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DOES HOME-FIELD ADVANTAGE REALLY MATTER?

An Analysis of NFL Team Performance in the Regular Season 2015–2024

Bachelor's thesis

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I solemnly declare that I have prepared the bachelor’s thesis entitled “Does Home-Field Advantage Really Matter?” independently under the professional supervision of my thesis advisor and that I have listed all sources and literature used.

In Olomouc on April 20, 2026 Signature ....

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INTRODUCTION

The choice of the topic of this bachelor's thesis stemmed from my long-term interest in the intersection of sport and data analysis. The sports environment has accompanied me since childhood, and during my time competing in the top domestic ball hockey league, I first realized the great potential of working with data for understanding performance as well as for the preparation of athletes themselves. Over time, this interest deepened, and I became increasingly attracted to the environment of American football. In this sport, data analysis is exceptionally developed and represents an essential part of decision-making processes across teams in the top league, the National Football League (NFL). A wide range of detailed data is available, covering technical, tactical, and environmental aspects of the game, from precise statistics of player actions to meteorological conditions, the nature of the playing surface, or the distance traveled between individual stadiums.

My experience as a professional athlete was also an important starting point in selecting the specific topic. I repeatedly encountered how significantly the environment of home and away games can influence both the psychology and performance of players. In my case, this involved at most thousands of spectators in the stands, whereas NFL stadiums are regularly filled with crowds ranging from 61,000 to over 80,000 people. The pressure and intensity of this environment are incomparable, which naturally raises the question of how strong the influence of home-field advantage is on team performance at such a high level. The phenomenon of home-field advantage therefore became a natural choice, as it includes not only the stadium atmosphere but also other factors such as the type of playing surface, the quality of the opponent, the level of recovery, and the distance players must travel throughout the season.

The American NFL is among the competitions that have long invested in the development of technology, recovery, nutrition, and overall player care. The high availability of data makes it an ideal environment for a systematic analysis of how individual home-field factors influence sports performance. The geographical distribution of teams across the continental United States creates a natural experiment, where some teams must regularly cross multiple time zones, face extreme climatic conditions, or play on different types of surfaces. Teams from the West Coast, such as the Seattle Seahawks or Los Angeles

Rams, travel to the East Coast over distances exceeding 4,000 kilometers, requiring flights lasting approximately five to six hours and crossing three time zones. This variability makes it possible to examine how travel, weather, and other environmental factors interact with physiological processes such as circadian rhythms or cumulative fatigue.

Research on home-field advantage has a long tradition in academia, dating back to the work of Schwartz and Barsky (1977), who were among the first to systematically describe this phenomenon in organized sports. Since then, research methods have significantly evolved from simple description toward sophisticated causal models that aim to isolate and quantify the individual mechanisms underlying this phenomenon. The COVID-19 pandemic provided researchers with a unique opportunity to examine home-field advantage in conditions without spectators, helping to reveal which factors truly play a key role. Interestingly, in the context of the NFL, it has been shown that the influence of the crowd is not as strong as in other sports, suggesting that in American football, other factors—particularly those related to travel and environmental conditions—may play a more dominant role.

Travel in the NFL represents a specific challenge. Players spend more time above 30,000 feet than athletes in any other American team sport, which brings physiological consequences associated with hypoxia, sleep disruption, and cumulative fatigue. Studies from the NBA and other professional leagues have shown that travel across time zones can significantly affect performance, with an interesting asymmetric pattern emerging. Teams traveling from west to east may gain a circadian advantage in evening games, as their internal biological clocks indicate a time close to peak performance, whereas teams traveling in the opposite direction play at a time when their bodies expect rest.

The aim of this thesis is therefore to analyze how home-field advantage affects team performance in the NFL, using available data from the past ten seasons (2015–2024). The thesis will primarily examine how various environmental, game-related, and situational factors contribute to game outcomes and whether their effects can be quantitatively captured using advanced statistical methods. The work will focus on a comprehensive analysis including travel across time zones, meteorological conditions, the type of playing surface, and their interactions, which should provide a comprehensive view of the mechanisms of home-field advantage in professional American football.

During the preparation of this thesis, I used tools based on artificial intelligence. The Elicit tool was used for exploratory literature searches. NotebookLM was used for working with texts, particularly for identifying relevant variables, methodological approaches, and their applicability to the defined hypotheses. For language purposes, the Claude AI tool was used to translate the thesis into English. Artificial intelligence was also used as a supporting tool in the creation and modification of scripts in the R environment, particularly in the implementation of statistical analyses. All outputs were subsequently reviewed and adjusted by the author of the thesis.

THEORETICAL PART

1 American Football and the National Football League

1.1 History of the NFL

The National Football League (NFL) represents an organization with a rich and complex history that has developed over more than one hundred years. The league was founded in 1920, originally under the name American Professional Football Association (APFA). In its early years, it consisted of fourteen teams, most of which were concentrated in the American Midwest. This early phase was characterized by its informality, as evidenced by the low franchise fee and the absence of official team logos. Due to his reputation and potential to promote the new national professional football league, Jim Thorpe was unanimously elected as the first president. Of the original fourteen founding members, only two clubs survived the league's centennial: the Decatur Staleys, now known as the Chicago Bears, and the Chicago Cardinals, who later relocated to Arizona.

A key step toward establishing the current organization occurred in 1922, when the APFA was renamed the National Football League (NFL). This change reflected the league's effort to be perceived as a national organization. During the 1920s and early 1930s, teams frequently changed, with some franchises leaving the league while others joined. This unstable period began to stabilize in 1933, which brought the establishment of two permanent franchises: the Pittsburgh Pirates, later known as the Steelers, and the Philadelphia Eagles. In the same year, the NFL introduced its own rule modifications aimed at creating a more attractive and dynamic product for fans, distinct from college football. The most significant change was the allowance of the forward pass from any point behind the line of scrimmage, which led to a dramatic opening of the game.

To ensure fairness and prevent the concentration of the best talent in the wealthiest clubs, a draft system was introduced for the first time in 1936. Before this reform, all college players were free agents who often signed contracts with teams offering the highest financial compensation. In 1939, the seeds of future mass popularity were sown when the first televised professional football game took place. Although the broadcast was limited to certain areas of New York, the connection between the NFL and television was seen as a guarantee of the league's future financial stability and popularity.

During the 1940s, the league was severely affected by World War II, which caused a significant outflow of players into military service. The shortage of players forced some teams to temporarily suspend operations, while others, such as the Eagles and Steelers, had to merge into a single team for one season, nicknamed the "Steagles."

After the end of World War II, the NFL faced new competition in the form of the All-America Football Conference (AAFC). After several years of rivalry, the NFL and AAFC merged in 1950, expanding the league by three major clubs: the San Francisco 49ers, Baltimore Colts, and Cleveland Browns. The Browns, named after their coach and general manager Paul Brown, immediately shocked the football world upon entering the NFL by decisively winning their first game.

The golden age of professional football began with the 1958 NFL Championship game between the New York Giants and the Baltimore Colts. This game, the first to be broadcast nationwide on television and decided in sudden-death overtime, became the most-watched sporting event in television history at the time. It was nicknamed "the greatest game ever played" and definitively helped the NFL surpass baseball as America's national pastime.

In 1960, another competing league was established, the American Football League (AFL), founded by Lamar Hunt after unsuccessful attempts to obtain an NFL franchise. The AFL quickly established itself as a legitimate rival, thanks to its aggressive recruitment policy, for example by offering record-breaking contracts to Joe Namath, and innovations such as placing players' names on jerseys. The AFL also focused on a more pass-oriented and offensive style of play. Intense rivalry over talent and audiences led to merger negotiations, which were agreed upon in 1966 and officially completed in 1970. Part of the agreement was the introduction of an annual championship between the winners of both leagues, known as the Super Bowl. Victories by AFL teams, the New York Jets in Super Bowl III and the Kansas City Chiefs in Super Bowl IV, helped eliminate the perceived difference in quality between the leagues before the final merger.

After the completion of the merger in 1970, the league was reorganized into two conferences, the AFC and NFC, each divided into divisions. In the following decades, the NFL continued to expand, with teams such as the Seattle Seahawks and Tampa Bay Buccaneers joining in 1976. In addition to expansion, the evolution of rules continued with the aim of promoting offensive play. In 1974, the sudden death overtime system was introduced in the regular season. The most important rule change of this period was the 1978 adjustment known as the “Mel Blount Rule,” which limited defenders’ contact with receivers to five yards beyond the line of scrimmage. This change significantly revitalized the passing game and led to an increase in high-quality passing statistics.

With growing popularity, television broadcasting also evolved. In the mid-1990s, time and score information began to be continuously displayed on screens, fundamentally changing the viewing experience. Subsequently, in 1998, the revolutionary yellow first down line technology was introduced, helping viewers, especially newcomers, better understand critical game situations.

Through continuous expansion, relocation of teams, and strategic mergers, the NFL transformed from an informal group of regional clubs into a dominant sports league in North America. The role of a professional player evolved from a pastime into a full-fledged, lucrative career, and the league continues to adapt to the demands of the modern era.

2 Sports Performance and Its Measurement

The evaluation of sports performance in contemporary professional sport has become a complex multidisciplinary field that connects traditional approaches of sports psychology with modern methods of data analytics (Baumer et al., 2023; Lochbaum et al., 2022). This complexity arises from the effort to distinguish to what extent sports outcomes are influenced by skills and training and where chance or luck begins to play a role (Severini, 2020).

2.1 Definition of Performance in the Context of Sports Psychology and Analytics

Sports psychology has a nearly two-hundred-year history and has consistently addressed the question of how psychological techniques can be used to improve athletes’ performance (Lochbaum et al., 2022). According to this approach, performance is the product of the interaction between physical abilities and psychological factors, which can either support or hinder performance (Németh & Balogh, 2021). Research suggests that psychological interventions and constructs considered beneficial for performance, such as team cohesion, self-confidence, or mindfulness, have an overall slightly positive effect (Lochbaum et al., 2022). In contrast, factors perceived as harmful, such as cognitive anxiety, depression, or the so-called ego climate, show a weak negative effect (Lochbaum et al., 2022).

Within sports psychology, performance is evaluated primarily based on the subjective experiences and states of athletes, that is, based on how they perceive stress, anxiety, self-confidence, or motivation (Németh & Balogh, 2021). One line of research works with the concept of Individual Zones of Optimal Functioning (IZOF), which is based on the assumption that athletes achieve their highest performance when the intensity of their emotions lies within an optimal range determined individually for each of them (Robazza, 2006, as cited in Németh & Balogh, 2021). A challenge remains the precise measurement of the psychological influence on performance, which often relies on subjective questionnaires, although more objective physiological methods aimed at detecting arousal levels are also beginning to be used (Németh & Balogh, 2021).

From the perspective of data analytics, sports performance is understood as the result of a quantifiable description of the game state and its expected value, with the goal of predicting or explaining the outcome of a match (Baumer et al., 2023). Sports analytics seeks to distinguish what is the result of true skill and what can be attributed to randomness (Severini, 2020). For statistical analysis, American football is typically modeled as a discrete sport, where individual actions are divided into short, clearly defined segments based on each down (Baumer et al., 2023).

2.2 Micro-Level of Performance: Penalties, Third-Down Efficiency, Quarterback Performance, and Others

Micro-level analysis examines specific events and actions during the game that have a demonstrable impact on the overall outcome (Snyder & Lopez, 2015). Although the final result of a game is always binary (either a win or a loss), detailed examination of individual game situations allows teams to improve decision-making and strategic organization (Long & Magel, 2013).

Statistical models repeatedly identify several key factors that significantly contribute to success in American football. These include the difference in the number of turnovers, the difference in the percentage success rate of third-down conversions, and the difference in yards lost due to sacks (Long & Magel, 2013). Turnovers are among the factors that most quickly and dramatically reduce a team's chances of winning (Pelechrinis & Papalexakis, 2016).

An important part of microanalysis is penalties, which represent violations of rules or deviations from standard behavior on the field (Snyder & Lopez, 2015). Penalties can be divided into discretionary ones, which require subjective judgment by the referee (for example holding fouls on offense or defense), and non-discretionary ones, which are easier to recognize and less controversial (Snyder & Lopez, 2015). Analysis of referee behavior in the NFL shows that discretionary fouls are called less frequently at the beginning and at the end of games, while they occur most often in the second and third quarters (Snyder & Lopez, 2015).

Micro-level analysis also focuses on evaluating the performance of key players. A typical example is the evaluation of quarterbacks (QB), the players responsible for organizing offensive play. Statistical models are used that estimate the success of individual plays based on the game situation, especially the current down (attempt number), the number of yards needed to gain a new first down, and the distance from the end zone, that is, the target area (White & Berry, 2002, as cited in Baumer et al., 2023). Another important area is the analysis of play calling, where it has been shown that some teams underutilize passing plays in certain situations (Alamar, 2010, as cited in Baumer et al., 2023).

2.3 Advanced Metrics: EPA, DVOA, Tracking Data, and Offensive and Defensive Efficiency

While traditional metrics provide a basic picture of the course of the game, advanced sports analytics works with more sophisticated models that allow a deeper understanding of the value of each individual action (Baumer et al., 2023). A key concept in American football analytics is the expected value of a game state, which is practically implemented through the Expected Points (EP) metric. This metric estimates how many points a team is likely to score from a given field position (Baumer et al., 2023). The first attempts to estimate EP date back to the 1970s, when points were estimated for 1st and 10 situations based on the position of the ball on the field (Carter & Machol, 1971, as cited in Baumer et al., 2023).

