



ARTICLE



<https://doi.org/10.1057/s41599-022-01193-6>

OPEN

# Major League Baseball during the COVID-19 pandemic: does a lack of spectators affect home advantage?

Yung-Chin Chiu<sup>1</sup> & Chen-Kang Chang<sup>2</sup>  

A home advantage is present in most professional sports leagues. Spectators may be a major factor in home advantage, but empirical results have been mixed. Professional games were played without spectators during the 2020 season amid the COVID-19 pandemic. This study investigated home advantage in Major League Baseball (MLB) during 2020 as compared with the 2015–2019 seasons. A total of 13,044 regular-season games (898 in 2020 and 12,146 in 2015–2019) were analyzed. The sum of wins above replacement of all players was used as an indicator of team quality. The likelihood of a home-team win with spectators was not significantly different to that without spectators (odds ratio = 1.068; 95% confidence interval = 0.932–1.224,  $p > 0.05$ ). The relative home advantage, percentage of home wins of total wins by a team in a specific season, was not significantly different across years, team quality, and attendance. Factorial analysis of variance models that included the variables of year, team quality, and attendance also revealed that none of these variables significantly affected the relative home advantage. The results suggest that spectators may not be an important factor of home advantage in MLB.

<sup>1</sup>Office of Institutional Research, National Taiwan University of Sport, Taichung 404, Taiwan. <sup>2</sup>Department of Sport Performance, National Taiwan University of Sport, Taichung 404, Taiwan. email: [wspahn@seed.net.tw](mailto:wspahn@seed.net.tw)

## Introduction

Winning in professional sports is usually associated with teams' financial success (Lemke et al., 2010). Therefore, the potential factors that can improve the chance of winning have attracted the interest of coaches, managers, and scholars (Nevill and Holder, 1999). Advancements in training regimens and techniques, equipment, sports medicine, and nutrition have significantly improved professional athletes' physical and psychological abilities. The application of big data analysis has led to tactical adjustments, such as defensive shifts in baseball and the emphasis on 3-point shots in basketball (Harris and Roebber, 2019), which foster a team's advantage over their opponents. However, other teams can replicate these training and tactical improvements when they see the benefits of them. If most teams adopt the same strategy, its advantages are diminished. One of the few unchangeable and consistent factors that can influence victories in professional sports is game location.

The home advantage, home teams win over 50% of the games played under a balanced home and away schedule, has been identified in most major professional team sports leagues, such as Major League Baseball (MLB), the National Basketball Association (NBA), the National Hockey League (NHL), and European football, in scientific literature for several decades (Courneya and Carron, 1992; Schwartz and Barsky, 1977). It has been shown that the winning percentages of home teams are all significantly higher than 50% across the major professional sports leagues in the United States. Major League Soccer had the highest home winning percentage at 62.29%, whereas MLB had the lowest, at 54.85%, from 2006 to 2009 (Pollard and Gomez, 2015). Home advantage is also present in European football. The average home winning percentage was 60% in men's and 54.2% in women's professional football leagues in 26 European countries (Pollard and Gomez, 2014).

Several studies have proposed factors that may contribute to home advantage. One of the major factors is spectators. Spectators' cheering for home teams can lead to home players' increased performance (Greer, 1983) and improved psychological states in home players (Smith, 2005), whereas booing can reduce visiting players' performance (Greer, 1983). Other factors, such as familiarity with playing facilities, fatigue associated with travel, disruption of routines, territoriality, special tactics, rules, and psychological, physiological, and behavioral states, have also been explored (Nevill and Holder, 1999; Pollard and Pollard, 2005). Most, if not all, of these factors may contribute to home advantage to various degrees in different sports and leagues. However, identifying the individual effects of these factors is difficult because they usually coexist.

