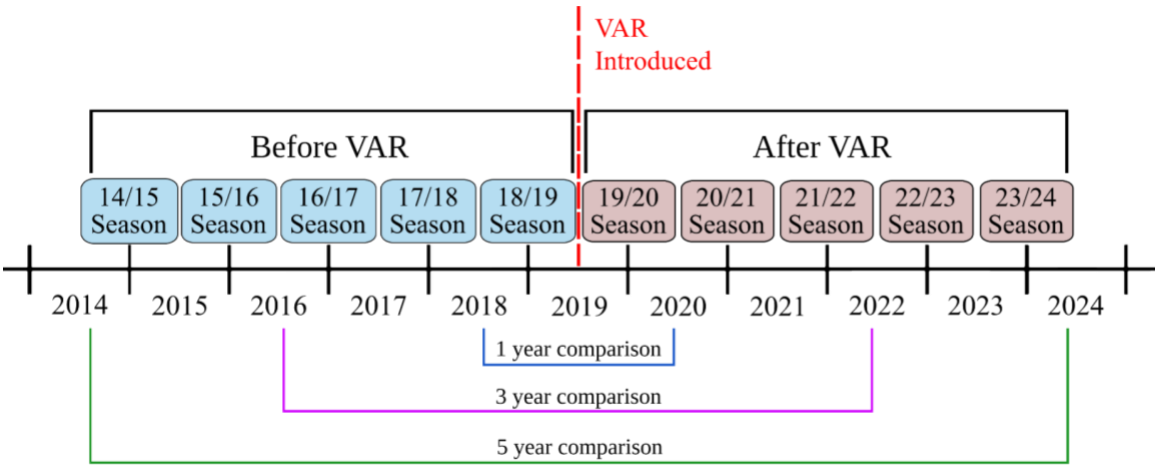

Figure 1. A timeline of the English Premier League seasons used in the data analysis and the different subsets of data used for comparison

Table 4. Average total match statistics for the 10 most recent English Premier League seasons

Season	Goals	xG	Shots	Shots on Target	Assists	Red Cards	Yellow Cards	PKs Awarded	PKs Made	PK Conv. Rate	Own Goals	Crosses	Offsides	Tackles	Fouls	Interceptions	Saves
14/15	2.487	NaN	25.795	8.332	1.684	0.187	3.766	0.218	0.166	0.753	0.079	41.637	3.792	29.179	22.342	30.163	5.558
15/16	2.618	NaN	25.745	8.532	1.842	0.155	3.263	0.237	0.195	0.823	0.082	41.161	3.953	31.666	21.597	34.176	5.703
16/17	2.711	NaN	25.611	8.721	1.892	0.108	3.768	0.276	0.211	0.767	0.089	40.111	3.924	26.053	23.082	27.974	5.771
17/18	2.600	2.491	24.255	7.976	1.916	0.103	3.150	0.211	0.147	0.712	0.079	37.455	4.126	32.811	20.708	23.221	5.532
18/19	2.737	2.688	25.082	8.268	1.950	0.124	3.311	0.271	0.221	0.804	0.084	35.089	4.121	34.021	20.442	22.613	5.734
19/20	2.637	2.742	24.487	8.203	1.858	0.118	3.468	0.242	0.189	0.782	0.084	38.037	3.387	32.616	21.442	21.495	5.745
20/21	2.595	2.590	23.866	8.150	1.803	0.126	2.958	0.329	0.268	0.825	0.100	36.218	3.424	31.047	21.797	20.613	5.789
21/22	2.729	2.677	25.379	8.329	1.955	0.113	3.526	0.271	0.221	0.809	0.089	35.763	3.332	32.658	20.229	19.239	5.803
22/23	2.734	2.843	25.026	8.308	1.911	0.076	3.661	0.261	0.195	0.763	0.118	34.458	3.403	33.976	21.566	17.874	5.741
23/24	3.150	3.101	27.318	9.334	2.261	0.153	4.345	0.282	0.253	0.890	0.129	34.618	3.813	35.316	22.121	16.595	6.404

Chapter 4

RESULTS

Considering the already-existing conclusions discussed in the Literature Review section above, it would be surprising to find remarkable differences in most of our variables. Further, there is of course no control group of an equivalent English Premier League that did not use VAR for the past 5 years to make comparisons against, so we cannot make causal inference. However, we can quantify how much the variables of interest have changed since the implementation of VAR in the EPL, as seen in Table 5 below. Also, one would intuitively assume that the global COVID-19 pandemic, which temporarily stopped games for 3 months during the 2019/20 season and had limited fan attendance once resuming, had some effect on these variables, as well as the previously discussed rule changes for the 2023/24season. A more in-depth summary table can be found in Appendix B below, which includes Z-test p-values, T-test, GLM, and Z-test 95% confidence intervals, and the AIC values for each GLM model.

Table 5. A summary table of the analyses performed on the 10 variables of interest over the last 10 seasons of the English Premier League