From EP, the Net Expected Points (NEP) metric is derived, which expresses the change in expected points before and after a play (Alamar, 2010; Yurko et al., 2020). The EP model usually includes variables such as down, time remaining, yards to the end zone, and yards needed to achieve a first down (Yurko et al., 2019). Expected points are calculated as the sum of the products of the point values of individual possible scoring outcomes (touchdown, field goal, safety, or no score) and their estimated probabilities (Yurko et al., 2019; Baumer et al., 2023). This approach allows for an objective quantification of how much a specific action influenced the overall scoring outcome (Yurko et al., 2020).

2.4 The Importance of Accurate Performance Measurement for Empirical Analyses

Another important tool is Win Probability (WP), which estimates the probability of a team winning at any given moment of the game based on the current game situation (Baumer et al., 2023; Lock & Nettleton, 2014, as cited in Baumer et al., 2023). One of the most important factors in predicting WP is the score differential between teams (Lock & Nettleton, 2014, as cited in Baumer et al., 2023). WP is also used to evaluate strategic decisions, for example in 4th down situations, where analyses suggest that NFL coaches have historically been too conservative (Romer, 2006, as cited in Baumer et al., 2023; Yam & Lopez, 2019, as cited in Baumer et al., 2023).

A fundamental breakthrough in analytics is represented by Player Tracking Data, which capture the position and movement of players and the ball in an almost continuous stream, usually 10 to 25 times per second (Yurko et al., 2020). These data make it possible to continuously evaluate the value of what is happening during a play (within-play valuation), which was not previously possible (Yurko et al., 2020). With the help of machine learning models, such as recurrent neural networks, it is possible to estimate the expected yard gain of the ball carrier from their current position based on the position and movement of all players on the field (Yurko et al., 2020). This opens up space for detailed evaluation of the contribution of players who do not have the ball, for analysis of quarterback decision-making, and for assessing the value of blocking (Yurko et al., 2020).

Accurate measurement of sports performance is essential for the credibility and validity of empirical analyses as well as for subsequent strategies (Severini, 2020; Yang et al., 2019). Analytical methods take into account that data contain inherent randomness and are therefore designed to extract useful information despite this noise (Severini, 2020). In this process, statistical models play a key role, as they are usually empirical in nature and describe general features of relationships between variables rather than being based on a fundamental theory (Severini, 2020).

The quality and accuracy of measurement are critical, because measurement errors or incorrect classification of variables, which are often obtained using data mining techniques, can cause systematic bias in the coefficients of subsequent econometric models (Yang et al., 2019). This bias may in some cases lead to attenuation of the estimated relationships (attenuation bias), while in other cases it may amplify the effect (Yang et al., 2019). In logistic regression, for example, the bias of the coefficient estimate may be determined by the sum of the accuracy rates for both classes (Yang et al., 2019).

To reduce these risks and increase the reliability of results, research designs must be sufficiently sensitive to potential confounding variables that may influence the relationship between psychological factors and sports performance (Lochbaum et al., 2022). These include, for example, the type of sport, the duration of the activity, or the level of competition (Lochbaum et al., 2022). Equally important is the use of appropriate statistical methods, such as SIMEX (Simulation Extrapolation) or MC-SIMEX (Misclassification SIMEX), which were specifically developed to correct bias caused by measurement error or misclassification in regression models (Yang et al., 2019).

3 The Phenomenon of Home-Field Advantage (HFA)

3.1 Definition of HFA and Its Research Context

Home-field advantage (HFA) is one of the longest-studied and at the same time most interesting phenomena in sports science (Legaz-Arrese et al., 2013). It refers to the observation that home teams and individual athletes win more often than would be expected by chance alone (Jamieson, 2010). This tendency is consistent and demonstrable across different sports. Although the existence of home-field advantage itself is well documented, the mechanisms and causes behind this phenomenon remain the subject of research interest (Pollard, 2008).

3.1.1 Definition and Research History of HFA

Research on home-field advantage has its roots in the early twentieth century. The work of Schwartz and Barsky from 1977 is often considered the key study that established this phenomenon as a full-fledged scientific concept. These authors described home-field advantage in organized sports and explained it through three main factors: travel, familiarity with the playing environment, and the presence of fans (Schwartz & Barsky, 1977).

From a definitional perspective, HFA can be understood as a significantly higher proportion of wins by home teams, with the overall average effect across sports competitions historically exceeding fifty percent (Jamieson, 2010).

The theoretical framework of this phenomenon is captured by the Standard Model of HFA (Courneya & Carron, 1992; Carron et al., 2005). The model works with causal processes that link factors related to the location of the game with performance outcomes (Bilalić et al., 2025). According to it, four main factors can be identified (Legaz-Arrese et al., 2013):

Audience: The influence of the number of spectators, their density, and their physical proximity to the playing area (Nevill et al., 2002).

Familiarity: Knowledge of the environment, field, and facilities (Moore & Brylinsky, 1995).

Travel: Fatigue of the visiting team resulting from travel, both physical and psychological (Steenland & Deddens, 1997). However, some studies show that travel explains only a small part of the variability in HFA (Legaz-Arrese et al., 2013).

Territoriality: Behavioral and hormonal responses associated with defending one's own territory (Neave & Wolfson, 2003).

These factors affect the physiological and psychological states of all involved, including players, coaches, and referees (Legaz-Arrese et al., 2013; Bilalić et al., 2025). An interesting finding, for example, is that testosterone levels after a win depend on whether the team played at home or away (Carré, 2009). Research has also recorded opposite effects, where the home crowd in key phases of championships may paradoxically lead to a decrease in performance (Baumeister & Steinhilber, 1984; Wallace et al., 2005).

3.1.2 Occurrence of HFA in Different Sports

Home-field advantage occurs in a wide range of sports disciplines (Legaz-Arrese et al., 2013).

Soccer is among the most frequently studied sports with regard to HFA and accounts for roughly half of all studies in this area (Avugos, 2024). Meta-analyses confirm that soccer shows a stronger home advantage than any other sport (Jamieson, 2010).

The strong effect in soccer is mainly attributed to the influence of spectators on referees' decision-making (Boyko et al., 2007; Sutter & Kocher, 2004; Garicano et al., 2005). Referees are susceptible to social pressure from crowds, which is reflected, for example, in the number of cards awarded (Nevill et al., 2002) or in the length of added time, especially when the home team is losing (Dohmen, 2008). Research on HFA has been conducted in a number of leagues, such as the German Bundesliga (Dohmen, 2008), the English Premier League (Thomas et al., 2004), and international tournaments such as the World Cup (Brown et al., 2002).

In basketball, home-court advantage is evident in both professional and college competitions (Snyder & Purdy, 1985). An analysis of NBA data from 1950 to 2010 showed that the success rate of home teams was statistically significantly higher than that of teams playing away in every year (Han et al., 2021).

Home-field advantage has been documented in all major professional team sports (Pollard & Pollard, 2005). In baseball and American football, HFA is weaker than in soccer (Jamieson, 2010). This difference may be related to season length, as sports with longer seasons tend to show smaller HFA (Jamieson, 2010), although the advantage was statistically significant in the NFL as well (Islam et al., 2021). In hockey, research on HFA has focused on hormonal and psychological variables of players (Carré et al., 2006).

The phenomenon of HFA also appears in individual sports, including disciplines represented at both the Summer and Winter Olympic Games (Balmer et al., 2001; Balmer et al., 2003). The advantage tends to be particularly strong in sports where the result depends on the subjective evaluation of referees or judges (Seltzer & Glass, 1991).

3.1.3 Methodological Approaches to Studying HFA

Current research on HFA has shifted significantly from simple descriptive analysis of home teams' success rates (Jamieson, 2010) toward methods that attempt to isolate and precisely quantify individual causal factors (Bilalić et al., 2025). Modern studies therefore use advanced statistical models, such as regression techniques, fixed- and random-effects models, or analyses based on the granularity of individual game situations. These approaches make it possible to separate the influence of the audience, travel, playing conditions, or opponent quality and provide a more accurate view of how individual mechanisms affect home-field advantage across different sports.

3.1.4 Methods of Quantification

Several procedures have been developed to measure HFA. Among the best known are Pollard's traditional method (PTM), Stefani's method (SM), and Pollard's rescaled method (PRM), which calculate the size of the advantage based on points or the difference between wins and losses (Leitner & Richlan, 2021). These methods represent a basic framework from which further analytical procedures using more advanced data sources are derived. Current research often combines them with expected-score models, probabilistic approaches, and metrics from play-by-play data, which allows the dynamics of a game to be captured more precisely and short-term fluctuations to be distinguished from stable and long-term home advantage.

3.1.5 Causal Models and Mediation

To explain how location-related factors influence performance through psychological and behavioral states, a mediation model is used (Hayes, 2017).

The newly developed Home Advantage Mediated (HAM) model builds on the classic framework of Courneya and Carron (1992) and emphasizes indirect effects and interactions among key HFA factors (Bilalić et al., 2025). This model extends the original concept in three directions: it includes interactive effects of physiological and psychological factors, specifies performance indicators as behavioral states, and explicitly accounts for possible referee bias (Bilalić et al., 2025). The HAM model thus makes it possible to test whether home advantage arises from improved team performance or whether it is caused by biased referee decision-making (Bilalić et al., 2025).

3.1.6 The Natural Experiment of COVID-19

A significant methodological shift came with the use of the COVID-19 pandemic as a natural experiment (Fernández-Cortés et al., 2024). Games played without spectators provided researchers with a unique opportunity to isolate and examine the effect of the absence of the audience, which is one of the main factors of HFA (Bryson et al., 2020).

Systematic reviews showed that in most of the leagues studied, HFA decreased during the period without spectators (Fernández-Cortés et al., 2024). These results supported the theory of social facilitation and confirmed the importance of the role of the audience, which influences referees by creating social pressure (Leitner & Richlan, 2021; Unkelbach & Memmert, 2010). The absence of spectators led to a reduction in referee bias, as referees were no longer exposed to loud pressure from fans (Bryson et al., 2020).

3.1.7 Control of Confounding Variables

For high-quality analysis, it is essential to control for confounding variables, such as team strength or opponent quality, which could otherwise distort the results of HFA measurement (Han et al., 2022). Data such as the preseason market value of players are therefore used to estimate team strength (Han et al., 2022). These advanced procedures ensure that analyses truly measure the effect of location and not merely differences in the quality of opponents (Liu et al., 2019).

3.2 Psychological and Environmental Determinants of HFA

The following section focuses on the specific psychological and environmental mechanisms behind home-field advantage. The key HFA factors defined in Chapter 3.1 (audience, familiarity, travel, rules, and territoriality) manifest themselves with different intensity across individual sports (Szabó, 2022). The following subsections therefore focus on the specific mechanisms through which these factors operate, with particular emphasis on the specifics of the NFL.

3.2.1 The Audience Effect and Its Influence on Players and Referees

The presence of an audience in the stadium represents one of the most important factors contributing to HFA. Its effect is mainly mediated by social pressure (Avugos, 2024; Legaz-Arrese et al., 2013; Nevill & Holder, 1999). The intensity and size of fan support can fundamentally influence the psychological state of all participants in the game (Agnew & Carron, 1994; Legaz-Arrese et al., 2013).

3.2.2 Psychological Influence on Players

In athletes, the psychological impact is manifested mainly through changes in emotional and motivational states. Home players usually show a more favorable psychological state, reflected in lower levels of anxiety and higher self-confidence compared with situations in which they compete on the opponent's field (Terry et al., 1998). The concept of territoriality is often mentioned in this context, suggesting that athletes may show an evolutionarily rooted tendency toward a defensive response on their own territory, which may also be reflected in increased testosterone levels (Neave & Wolfson, 2003). However, it should be added that in games with exceptionally high pressure, such as championships, massive crowd support may paradoxically act as a source of stress. In such cases, a so-called home-field disadvantage (HFD) or performance failure under pressure, known as choking under pressure, may occur (Baumeister & Steinhilber, 1984; Wallace et al., 2005).

3.2.3 Social Pressure and Referee Bias

A key mechanism through which the audience contributes to HFA is referee bias (Boyko et al., 2007; Sutter & Kocher, 2004; Avugos, 2024). Especially in sports where the degree of subjective judgment is high, such as soccer, referees are influenced by crowd pressure. This influence may be conscious, when referees try to avoid unpopular decisions (Nevill et al., 2002), or unconscious, when it results from cognitive anxiety and mental load (Balmer et al., 2007; Ansorge & Scheer, 1988).

In soccer, referee bias is reflected, for example, in time-related decisions and the awarding of disciplinary sanctions (Garicano et al., 2005; Dohmen, 2008). Referees tend to give home teams fewer cards (Unkelbach & Memmert, 2010; Dawson et al., 2007; Boyko et al., 2007) and more often add stoppage time when the home team is losing (Dohmen, 2008; Garicano et al., 2005). The intensity of social pressure also increases when spectators are physically closer to the playing area, which is typical of stadiums without running tracks, where the intensity of social influence is higher (Dohmen, 2008; Unkelbach & Memmert, 2010). This psychological relationship is explained by the cue learning hypothesis, according to which noise created by the crowd functions as an unconscious cue. Referees use this noise to evaluate the severity of a given situation, learning an association between the intensity of the noise and the criterion they are supposed to judge (Unkelbach & Memmert, 2010).