The coronavirus disease 2019 (COVID-19) pandemic has had a huge global impact on people's health, society, and lifestyles. At the onset of the pandemic, many governments attempted to slow the spread of the virus by implementing lockdowns and social distancing policies. Most professional sports leagues postponed their games under such policies. Several months after the COVID-19 outbreak started, professional sport leagues, including MLB, resumed games without live spectators. This unique

situation, although devastating to society and sports businesses, provides an unprecedented opportunity to investigate the role of spectators in home advantage in professional sports. It is noteworthy that other factors associated with the pandemic, such as the shortened schedule, rule changes, and psychological stress for players' and their family's health may also contribute to the changes in home advantage. The results on professional football, the leagues with one of the highest home advantage (Pollard and Gomez, 2014; Pollard and Gomez, 2015), were mixed. It has been shown that home advantage remained similar to its prepandemic level across 10 major European professional football leagues during the COVID-19 pandemic (Wunderlich et al., 2021). By contrast, another study on four major European football leagues reported a decrease in home advantage during the pandemic (Sors et al., 2021). Teams in the German football league Bundesliga even won fewer games at home than they won on the road during the COVID-19 pandemic (Tilp and Thaller, 2020). The purpose of this study was to investigate home advantage in MLB in all 898 regular-season games, in which no spectators were allowed, during the 2020 season. The results of the 2020 season were compared with those of 2015–2019 to estimate the effect of spectators on home advantage in MLB. We hypothesize that home advantage in MLB, the league with one of the lowest home advantage among major professional sports (Pollard and Gomez, 2014; Pollard and Gomez, 2015), was less affected by a lack of spectators.

## Methods

**Data.** The results and attendance of each MLB regular-season game in MLB during the 2015–2020 seasons were obtained from Retrosheet ([www.retrosheet.org](http://www.retrosheet.org)). A total of 13,044 games, 12,146 games in 2015–2019 before the COVID-19 pandemic and 898 games in 2020 during the pandemic, were included for analysis. No live spectators were present for any regular-season game during the 2020 season. Yearly home advantage has been relatively consistent in MLB since 1904, averaging ~54% in both the National and American Leagues (Jones, 2015). Therefore, five seasons of prepandemic data were included in this study for convenience.

**Variables.** The definitions of the variables used are presented in Table 1.

**Home advantage.** The home advantage is represented by the following three variables for different analysis.

Home win is a game-level dummy variable, with home-team win = 1 and home-team loss = 0.

Home advantage is a team-level variable for the percentage of home games won by home teams in a season.

Relative home advantage is a team-level variable that accounts for home-team quality. Poorer teams usually won fewer home games compared with better teams, which can result in bias in home advantage at the season level. Therefore, relative home

**Table 1** Definitions of variables.

Variable	Definition
Home win	Dummy variable, home-team win = 1, home-team loss = 0
Home advantage	Home-team wins/total home games played in a season, in %
Relative home advantage	Home wins/total wins in a season, in %
Wins above replacement (WAR)	Batting WAR + hitting WAR in a season, dummy variable in ANOVA, in tertiles of each season
Attendance ratio	Average home attendance/home stadium capacity in a season, dummy variable in ANOVA, in quartiles of each season

advantage is calculated as the percentage of home wins out of total wins by a team in a specific season (Romanowich, 2012).

WAR is an estimate of a player’s total value relative to a typical minor-league free agent. The detailed calculations for WAR in hitters and pitchers can be found on Fangraphs (<https://library.fangraphs.com/war/war-position-players/>, <https://library.fangraphs.com/war/calculating-war-pitchers/>). The sum of WAR of all hitters and pitchers in a season serves as a quality indicator for home teams. The teams are categorized into tertiles by WAR within a season. This study did not use winning percentages or final standings as an indicator for team quality because of the unbalanced schedule in MLB. Not all teams played against opponents with equal ability.

**Attendance ratio.** Studies have suggested that relative crowd size has a larger impact on home advantage than the absolute attendance number does (Goumas, 2014a). Therefore, the attendance ratio, calculated by dividing the average home attendance by the capacity of the home stadium, was used. The capacity of each stadium was obtained from Wikipedia ([https://en.wikipedia.org/wiki/List\\_of\\_current\\_Major\\_League\\_Baseball\\_stadiums#cite\\_note-6](https://en.wikipedia.org/wiki/List_of_current_Major_League_Baseball_stadiums#cite_note-6)). The teams were categorized into quartiles by attendance ratio in a season.

