A complete season with attendance restrictions confirms the relevant contribution of spectators to home advantage and referee bias in association football

Fabrizio Sors, Michele Grassi, Tiziano Agostini and Mauro Murgia
Department of Life Sciences, University of Trieste, Trieste, Italy

ABSTRACT

Background: Due to the unfortunate pandemic situation, the phenomena of home advantage and referee bias in sports have recently received a particular research attention, especially in association football. In this regard, several studies were conducted on the last portion of the 2019–20 season: the majority of them suggests a reduction—but not the elimination—of the two phenomena, with some exceptions in which no reduction was found or, at the other extreme, the phenomena were not observed at all.

Methods: The continuation of the pandemic made it possible to replicate the previous studies considering the complete 2020–21 season, thus with the important added value of having a fully balanced home/away schedule—and a higher number of matches—in the various leagues. In particular, the sample of the present study consisted of 3,898 matches from the first and second divisions of the UEFA top five ranked countries, that is, England, Spain, Italy, Germany, and France. For the home advantage, the following variables were examined: distribution of matches outcomes and home advantage for points (also for previous seasons from the 2014–15 one); ball possession; total shots; shots on goal; and corner kicks. Instead, for the referee bias, the following variables were examined: fouls; yellow cards; red cards; penalty kicks; and extra time. Chi-square tests were used to compare the distribution of matches outcomes, and t-tests to compare home vs. away data for the other variables in the 2020–21 season; Bayesian and equivalence analyses were also conducted.

Results: The main results are as follows: (a) the distribution of matches outcomes in the 2020–21 season was significantly different from that of the last five complete seasons with spectators (Chi-square = 37.42, df = 2, p < 0.001), with fewer home victories and more away victories; the resulting values of the home advantage for points were 54.95% for the 2020–21 season, and 59.36% for the previous seasons; (b) for the other home advantage variables, a statistically significant overall advantage for the home team emerged; nevertheless, the strength of the differences between home and away teams was generally small (0.09 < Cohen’s d < 0.17), and the corresponding means can be considered statistically equivalent for all variables but the total shots; (c) no statistically significant differences emerged between home and away teams for any of the referee bias variables.
**Discussion:** These findings demonstrate that the absence of spectators significantly reduced the home advantage compared to previous seasons with spectators. A slight home advantage persisted in the 2020–21 season, probably due to other factors, namely, learning and travel, according to the model by Courneya & Carron (1992). Conversely, the referee bias was not observed, suggesting that it mainly derives from the pressure normally exerted by spectators.

**Subjects** Psychiatry and Psychology, Sports Injury, Sports Medicine  
**Keywords** Crowd, Football, Officials, Social pressure, Support

**INTRODUCTION**

In sport scientific literature, two phenomena have recently received a particular research attention: the *home advantage* and the *subconscious referee bias*. Such phenomena have a long research tradition, starting in the ‘70s with the study of Schwartz & Barsky (1977), and steadily continuing in the ‘80s (e.g., Pollard, 1986), ‘90s (e.g., Courneya & Carron, 1992), and in the new millennium (e.g., Carron, Loughhead & Bray, 2005; Dohmen & Sauermann, 2016; Jamieson, 2010; for a historical overview, see Gómez-Ruano & Pollard, 2022). These and other related studies have consistently documented that professional athletes/teams obtain significantly better results at home than away, also thanks to the more favorable treatment they receive from the referees/officials in the former case. In particular, the sport in which the two phenomena have been studied the most is association football, where the proportion of points won at home is normally higher than the proportion of points won away (Leite & Pollard, 2018; Pollard, 1986, 2006; Pollard & Gomez, 2009, 2014), and referees award fewer sanctions against the home team than against the away team (e.g., Goumas, 2014; Nevill, Balmer & Williams, 2002; Sutter & Kocher, 2004; Unkelbach & Memmert, 2010).