In the context of the NFL, however, analysis of the influence of the audience on referees' decision-making, measured through penalties awarded, has not provided convincing empirical evidence. A study examining data from the 2011–2012 season to the 2020–2021 season found no significant effect of audience size on referees' decision-making in the NFL (Szabó, 2022). This suggests that the mechanism of social pressure, which is clearly demonstrable in sports such as soccer or basketball (NBA), may not have the same intensity in the NFL. This may be due to the often greater distance between the stands and the field, as well as the less subjective nature of penalty decisions (Szabó, 2022). It was also shown that in the NFL, audience size does not affect the performance of the home team (Szabó, 2022).

The period of the COVID-19 pandemic, when professional sports competitions, including European soccer leagues and North American leagues such as the NBA, NHL, and NFL, were forced to play games without spectators (so-called ghost games or behind closed doors, BCD), provided a unique opportunity for a natural experiment (Bryson et al., 2021; McCarrick et al., 2021; Avugos, 2024). The aim was to isolate the role of the audience as the main cause of HFA (McCarrick et al., 2021).

Analysis of North American leagues (NBA, NFL, NHL) during the COVID-19 pandemic showed that the impact of the absence of spectators is strongly sport-specific (Szabó, 2022).

In the case of the NFL, empirical analysis of data from 2011–2021, which also included BCD games, did not find that audience size affected home team performance or referees' decision-making (Szabó, 2022). These findings, which included penalties as key indicators of decision-making, were robust and applied both to the 2020–2021 season with limited attendance and to previous seasons with normal attendance (Szabó, 2022). It follows that in the NFL, unlike in other sports such as soccer, the audience factor does not appear to be a significant causal mechanism of HFA, at least with regard to the measured parameters of penalties and wins (Szabó, 2022).

3.3 Environmental Determinants of HFA in the NFL

Home-field advantage (HFA) in sports such as American football (NFL) is influenced by a number of environmental factors that go beyond the mere influence of spectators. The geographical size of the United States and the demanding NFL season schedule require players to travel regularly and extensively across time zones. Factors such as fatigue, disruption of circadian rhythms, and adaptation to a new environment therefore become key determinants of the visiting team's performance and indirectly strengthen HFA (Huyghe et al., 2018; Janse van Rensburg et al., 2021). Travel demands in the NFL are substantial compared with other professional leagues, such as the NBA. NFL players spend more time above 30,000 feet than athletes in any other American team sport (Huyghe et al., 2018).

3.3.1 Physiological Aspects (Fatigue, Adaptation, Home Comfort Effect)

To understand the influence of the environment on sports performance, it is essential to distinguish between jet lag and travel fatigue (Samuels, 2012). Jet lag is primarily an episodic syndrome caused by the desynchronization of the circadian rhythm after rapidly crossing three or more time zones. Travel fatigue, by contrast, is a more complex and cumulative phenomenon (Samuels, 2012; Janse van Rensburg et al., 2021). It is a multidomain disorder that may be acute after an individual long journey or chronic as a result of repeated travel during the season. Importantly, it occurs regardless of the direction of travel or the number of time zones crossed (Janse van Rensburg et al., 2021).

3.3.2 Travel Fatigue and Physiological Impact

Travel fatigue, which is also examined by studies dealing with the NFL schedule, results from the demands of travel itself. These include prolonged exposure to mild hypoxia, cramped conditions, changes in diet, and sleep disruption (Huyghe et al., 2018; Janse van Rensburg et al., 2021). Other factors include transportation-related vibrations, mental monotony of the journey, and concerns related to logistics (Janse van Rensburg et al., 2021).

One of the primary physiological problems associated with air travel, which is common in the NFL, is a significant decrease in oxygen saturation (Huyghe et al., 2018). Oxygen saturation may drop from approximately 97% at ground level to 93% at cruising altitude (Huyghe et al., 2018). This level, which in hospitalized patients might require supplemental oxygen, may slow muscle recovery in athletes (Huyghe et al., 2018). Hypoxia caused by a simulated long-duration flight may also lead to changes in restorative sleep, body temperature, and free cortisol levels (Coste et al., 2009).

The accumulation of travel fatigue over the course of a season has serious consequences. It manifests itself in persistent fatigue, repeated illnesses, mood changes, and loss of motivation (Samuels, 2012). NFL studies have shown that the overall injury rate during the season is significantly higher among players in away games, suggesting that travel load and fatigue increase the risk of injury (Teramoto et al., 2017; Huyghe et al., 2018). Injury risk increases with time shifts. It is therefore important for NFL management to focus on mitigating these effects (Huyghe et al., 2018).

3.3.3 The Influence of Rest and Familiarity with the Environment

The ability to recover is critically affected by the amount of time between games. Studies conducted in the NBA, which faces a similarly intense schedule as the NFL, found that more than one day of rest between games significantly improves performance (Steenland & Deddens, 1997; Huyghe et al., 2018). The maximum score was recorded among teams with three days of rest (Steenland & Deddens, 1997). In the context of the NFL, where the season is long and travel is frequent, the team playing at home often has more time to rest than the visiting team (Steenland & Deddens, 1997).

Returning home after an away trip may offer a significant advantage. Analysis of game sequences in the NBA, for example, showed that an Away-Home sequence increases the probability of winning compared with Away-Away and Home-Away sequences (Charest et al., 2021). This suggests that returning to a familiar environment and home comfort provide an important psychological and physiological recovery advantage that helps reduce accumulated travel fatigue (Charest et al., 2021).

3.3.4 The Effect of Travel and Time Zones (Travel Fatigue, Jet Lag)

Jet lag occurs when athletes rapidly cross three or more time zones, leading to temporary desynchronization of the internal clock and biological rhythms (Bullock et al., 2007; Janse van Rensburg et al., 2021). This phenomenon disrupts sleep and wakefulness, reduces concentration and motivation, and may negatively affect both mental and physical performance (Bullock et al., 2007; Leatherwood & Dragoo, 2013). For professional teams such as those in the NFL, it is crucial that optimal athletic performance often peaks in the late afternoon and early evening, which corresponds with the maximum values of the circadian rhythm of alertness (Smith et al., 1997; Huyghe et al., 2018).

3.3.5 Directional Asymmetry and Circadian Advantage in the NFL

The direction of travel is essential because human circadian rhythms adapt asymmetrically. It is generally considered easier to delay the circadian rhythm (westward travel), which lengthens the day, than to advance it (eastward travel), which shortens the day (Sack, 2010; Lemmer et al., 2002; Fowler et al., 2017). Adaptation to a new time zone occurs at a rate of approximately 0.5 days per time zone when traveling west and 1 day per time zone when traveling east (Janse van Rensburg et al., 2021). This should theoretically mean that eastward travel is more harmful in terms of jet lag (Song et al., 2016).

In highly organized and time-specific leagues such as the NFL and NBA, however, a specific pattern emerges that emphasizes the role of time displacement in relation to optimal performance:

Disadvantage when traveling westward (East-to-West, E-W): Some retrospective studies, including early analyses of NFL data, suggest that the West Coast has a disadvantage when teams from the East Coast travel west (Roy & Forest, 2018). This disadvantage can be explained by the fact that teams traveling E-W play evening games, typically at 7:00 p.m. local time, at a time that is close to midnight for their internal clocks (Smith et al., 1997; Huyghe et al., 2018). For an Eastern team playing at 7:00 p.m. in the West, this corresponds to 10:00 to 11:00 p.m. according to their internal clocks, a time when performance declines (Smith et al., 1997).

Advantage when traveling eastward (West-to-East, W-E): Studies analyzing NFL Monday Night Football games found that West Coast teams won more often when traveling to the East Coast (Smith et al., 1997). An evening game starting at 9:00 p.m. EST translates for Western teams as 6:00 p.m. according to their internal clocks, a time close to the circadian peak of performance (Smith et al., 1997; Huyghe et al., 2018). This circadian factor may be reflected in increased athletic performance (Smith et al., 1997).

This phenomenon has also been confirmed in other leagues. Analysis of NBA games showed that teams traveling W-E had a higher winning percentage than teams traveling E-W (Roy & Forest, 2018; Huyghe et al., 2018). In the NBA study, it was even shown that an away team traveling coast-to-coast eastward (W-E) performed statistically better, by approximately four points in score, than when traveling E-W. This almost eliminated home advantage (Steenland & Deddens, 1997).

3.3.6 Travel Distance and the Cumulative Effect

Although circadian rhythm disruption (jet lag) has a significant impact, newer research suggests that the distance a team travels for a given game may be a stronger predictor of worsened performance than the time zone shift itself (Cook et al., 2022).

A retrospective analysis of NBA data, which is highly analogous to the NFL in this context, showed that greater travel distance (GameDistance) for a specific game is consistently associated with worse overall performance (point differential) and even with a reduced free throw percentage. This finding holds even after controlling for circadian variables (Cook et al., 2022). This suggests that even if teams have the opportunity to acclimatize to a new time zone to some extent, the physical load and fatigue associated with long-distance travel contribute to the visiting team's performance disadvantage (Cook et al., 2022).

3.4 Geographical Determinants in the NFL

Home-field advantage in professional American football is largely influenced by geographical and environmental factors. The league covers an enormous geographical area and includes cities with extreme climatic conditions. Weather, altitude, and specific climatic adaptations therefore become key elements that may provide home teams with an advantage, especially against opponents who are not accustomed to these conditions (Draper et al., 2022). Environmental stressors, which include primarily temperature and altitude, affect sports performance through physiological mechanisms (Draper et al., 2022).

3.4.1 The Influence of Weather

Atmospheric conditions play an important role in the NFL. Rain, snow, strong wind, and temperature extremes affect not only players' physical performance but also the flight of the ball (Paul, 2017).

High temperature and humidity represent a considerable physiological stressor for athletes. Heat can reduce athletic performance because of the thermoregulatory limits of the human body (Draper et al., 2022; Brocherie et al., 2015). In football sports, high temperatures have been shown to generally have harmful effects on performance, reflected in decreases in physical activity indicators (Draper et al., 2022; Özgünen et al., 2010).

In the context of the NFL, humidity has been shown to play a statistically significant role in gameplay and scoring. An analysis of scoring found that humidity has a positive effect on total scoring in a game (Paul, 2017). Although this might seem counterproductive given the physical exhaustion caused by high humidity (Paul, 2017), it has been suggested that humidity could unexpectedly positively affect the running game, leading to higher scores than would be expected (Paul, 2017). Temperature, by contrast, often did not represent a significant determinant of total scoring in more complex regression models, even though earlier studies showed a positive effect on scoring (Paul, 2017; Borghesi, 2008).

The effect of cold weather and precipitation on performance and scoring is more evident. Precipitation, whether rain or snow, and strong wind showed a negative and significant impact on combined scoring in the NFL (Paul, 2017). Heavy precipitation not only reduces the total number of yards gained and passing performance but also leads to a higher number of turnovers through fumbles and interceptions (Paul, 2017).

Geographical influences, specifically cold and wet weather, also significantly affect player safety and injury risk in the NFL (Orchard & Powell, 2003). A study from 1989–1998 showed that cold weather is associated with a lower risk of serious knee and ankle injuries in open stadiums, both on natural grass and on artificial AstroTurf (Orchard & Powell, 2003; Orchard, 2002). This phenomenon can be explained by the physical properties of the surface: cold reduces the coefficient of friction and torsional resistance at the interface between footwear and the playing surface, resulting in less foot fixation and thus a lower risk of joint injury (Orchard & Powell, 2003; Torg et al., 1996). Serious knee injuries were recorded most frequently in hot and dry conditions (Orchard & Powell, 2003). In contrast, indoor stadiums with artificial surfaces were not exposed to the influence of external weather, so climatic conditions did not have a significant effect on injury risk in them (Orchard & Powell, 2003).

3.4.2 Long Distances and the Influence of the Geographical Distribution of Teams

The NFL, given the need to cover substantial distances across the continent, faces a complex problem of travel fatigue and geographical distribution, which contribute to home-field advantage.

Altitude is an important component of air density that affects performance (Paul, 2017; Bahill et al., 2009). Higher altitude is theoretically more favorable for passing because of thinner air, which could lead to increased scoring (Paul, 2017). Although one study did not find a significant effect of altitude on total scoring (Paul, 2017), another analysis showed that higher altitude is associated with fewer turnovers (Paul, 2017). It is assumed that thinner air causes passes to be overthrown rather than underthrown, making it more difficult for defensive players to intercept the ball (Paul, 2017).

From a physiological perspective, acute exposure to moderate to high altitude, that is, above 500 meters, is associated with a decline in physical performance in team sports. In European soccer, for example, a reduction in total distance covered and the number of high-intensity sprints was observed during acute acclimatization to altitudes above 1,200 meters (Nassis, 2012; Aughey et al., 2013; Draper et al., 2022). Visiting NFL teams traveling to stadiums at higher altitude therefore face an acute physiological challenge that increases the advantage of home teams accustomed to local conditions.

The geographical location of NFL stadiums and the resulting climatic conditions, especially in the later part of the season, lead to a substantial and statistically supported home-field advantage for teams from cold regions (Joly & Dik, 2021). The study defined so-called Cold Weather Teams as teams playing outdoors above 39° north latitude (Joly & Dik, 2021).

During the key months of the season, December, January, and February, when the coldest conditions prevail, Cold Weather Teams showed a statistically significant advantage in home games compared with the average results of all teams playing at home or with teams playing in domes. These findings suggest that adaptation to harsh winter conditions, combined with unfamiliarity for visiting teams that often travel from milder or controlled environments, creates a strong geographical determinant of home-field advantage (Joly & Dik, 2021). These teams have a higher average winning percentage in home games during these cold periods, which may also be a factor contributing to their overall success in the playoffs, where games are played at the stadium of the higher-seeded team (Joly & Dik, 2021).