	# Years Pre/Post VAR	Pre-VAR mean	PostVAR mean	PostVAR - PreVAR Point Estimate	PostVAR - PreVAR T-test 95% CI	T-test p-value	U-test p-value	GLM p-value
Goals	1	2.74	2.64	-0.10	(-0.319, 0.119)	0.3705	0.5060	0.4004
	3	2.68	2.65	-0.03	(-0.162, 0.104)	0.6701	0.6644	0.6722
	5	2.68	2.77	0.07	(0.034, 0.243)	0.0094	0.0160	0.0094
Fouls	1	20.44	21.44	1.00	(0.243, 1.757)	0.0097	0.0162	0.0096
	3	21.41	21.16	-0.25	(-0.687, 0.178)	0.2492	0.1445	0.2493
	5	21.63	21.43	-0.21	(-0.532, 0.126)	0.2265	0.1287	0.2268
PKs Awarded	1	0.27	0.24	-0.03	(-0.100, 0.043)	0.4267	0.8943	0.4311
	3	0.25	0.28	0.03	(-0.014, 0.070)	0.1923	0.1040	0.1946
	5	0.24	0.28	0.03	(0.002, 0.067)	0.0395	0.0176	0.0396
PKs Scored	1	0.22	0.19	-0.03	(-0.097, 0.033)	0.3404	0.6685	0.3403
	3	0.19	0.23	0.04	(-0.004, 0.071)	0.0822	0.0487	0.0826
	5	0.19	0.22	0.04	(0.008, 0.066)	0.0115	0.0050	0.0115
PK Conversion Rate	1	0.80	0.78	-0.02	(-0.143, 0.097)	0.7102	0.9059	0.8671
	3	0.77	0.81	0.04	(-0.025, 0.111)	0.2192	0.1889	0.5799
	5	0.77	0.81	0.04	(-0.011, 0.094)	0.1230	0.1261	0.4978
Shots	1	25.08	24.49	-0.59	(-1.385, 0.196)	0.1400	0.1335	0.1392
	3	24.98	24.58	-0.41	(-0.863, 0.053)	0.0829	0.0881	0.0826
	5	25.30	25.22	-0.14	(-0.451, 0.287)	0.6624	0.5688	0.6619
Offsides	1	4.12	3.39	-0.73	(-1.052, -0.416)	0.0000	0.0000	0.0000
	3	4.06	3.38	-0.68	(-0.859, -0.494)	0.0000	0.0000	0.0000
	5	3.98	3.47	-0.51	(-0.652, -0.371)	0.0000	0.0000	0.0000
Red Cards	1	0.12	0.12	-0.01	(-0.055, 0.044)	0.8341	0.8999	0.8348
	3	0.11	0.12	0.01	(-0.020, 0.036)	0.5803	0.5473	0.5803
	5	0.14	0.12	-0.02	(-0.041, 0.005)	0.1213	0.1183	0.1214
Yellow Cards	1	3.31	3.47	0.16	(-0.118, 0.434)	0.2617	0.4231	0.2624
	3	3.41	3.32	-0.09	(-0.255, 0.071)	0.2675	0.2762	0.2702
	5	3.45	3.59	0.14	(0.002, 0.261)	0.0467	0.0546	0.0339
Tackles	1	34.02	32.62	-1.41	(-2.502, -0.309)	0.0121	0.0190	0.0122
	3	30.96	32.11	1.15	(0.502, 1.789)	0.0005	0.0004	0.0005
	5	30.75	33.12	2.37	(1.869, 2.876)	0.0000	0.0000	0.0000
Interceptions	1	22.61	21.49	-1.12	(-1.889, -0.348)	0.0045	0.0043	0.0044
	3	24.60	20.45	-4.15	(-4.673, -3.634)	0.0000	0.0000	0.0000
	5	27.63	19.16	-8.47	(-8.927, -8.005)	0.0000	0.0000	0.0000

CI = Confidence Interval

4.1 Goals

The most exciting and celebrated aspect of any sport or game is often the moment in which points are scored. As such, the most exciting part of soccer is undoubtedly the goals scored. While the main goal of implementing VAR is to improve the accuracy of refereeing decisions with minimal disruption, most fans of the game would likely welcome an increase in goals, as long as it doesn't unfairly affect their team. Unfortunately, when using 1 year and 3 year comparisons, we find that the average number of total match goals slightly decreased, by 0.10 and 0.03, respectively, although these differences were not found to be statistically significant. However, when using the 5 year comparison, there is a statistically significant increase of 0.14 in the average total match goals after the implementation of VAR. Notably, the recently completed 2023/24 English Premier League season, which is included in the 5 year comparison only, recorded the highest number of goals scored of any season since the English Premier League began in 1992, with 1,197 total goals scored (not including own goals).

4.2 Fouls

Some might assume that the number of average total match fouls has decreased since the implementation of VAR, as players may be more hesitant to play aggressively and commit fouls, fearing that slow-motion VAR replays might upgrade their fouls to red cards. Our literature review seems to confirm this assumption to some extent, with several studies finding evidence of a decrease in the number of fouls after the implementation of VAR. However, when using 3 year and 5 year comparisons, all three analyses find that there has been no significant change in the average number of total match fouls, which are -0.25 and -0.20, respectively. Conversely, when using the 1 year comparison, all three analyses found evidence of a statistically significant increase of 1.00 in the average number of total match fouls. These results appear inconsistent with much of the prior research including other elite soccer leagues highlighted in the literature review section above.

4.3 Penalty Kicks Awarded

Once again, goals are the most exciting part of the game of soccer, and some of the most dramatic goals come from penalty kicks (PKs). As stated in the introduction, penalty kicks are one of the four scenarios in which VAR may intervene. In competitions using VAR, the decision of awarding or appeals for awarding any penalty kick is always checked by VAR. Many believe that the VAR's use of slow-motion replay often makes fouls look much more sinister and serious than they do in full speed, and as a result, penalty kicks are being awarded much more liberally since VAR's implementation, especially in the English Premier League. Especially considering the mixed results in the literature review regarding previous analysis of VAR's impact on the number of awarded penalty kicks, it is of great interest as to how VAR has impacted penalty kicks in the English Premier League.

Using 1 year and 3 year comparisons, our analyses found no evidence of a significant difference in the number of average total match penalty kicks awarded, which were -0.03 and 0.03, respectively. However, when using the 5 year comparison, all three analysis methods found a statistically significant increase of 0.04 in the number of average total match penalty kicks awarded. Again, it is worth remembering that the 2023/24 season, included in the 5 year comparison only, saw a deliberate increase in added time and thus effective playing time, leading to a general increase in all other match statistics. Therefore, attributing the observed statistically significant increase of 0.04 in penalty kicks solely to VAR would be challenging.

4.4 Penalty Kicks Scored

Many would naturally expect the extended wait during VAR checks to have a negative, “icing” effect on the penalty kick taker or even the goalkeeper. As players must wait for possibly several minutes while VAR checks are conducted, one may think they could get nervous or overthink their approach to the ensuing penalty kick.

Comparing 5 years before and after VAR in the English Premier League, our three analysis methods found a statistically significant increase of 0.04 in the average number of total match penalty kicks scored. However, when comparing 1 year and 3 years before and after VAR, we found no majority consensus of a statistically significant difference in the average number of total match penalty kicks scored, which were -0.03 and 0.04, respectively. Although, referencing Table 5 above, the Mann-Whitney U test produced a p-value of 0.0487 (<0.05) for the 3 year comparison, while the T-test and GLM produced p-values of 0.0822 and 0.0826, respectively. Nevertheless, because we did not achieve a majority consensus among the 3 tests, we will not conclude there is evidence of a statistically significant difference in the average number of total match penalty kicks scored for the 3 year comparison.