In addition to documenting the two phenomena, some researchers also proposed conceptual frameworks to try to explain their causes and the relations among them (see Courneya & Carron, 1992; Pollard, 2006; Pollard & Pollard, 2005). In this regard, Courneya and Carron suggested that the game location factors—crowd, learning, travel, and rules—affect the psychological and behavioral states of athletes, coaches and referees, which in turn influence the performance outcomes. Other studies tried to disentangle the relative “weight” of such factors, and especially that of crowd support, reasonably considered among the most influential ones. Normally, this was done by adopting one of three approaches: (a) analyzing the crowd size, proximity, and/or density (Buraiamo, Forrest & Simmons, 2010; Buraimo, Simmons & Maciaszczyk, 2012; Downward & Jones, 2007; Goumas, 2014; Page & Page, 2010); (b) studying a few “unusual matches” like those behind closed doors and/or the same-stadium derbies (Pettersson-Lidbom & Priks, 2010; Ponzo & Scoppa, 2018; van de Ven, 2011); (c) specifically for the referee bias, manipulating the crowd noise in laboratory settings (Balmer et al., 2007; Nevill, Balmer & Williams, 2002; Unkelbach & Memmert, 2010). Such studies—even those characterized by similar approaches—often yielded conflicting results.
The abovementioned particular attention recently received by the home advantage and the referee bias is due to the unfortunate pandemic situation, which is giving the unprecedented opportunity to study large samples of matches played with no or severely limited attendance, allowing for large-scale natural experiments on the effects of the absence of spectators support. An overview of the first studies conducted during the pandemic was provided by Lago-Peñas & Gómez-Ruano (2022), who observed a reduction of both phenomena. This observation was further confirmed in a systematic literature review by Leitner et al. (2022), who identified 26 studies that analyzed the last portion of the 2019–20 season, when all matches were played behind closed doors. Out of these 26 studies, only six did not observe a significant and consistent overall decrease of the home advantage and referee bias in the considered leagues (Almeida & Werlayne, 2021; Benz & Lopez, 2021; Krawczyk & Strawinski, 2020; Matos et al., 2021; Ramchandani & Millar, 2021; Wunderlich et al., 2021), while the other 20 ones did observe a significant decrease of these phenomena (Bryson et al., 2021; Correia-Oliveira & Andrade-Souza, 2021; Cross & Uhrig, 2020; Cueva, 2020; Dilger & Vischer, 2020; Endrich & Gesche, 2020; Ferraresi & Gucciardi, 2020, 2021; Fischer & Haucap, 2020; Hill & Van Yperen, 2021; Jimenez Sanchez & Lavin, 2021; Konaka, 2021; Leitner & Richlan, 2021a; Link & Anzer, 2021; McCarrick et al., 2021; Rotetta & Abate, 2021; Santana, Bettiga & Dellagranza, 2021; Scoppa, 2021; Sors et al., 2021; Tilp & Thaller, 2020). Considering exclusively the peer-reviewed, multi-leagues studies, they found that nine out of 13 studies observed such a decrease (Bryson et al., 2021; Correia-Oliveira & Andrade-Souza, 2021; Ferraresi & Gucciardi, 2020, 2021; Hill & Van Yperen, 2021; Jimenez Sanchez & Lavin, 2021; Leitner & Richlan, 2021a; McCarrick et al., 2021; Scoppa, 2021; Sors et al., 2021). Based on these findings, Leitner et al. (2022) conclude that spectators support significantly contributes to determine the outcome of matches in professional football.

As mentioned, these studies could only rely on a portion of the 2019–20 season; this means that the home/away schedule of the leagues was not balanced. Aware of this, the majority of the researchers considered several leagues, and included in the analyses some variables to control for the relative strength of the teams playing against each other (e.g., points per match ratio), thus ensuring the results an acceptable level of reliability and validity. Due to the continuation of the pandemic, the whole 2020–21 season took place under severe attendance restrictions, with the vast majority of matches played behind closed doors, and the remaining ones with limited attendance. This situation made it possible to replicate the previous studies, but with the important added value of having a fully balanced home/away schedule—and a higher number of matches—in the various leagues. In light of these considerations, the aim of the present study is to investigate whether—and in case how—the home advantage and the referee bias occurred in the domestic leagues during the complete 2020–21 season. Based on recent studies on matches behind closed doors, our hypotheses are: (a) a significant reduction of the home advantage with respect to previous seasons with spectators; (b) a slight occurrence of the home advantage (due to the permanence of learning and travel factors); and (c) no occurrence of the referee bias.
MATERIALS AND METHODS