RESEARCH PART

This bachelor's thesis aims to analyze the effect of travel across time zones on player and team performance in the National Football League. The previous chapters presented the theoretical foundations related to home-field advantage, circadian rhythms, jet lag, and their impact on sports performance, as well as the specific characteristics of professional American football as a research setting. The following text synthesizes the findings from both theoretical chapters, defines the key variables for the empirical analysis, and formulates the general hypotheses that will be tested in the practical part of the thesis.

4 Research Hypotheses

Based on the synthesized theoretical findings, several testable hypotheses can be formulated regarding the effect of travel across time zones on performance in the NFL. These hypotheses are based on the biological mechanisms of jet lag, findings on circadian rhythms, and the specific characteristics of professional American football as the research context.

H1: Teams traveling across two or more time zones show lower performance compared with teams that did not travel across time zones or traveled across only one time zone. This hypothesis is based on the assumption that crossing a greater number of time zones leads to more pronounced desynchronization of circadian rhythms and more severe symptoms of jet lag, which subsequently translate into reduced physical and cognitive performance during the game.

H2: Teams traveling from the West Coast to the East Coast will show better performance in evening games than teams traveling in the opposite direction, due to a circadian advantage. Conversely, teams traveling from east to west will face a greater performance deficit in evening games, when their biological clocks signal late-night hours. This hypothesis directly follows from empirical findings on the asymmetric effect of travel depending on the interaction between travel direction and game time.

H3: Home-field advantage is greater in covered stadiums (dome, retractable roof) than in open stadiums.

H4: It is assumed that adverse meteorological conditions (extreme temperatures, strong wind) reduce the point differential between the home and visiting team.

5 Type of Research and Methods Used

The present study is a quantitative correlational study. Its aim is to verify whether selected environmental factors (crossing time zones, direction and timing of travel, stadium type, meteorological conditions) are systematically associated with home-field advantage in the NFL during the 2015 to 2024 regular seasons. The thesis does not meet the conditions of an experimental design, because the independent variables were not manipulated by the researcher. It is a secondary analysis of archival data that were publicly available through NFL data interfaces and cooperating meteorological services.

The analytical tool is a linear regression model in a parameterization referred to as paired comparison (Massey, 1997). This model estimates the point differential in a game (home score minus away score) as the sum of three components: (a) season-specific home-field advantage, (b) the difference in the latent strengths of the two participating teams, and (c) observed regressors corresponding to the tested hypotheses.

Formally, the model can be written as follows: the point differential in game g equals the seasonal home-field advantage plus the strength of the home team in the given season minus the strength of the visiting team in the given season plus a linear combination of observed regressors and the residual error. The strength of each team is a single parameter that enters the model with a positive sign for the home role and a negative sign for the away role. This ensures that the model does not work with separate parameters for "team at home" and "team away," but with a single latent ability of the given team in the given season. For model identification, a zero-sum constraint is imposed on team strengths in each season, so that the estimated parameters express deviation from the league average.

The model parameterization responds to the specific structure of sports data, which has pointed to asymmetry when using separate fixed effects for the home and visiting team. The classical approach with separate fixed effects treats one team as two different entities depending on whether it plays at home or away. This creates the risk that part of the variability in results that should be attributed to the observed factors is instead absorbed into unequal parameters for the two roles.

The chosen parameterization also allows team strength to vary between seasons. The model contains a separate parameter for each team-season combination, thereby controlling for the fact that team performance in the NFL fluctuates. This approach replaces the need to include the spread variable (pre-game market estimate of the point differential), which in the original specification served precisely to control for the current strength of both opponents. It should be taken into account that the spread may absorb part of the observed effects, because it itself contains information about travel, stadium type, and other factors. Therefore, for each hypothesis, a model without the spread variable (estimate of the total effect) and a model with the spread variable (estimate of the residual effect beyond market expectation) are constructed. Comparing the two versions shows what part of the observed effect is absorbed by the market estimate.

The standard errors of all coefficients are estimated using the robust HC1 method (White, 1980), which corrects for possible heteroskedasticity of residuals. This procedure ensures more conservative inference than classical standard errors under the assumption of homoskedasticity.

5.1 Dependent Variable

The dependent variable in all models is the point differential, defined as the difference between the final score of the home and visiting team. A positive value indicates a home win, a negative value indicates an away win, and a zero value indicates a tie. This metric is commonly used in the literature on home-field advantage in the NFL (Boulier & Stekler, 2003; Pollard, 2008) and, compared with the binary win/loss variable, preserves information about the size of the performance difference.

5.2 Independent Variables and Hypotheses

To test hypothesis H1 (the effect of travel across time zones), the main independent variable is a binary indicator of the visiting team crossing three time zones. A value of 1 indicates games in which the visiting team traveled across three or more time zones (coast to coast), while a value of 0 indicates all other games. This operationalization is based on exploratory analysis, which showed that the originally assumed threshold of two time zones did not show a statistically significant effect, whereas the effect appeared only at three time zones.

To test hypothesis H2 (circadian asymmetry in relation to travel direction and game time), two binary indicators of the visiting team's travel direction are used (eastward, westward; the reference category is a game in the same time zone), together with a binary indicator of an evening game and two interactions between travel direction and evening game. The interactions capture the assumed asymmetry, whereby teams traveling from west to east should have a circadian advantage in evening games, whereas teams traveling in the opposite direction should be disadvantaged.

To test hypothesis H3 (the effect of a covered stadium), a binary indicator is used for whether the game was played in a covered stadium. In the context of this model, it is necessary to note an identification limitation: the is_dome variable is constant for most teams throughout the observed period. The model with team effects therefore identifies the stadium effect only from those teams whose roof type changed during the observed period, for example due to relocation to a new stadium or in stadiums with a retractable roof. In the analyzed sample, this concerns approximately 12 of 32 teams. This limitation is transparently discussed in the thesis.

To test hypothesis H4 (the effect of meteorological conditions), two continuous variables are used: temperature (in degrees Fahrenheit) and wind speed (in miles per hour), both centered on the subsample mean. The H4 analysis is conducted exclusively on the subsample of games played in open stadiums for which meteorological data are available. This subsample represents approximately 66% of the total dataset and is not directly comparable with the dataset used to test H1 to H3.

5.3 Control Variables

In all models, the difference in rest days between the home and visiting team (rest differential) and a binary indicator of a divisional game are included as control variables. The difference in rest days controls for situations in which one of the teams had a shorter preparation period for the game. For Week 1 games, where rest information is missing, the value is imputed as zero because both teams enter the season under the same conditions. The divisional game indicator controls for the higher degree of familiarity between opponents from the same division, who play each other twice a year.

5.4 Software Tools

All analyses were conducted in the R programming language (R Core Team, 2024). Models were estimated using the lm functions from the base package, and the coeftest and vcovHC functions from the lmtest (Zeileis & Hothorn, 2002) and sandwich (Zeileis, 2004) packages were used to calculate robust standard errors. Visualizations were created using the ggplot2 package (Wickham, 2016). Statistical power analysis for evaluating H2 was conducted using the pwr package (Champely, 2020).

6 Data Collection and Research Sample

6.1 Data Sources

The analysis uses publicly available archival data from NFL regular seasons from 2015 to 2024. The source of game data is official NFL statistics, which include final score, identification of the home and visiting team, game start time, season type (regular season or playoff), week of the season, and other contextual information. The game data were supplemented with meteorological data (temperature, wind speed) obtained from public meteorological services and information on stadium characteristics (roof type, artificial surface) from publicly accessible databases.

The geographical information needed to calculate the number of time zones crossed and the direction of travel was derived from the official locations of individual teams and the assignment of their stadiums to time zones within the United States (Eastern, Central, Mountain, Pacific). The variable indicating the number of time zones crossed was calculated as the absolute value of the difference between the time zone of the home team's stadium and the time zone of the visiting team's location. Travel direction was defined as a categorical variable with three levels: eastward travel, westward travel, and a game in the same time zone.

The pre-game market estimate of the point differential (spread) comes from closing betting lines and is coded in the data from the perspective of the home team. A positive value means that the home team was favored before the game.

6.2 Research Sample

The research sample consists of 2,623 NFL regular season games played over ten seasons (2015 to 2024). Playoff games were not included in the analysis because playoff games take place under specific conditions (higher motivation, longer preparation, different scheduling), and their inclusion could bias estimates of regular home-field advantage. Each row of the data matrix represents one game and contains information about both participating teams, the result, game conditions, and derived variables.

The sample includes all 32 NFL teams and covers the four time zones of the continental United States. The number of games in individual seasons differs due to the expansion of the regular season from sixteen to seventeen games per team starting with the 2021 season. The average number of games per season is approximately 262.

Nine games in the observed period ended in a tie. These games enter the main models with a point differential equal to zero. In the case of supplementary logistic models, where the dependent variable is a binary indicator of a home win, ties are excluded from the dataset because assigning them to either the win or loss category would be ambiguous.

6.3 Specifics of the 2020 Season (COVID-19)

The 2020 season took place under substantially restricted conditions due to the COVID-19 pandemic. Most games were played without spectators or with significantly reduced stadium capacity. This season represents a natural experiment that makes it possible to assess the role of the audience as a component of home-field advantage (Bryson et al., 2021). The 2020 season is retained in the analysis because the model with team-specific parameters for each season naturally distinguishes it from other seasons. For robustness purposes, however, a comparison with a model excluding the 2020 season is always reported.

6.4 Subsample for Weather Analysis (H4)

The analysis of hypothesis H4 requires data on temperature and wind speed at the time of the game. Meteorological data are available only for games played in open stadiums, because the climate is controlled in covered stadiums. After excluding games in covered stadiums and games with missing meteorological data, the H4 subsample consists of 1,723 games, corresponding to approximately 66% of the full dataset. The average temperature in this subsample was 52.8°F (approximately 11.6°C), and the average wind speed was 8.4 miles per hour. The H4 results are therefore not directly comparable with the results for H1 to H3, which use the full dataset of 2,623 games.

6.5 Ethical Aspects

The research works exclusively with publicly available archival data that do not contain personal data of individual players or other sensitive information. All analyzed data concern game results and the conditions under which the games took place, not the performance of specific players. In view of this, it was not necessary to obtain informed consent from participants or apply for approval from an ethics committee. The data matrix is archived and available for inspection.

6.6 Overview of Variables

Table 1 *Overview of variables used in the analysis*

Variable	Type	Description
point_diff	continuous	Point differential (home team minus away team)
tz_3	binary	Away team crossed 3+ time zones
travel_east	binary	Away team traveled east
travel_west	binary	Away team traveled west
evening_game	binary	Game was played in the evening slot
east_x_eve	binary	Interaction: eastward travel and evening game
west_x_eve	binary	Interaction: westward travel and evening game
is_dome	binary	Game played in a domed stadium
temp_centered	continuous	Temperature (°F), centered on the subsample mean
wind_centered	continuous	Wind speed (mph), centered on the mean
rest_diff	continuous	Difference in days of rest (home team minus away team)
div_game	binary	Game between teams from the same division
spread	continuous	Pre-game market estimate of the point differential

Note: The variables temp_centered and wind_centered are available only for the subsample of open stadiums (N = 1,723). Spread enters the model only in the comparative version (see Chapter 5)

7 Data Processing and Results

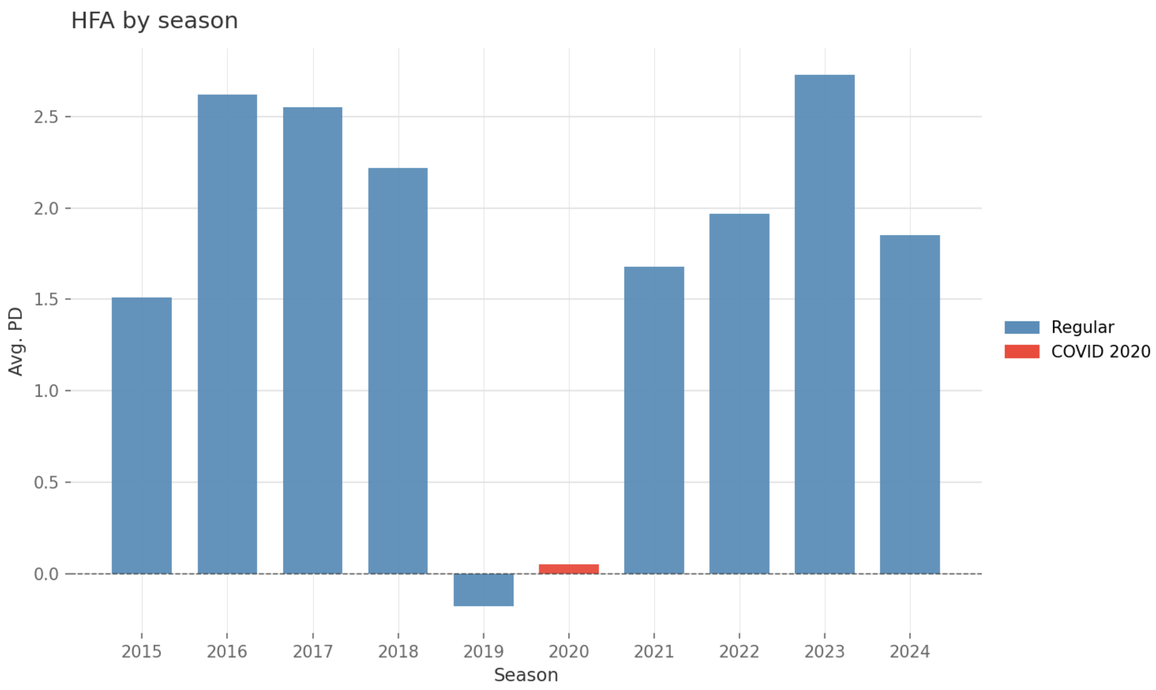
This chapter presents the results of the analysis in the order corresponding to the stated hypotheses. First, the overall descriptive statistics of home-field advantage and its development over time are presented, followed by the testing of hypotheses H1 to H4. All regression models use paired-comparison parameterization with team-specific parameters for each season and HC1 robust standard errors, as described in Chapter 5.