4.5 Offsides

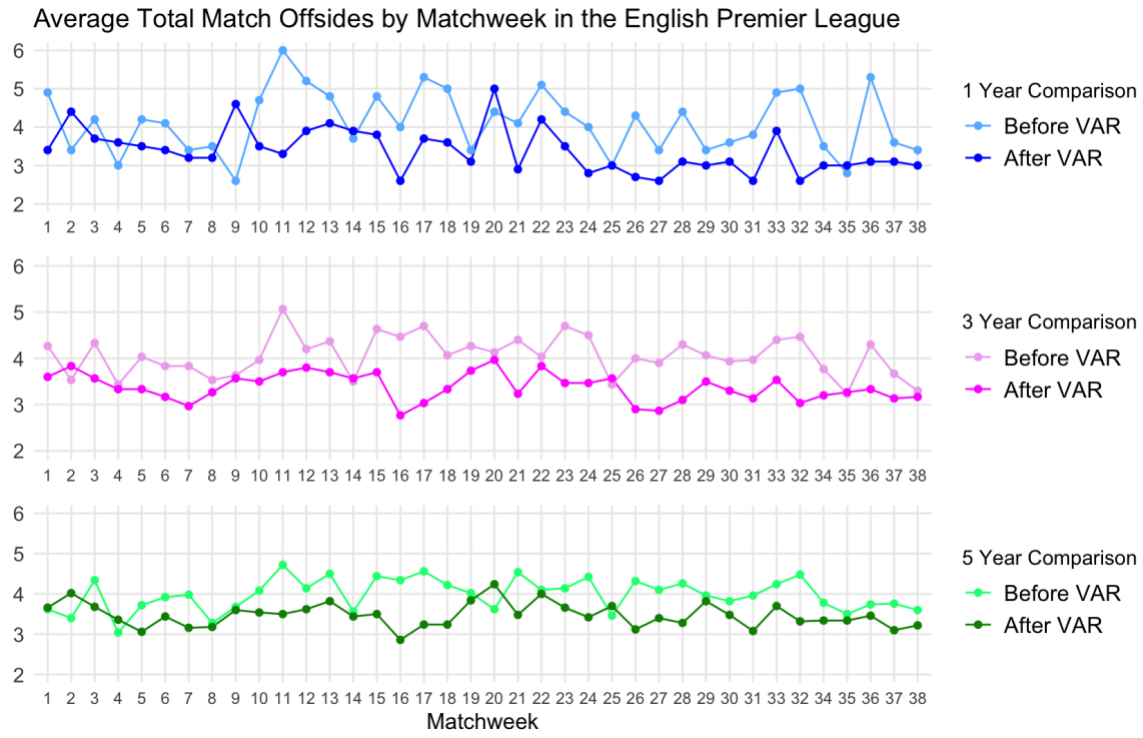

Figure 2. Graphs of average total match offsides by match week in the English Premier League averaged across three different time periods before and after the implementation of VAR.

Determining offsides is one of the most important responsibilities in soccer refereeing and a major focus of the Video Assistant Referee's role. Our literature review leads us to expect a statistically significant decrease in the number of offsides per match. When comparing 1, 3, and 5 years before and after the implementation of VAR, we have strong evidence of a significant decrease in the average number of total match offsides for all three time comparisons. As shown in Figure 2 above, the darker lines representing post-VAR averages by match week are consistently lower than the lighter lines indicating pre-VAR averages. This indicates that the on-field assistant referees are properly following VAR protocol by not raising their flags for offsides, and allowing play to go on, to eventually let VAR check for offsides should a goal, or other reviewable incident result, from the play. Further, we must note that this very evident decrease in offsides after the implementation of VAR in the English Premier League may directly affect other match statistics as well, as it allows for more attacking plays to ensue. As such, it makes sense

that a decrease in offsides would lead to an increase in corner kicks. The assistant referees are told to keep their flags down if a play is not clearly and obviously offside and just let VAR intervene if a goal is scored. Therefore, many attacks that don't result in a goal may still result in a corner kick being awarded, because VAR can only intervene and call offsides if a goal is scored, but not for a corner kick.

Unfortunately, the number of corner kicks was not provided for English Premier League matches on FBref until the 2017/18 season. Nevertheless, we performed a separate, one-off analysis on the number of average total match corner kicks for the 2 seasons before VAR (17/18 and 18/19) and the 2 seasons after VAR (19/20 and 20/21) in the English Premier League. When comparing these two seasons before and after VAR, we found there is some evidence ($0.05 < p\text{-values} < 0.10$) but not enough to conclude the 0.855 increase in the number of average total match corner kicks as statistically significant.

4.6 Yellow Cards

While yellow cards are not as directly related to the jurisdiction of VARs, they are another measure of players' discipline and of interest due to the aforementioned logic that players may now be hesitant to play as aggressively and commit fouls, resulting in yellow cards, out of fear that their fouls will be checked in a slow-motion replay by the VAR and possibly be upgraded to a red card. Using the 1 year and 3 year comparisons, we found no evidence of a statistically significant difference in the average number of total match yellow cards, which were 0.16 and -0.09, respectively. However, when analyzing the 5 year comparison data, our analyses provided a majority consensus of a statistically significant increase of 0.14 in the average number of total match yellow cards. Although only the T-test and GLM yielded p-values less than 0.05 (0.0331 and 0.0339, respectively) while the U-test yielded a p-value of only 0.0546. However, it is again worth recalling that beginning with the 2023/24 season in the English Premier League, referees were instructed to much more strictly enforce smaller offenses, like dissent or time-wasting, and brandish a yellow card in such cases. This is almost certainly why we found statistically significant

evidence of an increase in yellow cards using the 5 year comparison, which included the 2023/24 season, unlike the 1 year and 3 year comparisons.