Sample

The database for the present study was represented by all the 2020–21 regular season’s matches of the first and second divisions of the UEFA top five ranked countries—England, Spain, Italy, Germany, and France; the only matches that were excluded are the same-stadium derbies (six matches, all from the Italian first division) and those matches whose win was awarded by forfeit (two matches, one from the Italian second division and one from the French second division). The final sample consisted of 3,898 matches: 3,535 (90.7% of the sample) were played behind closed doors, that is, in total absence of spectators, while in the remaining 363 (9.3% of the sample) there was an average attendance of 2,937 ± 2,359 spectators. Moreover, matches outcomes were retrieved also for the last five complete seasons without attendance restrictions (i.e., from 2014–15 to 2018–19), as well as for the 2019–20 season (partially played without spectators).

Variables

The variables taken into consideration are reported in Table 1. Data collection was similar to Sors et al. (2021). In particular, as normally done in previous studies, the data were retrieved from the official websites of the leagues; data that were not available on these websites were retrieved from other trusted ones (e.g., bbc.com/sport and soccerway.com). To check for the reliability of the sources, the data of 200 random matches (i.e., 20 for each league) were retrieved from two different sources and compared between them; data were highly consistent (average r = 0.98).

Statistical analysis

The distribution of matches outcomes of the 2020–21 season was compared with the expected frequencies calculated based on the last five complete seasons without attendance restrictions (from 2014–15 to 2018–19) of the same leagues. In particular, we used the Chi-square test to evaluate statistically significant differences among the observed/expected counts of the three mutually exclusive outcomes—home victory, tie, away victory. Moreover, a set of Chi-square tests was carried out season by season to compare the distribution of the 2020–21 matches outcomes with those observed for each single season (from 2014–15 to 2018–19); this was done also for the 2019–20 season, separately for

---

### Table 1 Variables considered and their grouping.

| Group of variables         | Variables                                                                 |
|----------------------------|---------------------------------------------------------------------------|
| Home advantage variables   | Match outcome\(^a\), Home advantage for points\(^{ab}\), Goals scored, Ball possession (%), Total shots, Shots on goal, Corner kicks |
| Referee bias variables     | Fouls, Yellow cards\(^c\), Red cards\(^d\), Penalty kicks (against), Extra time\(^e\) |

Notes:

\(^a\) Also for previous seasons from the 2014–15 one.
\(^b\) Percentage of points earned by home teams out of the total number of points earned by both home and away teams (i.e., Pollard’s traditional method; Matos, Amaro & Pollard, 2020).
\(^c\) Both first and second yellow cards, issued against players on the pitch within the end of the match.
\(^d\) Both double-yellow and straight red cards, issued against players on the pitch within the end of the match.
\(^e\) Minutes of extra time played in the second half of matches whose result at 90’ had a difference of one goal.

\(^1\) In the same leagues, the average attendance in the five seasons before the pandemic (from 2014–15 to 2018–19) was of 20,851 spectators (source: transfermarkt.com).
matches with and without spectators. Based on the same data, we calculated the home advantage for points using the Pollard’s traditional method (Matos, Amaro & Pollard, 2020) for each season taken into consideration (and separating matches with and without spectators in the 2019–20 season).

As for the performance-related home advantage variables (goals scored, ball possession, total shots, shots on goal, and corner kicks) and the referee bias variables (fouls, yellow cards, red cards, penalty kicks, and extra time), we performed a paired sample t-test on Home and Away team’s data within each match for each variable. Preliminarily, distribution properties of each variable were inspected by computing asymmetry and kurtosis indices, along with the result of Kolmogorov–Smirnov tests for normality assumption ($p > 0.05$). Based on the expected direction of the effects, the t-tests were one-sided.

To quantify the extent to which the data are in favor of a null-hypothesis compared to the alternative hypothesis, we computed the null/alternative Bayes Factor (BF01). The Bayes Factor is a continuous likelihood-ratio statistical index, whose strength in supporting the null over the alternative hypothesis can be graded as follows: “Inconclusive” – BF01 = 0.33–3; “Substantial” – BF01 = 3–10; “Strong” – BF01 = 10–30; “Very strong” – BF01 = 30–100; and “Decisive” – BF01 >100 (Jarosz & Wiley, 2014; Morey & Rouder, 2018).