**Statistical analysis.** To compare home advantage at the game level with and without spectators, logistic regression was used with home win as the dependent variable and year as an independent variable. The dummy variable year was coded as 0 for prepandemic seasons and coded as 1 in 2020 for the pandemic season.

The difference in relative home advantage at the team level with and without spectators was analyzed through one-way analysis of variance (ANOVA) in which year was the independent variable. The difference in relative home advantage at the team level among teams of different qualities or number of spectators was analyzed through one-way ANOVA in which WAR or attendance ratio was the independent variable. The difference in relative home advantage was further analyzed with a factorial ANOVA that included different combinations of the following independent variables: year, WAR, and attendance ratio.

The data from different sources were compiled using SAS v9.4 (SAS Institute, Cary, NC, USA). All the statistical analyses were performed using SPSS for Windows, version 21.0 (IBM, Armonk, NY, USA). A *p*-value <0.05 was considered statistically significant.

**Results**

The descriptive statistics of the variables in MLB in the 2015–2020 seasons is presented in Table 2. Average home advantage ranged between 52.77–54.98% which aligned with results from previous seasons (Jones, 2015; Pollard and Gomez, 2015). Mean relative home advantage, which accounts for the quality of home teams, was significantly higher than 50% (*p* <0.01) in each investigated season. Three to seven teams each

year between 2015–2019 had relative home advantages below 50%, which indicated that these teams won fewer games at home than on the road. Four teams had relative home advantages below 50% in 2020.

The results of logistic regression are presented in Table 3. The odds ratio for the variable year, which is coded as prepandemic or pandemic season, is 1.068 (*p* = 0.344). This result indicated that the likelihood that the home-team would win was slightly but insignificantly increased by 6.8% in 2020 compared with 2015–2019.

The results of one-way ANOVA showed that relative home advantages were not significantly different across year, team qualities (indicated by WAR), and attendance ratio (Table 4). To further investigate the effects of interactions between year, WAR, and attendance ratio on the relative home advantage, different combinations of these variables were included in a factorial ANOVA (Table 4). Model 1 included year and WAR, model 2 included year and attendance ratio, and model 3 included all three variables. None of the variables or interaction terms was significant in any of the models, which indicated that these three variables had no significant effect on home advantage.

**Discussion**

The results of this study revealed that home advantage in the 2020 season was not significantly different from that in 2015–2019 in MLB. This indicated that spectators may not be a crucial factor in home advantage in professional baseball. The results obtained after controlling for the quality of home teams were similar. By applying a commonly used research design, this study showed that home advantage in MLB may result from different factors from other professional sports leagues in Europe and the United States. Spectators play a less important role in home advantage in MLB than in European football and NBA. Furthermore, relative home advantage, in addition to home advantage, was analyzed in this study to account for the difference in home-team quality.

Crowd support has often been believed to exert a particularly potent effect on home advantage in many sports, but the empirical results have been mixed. Football games in Europe and North America have the highest home advantage among major professional sports leagues (Pollard and Gomez, 2014; Pollard and Gomez, 2015). In more than 1,000 professional matches without spectators during the COVID-19 pandemic across 10 major European professional football leagues, home advantage remained similar to its prepandemic level (Wunderlich et al., 2021). Home advantage in eight professional football leagues in four European countries were also unchanged during the pandemic (Jimenez Sanchez and Lavin, 2021). Additionally, home advantage varies little between the first and second divisions in the football leagues of Germany, England, France, Spain, and Italy, despite large differences in crowd size. Home advantage was also similar across the four divisions of football in England despite wide variation in the quantities of spectators (Pollard, 2006). In a natural experiment conducted within Brazilian football, games were quasi-randomly assigned to be played in alternative sites. This change significantly increased crowd size, and although

**Table 2 Descriptive statistics of variables, 2015–2020 seasons (mean ± standard deviation of 30 teams in each season).**