4.7 Tackles

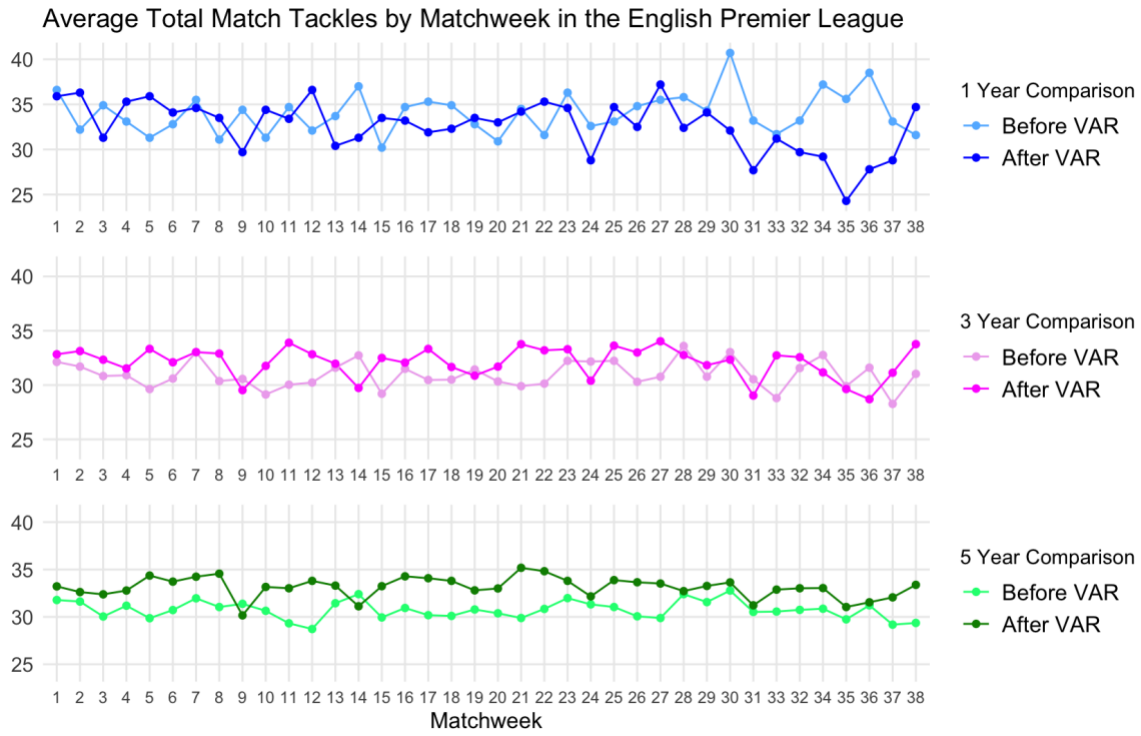

Figure 3. Graphs of average total match tackles by match week in the English Premier League averaged across three different time periods before and after the implementation of VAR.

Across all of the 1 year, 3 year, and 5 year comparisons, our analyses found evidence of statistically significant difference in the average number of total match tackles, however, the changes are not in the same direction for all three comparisons. When comparing 1 year before and after VAR in the EPL, the average number of total match tackles decreased by -1.41. However, surprisingly, when analyzing the 3 and 5 year comparisons, we found evidence of statistically significant increases in the average number of total match tackles of 1.15 and 2.37, respectively. Again, such increases go against intuition, as one would expect the number of tackles to decrease due to players being hesitant to execute tackles out of fear that if the tackle fails and results in a foul, VAR may check the incident and award a penalty and/or issue a red

card. However, this logic appears to be true when assessing the average number of total match interceptions.

4.8 Interceptions

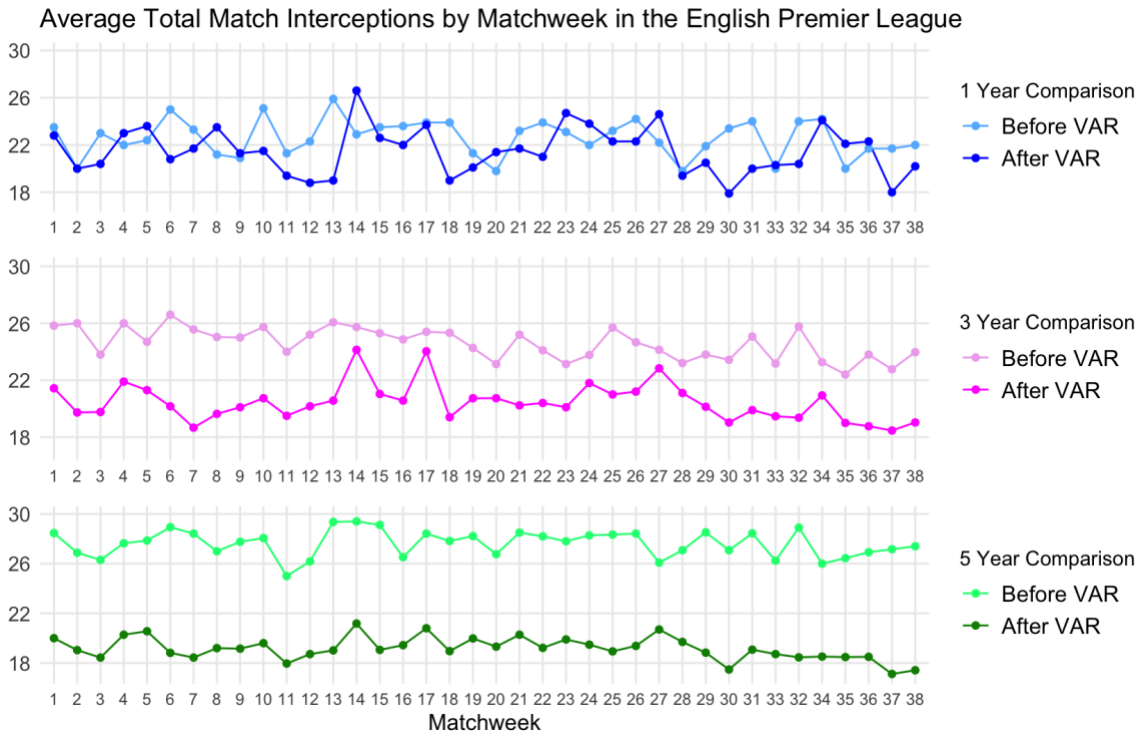

Figure 4. Graphs of average total match interceptions by match week in the English Premier League averaged across three different time periods before and after the implementation of VAR.