Furthermore, with very large sample sizes approaching the size of the population—in which theoretically any difference will be significant—statistical tests might have sufficient power to detect even tiny effects, often practically and theoretically irrelevant. In this connection, going further than the simple rejection of the null hypothesis of no effect, we tested for the presence of a meaningful effect, performing an equivalence analysis with the TOST procedure (Lakens, 2017; Lakens, 2018). A composite null hypothesis is formulated in this statistical approach, which states that a difference is at least as extreme as a threshold value expressed in standardized effect size. We used a small effect size (Cohen’s $d \pm 0.20$) for the equivalence benchmarks in this study. The alternative hypothesis $H_1$: ($-0.20 < d < 0.20$) of a true effect lying within the equivalence bounds, thus close enough to zero that the compared means can be considered practically similar, is set against the composite null hypothesis $H_0$: ($d \leq -0.20 \cup d \geq 0.20$) of a true effect large enough to be worth examining. It should be concluded that the observed values for the Home and Away teams are statistically equivalent if the composite null hypothesis can be rejected in two one-sided tests (TOST procedure).

As an additional set of analyses, to test for possible effects of Division and Country along with their interaction effect on Home advantage and Referee bias variables, we entered within-match differences as dependent variable into a $2 \times 5$ ANOVA model, with two between-matches factors: Division (two levels) and Country (five levels).

Statistical analyses of the present study were performed using R programming language (R Core Team, 2020).
RESULTS

The overall comparison for matches outcomes showed a statistically significant difference between the observed distribution in 2020–21 season and the expected frequencies calculated on the last five complete seasons without attendance restrictions (Chi-square = 37.42, df = 2, p < 0.001). Inspection of Pearson’s residuals within each cell showed that the observed frequency of home victories was significantly lower (z = −3.56, p < 0.001; 1/BF01 > 100, “Decisive” support to H1) and the observed frequency of away victories was significantly higher (z = 4.95, p < 0.001; 1/BF01 > 100, “Decisive” support to H1), compared to the expected distribution. The season by season analyses revealed a significant difference between the distributions of matches outcomes of the 2020–21 season and each season with spectators, but no difference with the portion of the 2019–20 season without spectators (see Table 2). The resulting values of the home advantage for points are 54.95% in the 2020–21 season, and 59.36% for the last five complete seasons without attendance restrictions; the home advantage values season by season are reported in Fig. 1.

The results for the performance-related home advantage variables and the referee bias variables are reported in Table 3. As for the home advantage variables, a statistically significant overall advantage for the home team emerged. Nevertheless, the strength of the differences between home and away teams was generally small (0.09 < Cohen’s d < 0.17), and the corresponding means can be considered statistically equivalent for all variables.

Table 2 Comparison between expected and observed frequencies of matches’ outcomes.

|            | Home victories | Ties   | Away victories | N  |
|------------|----------------|--------|----------------|----|
| 2020/21a   | 1,592          | 1,065  | 1,241          | 3,898 |
| 2019/20 (closed doors) | 349          | 216    | 276            | 841  |
| Standardized Pearson’s residuals (z) | 0.351 | −0.970 | 0.553 | χ²(2) = 0.97 |
| 2019/20 (open doors) | 1,235         | 794    | 832            | 2,861 |
| Standardized Pearson’s residuals (z) | 1.915 | 0.392 | −2.428 | χ²(2) = 6.33 |
| 2018/19    | 1,700          | 1,084  | 1,081          | 3,865 |
| Standardized Pearson’s residuals (z) | 2.802 | 0.714 | −3.721 | χ²(2) = 14.60 |
| 2017/18    | 1,782          | 1,062  | 1,144          | 3,988 |
| Standardized Pearson’s residuals (z) | 3.448 | −0.692 | −3.046 | χ²(2) = 13.62 |
| 2016/17    | 1,863          | 1,062  | 1,063          | 3,988 |
| Standardized Pearson’s residuals (z) | 5.256 | −0.692 | −5.059 | χ²(2) = 33.99 |
| 2015/16    | 1,747          | 1,131  | 1,110          | 3,988 |
| Standardized Pearson’s residuals (z) | 2.664 | 1.029 | −3.886 | χ²(2) = 15.45 |
| 2014/15    | 1,757          | 1,147  | 1,084          | 3,988 |
| Standardized Pearson’s residuals (z) | 2.888 | 1.423 | −4.533 | χ²(2) = 20.75 |