7.1 Descriptive Statistics of Home-Field Advantage

Over the entire observed period from 2015 to 2024, the average point differential in favor of home teams was +1.71 points (N = 2,623). Home teams won 54.5% of games. Both findings indicate the existence of a statistically significant, although not dramatically large, home-field advantage in the NFL.

The development of home-field advantage over time is not constant. Figure 1 shows the average point differential of home teams in individual seasons. The highest home-field advantage was observed in the 2016 and 2023 seasons, whereas the 2019 season recorded a negative average value, meaning that visiting teams won slightly more often on average in that season. The 2020 season, which took place with limited spectator attendance due to the COVID-19 pandemic, showed an almost zero point differential (+0.07 points), which is consistent with the assumption that the presence of an audience represents one component of home-field advantage.

Figure 1. *Average point differential of home teams in individual NFL seasons (2015–2024)*



Note: The 2020 season (COVID-19) is highlighted in a different color

The season-specific home-field advantage estimated from the regression model (parameter αs) confirms this picture. Table 2 shows estimates of home-field advantage for individual seasons after controlling for team strength and other regressors. In most seasons, home-field advantage is statistically significant and ranges between 2 and 3 points. The 2019 and 2020 seasons are exceptions, where the model did not demonstrate statistically significant home-field advantage.

Table 2 *Season-specific home-field advantage (αs) estimated from the H1 model without the spread variable. Robust SE (HC1)*

Season	**αs**	**SE**	**t**	**p**
2015	2.190	0.803	2.73	0.006
2016	3.183	0.755	4.21	< 0.001
2017	3.098	0.824	3.76	< 0.001
2018	2.737	0.821	3.33	< 0.001

2019	0.476	0.807	0.59	0.555
2020	0.731	0.794	0.92	0.358
2021	2.342	0.861	2.72	0.007
2022	2.467	0.714	3.46	< 0.001
2023	3.209	0.814	3.94	< 0.001
2024	2.390	0.768	3.11	0.002

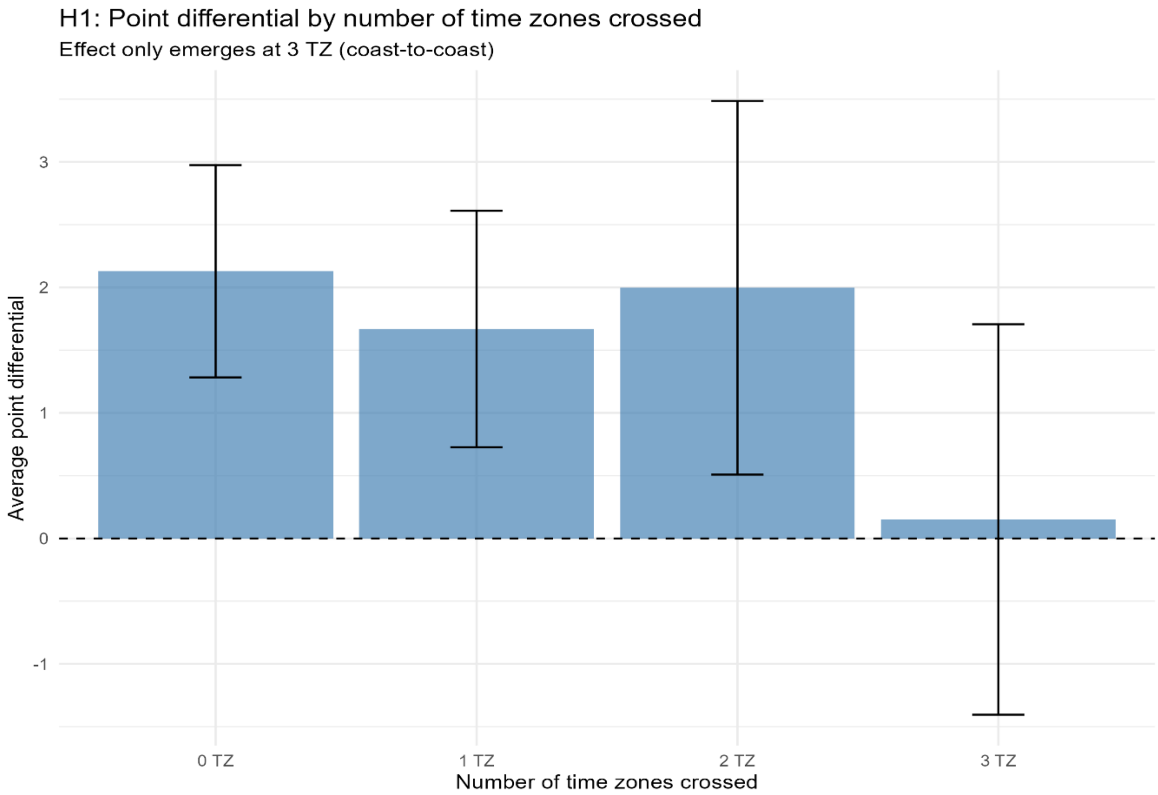
Note: The αs value expresses the expected point differential in favor of the home team in a game between two average teams in the given season

7.2 H1: The Effect of Crossing Time Zones

Hypothesis H1 assumes that teams traveling across a greater number of time zones show lower performance. The original formulation worked with a threshold of two or more time zones. However, exploratory analysis showed that this threshold did not show a statistically significant effect. Only when three time zones were crossed (coast-to-coast games) did a substantial decrease in home-field advantage appear.

Figure 2 shows the average point differential depending on the number of time zones crossed. While games with zero, one, and two time zones crossed show a positive point differential (home-field advantage), games in which three time zones were crossed show an average point differential close to zero. The wide confidence intervals in the three-time-zone category reflect the smaller number of games in this group (N = 331).

Figure 2 *Average point differential of home teams by the number of time zones crossed by the visiting team*



Note: Error bars show the 95% confidence interval

Table 3 summarizes the results of the regression models for H1. In the model without the spread variable (total effect), the coefficient of the tz_3 variable is −1.862 (SE = 0.763, $p = 0.015$). This means that in games where the visiting team crossed three time zones, the point differential in favor of the home team is on average almost two points higher than in games without such travel. In other words, home-field advantage increases by approximately 1.9 points in coast-to-coast games.

In the model including the spread variable, the coefficient remains practically unchanged ($\beta = -1.828$, $p = 0.017$). The spread variable itself is not statistically significant in this model ($\beta = -0.097$, $p = 0.289$), confirming that the team-specific parameters in the paired-comparison model already sufficiently control for the current strength of both opponents. The spread absorbed only 2% of the effect of travel across time zones, meaning that the market does not substantially incorporate this factor into its estimates.

Among the control variables, rest_diff was statistically significant ($\beta = 0.082$, $p < 0.001$): each additional day of rest for the home team compared with the visitors is associated with an increase in the point differential of 0.08 points. The div_game variable shows a marginally significant negative effect (β = −0.959, p = 0.067), suggesting that home-field advantage is slightly lower in divisional games, probably due to greater familiarity between opponents.

Table 3. *Results of regression models for H1 (effect of crossing three time zones)*

Variable	No spread	SE	With spread	SE
tz_3	−1.862*	0.763	−1.828*	0.762
rest_diff	0.082***	0.018	0.084***	0.019
div_game	−0.959.	0.524	−0.974.	0.524
spread	—	—	−0.097	0.092
N	2 623		2 623	
R^2	0.355		0.355	
RMSE	11.49		11,49	

Note: Dependent variable: point differential. Robust SE (HC1). *** p < 0.001, * p < 0.05, . p < 0.10

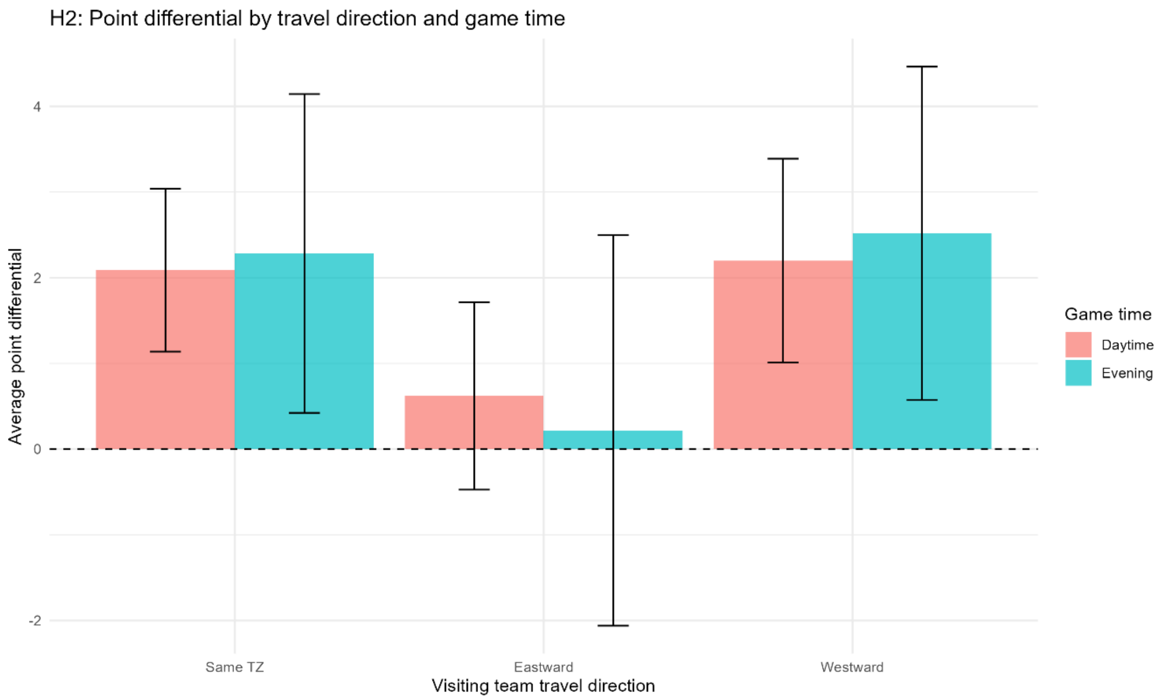
The results provide support for hypothesis H1 in its modified form (threshold of three time zones accepted). The negative coefficient of the tz_3 variable means that a visiting team that crossed three time zones achieves a worse result, thereby increasing the point differential in favor of the home team. The effect is statistically significant and robust to the inclusion of the market estimate. The original formulation with a threshold of two time zones was not confirmed.

7.3 H2: Travel Direction and Circadian Asymmetry

Hypothesis H2 assumes that teams traveling from the West Coast to the East Coast will show better performance in evening games than teams traveling in the opposite direction. The mechanism should be a circadian advantage: for a West Coast team, an evening game in the East corresponds to a time close to their circadian performance peak, whereas for an East Coast team playing in the evening in the West, internal time is already close to midnight.

Figure 3 shows the average point differential of home teams by the visiting team's travel direction and game time. Visually, a trend in the expected direction is apparent: in games where visitors traveled east, home-field advantage is lower (visitors perform better) than in games in the same time zone. However, the wide confidence intervals indicate that the differences are not statistically conclusive.

Figure 3 *Average point differential by the direction of the visiting team's travel and game timing (day vs. evening)*



Note: Error bars represent 95% confidence intervals

Table 4 summarizes the results of the regression model for H2. The key interaction terms are not statistically significant. The interaction between eastward travel and an evening game has a coefficient of −2.068 (SE = 1.612, $p = 0.200$), and the interaction between westward travel and an evening game has a coefficient of +0.799 (SE = 1.460, $p = 0.585$). Neither the main effects of travel direction nor the main effect of an evening game reached statistical significance.

Table 4 *Results of regression models for H2 (travel direction and circadian asymmetry)*

Variable	No spread	SE	With spread	SE
travel_east	−1.207	1.103	−1.152	1.105
travel_west	−0.257	1.136	−0.240	1.135
evening_game	0.362	0.979	0.361	0.980
east × evening	−2.068	1.612	−2.052	1.610
west × evening	0.799	1.460	0.774	1.461
rest_diff	0.083***	0.018	0.085***	0.018
div_game	−0.746	0.511	−0.758	0.511
spread	—	—	−0.093	0.092
N	2 623		2 623	
R^2	0.355		0.355	

Note: Robust SE (HC1). *** $p < 0.001$. None of the interaction terms reached statistical significance

However, the absence of statistically significant results cannot automatically be interpreted as a rejection of the hypothesis. The statistical power analysis showed that the critical cell on which the testing of circadian asymmetry is based, namely coast-to-coast eastward games played in the evening slot, contains only 21 games. An indicative power calculation, conducted in the context of a simple bivariate test rather than within the full model with covariates, showed that approximately 64 observations in each group would be needed to detect a medium-sized effect ($d = 0.5$) at the 5% significance level. The statistical power of the test at $N = 21$ is approximately 34%, meaning that even if a true effect existed, the test would detect it in only about one third of cases.