Figure 4 above paints a rather damning picture. Across all three comparisons, our analyses found evidence of a significant decrease in the average number of total match interceptions, which are -1.12, -4.15, and -8.47, respectively. These statistically significant decreases in the number of interceptions might logically be explained by the fact, as mentioned in the fouls, yellow cards, and tackles sections above, that players may now be more reluctant to play tenaciously and aggressively out of fear that if they commit a foul, VAR can review multiple slow-motion replay angles of the incident, providing possible evidence of upgrading the foul to a red card and/or awarding a penalty kick for the other team, if the foul is in the box.

However, it is interesting how interceptions had a significant decrease over the three different comparisons, meanwhile tackles decreased only when analyzing the 1 year comparison but increased when analyzing the 3 year and 5 year comparison. As lovers and decent understanders of the game of soccer, we theorize that compared to interceptions, tackles are often performed with less aggression and against a player who is in closer proximity and already has possession of the ball. Meanwhile, interceptions require players to more aggressively jump in front of a player whom the ball is being passed to. This more aggressive nature of performing interceptions compared to tackles may explain why there has been an intermediate and long-term decrease in the number of total match interceptions, but not tackles, since the implementation of VAR. We theorize there is a possible psychological impact of VAR on players, resulting in players being more reluctant to play aggressively out of fear that the VAR will check fouls and possibly issue a red card or award the other team a penalty kick.

4.9 Non-Significant Variables

All three of the types of analysis used in this paper (T-tests, U-tests, and GLMs), found no statistically significant difference in the average number of total match shots or red cards before and after the implementation of VAR in the English Premier League, across all three time periods used for comparison (1 year, 3 year, and 5 year). Table 5 displays the p-values for all three types of analysis for these three variables, all of which were greater than 0.05. These non-significant changes could be a promising sign to English Premier League executives who hoped VAR's implementation would have little-to-no impact on the gameplay of matches while increasing referees' decision-making accuracy.

4.9.1 Shots

Comparing 1 year, 3 years, and 5 years before and after VAR in the English Premier League, our analyses found no statistically significant difference in number of total match shots. This is not a surprising result as most of the literature reviewed either didn't analyze the change in the number of total match shots or did not find a significant difference if they did analyze it.

Further, the VAR's jurisdiction doesn't really affect shots, however, it was still of interest to us to see whether the offensive nature of the game has changed for whatever reason since the implementation of VAR.

4.9.2 Red Cards

Comparing 1 year, 3 years, and 5 years before and after VAR in the English Premier League, our analysis found no statistically significant difference in the number of total match red cards. Although the implementation of VAR places special focus on decisions regarding red cards, they are still such an infrequent part of the game. According to our data, there have only been 480 red cards in the 3800 games of the last 10 English Premier League seasons. These 480 red cards have occurred in 449 games, meaning that 88.18% of games in the last 10 English Premier League seasons have had no red cards. As such, there would truly have to be a drastic change in order to observe a statistically significant difference, which would more likely be an increase than a decrease. Nevertheless, red cards are still a very important part of the game as they can lead to penalties being awarded, and thus goals being scored, or players being suspended 1 to 3 matches as a result.

Chapter 5

FUTURE ANALYSES

In the future, if possible, we would also like to acquire match data on the total time of each half, the total effective playing time of each half, the number of VAR checks per match, the average length of each VAR check in seconds, the number of VAR interventions, and the number of injuries. This would bolster our analysis as we would love to analyze data directly related to VAR, instead of match statistics which are more indirectly related.

Further, we also hypothesized that VAR interventions may cause a “tipping point” effect, in that when a big decision regarding red cards or goals is made, it can drastically affect the momentum and morale of teams. As such, we would love to analyze how games changed after VAR intervened. As a part of this, we would be able to analyze which teams have benefited and lost the most from VAR interventions. Also, instead of doing total match statistics, we could also analyze home and away team variables separately to see how VAR impacts home and away teams differently, with the motivation being that referees may feel more pressured or biased towards helping the home team to avoid immediate backlash from the fans.

In terms of other statistical analysis methods, we believe it would also be interesting to explore using Z-tests instead of T-tests, time series analysis, and possibly other types of regression models. We did perform Z-tests, whose p-values and 95% confidence intervals can be found in the full summary table in Appendix A below, however, we felt that T-tests were more appropriate given how we were performing analysis on 3 different subsets of the data. Further, it would be of great interest to explore effect sizes using methods like Cohen’s d or Hedge’s d. Our thinking is that with such large sample sizes, many of our results are likely statistically significant, but not as practically significant. Using effect sizes instead of p-values to analyze our variables would allow us to better quantify our results in terms of practical significance that can be applied to the real world. We would also be interested in at least trying out pairwise analysis, like pairwise Z-tests or pairwise Mann–Whitney tests. However, we believe any kind of pairwise analysis would be inappropriate, as there are 3 new teams in the English Premier League each year due to the

relegation/promotion structure of English soccer, so the paired samples of data are not from the exact same subjects, which is teams in this context. Finally, as mentioned in the methods section above, we would strongly consider using some sort of correction or adjustments to account for the family-wise error rate or false discovery rate, like the Bonferroni correction or Benjamini-Hochberg method, for potential future analyses.

Upon doing the literature review, we also discovered several nonparametric statistics tests that we were less familiar with, including a Kruskal Wallis test, Dunn's Test, and the Conover–Iman test, which all seem to be extensions of the Mann-Whitney U-test. We would love to further explore all of these in any potential future analyses. We would also be interested in doing a weighted meta-analysis to combine lots of the results of existing literature attempting to analyze the impact of VAR across other elite professional soccer leagues. Further, it would be interesting to use the meta-analysis as a possible prior in Bayesian analysis.

Finally, we strongly encourage anybody reading this and interested in other match variables to go to the GitHub repository in the Appendices below and use the reproducible code to scrape the data and analyze the differences of any of the other variables listed in Table 4 which we did not analyze in this paper.

Chapter 6

CONCLUSION

In the end, our analysis allowed us to discover several immediate, intermediate, and long-term statistically significant differences in key match metrics after the implementation of VAR in the English Premier League, using a variety of statistical analysis methods. Comparing 1 year before and after the implementation of VAR in the English Premier League, we found a significant increase in the number of average total match fouls, and significant decreases in the number of average total match offsides, tackles, and interceptions. Next, when comparing 3 years before and after VAR in the English Premier League, we found a significant increase in the number of average total match tackles, and significant decreases in the number of average total match offsides and interceptions. Finally, when comparing 5 years before and after VAR in the English Premier League, we found significant increases in the number of average total match goals, penalty kicks awarded, penalty kicks scored, yellow cards, and tackles, and significant decreases in the number of average total match offsides, and interceptions. However, as emphasized throughout the results section, it is worth noting that the new rules beginning in the 2023/24 season, regarding stricter enforcement of yellow card offenses and increased added time leading to a general increase in all match variables, may influence several of these variables in the 5 year comparison analyses, including goals, penalty kicks awarded and scored, and yellow cards.