Season	Home win	Home loss	Home advantage (%)	Relative home advantage (%)	Wins above replacement	Attendance ratio
2015	43.9 ± 6.6	37.1 ± 6.6	54.18 ± 8.19	54.16 ± 4.04	33.33 ± 9.43	0.72 ± 0.14
2016	42.9 ± 6.9	38.0 ± 6.8	53.03 ± 8.46	52.94 ± 3.71	33.31 ± 10.80	0.71 ± 0.15
2017	43.7 ± 5.0	37.3 ± 5.0	53.95 ± 6.19	54.27 ± 3.93	33.35 ± 11.50	0.70 ± 0.15
2018	42.8 ± 7.3	38.3 ± 7.3	52.77 ± 9.03	53.07 ± 4.57	33.34 ± 13.04	0.67 ± 0.18
2019	42.9 ± 9.5	38.1 ± 9.5	52.94 ± 11.74	52.76 ± 4.01	33.32 ± 15.22	0.66 ± 0.19
2020	16.5 ± 3.3	13.5 ± 3.2	54.98 ± 10.80	55.27 ± 6.98	12.31 ± 5.24	0.00 ± 0.00

**Table 3 Logistic regression results of home-team win in Major League Baseball, 2015–2020 seasons<sup>a</sup>.**

Variable	Coefficient	Standard error	Odds ratio	95% Confidence interval	p-value
Intercept	0.135	0.018			<0.001
Year	0.066	0.070	1.068	0.932-1.224	0.344
Likelihood ratio	0.900				0.343
N	13044				

<sup>a</sup>Dependent variable: home-team win = 1; home-team loss = 0; independent variable: Year = 1 if season 2020; otherwise Year = 0.

**Table 4 Results of one-way and factorial ANOVA of the relative home advantage in Major League Baseball, 2015–2020 seasons (n = 180 team-seasons).**

Independent variable	One-way ANOVA		Factorial ANOVA					
	F	p	Model 1		Model 2		Model 3	
			F	p	F	p	F	p
Year <sup>a</sup>	1.328	0.254	1.321	0.258	1.507	0.203	0.880	0.478
WAR <sup>b</sup>	0.996	0.371	1.000	0.370			0.744	0.477
Attendance ratio <sup>c</sup>	1.455	0.228			0.161	0.851	0.039	0.961
Year x WAR			0.909	0.527			0.754	0.644
Year x Attendance ratio					1.209	0.296	0.760	0.638
WAR x Attendance ratio							0.143	0.966
Year x WAR x Attendance ratio							1.016	0.433

<sup>a</sup>Year: individually coded for each season.

<sup>b</sup>WAR: wins above replacement, in tertile of each season.

<sup>c</sup>In quartile of each season.

most spectators supported home teams, they had no additional impact on existing home advantage (Belchior, 2020). Furthermore, crowd size was determined to be a nonsignificant factor for home advantage in NBA (Harris and Roebber, 2019). These results appeared to correspond with that of the present study that spectators have no significant effect on home advantage.

By contrast, another study on four major European football leagues during the COVID-19 pandemic reported a decrease in home advantage (Sors et al., 2021). Teams in the German football league Bundesliga even won fewer games at home than they won on the road during the COVID-19 pandemic (Tilp and Thaller, 2020).

Another unique method for investigating crowd effects on home advantage involves using a rare setting of head-to-head competitions between two professional teams that share the same home facility. This natural experiment provides an environment in which the effect of crowds can be isolated because the familiarity and travel factors of both teams are almost identical. The likelihood of a home-team win increased by 21.0% to 22.8% in regular-season games between two NBA teams, the Los Angeles Lakers and the Los Angeles Clippers, which share the Staples Center as their home stadium (Boudreaux et al., 2017). This magnitude of home advantage was similar to the league average, which implied that the crowd effect contributes the most to home advantage in the NBA (Boudreaux et al., 2017). Additionally, in head-to-head competitions between Italian football league Serie A teams that shared the same home facility, the crowd support effect was estimated to contribute to ~60% of the home advantage (Ponzo and Scoppa, 2018).

Professional players have credited home advantage to the support from the home crowd (Bray and Widmeyer, 2000). Players were more self-confident and had higher self-efficacy before home games (Bray et al., 2002) but were more anxious before road games (Smith, 2005). Some of this psychological advantage was reflected in teams' performance at home. According to an analysis of play-by-play events in NBA games,

home teams had higher scoring rates and smaller time intervals between scores than visiting teams did (Ribeiro et al., 2016). European football teams also scored more goals at home than on the road (Goumas, 2014a). Furthermore, when there was no spectators to support home teams during the COVID-19 pandemic, average goals by home teams in European football leagues were significantly decreased (Sors et al., 2021).