Based on these results, hypothesis H2 cannot be accepted. However, the null hypothesis also cannot be accepted with sufficient certainty, because the test is underpowered for this type of effect. The conclusion regarding H2 is therefore inconclusive.

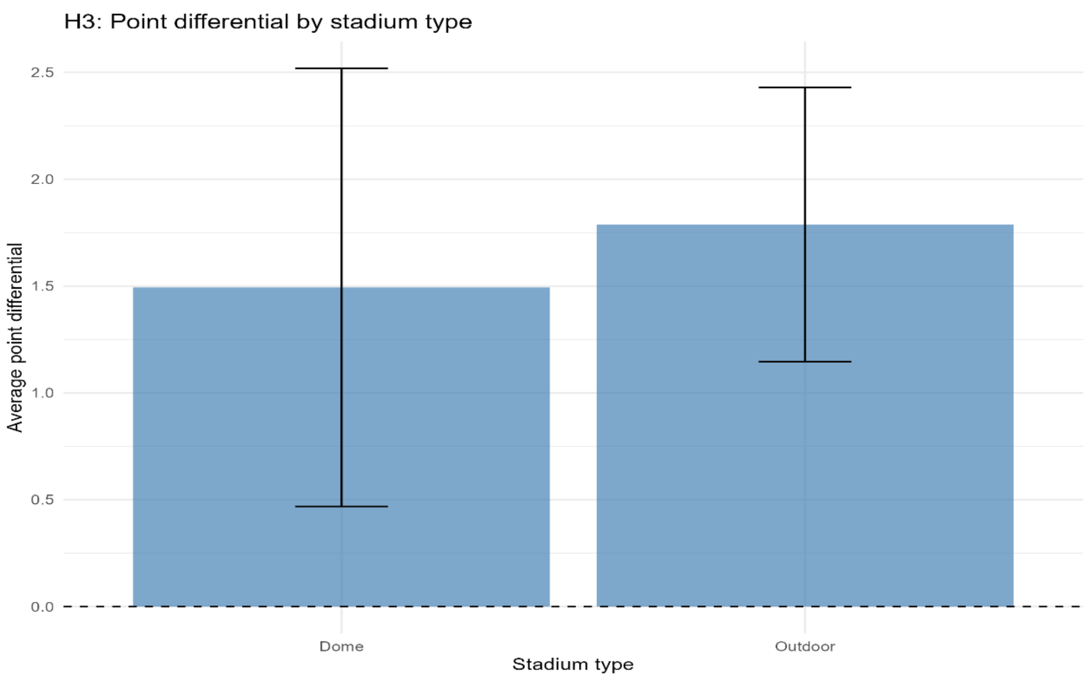
7.4 H3: Home-Field Advantage in Covered Stadiums

Hypothesis H3 assumes that home-field advantage is greater in covered stadiums than in open stadiums. The assumption is that the home team is adapted to its stadium type, whereas the visiting team, which usually plays in a different environment, loses the opportunity to use its possible adaptation to outdoor conditions.

Before presenting the regression results, it is necessary to point out the identification limitation of this hypothesis. The is_dome variable is constant for the vast majority of teams throughout the observed period: a team either always plays in a covered stadium or always plays in an open stadium. The model with team-specific parameters absorbs this constant component, so the effect of is_dome is identified only from teams whose roof type changed during the observed period. These are mainly teams that moved to a new stadium or stadiums with a retractable roof, where conditions differ from game to game. In total, this concerns 12 of 32 teams.

Figure 4 shows the average point differential in games played in covered and open stadiums. The difference between the two groups is minimal, and the confidence intervals overlap substantially.

Figure 4 *Average point differential of home teams in games played in covered and open stadiums*



Note: Error bars show the 95% confidence interval

Table 5 summarizes the regression results. The coefficient of the is_dome variable in the model without the spread variable is −1.232 (SE = 0.738, p = 0.095). The effect is marginally significant at the 10% level, but not at the conventional 5% level. Moreover, the sign of the coefficient is negative, meaning that games in covered stadiums show rather lower home-field advantage than games in open stadiums. This is contrary to the direction of the effect assumed in H3.

In the model with the spread variable, the coefficient remains practically identical (β = −1.239, p = 0.094). Absorption of the effect by the spread variable is negligible (−1%), meaning that the market estimate does not substantially incorporate stadium type into its predictions.

Table 5 *Results of regression models for H3 (effect of a covered stadium)*

Variable	**No spread**	**SE**	**With spread**	**SE**
is_dome	−1.232.	0.738	−1.239.	0.739
rest_diff	0.084***	0.018	0.087***	0.018
div_game	−0.588	0.499	−0.611	0.499
spread	—	—	−0.105	0.092
N	2 623		2 623	
R^2	0.354		0.354	
Identification	12/32 teams		12/32 teams	

Note: Robust SE (HC1). *** $p < 0.001$, . $p < 0.10$. The effect of is_dome is identified only from 12 teams with variable roof type

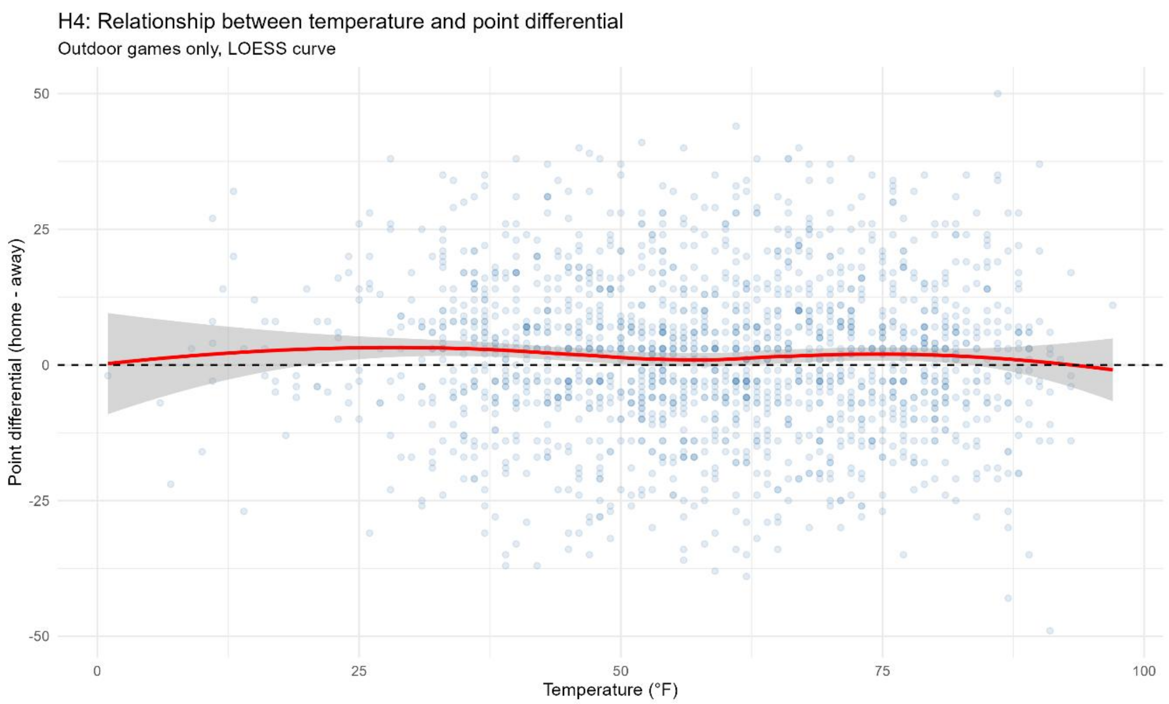
Based on these results, hypothesis H3 cannot be accepted. The estimated effect does not reach the conventional level of significance, and its direction is opposite to that assumed by the hypothesis. In addition, it must be kept in mind that the estimate is based only on within-team variation in roof type among a minority of teams, not on a global comparison of dome and outdoor franchises. These results are discussed further in Chapter 8.

7.5 H4: The Effect of Meteorological Conditions

The dependent variable in this analysis is the score differential, defined as the difference in score between the home and visiting team. This variable serves as an indicator of the size of home-field advantage. Hypothesis H4 assumes that adverse weather conditions (extreme temperatures, strong wind) will reduce differences in performance between strong and weak teams and thereby affect home-field advantage. The analysis of this hypothesis is conducted exclusively on the subsample of games played in open stadiums with available meteorological data (N = 1,723, i.e., 66% of the total dataset). Temperature and wind speed enter the model as continuous variables centered on the subsample mean.

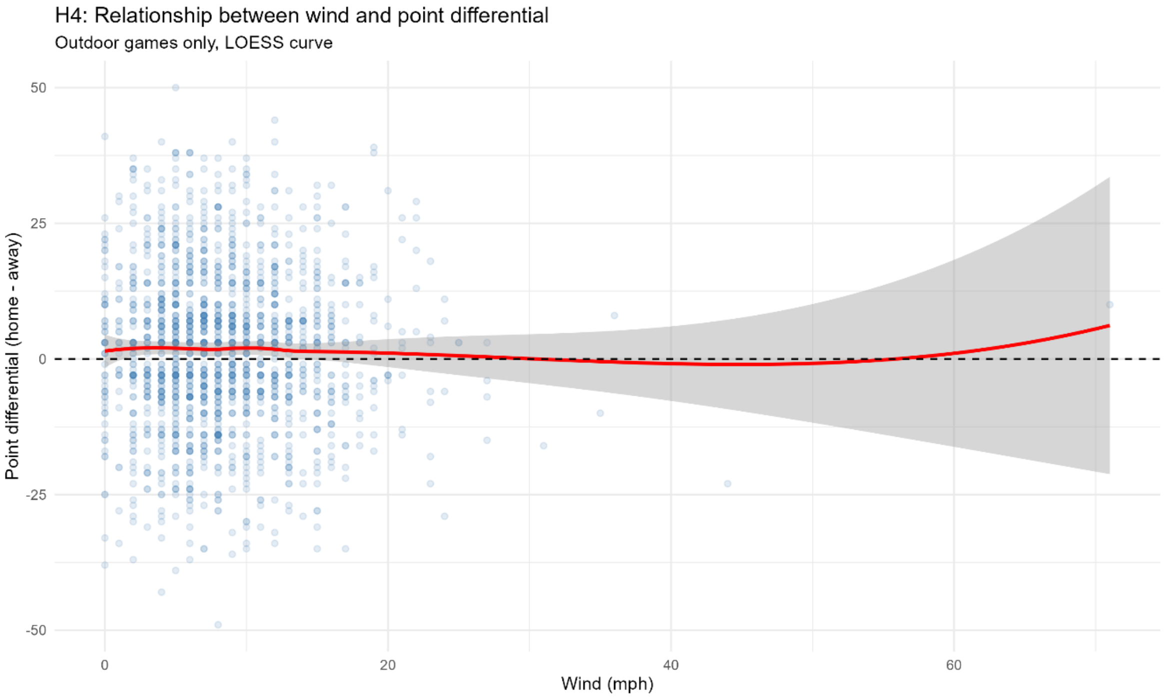
Figures 5 and 6 show the relationship between temperature, respectively wind speed, and the point differential in games played in open stadiums. In both cases, the LOESS curve is almost flat and remains close to zero, visually indicating the absence of a systematic relationship between meteorological conditions and game outcome. For wind, the confidence band widens at values above 30 miles per hour, reflecting the small number of games under these conditions.

Figure 5 *Relationship between temperature and point differential in open stadiums*



Note: (N = 1,723). LOESS curve with 95% confidence band

Figure 6 *Relationship between wind speed and point differential in open stadiums*



Note: (N = 1,723). LOESS curve with 95% confidence band

Table 6 summarizes the regression results. Neither temperature (β = 0.002, SE = 0.020, p = 0.907) nor wind speed (β = 0.018, SE = 0.065, p = 0.780) shows a statistically significant relationship with the point differential. The coefficients of both variables are substantively negligible: a one-degree Fahrenheit change in temperature is associated with a change in the point differential of 0.002 points, which is completely insignificant from the perspective of the game.

Including the spread variable in the model does not change the results in the slightest (temperature β = 0.002, p = 0.903; wind β = 0.018, p = 0.776). The spread itself is not statistically significant in this subsample (β = −0.040, p = 0.737), as was also the case in the H1 to H3 models.

It is worth mentioning that in the subsample of outdoor games, the div_game variable was statistically significant (β = −1.318, p = 0.040), meaning that in divisional games played in open stadiums, home-field advantage is lower by approximately 1.3 points. This effect is stronger than in the full dataset and may reflect the fact that teams from the same division share similar climatic conditions and are comparably adapted to them.

Table 6 *Results of regression models for H4 (effect of weather)*

Variable	No spread	SE	With spread	SE
temp_centered	0.002	0.020	0.002	0.020
wind_centered	0.018	0.065	0.018	0.065
rest_diff	0.069***	0.018	0.070***	0.018
div_game	−1.318*	0.641	−1.329*	0.642
spread	—	—	−0.040	0.120
N	1 723		1 723	
R^2	0.413		0.413	
RMSE	11.10		11.10	

Note: Subsample of open stadiums with meteorological data. Robust SE (HC1). *** $p < 0.001$, * $p < 0.05$

Based on these results, hypothesis H4 cannot be accepted. Neither temperature nor wind speed shows any statistically significant relationship with the point differential in the game. The LOESS curves confirm that this conclusion also holds for possible nonlinear effects. It should be emphasized that the dependent variable is the point differential (home minus away), which captures only the asymmetric effect of weather, that is, a situation in which weather favors one team over the other. The null result therefore does not mean that weather has no influence on the game, but rather that this influence affects both teams approximately symmetrically and does not provide the home team with a measurable advantage.