Although there are some slight differences in certain match statistics before and after the implementation of VAR in the English Premier League it would be statistically inappropriate to conclude that VAR has caused these changes. In conclusion, despite the statistically significant differences, VAR does not seem to drastically affect gameplay overall in the English Premier League. Nevertheless, the findings highlighted in this paper can help coaches and players better understand the impact of VAR on the game. This analysis can also help the IFAB, FIFA, the English Premier League, the English Football Association, and other similar entities to identify possible areas of improvement for the betterment of future refereeing and the continued commitment to the equitable implementation of VAR.

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APPENDICIES

Appendix A: Code

https://github.com/jack23brown/Impact-of-VAR-on-the-EPL

Appendix B: Supplemental Tables & Figures

Table 6. An extended summary table of the analyses performed on the 10 variables of interest over the last 10 seasons of the English Premier League

	# Years Pre/Post VAR	Pre VAR mean	Post VAR mean	Post VAR mean - Pre VAR mean	Percent Change	T-test p-value	U-test p-value	Z-test p-value	GLM p-value	GLM AIC	Post VAR - Pre VAR T-test 95% CI	Post VAR - Pre VAR GLM 95% CI	Post VAR - Pre VAR Z-test 95% CI
Goals	1	2.74	2.64	-0.10	-3.65%	0.3705	0.5060	0.4016	0.4004	2776.01	(-0.319, 0.119)	(-0.333, 0.133)	(-0.334, 0.134)
	3	2.68	2.65	-0.03	-1.08%	0.6701	0.6644	0.6741	0.6722	8509.50	(-0.162, 0.104)	(-0.163, 0.105)	(-0.164, 0.106)
	5	2.63	2.77	0.14	5.26%	0.0094	0.0160	0.0182	0.0094	14267.50	(0.034, 0.243)	(0.034, 0.243)	(0.034, 0.243)
Fouls	1	20.44	21.44	1.00	4.89%	0.0097	0.0162	0.0077	0.0096	4693.88	(0.243, 1.757)	(0.243, 1.757)	(0.263, 1.736)
	3	21.41	21.16	-0.25	-1.19%	0.2492	0.1445	0.2405	0.2493	14030.41	(-0.687, 0.178)	(-0.687, 0.178)	(-0.679, 0.170)
	5	21.63	21.43	-0.20	-0.96%	0.2265	0.1287	0.2144	0.2268	23257.90	(-0.532, 0.126)	(-0.533, 0.126)	(-0.532, 0.126)
PKs Awarded	1	0.27	0.24	-0.03	-10.68%	0.4267	0.8943	0.4360	0.4311	957.21	(-0.100, 0.043)	(-0.101, 0.043)	(-0.102, 0.044)
	3	0.25	0.28	0.03	11.11%	0.1923	0.1040	0.1907	0.1946	2933.98	(-0.014, 0.070)	(-0.014, 0.070)	(-0.014, 0.070)
	5	0.24	0.28	0.04	13.89%	0.0395	0.0176	0.0425	0.0396	4815.66	(0.002, 0.067)	(0.002, 0.067)	(0.002, 0.067)
PKs Scored	1	0.22	0.19	-0.03	-14.29%	0.3404	0.6685	0.3391	0.3403	834.63	(-0.097, 0.033)	(-0.096, 0.033)	(-0.097, 0.033)
	3	0.19	0.23	0.04	17.27%	0.0822	0.0487	0.0805	0.0826	2520.72	(-0.004, 0.071)	(-0.004, 0.071)	(-0.004, 0.071)
	5	0.19	0.23	0.04	19.91%	0.0115	0.0050	0.0126	0.0115	4158.89	(0.008, 0.066)	(0.008, 0.066)	(0.008, 0.066)
Shots	1	25.08	24.49	-0.59	-2.37%	0.1400	0.1335	0.1562	0.1392	4759.83	(-1.385, 0.196)	(-1.383, 0.194)	(-1.417, 0.227)
	3	24.98	24.58	-0.40	-1.62%	0.0829	0.0881	0.0942	0.0826	14281.03	(-0.863, 0.053)	(-0.863, 0.052)	(-0.880, 0.069)
	5	25.30	25.22	-0.08	-0.32%	0.6624	0.5688	0.4138	0.6619	24069.40	(-0.451, 0.287)	(-0.450, 0.286)	(-0.450, 0.286)
Offsides	1	4.12	3.39	-0.73	-17.82%	0.0000	0.0000	0.0000	0.0000	3296.90	(-1.052, -0.416)	(-1.052, -0.416)	(-1.049, -0.419)
	3	4.06	3.38	-0.68	-16.67%	0.0000	0.0000	0.0000	0.0000	9873.45	(-0.859, -0.494)	(-0.859, -0.493)	(-0.858, -0.494)
	5	3.98	3.47	-0.51	-12.90%	0.0000	0.0000	0.0000	0.0000	16406.66	(-0.652, -0.371)	(-0.652, -0.371)	(-0.652, -0.371)
Red Cards	1	0.12	0.12	-0.01	-4.26%	0.8341	0.8999	0.8386	0.8348	585.41	(-0.055, 0.044)	(-0.055, 0.044)	(-0.056, 0.045)
	3	0.11	0.12	0.01	7.09%	0.5803	0.5473	0.5967	0.5803	1689.87	(-0.020, 0.036)	(-0.020, 0.036)	(-0.021, 0.037)
	5	0.14	0.12	-0.02	-13.23%	0.1213	0.1183	0.1182	0.1214	2992.77	(-0.041, 0.005)	(-0.041, 0.005)	(-0.041, 0.005)
Yellow Cards	1	3.31	3.47	0.16	4.77%	0.2617	0.4231	0.2818	0.2624	3123.86	(-0.118, 0.434)	(-0.118, 0.434)	(-0.130, 0.445)
	3	3.41	3.32	-0.09	-2.70%	0.2675	0.2762	0.2769	0.2702	9455.30	(-0.255, 0.071)	(-0.256, 0.072)	(-0.258, 0.074)
	5	3.45	3.59	0.14	4.06%	0.0331	0.0546	0.0455	0.0339	15919.72	(0.011, 0.269)	(0.011, 0.269)	(0.011, 0.269)
Tackles	1	34.02	32.62	-1.41	-4.13%	0.0121	0.0190	0.0155	0.0122	5261.21	(-2.502, -0.309)	(-2.505, -0.306)	(-2.543, -0.268)
	3	30.96	32.11	1.15	3.70%	0.0005	0.0004	0.0006	0.0005	15830.15	(0.502, 1.789)	(0.500, 1.791)	(0.489, 1.802)
	5	30.75	33.12	2.37	7.72%	0.0000	0.0000	0.0000	0.0000	26406.59	(1.869, 2.876)	(1.868, 2.877)	(1.864, 2.881)
Interceptions	1	22.61	21.49	-1.12	-4.95%	0.0045	0.0043	0.0660	0.0044	4721.63	(-1.889, -0.348)	(-1.888, -0.349)	(-2.311, -0.074)
	3	24.60	20.45	-4.15	-16.88%	0.0000	0.0000	0.0000	0.0000	14821.64	(-4.673, -3.634)	(-4.673, -3.634)	(-4.842, -3.465)
	5	27.63	19.16	-8.47	-30.64%	0.0000	0.0000	0.0000	0.0000	26406.59	(-8.927, -8.005)	(-8.923, -8.010)	(-9.000, -7.933)