Not all psychological effects caused by the home crowd are positive. Professional football players had a higher probability of choking in penalty kicks (i.e., missing the goal without the goalkeeper's interference) in home games than in road games (Dohmen, 2008). Winning was more difficult for superior and evenly matched home teams during 3-on-3 overtime play than during regulation time in the NHL (Hoffmann et al., 2021). Visiting teams had a significantly higher probability of scoring free direct hits than home teams in elite rink hockey (Arboix-Alio et al., 2021). These results suggested that the high pressure from the home crowd may reduce performance in home teams. Professional and semi-professional football players experienced higher levels of stress, indicated by their high salivary cortisol levels, after home games than they experienced after road games (Fothergill et al., 2017). Similarly, one study reported that, in the Union of European Football Associations (UEFA) Champions League, home advantage is mostly due to visiting teams scoring fewer goals rather than home teams scoring more goals. The study noted that negative crowd behavior reduced visiting players' performance, whereas supportive behavior had mixed results on home players' performance (Goumas, 2014b). The positive and negative psychological impacts of spectators may have canceled the crowd's effect on home advantage.

Referee bias toward home teams is another factor induced by spectators that affects home advantage. The number of yellow cards issued to home teams was significantly lower than those issued to the visiting teams in Bundesliga (Endrich and Gesche, 2020), the UEFA Champions League and the Europa League (Goumas, 2014a). Moreover, in Italian football, referee decisions on penalties and red



and yellow cards favored home teams in competitions between two teams that shared the same home stadium (Ponzo and Scoppa, 2018). Referee bias was supported in an experimental setting in which experienced referees watched video clips of incidents during real football matches with or without crowd noise in the background. The referees watching the video clips with crowd noise called significantly fewer fouls against home-team players than did referees in the silent group (Nevill et al., 2002). Furthermore, referee bias disappeared in European football leagues during the COVID-19 pandemic when live spectators were absent from stadiums (Sors et al., 2021; Tilp and Thaller, 2020; Wunderlich et al., 2021). It is estimated that the number of yellow cards issued to visiting teams decreased by 0.3 per match without spectators in European football (Reade et al., 2021). In addition, home teams received 0.2 more yellow cards per match than visiting teams in Bundesliga without spectators, whereas home teams received 0.4 fewer yellow cards before the pandemic (Endrich and Gesche, 2020). These findings indicated that live spectators were the major cause of referee bias toward home teams in European football. However, this bias may be unique to football. An examination of referee decisions in close game situations in the NBA found no bias toward either the home or visiting team (Deutscher, 2015). No available studies have investigated umpire bias in MLB.

One unique variable that may influence home advantage is the relative rarity of the playing facilities. Home advantage is significantly higher in domed stadiums than in open-air or retractable-roof stadiums in MLB (Romanowich, 2012). Visiting teams' unfamiliarity with the relatively rare domed stadiums and artificial turf may increase home advantage. English football teams whose home pitches had unusual dimensions or artificial surfaces also enjoyed increased home advantage (Clarke and Norman, 1995). Furthermore, in North American professional sports leagues, the home advantage of teams who moved into new stadiums decreased by 24% within the first year after moving despite larger crowd sizes. This may be because teams were still familiarizing themselves with their new home facilities during that first year (Pollard, 2002). In amateur sports, familiarity with the playing facility was considered by coaches (Gayton et al., 2001) and athletes (Bray and Widmeyer, 2000) to be one of the most important contributors to home advantage.