Notes:
a The 2020/21 season acts as a reference outcome for all subsequent seasons’ frequencies. The standardized Pearson residuals for the 2020/21 season are not reported because they are simply the reciprocal of those calculated in the comparative season. Values highlighted in bold are statistically significant (p-values < 0.05).
Figure 1 Home advantage for points season by season. The dashed line corresponds to the value observed in the 2020–21 season, to facilitate the comparison with the values of previous seasons. In the portion of the 2019–20 season behind closed doors, France is absent as both first and second divisions were not resumed after the lockdown.

Table 3 Statistical tests between home and away teams for home advantage and referee bias variables.

| Descriptive statistics | Paired t-tests |
|------------------------|---------------|
|                        | Home | Away | t  | df  | p   | ES | Bayes Factor (H_0/H_1) |
|                        | M    | SD  | M  | SD  |     |    |                       |
| Home advantage variables^a^ |      |      |    |      |     |    |                       |
| Goals scored           | 1.39 | 1.22 | 1.18 | 1.11 | 7.63 | 3,897 | *** | 0.12 | 0.00 | – |
| Ball possession (%)    | 50.88 | 10.26 | 49.12 | 10.26 | 5.36 | 3,897 | *** | 0.09 | 0.00 | – |
| Total shots            | 12.20 | 4.84 | 10.93 | 4.58 | 10.62 | 3,897 | *** | 0.17 | 0.00 | – |
| Shots on goal          | 4.36 | 2.51 | 3.86 | 2.27 | 8.94 | 3,897 | *** | 0.14 | 0.00 | – |
| Corner kicks           | 4.90 | 2.69 | 4.46 | 2.57 | 6.61 | 3,897 | *** | 0.11 | 0.00 | – |
| Referee bias variables^b^ |      |      |    |      |     |    |                       |
| Foul                   | 13.50 | 4.06 | 13.26 | 4.11 | 2.88 | 3,897 | n.s. | 0.05 | 401.36 | Decisive |
| Yellow cards           | 1.95  | 1.37 | 1.99 | 1.38 | −1.59 | 3,897 | n.s. | −0.03 | 15.13 | Strong |
| Red cards              | 0.09  | 0.30 | 0.11 | 0.33 | −1.96 | 3,897 | n.s. | −0.03 | 7.54 | Substantial |
| Penalty kicks (against)| 0.16  | 0.39 | 0.18 | 0.42 | −2.52 | 3,897 | n.s. | −0.04 | 2.11 | Inconclusive |
| Extra time^c^          | 5.14  | 1.29 | 5.31 | 1.45 | −2.44 | 1,484.1 | n.s. | −0.12 | 0.81 | Inconclusive |

Notes:
^a^ Calculated considering a one-sided null hypothesis. Expected positive Home-Away differences (Right tailed t-test).
^b^ Calculated considering a one-sided null hypothesis. Expected negative Home-Away differences (Left tailed t-test).
^c^ For this variable it was run an independent samples Welch’s t-test with adjusted degrees of freedom on the 1,567 matches whose result at 90’ had a difference of one goal (832 home team winning vs. 735 away team winning).
*** p < 0.001; n.s. = not significant.
Bayes Factor (H_0/H_1) = BF_{01}, Null/Alternative hypothesis likelihood ratio; ES = Effect Size, Cohen’s d; M = Mean; SD = Standard Deviation.
but the total shots (see Table 4 and Fig. 2). This variable, in particular, produced nonsignificant results on the TOST procedure’s upper bound (set to Cohen’s $d = 0.20$; see Fig. 2); thus, the equivalence test was nonsignificant, therefore it cannot be rejected the null hypothesis that the true effect size of the positive difference in total shots between home and away teams is small, at least.

As for the referee bias variables, there were no statistically significant differences between home and away teams for any of them, with substantial to decisive support to the null hypothesis for fouls, yellow cards, and red cards (see Table 3). For all variables, the means for home and away teams were statistically equivalent, with the only exception of extra time, where a negative small effect cannot be excluded (nonsignificant results on the lower bound set to Cohen’s $d \leq -0.20$; see Table 4 and Fig. 2).