7.6 Summary Overview of Results

Table 7 summarizes the results of testing all four hypotheses. The reported coefficients come from models without the spread variable (total effect). In all models, team-specific parameters for each season, the difference in rest days, and the divisional game indicator are controlled for.

Table 7 *Summary overview of hypothesis testing results*

Hypothesis	**Variable**	***β***	**SE**	***p***
H1	*tz_3*	−1.862	0.763	0.015
H2	*east* × *eve*	−2.068	1.612	0.200
H3	*is_dome*	−1.232	0.738	0.095
H4	*temp_c*	0.002	0.020	0.907

Note: Coefficients from models without the spread variable. * H1 confirmed in modified form (threshold of 3 time zones, not the original threshold of 2 time zones)

From an overall perspective, the only statistically significant environmental factor of home-field advantage is travel across three time zones (H1). In coast-to-coast games, home-field advantage increases by approximately two points, which represents a substantively meaningful contribution in the context of a league where the average home-field advantage is around 1.7 points. The other tested factors, namely travel direction in interaction with game time, stadium type, and meteorological conditions, either did not reach statistical significance or showed an effect in the opposite direction than expected by the hypothesis.

The consistent significance of the rest_diff variable across all models is also worth noting. Each additional day of rest for the home team compared with the visitors is associated with an increase in the point differential of approximately 0.07 to 0.08 points, which, with a typical rest difference of two to three days, represents an effect comparable to approximately 0.2 points. This finding is consistent with the literature on the importance of recovery in sports performance (Steenland & Deddens, 1997).

The spread variable was not statistically significant in any of the models. This confirms that the paired-comparison parameterization with team-specific parameters for each season sufficiently controls for the current strength of both opponents, and the pre-game market estimate has nothing further to add. Absorption of the observed effects by the spread variable ranged from −4% to 2%, meaning that the market does not substantially incorporate these environmental factors into its estimates.

8 Discussion

The aim of this thesis was to analyze how selected environmental factors influence home-field advantage in the National Football League during the period from 2015 to 2024. Four hypotheses were tested concerning the effects of travel across time zones, circadian asymmetry, stadium type, and meteorological conditions. The following discussion places the results in the context of existing knowledge, offers possible explanations, and critically evaluates the methodology of the thesis.

8.1 Overall Home-Field Advantage in the NFL

The average point differential in favor of home teams reached +1.71 points during the observed period, and home teams won 54.5% of games. These values correspond to the findings of Islam et al. (2021), who report a home-team winning percentage of around 57% based on data from 2002 to 2019, and are consistent with the conclusions of the meta-analysis by Jamieson (2010), which classifies American football among sports with a weaker but statistically significant home-field advantage. The fact that home-field advantage in the NFL is less pronounced than, for example, in soccer is consistent with the assumption that subjective referee decision-making plays a smaller role in the NFL than in sports with a higher degree of discretionary interventions (Szabó, 2022).

The decline in home-field advantage in the 2019 season, when the average point differential fell into negative values, is worth noting. This decline cannot be attributed to the absence of spectators, because the 2019 season took place before the pandemic. A more likely explanation is random variability in a relatively short season (256 games), where a small number of results can substantially shift the average. Similar fluctuations between seasons are also described by Boulier and Stekler (2003), who point out the relatively large variance of home-field advantage in the NFL compared with other leagues.

The 2020 season represents an important methodological opportunity. The average point differential in this season reached only +0.07 points, and the model estimated home-field advantage at 0.73 points ($p = 0.358$), making it the only season besides 2019 in which the estimate did not reach statistical significance. This result is consistent with the finding by Szabó (2022) that the absence of spectators in the NFL led to a reduction in home-field advantage, and with the more general findings of Bryson et al. (2021) and Fernández-Cortés et al. (2024) regarding the decline in home-field advantage across sports during the pandemic. Interestingly, however, unlike in soccer, where the absence of spectators led to the almost complete disappearance of home-field advantage (Leitner & Richlan, 2021), in the NFL the point differential remained low but positive. This suggests that there are other components of home-field advantage in the NFL beyond the crowd itself, with factors related to travel being a likely candidate.

8.2 H1: Travel Across Time Zones

The main finding of this thesis is the statistically significant effect of crossing three time zones on the point differential in a game ($\beta = -1.862$, $p = 0.015$). In coast-to-coast games, that is, games involving travel between the East and West Coasts, home-field advantage increases by approximately two points. This effect is substantively meaningful: with an average home-field advantage of around 1.7 points, it represents a doubling of the home team's advantage.

This finding is consistent with earlier studies that identified the effect of crossing time zones on performance in professional sports. Smith et al. (1997) found a significant effect of time zones on Monday Night Football game outcomes, and Roy and Forest (2018) describe a similar pattern in the NBA. Cook et al. (2022), using NBA data, show that travel distance is a stronger predictor of worsened performance than the time zone shift itself, suggesting that the mechanism may not be only jet lag but also cumulative travel fatigue (Janse van Rensburg et al., 2021).

It is worth noting that the originally defined threshold of two time zones did not prove statistically significant. The effect appears only when three time zones are crossed, that is, in a situation where a team flies across the entire continent. This finding can be interpreted in light of the threshold theory of the jet lag effect. Samuels (2012) and Janse van Rensburg et al. (2021) describe that clinically significant symptoms of jet lag typically appear only after crossing three or more time zones, whereas a smaller shift, often one or two time zones, can be compensated for by the body without a substantial impact on performance. Our data empirically support this threshold model: the categorical analysis showed that the average point differential at zero, one, and two crossed time zones is practically the same, ranging between 1.7 and 2.1 points, whereas at three time zones it drops to 0.15 points.

From a methodological perspective, it is important that the travel effect remained practically unchanged after the spread variable was included in the model, with only 2% absorption. This means that the pre-game market estimate does not substantially incorporate this factor into its predictions. Sportsbooks therefore seem to underestimate the effect of coast-to-coast travel, which is an interesting secondary finding with potential implications for sports analytics. This finding is nevertheless consistent with the literature on betting market inefficiencies, in which several authors document systematic underestimation of environmental factors (Borghesi, 2007).

8.3 H2: Circadian Asymmetry

None of the interaction terms in the H2 model reached statistical significance. The interaction between eastward travel and an evening game ($\beta = -2.068$, $p = 0.200$) shows the direction of the effect consistent with the assumed circadian advantage described by Smith et al. (1997), but the size of the effect is not sufficient for a reliable conclusion.

This result must be interpreted with awareness of the substantial limitation in statistical power. The critical cell, namely coast-to-coast eastward games played in the evening slot, contains only 21 observations, which gives a statistical power of only 34% for a medium-sized effect ($d = 0.5$). For this reason, nonsignificance cannot be interpreted as a lack of support for the hypothesis, but only as evidence that the available data do not allow this question to be reliably decided.

The small number of observations in the critical cell is not a random consequence of data collection, but follows from the logic of the NFL schedule. Coast-to-coast games make up approximately 13% of all games in a season, and evening slots are reserved only for selected attractive games. The combination of both criteria therefore naturally leads to a small cell. For future research, it would be desirable to extend the time frame of the analysis to more seasons or include playoff games, although this would introduce other methodological complications related to the different context of such games.

Earlier studies that identified a circadian advantage in the NFL (Smith et al., 1997) worked with a narrower selection of games (Monday Night Football only) and without controlling for team strength. The model used in this thesis includes team-specific parameters for each season, which may absorb part of the variability that earlier studies attributed to the circadian effect. It is therefore possible that earlier findings partly reflected differences in team strength rather than a true circadian effect.

8.4 H3: Stadium Type

The effect of a covered stadium did not reach the conventional level of significance ($\beta = -1.232$, $p = 0.095$), and its sign is opposite to what the hypothesis predicted. Games in covered stadiums do not show higher but rather lower home-field advantage. This result contradicts the original assumption, but several possible explanations exist.

First, the identification limitation must be emphasized. The is_dome variable is constant for most teams throughout the observed period, and the model with team parameters absorbs this constant component. The effect is therefore identified only from approximately 12 teams whose roof type changed, due to relocation to a new stadium or a retractable roof. This means that the H3 result refers to a different type of comparison than the one formulated by the original hypothesis. Hypothesis H3 implies a global contrast between dome franchises and outdoor franchises. The model, however, tests only within-team change, that is, situations in which the same team played some games under a roof and others without one.

Second, it is possible that the lower home-field advantage in covered stadiums reflects the absence of environmental advantage. In open stadiums, home teams may benefit from adaptation to local climatic conditions, especially in the later part of the season, when teams from cold regions face opponents unaccustomed to low temperatures (Joly & Dik, 2021). In the controlled environment of a dome stadium, this advantage disappears, which could explain the relatively lower home-field advantage. Clarke and Norman (1995), in the context of other sports, similarly argue that familiarity with the playing surface and its specific characteristics is one of the mechanisms of home-field advantage, which is naturally weakened in the controlled environment of a dome stadium.

Third, it must be acknowledged that the is_dome variable may be confounded with other characteristics of teams that play in dome stadiums. Teams from southern states (Atlanta, Houston, New Orleans) acquired dome stadiums precisely because the local climate (high humidity, extreme heat) is unfavorable for outdoor football. The effect of is_dome may therefore partly reflect the specific characteristics of these franchises, which are not fully captured by team parameters.

A cleaner test of H3 would require a longer time frame in which more teams changed their stadium, or experimental manipulation, which is understandably impossible in the context of a professional league.

8.5 H4: Meteorological Conditions

Neither temperature nor wind speed showed any statistically significant relationship with the point differential in a game. The coefficients of both variables are substantively negligible, and the LOESS curves confirm the absence of nonlinear effects as well. At first glance, this finding is surprising, because a number of studies document the effect of weather on performance and scoring in the NFL (Paul, 2017; Borghesi, 2007).

The difference, however, lies in what exactly the weather affects. Earlier studies, such as Paul (2017), examined the effect of weather on total scoring, that is, the sum of points scored by both teams. Precipitation and wind not only reduce the total number of yards and passing efficiency, but also lead to more turnovers. However, these effects affect both teams approximately symmetrically. Our dependent variable is the score differential (home minus away), which captures only the asymmetric effect of weather, that is, a situation in which weather favors one team over the other. The results suggest that weather acts more as a symmetric shock that reduces the overall performance of both teams, but does not provide the home team with a distinct advantage.

This interpretation is consistent with the findings of Orchard and Powell (2003), who document that cold reduces the risk of injury for both teams, not only for visitors, and with the assumption that professional teams prepare for the known conditions of their home stadium, but visitors also adapt to them sufficiently during pre-game preparation.

However, it should be noted that the chosen dependent variable (point differential) may not fully capture the effect of meteorological conditions, which probably influence total points or scoring variability more than the point differential. Joly and Dik (2021), for example, show that Cold Weather Teams have higher home-field advantage from December to February. This effect may have been partly absorbed in our model by the team-specific parameters, because teams from cold regions have a systematically different home-game profile than teams from warmer regions. For future research, it would be desirable to test the interaction between weather and the geographical location of the team, which would require a finer operationalization than simple centered variables.

8.6 The Role of the Spread Variable and Model Choice

A secondary but methodologically important finding of this thesis is that the spread variable was not statistically significant in any of the models. In the original specification with separate fixed effects for the home and visiting team, however, spread was an absolutely dominant predictor ($\beta \approx 0.92$, $p < 0.001$). This contrast shows that spread in the original model did not function as a control for market expectations, but rather as a substitute for the missing control for current team strength. Once the model includes team-specific parameters for each season, spread has nothing further to add.

This finding has important implications for interpreting earlier studies that include spread as a control variable. As the thesis supervisor pointed out, if spread already contains information about travel, stadium type, or weather, then including it in the model mechanically attenuates the coefficients of the observed variables. In our results, this appeared only minimally, with absorption up to 4%, because team parameters took over the role that spread played in the original specification. This confirms that the selected paired-comparison parameterization is more appropriate in this context than a model with separate fixed effects and spread as a control.

8.7 Secondary Findings

Across all models, the rest_diff variable, that is, the difference in rest days between the home and visiting team, was consistently significant. Each additional day of rest is associated with an increase in the point differential of approximately 0.08 points. Although this effect is relatively small at the level of one day, it becomes substantively meaningful for teams with a short week, for example after a Thursday game followed by a Sunday game. Analogous findings are described by Steenland and Deddens (1997) in the NBA, where more than one day of rest significantly improves performance.

The div_game variable showed a marginally significant negative effect in some models, suggesting that home-field advantage is slightly lower in divisional games. This is a natural consequence of the greater familiarity between opponents from the same division, who play each other twice a year and share a similar geographical and climatic context. Moore and Brylinsky (1995) describe familiarity with the environment as one factor of home-field advantage, and our result suggests that this asymmetry is smaller in divisional games.

8.8 Limitations of the Thesis

The present study has several limitations that must be considered when interpreting the results.

The first limitation is the nature of the dependent variable. Point differential is a coarse metric that does not capture the mechanisms through which effects occur. A game can end with a large margin for reasons unrelated to travel, such as injury to a key player or defensive errors. The use of more granular metrics, such as Expected Points Added at the level of individual plays (Yurko et al., 2020), would allow a more precise localization of the parts of the game in which the travel effect appears.