Travel-related fatigue experienced by visiting teams has been suggested to be a significant factor for home advantage. In the NBA, visiting teams who traveled across more time zones won significantly fewer games, especially during the second half of the season, due to accumulated fatigue. Home teams located in western time zones also enjoyed higher home advantage in the second half of the season (Nutting, 2010). A study that used recent data from the NBA and NHL confirmed that visiting teams that traveled westward had significantly lower winning percentages than did teams that traveled eastward. This phenomenon was more apparent in evening games and when visiting teams traveled across more time zones (Roy and Forest, 2018). These results indicated that, in addition to fatigue, travel results in a circadian disadvantage to visiting teams, which can be advantageous to home teams. However, visiting teams in MLB usually remain in the same city to play on the same field for 3 to 4 consecutive days before they travel to the next destination. This schedule could reduce travel-related fatigue and increase the visiting team's familiarity with the playing field. This could be one reason for the relatively low home advantage in MLB compared with other professional sport leagues.

Remarkably, yearly home advantage has been relatively consistent in MLB since 1904, averaging ~54% in both the National and American Leagues (Jones, 2015). This value is consistently lower than that in other American major professional sport leagues and European football leagues (Pollard and Pollard, 2005). The results of this study indicate that a lack of live spectators has no significant effect on home advantage in MLB, whereas some studies have

reported positive crowd effects in other sports, especially European football. This discrepancy may result from the differences in fan attitude and behavior between the sports. Studies have also reported that MLB fans attend games as a habit (Lee and Smith, 2008) and exhibit less animosity toward rival teams than National Football League and NHL fans do (Cobbs et al., 2017). By contrast, European football fans felt responsible for inspiring their team to victory, distracting opponents, and inducing referee bias through aggressive approaches (Wolfson et al., 2005).

### Limitations and future directions

The present study adopted a quasi-experimental design by including all regular-season games in the 2015–2020 seasons. In addition to a lack of spectators, the pandemic led to other changes in the 2020 season, such as significantly fewer games played by each team, teams only played opponents in their division to reduce travel, more make-up games, and players missing more playing time due to infection and quarantine. Make-up games were usually played as double headers. The fatigue factor could be similar for both home and visiting teams. The shortened travel may reduce the fatigue visiting teams experienced and slightly reduce home advantage. Several rule changes were also introduced in 2020, including seven-inning double headers, a universal designated hitter in the National League, and a tiebreaker rule in extra innings. The designated hitter rule has nonsignificant effect on home advantage because it affected both home and visiting teams. The new tiebreaker rule may increase home advantage because the home-team bats after the visiting team, which may allow for more strategic options later in a game (Schwartz and Barsky, 1977). However, this hypothesis has not been examined at the professional level. Furthermore, most teams arranged screens or cardboard displaying images of fans in the stands and played supportive cheers on speaker systems to mimic a home crowd. These differences were not controlled for in the present study. Therefore, cautions should be taken when interpreting the results of this study as causal estimates.

### Conclusion

The results of this study indicated that a lack of spectators does not significantly affect home advantage in MLB. This inconsistency with other major professional sport leagues in North America and Europe may be the result of differences in fan culture and behavior. Home advantage in MLB may arise from other factors, such as familiarity with the playing facility or fatigue associated with travel.

### Data availability

The dataset analyzed during the current study is available in the Dataverse repository: <https://doi.org/10.7910/DVN/15CITZ>. The dataset was derived from <https://www.retrosheet.org/gamelogs/index.html>.

Received: 21 September 2021; Accepted: 5 May 2022;

Published online: 18 May 2022

### References

- Arboix-Alio J, Trabal G, Valente-Dos-Santos J, Aguilera-Castells J, Fort-Vanmeerhaeghe A, Busca B (2021) The influence of contextual variables on individual set-pieces in elite rink hockey. *Int J Perform Anal Sport* 21(3):1–12. <https://doi.org/10.1080/24748668.2021.1890525>
- Belchior CA (2020) Fans and match results: evidence from a natural experiment in Brazil. *J Sport Econ* 21(7):663–687. <https://doi.org/10.1177/1527002520930812>
- Boudreaux CJ, Sanders SD, Walia B (2017) A natural experiment to determine the crowd effect upon home court advantage. *J Sport Econ* 18(7):737–749. <https://doi.org/10.1177/1527002515595842>