Table 7. P-values for Shapiro-Wilk, Anderson-Darling, and Kolmogorov-Smirnov tests for normality on all 10 variables of interest, assessed at a 0.05 significance level

	1 year comparison			3 year comparison			5 year comparison		
Variable	**SW**	**AD**	**KS**	**SW**	**AD**	**KS**	**SW**	**AD**	**KS**
Goals	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Fouls	0.00082	0.00561	0.00056	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
PKs Awarded	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
PKs Scored	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Shots	0.00047	0.02031	0.00026	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Offsides	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Red	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Yellow	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Tackles	0.00710	0.02244	0.00340	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Interceptions	0.00087	0.01375	0.00021	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

SW = Shapiro-Wilk, AD = Anderson-Darling, KS= Kolmogorov-Smirnov

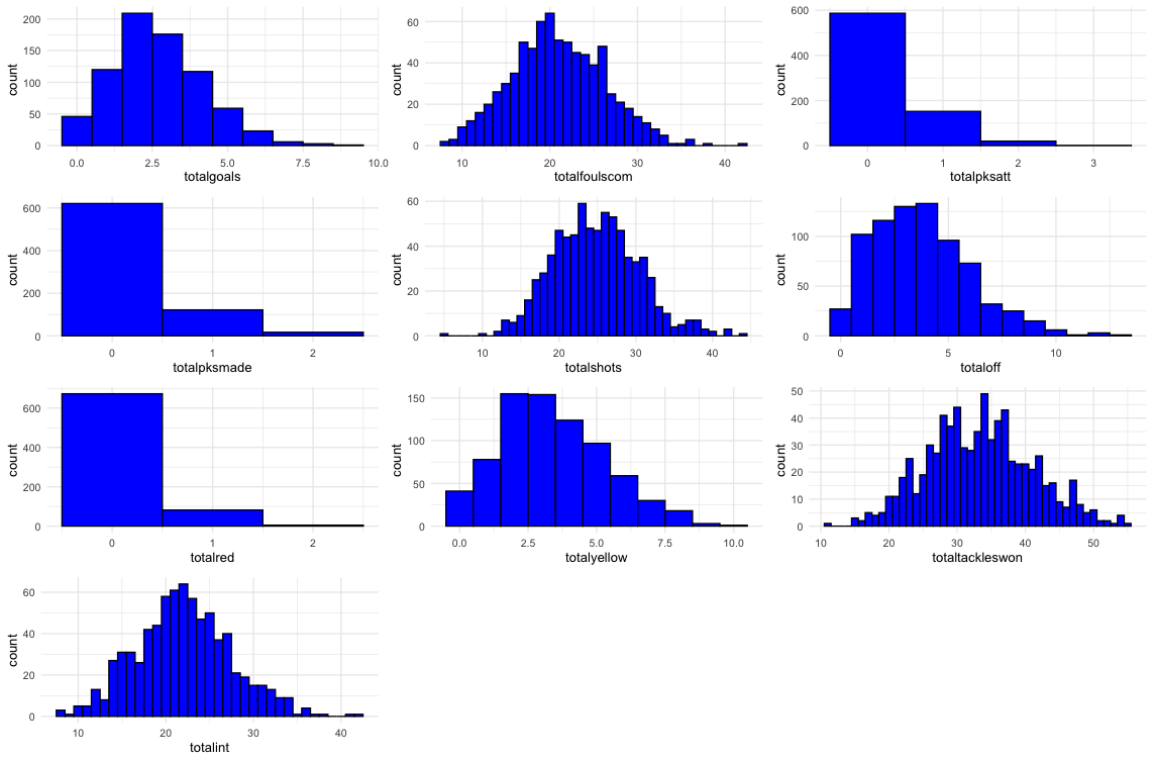