The second limitation is the parameterization of team strengths. The model uses a fixed parameter for each team-season combination, which assumes that team strength is constant within a season. In reality, team performance changes even during a season due to injuries, roster changes, or cumulative fatigue. A more ideal approach would use a hierarchical model in which team strength develops dynamically across weeks of the season. However, such a model would require Bayesian estimation, which exceeds the scope of this bachelor's thesis.

The third limitation is the identification of H3. As discussed repeatedly, the effect of is_dome is identified only from a narrow subset of teams. This means that the H3 results cannot be generalized to the question of whether dome stadiums generally increase home-field advantage. Answering this broader question would require a different research design, for example comparing team results before and after relocation to a new stadium over a longer time horizon.

The fourth limitation is the representativeness of the H4 subsample. The weather analysis was conducted on 66% of the full dataset, while the excluded games (in dome stadiums) are not a random selection but a systematically different group. The H4 results therefore cannot be directly compared with the results for H1 to H3.

The fifth limitation is that the thesis does not work with individual player-level data. All analyses are conducted at the game level, which does not allow us to distinguish whether the travel effect is caused by physiological impacts on players (circadian desynchronization, travel fatigue) or by strategic decisions made by coaches (game plan, player rotation). Distinguishing these mechanisms would require tracking data at the level of individual plays (Yurko et al., 2020) or physiological measurements of players.

The sixth limitation is causality. The present study is correlational and does not manipulate the independent variables. The identified effect of travel across three time zones cannot be definitively interpreted as causal. It is possible that coast-to-coast games systematically differ in other respects that the model does not capture, such as team motivation or the strategic importance of the game.

8.9 Contributions of the Thesis and Recommendations

Despite the limitations mentioned above, the thesis offers several contributions. First, it identifies the threshold nature of the time zone effect: the influence on home-field advantage appears only after crossing three time zones, which refines earlier findings. Second, it shows that the betting market does not substantially incorporate this factor into its estimates, which may be relevant for sports analytics. Third, it methodologically demonstrates that the choice of model parameterization (paired comparison vs. separate fixed effects) has a crucial influence on the role of the spread variable and thus on the interpretation of the observed effects.

Several recommendations can be formulated for future research. Expanding the dataset to include additional seasons would strengthen the statistical power of the H2 test and allow more reliable conclusions about circadian asymmetry. Including more granular metrics (EPA, DVOA) would make it possible to locate the parts of the game in which the travel effect appears. A hierarchical model with dynamically changing team strength would represent a methodological improvement, although it would require a Bayesian approach. Finally, it would be desirable to apply a similar analysis to other professional leagues (NBA, NHL) and compare whether the threshold nature of the time zone effect also applies outside the context of American football.

9 Conclusion

The aim of this bachelor's thesis was to analyze the effect of selected environmental factors on home-field advantage in the National Football League during the 2015 to 2024 regular seasons. Using a dataset of 2,623 games, the effects of travel across time zones, circadian asymmetry, stadium type, and meteorological conditions were tested using a regression model in paired-comparison parameterization. The analysis produced the following conclusions:

1. Home-field advantage exists in the NFL, but it is relatively weak. The average point differential in favor of home teams is +1.71 points, and home teams win 54.5% of games. The 2020 season, played mostly without spectators, confirmed that the

presence of an audience represents one component of home-field advantage, but not the only one.

2. Hypothesis H1 was confirmed in modified form. Crossing three time zones by the visiting team (coast-to-coast games) increases home-field advantage by approximately two points ($\beta = -1.862$, $p = 0.015$). The originally defined threshold of two time zones did not prove significant, which indicates the threshold nature of the jet lag effect, where clinically relevant symptoms appear only after crossing three or more time zones. This effect is robust and is not absorbed by the pre-game market estimate.
3. Hypothesis H2 (circadian asymmetry) cannot be accepted. The interaction between travel direction and evening game time did not show statistical significance, but the statistical power analysis showed that the critical cell contains only 21 observations. The test is underpowered for this type of effect, and the result is inconclusive.
4. Hypothesis H3 (higher home-field advantage in dome stadiums) was not confirmed. The estimated effect is marginally significant but in the opposite direction from what the hypothesis predicted. In addition, the result is identified only from a minority of teams with variable roof type (12 of 32) and cannot be generalized to a global contrast between dome and outdoor franchises.
5. Hypothesis H4 (effect of weather) was not confirmed. Neither temperature nor wind speed shows any statistically or substantively significant relationship with the point differential. Weather likely acts as a symmetric shock that reduces the overall performance of both teams but does not provide a distinct advantage to the home team.
6. The spread variable (pre-game market estimate) was not statistically significant in any of the models. This confirms that paired-comparison parameterization with team-specific parameters sufficiently controls for team strength, and the pre-game estimate has nothing further to add. This methodological finding is relevant for future studies considering the inclusion of spread as a control variable.
7. Across all models, the difference in rest days between teams was consistently significant. Each additional day of rest for the home team compared with the visitors is associated with an increase in the point differential of approximately 0.08 points, confirming the importance of recovery in sports performance.

Overall, the results suggest that among the tested environmental factors, the only reliably demonstrated predictor of home-field advantage in the NFL is travel across three time zones. This finding refines earlier knowledge by identifying the threshold nature of the effect and also shows that the betting market does not substantially incorporate this factor into its estimates. The thesis also methodologically demonstrated that the choice of model parameterization has a crucial influence on the role of control variables and thus on the interpretation of the observed effects. For future research, it is desirable to expand the time frame of the analysis, use more granular performance metrics, and apply a similar approach to other professional leagues.

Summary

Home-field advantage (HFA) is one of the longest-studied phenomena in sports science. It refers to the observation that home teams win more often than would be expected by chance alone (Jamieson, 2010). The standard model of this phenomenon works with five main factors: the audience, familiarity with the environment, travel, rules, and territoriality (Legaz-Arrese et al., 2013). In the context of American football in the NFL, this phenomenon is particularly interesting because the league spans the entire continental United States and teams must regularly travel distances exceeding 4,000 kilometers and cross up to three time zones. Travel in the NFL brings physiological consequences including hypoxia, sleep disruption, and desynchronization of circadian rhythms (Huyghe et al., 2018; Janse van Rensburg et al., 2021). Research from the NBA and other leagues has shown that travel across time zones can significantly affect performance, with an asymmetric pattern emerging in relation to travel direction and game time (Smith et al., 1997; Roy & Forest, 2018). The COVID-19 pandemic also provided a unique opportunity to examine home-field advantage in conditions without spectators (Bryson et al., 2021).

The aim of this thesis was to analyze the effect of selected environmental factors on home-field advantage in the NFL during the 2015 to 2024 regular seasons. Four hypotheses were tested: H1 assumed that travel across a greater number of time zones reduces the performance of the visiting team; H2 tested circadian asymmetry in relation to travel direction and game time; H3 examined whether home-field advantage is greater in covered stadiums; and H4 tested the effect of meteorological conditions on the point differential.

The study is a quantitative correlational study and uses publicly available archival data. The research sample consists of 2,623 NFL regular season games played by 32 teams over ten seasons. Game data were supplemented with meteorological data, stadium information, and geographical data needed to calculate the number of time zones crossed. The analytical tool is a linear regression model in paired-comparison parameterization, where each team has a single strength parameter for each season, entering the model with a positive sign for the home role and a negative sign for the away role. This parameterization responds to methodological analyses of the data structure, which pointed to the asymmetry of separate fixed effects and the risk that the observed effects would be absorbed by the spread variable. Therefore, for each hypothesis, both a model without the spread variable and a model including it were constructed. Standard errors were estimated using the robust HC1 method.

The average point differential in favor of home teams was +1.71 points, and home teams won 54.5% of games, confirming the existence of a statistically significant, although relatively weak, home-field advantage in the NFL. The 2020 season, played mostly without spectators, showed an almost zero point differential, which is consistent with the assumption that the presence of an audience represents one component of home-field advantage; however, the results suggest that there are also other relevant factors in the NFL, especially those related to travel.

The main finding of the thesis is the confirmation of hypothesis H1 in modified form. Crossing three time zones by the visiting team increases home-field advantage by approximately two points, which, given an average home-field advantage of around 1.7 points, represents its doubling. The originally defined threshold of two time zones did not prove significant, which empirically supports the threshold model of jet lag, according to which clinically relevant symptoms appear only after crossing three or more time zones (Samuels, 2012). The effect is robust and is not absorbed by the pre-game market estimate, suggesting that the betting market underestimates the effect of coast-to-coast travel.

Hypothesis H2 on circadian asymmetry could not be reliably verified. The interaction between travel direction and evening game time showed a direction of effect consistent with the assumptions, but did not reach statistical significance. The statistical power analysis showed that the critical cell contained only 21 observations, which is entirely insufficient for reliable testing. This result therefore cannot be interpreted as a rejection of the circadian hypothesis, but rather as a consequence of insufficient statistical power.

Hypothesis H3 on greater home-field advantage in covered stadiums was not accepted. The estimated effect is marginal and runs in the opposite direction from what the hypothesis predicted. Games in dome stadiums rather show lower home-field advantage, which may reflect the absence of environmental advantage that arises in open stadiums through home teams' adaptation to the local climate (Joly & Dik, 2021). However, this result must be interpreted with awareness of a substantial identification limitation, because the effect is estimated only from a minority of teams with variable roof type.

Hypothesis H4 on the effect of weather on home-field advantage was also not accepted. Neither temperature nor wind speed showed any statistically or substantively significant relationship with the point differential. Weather likely acts as a symmetric shock that reduces the overall performance of both teams but does not provide the home team with a distinct advantage over the visitors. This finding complements earlier studies that documented the effect of weather on total scoring, but not on the difference between teams (Paul, 2017).

From a methodological perspective, the thesis demonstrated that the choice of model parameterization has a crucial influence on the role of control variables. The spread variable, which in the original specification with separate fixed effects represented a dominant predictor, proved completely insignificant in the paired-comparison model with team-specific parameters. This means that in the original specification, spread did not substitute for market expectations but rather compensated for insufficient control of current team strength. This finding is relevant for future studies considering the inclusion of spread as a control variable.

The limitations of the thesis include the coarse nature of the dependent variable (point differential), the assumption of constant team strength within a season, the identification limitation of H3, the different subsample for H4, the absence of player-level data, and the correlational nature of the study. For future research, it would be desirable to expand the time frame of the analysis, use more granular performance metrics, such as Expected Points Added (Yurko et al., 2020), and apply a similar approach to other professional leagues.

Despite these limitations, the thesis provides three main contributions. It identifies the threshold nature of the time zone effect, refining earlier findings on the influence of travel on sports performance. It shows that the betting market does not substantially incorporate this factor into its estimates, which may be relevant for sports analytics. It also methodologically demonstrates that the choice of regression model parameterization fundamentally affects the interpretation of the observed effects and that the paired-comparison model represents a more suitable alternative in the context of sports data than a conventional model with separate fixed effects and spread as a control.

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Dataset: https://github.com/nflverse/nfl_data_py

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APPENDICES

List of appendices:

1. Abstract in English

2. Abstract in Czech

ABSTRACT OF THESIS

Title: Does Home-Field Advantage Really Matter? An analysis of home-field advantage in American football (NFL), 2015–2024

Author: Antonín Křemenák

Supervisor: PhDr. Daniel Dostál, Ph.D.

Number of pages and characters: 74 pages, 148 431 characters

Number of appendices: 2

Number of references: 78

Abstract (800–1200 characters):

This study examines the influence of selected environmental factors on home-field advantage in the National Football League during the 2015 to 2024 regular seasons. Four hypotheses concerning the effects of time zone travel, circadian asymmetry, stadium type, and weather conditions are tested on a sample of 2,623 games. The analytical framework is a linear regression model with a paired comparison parameterization, where each team has a single strength parameter per season. Results show that the only statistically significant factor is crossing three time zones by the visiting team, which increases home-field advantage by approximately two points. The effect emerges only in coast-to-coast games and is not absorbed by the pre-game point spread. Hypotheses regarding circadian asymmetry, dome stadiums, and weather were not supported.

Keywords: home-field advantage, NFL, time zones, travel fatigue, sports analytics

ABSTRAKT BAKALÁŘSKÉ PRÁCE

Název práce: Opravdu hraje domácí prostředí roli? Analýza domácí výhody v americkém fotbale (NFL) v letech 2015–2024

Autor práce: Antonín Křemenák

Vedoucí práce: PhDr. Daniel Dostál, Ph.D.

Počet stran a znaků: 74 stran, 148 431 znaků

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Počet titulů použité literatury: 78

Abstrakt (800–1200 zn.):

Tato bakalářská práce analyzuje vliv vybraných environmentálních faktorů na výhodu domácího prostředí v National Football League v období regulérních sezon 2015 až 2024. Na souboru 2 623 zápasů jsou testovány čtyři hypotézy týkající se vlivu cestování přes časová pásma, cirkadiánní asymetrie, typu stadionu a meteorologických podmínek. Analytickým nástrojem je lineární regresní model v parametrizaci paired comparison, kde každý tým má jednotný parametr síly pro každou sezonu. Výsledky ukazují, že jediným statisticky významným faktorem je překonání tří časových pásem hostujícím týmem, které zvyšuje domácí výhodu přibližně o dva body. Efekt nastupuje teprve u zápasů coast to coast a není absorbován předzápasovým tržním odhadem. Hypotézy o cirkadiánní asymetrii, typu stadionu a počasí potvrzeny nebyly.

Klíčová slova: domácí výhoda, NFL, časová pásma, cestovní únava, sportovní analytika