- Bray SR, Jones MV, Owen S (2002) The influence of competition location on athletes' psychological states. *J Sport Behav* 25(3):231–242
- Bray SR, Widmeyer WN (2000) Athletes' perceptions of the home advantage: an investigation of perceived causal factors. *J Sport Behav* 23(1):1–10
- Clarke SR, Norman JM (1995) Home ground advantage of individual clubs in English soccer. *J R Stat Soc Ser D Stat* 44(4):509–521. <https://doi.org/10.2307/2348899>
- Cobbs J, Sparks BD, Tyler BD (2017) Comparing rivalry effects across professional sports: National Football League fans exhibit most animosity. *Sport Mark Q* 26(4):235–246
- Courneya KS, Carron AV (1992) The home advantage in sport competitions: a literature review. *J Sport Exerc Psychol* 14(1):13–27
- Deutscher C (2015) No referee bias in the NBA: new evidence with leagues' assessment data. *J Sport Analyst* 1(2):91–96. <https://doi.org/10.3233/JSA-150012>
- Dohmen TJ (2008) Do professionals choke under pressure? *J Econ Behav Organ* 65(3–4):636–653. <https://doi.org/10.1016/j.jebo.2005.12.004>
- Endrich M, Gesche T (2020) Home-bias in referee decisions: evidence from “Ghost Matches” during the Covid19-pandemic. *Econ Lett* 197:109621
- Fothergill M, Wolfson S, Neave N (2017) Testosterone and cortisol responses in male soccer players: the effect of home and away venues. *Physiol Behav* 177:215–220. <https://doi.org/10.1016/j.physbeh.2017.04.021>
- Gayton WF, Broida J, Elgee L (2001) An investigation of coaches' perceptions of the causes of home advantage. *Percept Mot Skills* 92(3 Pt 1):933–936. <https://doi.org/10.2466/pms.2001.92.3.933>
- Goumas C (2014a) Home advantage and referee bias in European football. *Eur J Sport Sci* 14(Suppl 1):S243–S249. <https://doi.org/10.1080/17461391.2012.686062>
- Goumas C (2014b) How does crowd support contribute to home advantage in soccer? *J Sport Behav* 37(3):236–250
- Greer DL (1983) Spectator booing and the home advantage: a study of social influence in the basketball arena. *Social Psychol Quarterly* 46(3):252–261
- Harris AR, Roebber PJ (2019) NBA team home advantage: Identifying key factors using an artificial neural network. *PLoS One* 14(7):e0220630. <https://doi.org/10.1371/journal.pone.0220630>
- Hoffmann MD, McEwan D, Baumeister RF, Barnes JD, Guerrero MD (2021) Home team (dis)advantage patterns in the National Hockey League: changes through increased emphasis on individual performance with the 3-on-3 overtime rule. *Percept Mot Skills* 128(1):424–438. <https://doi.org/10.1177/0031512520966138>
- Jimenez Sanchez A, Lavin JM (2021) Home advantage in European soccer without crowd. *Soccer Soc* 22(1–2):152–165. <https://doi.org/10.1080/14660970.2020.1830067>
- Jones MB (2015) The home advantage in Major League Baseball. *Percept Mot Skills* 121(3):791–804. <https://doi.org/10.2466/26.PMS.121c25x1>
- Lee YH, Smith TG (2008) Why are Americans addicted to baseball? An empirical analysis of fandom in Korea and the United States. *Contemp Econ Policy* 26(1):32–48
- Lemke RJ, Leonard M, Tlhokwane K (2010) Estimating attendance at Major League Baseball games for the 2007 season. *J Sport Econ* 11(3):316–348
- Nevill AM, Balmer NJ, Williams AM (2002) The influence of crowd noise and experience upon refereeing decisions in football. *Psychol Sport Exerc* 3(4):261–272. [https://doi.org/10.1016/S1469-0292\(01\)00033-4](https://doi.org/10.1016/S1469-0292(01)00033-4)
- Nevill AM, Holder RL (1999) Home advantage in sport: an overview of studies on the advantage of playing at home. *Sports Med* 28(4):221–236. <https://doi.org/10.2165/00007256-199928040-00001>
- Nutting AW (2010) Travel costs in the NBA production function. *J Sport Econ* 11(5):533–548. <https://doi.org/10.1177/1527002509355637>
- Pollard R (2002) Evidence of a reduced home advantage when a team moves to a new stadium. *J Sport Sci* 20(12):969–973. <https://doi.org/10.1080/026404102321011724>