Figure 5. Histograms of all 10 variables of interest for 1 year comparison data

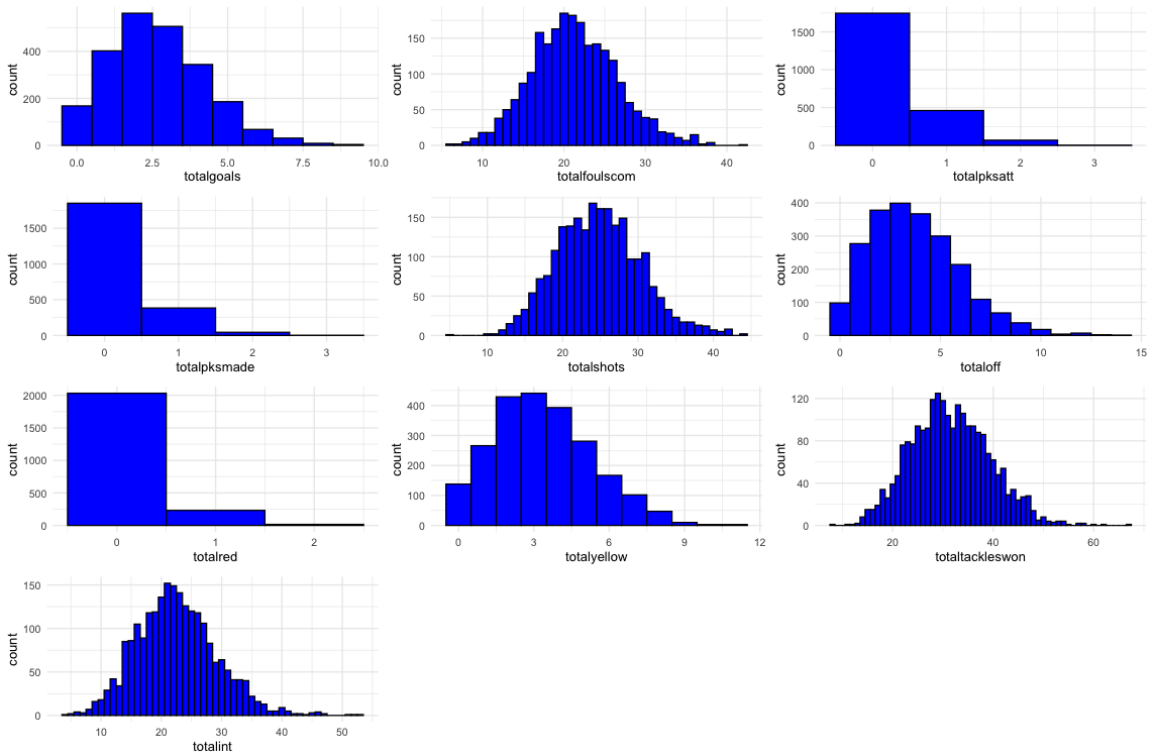

Figure 6. Histograms of all 10 variables of interest for 3 year comparison data

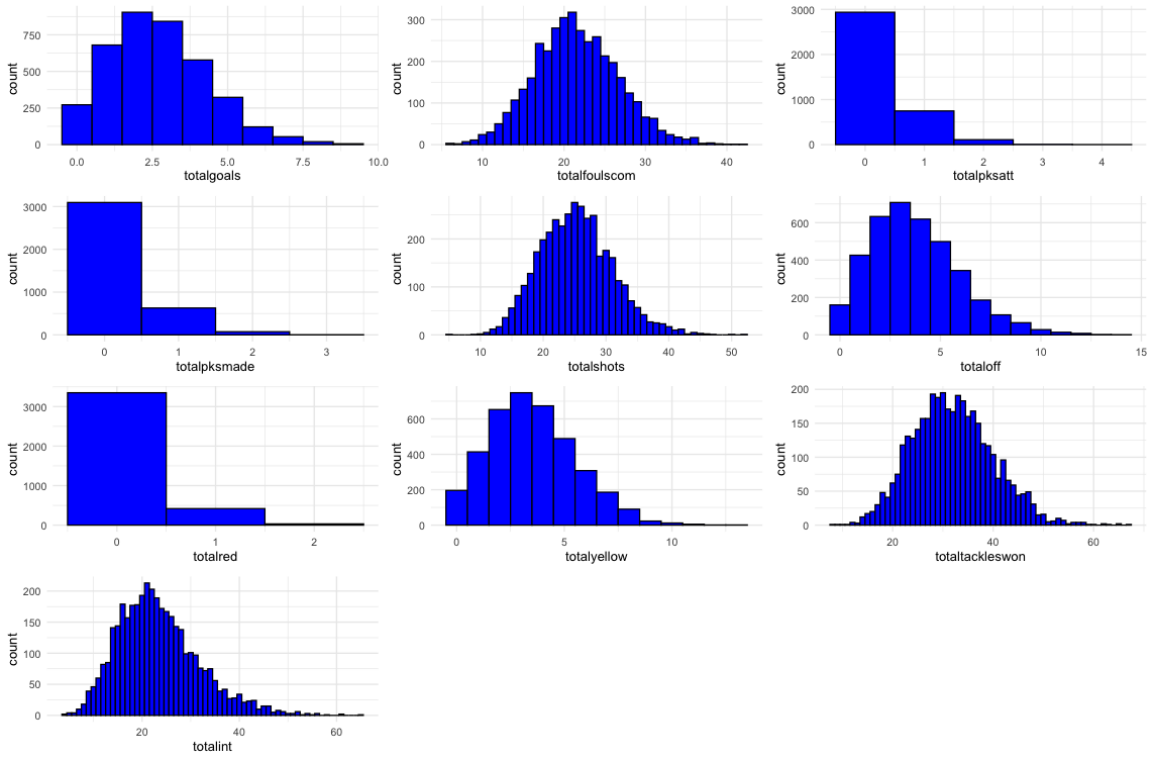

Figure 7. Histograms of all 10 variables of interest for 5 year comparison data

Table 8. P-values for Breusch-Pagan and Levene's test for equal variance on all 10 variables of interest, assessed at a 0.01 significance level

	1 year comparison		3 year comparison		5 year comparison	
Variable	**Breusch-Pagan**	**Levene's**	**Breusch-Pagan**	**Levene's**	**Breusch-Pagan**	**Levene's**
Goals	0.17934	0.30962	0.44498	0.61485	0.79976	0.54639
Fouls	0.05501	0.07112	0.08222	0.11661	0.01578	0.03097
PKs Awarded	0.42670	0.04243	0.19227	0.69431	0.03951	0.39257
PKs Scored	0.34036	0.06929	0.08220	0.29709	0.01147	0.10834
Shots	0.27233	0.30618	0.06266	0.26429	0.01238	0.05767
Offsides	0.11919	0.17039	0.00033	0.00073	0.00071	0.00764
Red	0.83408	0.72578	0.58031	0.69550	0.12128	0.18613
Yellow	0.13095	0.23849	0.16923	0.24259	0.35549	0.40557
Tackles	0.21983	0.15595	0.40066	0.64731	0.15917	0.03493
Interceptions	0.29876	0.15159	0.00002	0.00000	0.00000	0.00000