- Pollard R (2006) Home advantage in soccer: variations in its magnitude and a literature review of the inter-related factors associated with its existence. *J Sport Behav* 29(2):169–189
- Pollard R, Gomez MA (2014) Comparison of home advantage in men's and women's football leagues in Europe. *Eur J Sport Sci* 14(Suppl 1):S77–S83. <https://doi.org/10.1080/17461391.2011.651490>
- Pollard R, Gomez MA (2015) Comparison of home advantage in college and professional team sports in the United States. *Coll Antropol* 39(3):583–589
- Pollard R, Pollard G (2005) Long-term trends in home advantage in professional team sports in North America and England (1876–2003). *J Sport Sci* 23:337–350. <https://doi.org/10.1080/02640410400021559>
- Ponzo M, Scoppa V (2018) Does the home advantage depend on crowd support? Evidence from same-stadium derbies. *J Sport Econ* 19(4):562–582. <https://doi.org/10.1177/1527002516665794>
- Reade JJ, Schreyer D, Singleton C (2021) Eliminating supportive crowds reduces referee bias. *Econ Inq*. <https://doi.org/10.1111/ecin.13063>
- Ribeiro HV, Mukherjee S, Zeng XH (2016) The advantage of playing home in NBA: microscopic, team-specific and evolving features. *PLoS ONE* 11(3):e0152440. <https://doi.org/10.1371/journal.pone.0152440>
- Romanowich P (2012) Home advantage in retractable-roof baseball stadia. *Percept Mot Skills* 115(2):559–566. <https://doi.org/10.2466/06.20.23.pms.115.5.559-566>
- Roy J, Forest G (2018) Greater circadian disadvantage during evening games for the National Basketball Association (NBA), National Hockey League (NHL) and National Football League (NFL) teams travelling westward. *J Sleep Res* 27(1):86–89. <https://doi.org/10.1111/jsr.12565>
- Schwartz B, Barsky SF (1977) The home advantage. *Social Forces* 55(3):641–661
- Smith DR (2005) Disconnects between popular discourse and home advantage research: what can fans and media tell us about the home advantage phenomenon? *J Sport Sci* 23(4):351–364. <https://doi.org/10.1080/02640410400021633>
- Sors F, Grassi M, Agostini T, Murgia M (2021) The sound of silence in association football: home advantage and referee bias decrease in matches played without spectators. *Eur J Sport Sci* 21(12):1597–1605. <https://doi.org/10.1080/17461391.2020.1845814>
- Tilp M, Thaller S (2020) Covid-19 has turned home advantage into home disadvantage in the German soccer Bundesliga. *Front Sports Act Living* 2:593499. <https://doi.org/10.3389/fspor.2020.593499>
- Wolfson S, Wakelin D, Lewis M (2005) Football supporters' perceptions of their role in the home advantage. *J Sport Sci* 23(4):365–374. <https://doi.org/10.1080/02640410400021567>
- Wunderlich F, Weigelt M, Rein R, Memmert D (2021) How does spectator presence affect football? Home advantage remains in European top-class football matches played without spectators during the COVID-19 pandemic. *PLoS ONE* 16(3):e0248590. <https://doi.org/10.1371/journal.pone.0248590>

## Funding

This work was supported by the Ministry of Science and Technology, Taiwan (MOST 109-2627-H-028-004, 110-2627-H-028-002).

## Competing interests

The authors declare no competing interests.

## Ethical approval

Ethical approval for this study was not required according to local government regulations because the data used are publicly accessible and no individual player's information was used.

## Informed consent

Informed consent was not collected because the data used are publicly accessible and no individual player's information was used.

## Additional information

**Correspondence** and requests for materials should be addressed to Chen-Kang Chang.

**Reprints and permission information** is available at <http://www.nature.com/reprints>

**Publisher's note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.



**Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit <http://creativecommons.org/licenses/by/4.0/>.

© The Author(s) 2022