The results of the additional set of analyses for Division and Country showed no main effects of Division (all $p$ values $\geq 0.069$, and all BF01 $\geq 6.39$) nor any interaction with Country (all $p$ values $\geq 0.262$, and all BF01 $> 100$) for all the Home advantage and Referee bias variables. As for the Country, statistically significant main effects emerged only for Corner kicks ($F(4,3888) = 2.66, p = 0.031$), Fouls ($F(4,3888) = 3.75, p = 0.005$), and Penalty kicks ($F(4,3888) = 3.80, p = 0.004$); however, although significant, the differences among countries were not supported by the Bayes factors (Corner kicks BF01 = 174.56, “Decisive” support to H0; Fouls BF01 = 13.38, “Strong” support to H0; Penalty kicks BF01 = 18.41, “Strong” support to H0).

### Table 4 Two one-sided tests – TOST results for statistical equivalence.

|                   | Lower bound H0: $d \leq -0.20$ vs. H1: $d > -0.20$ | Upper bound H0: $d \geq 0.20$ vs. H1: $d < 0.20$ | Statistical equivalence |
|-------------------|--------------------------------------------------|--------------------------------------------------|--------------------------|
| **Home advantage variables** |                                                  |                                                  |                          |
| Goals scored      | $t = 20.12$ (df = 3,897)**                        | $t = -4.85$ (df = 3,897)**                       | X                        |
| Ball possession (%)| $t = 17.85$ (df = 3,897)**                        | $t = -7.12$ (df = 3,897)**                       | X                        |
| Total shots       | $t = 23.10$ (df = 3,897)**                        | $t = -1.87$ (df = 3,897) n.s.                    | X                        |
| Shots on goal     | $t = 21.43$ (df = 3,897)**                        | $t = -3.55$ (df = 3,897)**                       | X                        |
| Corner kicks      | $t = 19.10$ (df = 3,897)**                        | $t = -5.87$ (df = 3,897)**                      | X                        |
| **Referee bias variables** |                                                  |                                                  |                          |
| Fouls             | $t = 15.37$ (df = 3,897)**                        | $t = -9.60$ (df = 3,897)**                       | X                        |
| Yellow cards      | $t = 10.90$ (df = 3,897)**                        | $t = -14.08$ (df = 3,897)**                     | X                        |
| Red cards         | $t = 10.52$ (df = 3,897)**                        | $t = -14.45$ (df = 3,897)**                     | X                        |
| Penalty kicks (against) | $t = 9.96$ (df = 3,897)**                      | $t = -15.01$ (df = 3,897)**                     | X                        |
| Extra time        | $t = 1.49$ (df = 1,484.1) n.s.                    | $t = -6.38$ (df = 1,484.1)                      |                          |

Notes:
- **p < 0.01.**
- ***p < 0.001; n.s. = not significant.

The statistical equivalence criterion is met when the composite null hypothesis $H_0: (d \leq -0.20 \ U d \geq 0.20)$ can be rejected in two one-sided tests, in which the null hypothesis is the presence of a true effect, defined by standardized differences (Cohen’s $d$) of $d \leq -0.20$ (Lower Bound) or $d \geq 0.20$ (Upper Bound), and the alternative hypothesis is the absence of an effect larger than these equivalence bounds.
In the present study, we examined the statistics of a complete football season with attendance restrictions due to the COVID-19 pandemic, in order to investigate how the absence of spectators influence the home advantage and the subconscious referee bias in the first and second divisions of the top five ranked European countries. Based on previous studies, we hypothesized a significant reduction of the home advantage with respect to previous seasons with spectators, a slight occurrence of the home advantage (due to the permanence of learning and travel factors), and no occurrence of the referee bias. The results support our hypotheses, providing more solid empirical evidence to the results initially observed in the 2019/20 season after the interruption because of the pandemic.

The majority of studies conducted on the 2019/20 season suggests a reduction – but not the elimination – of the home advantage (e.g., Bryson et al., 2021; Hill & Van Yperen, 2021; Jimenez Sanchez & Lavin, 2021; McCarrick et al., 2021; Scoppa, 2021; Sors et al., 2021), with some exceptions in which no reduction was found (e.g., Almeida & Werlayne, 2021), or—at the other extreme—no home advantage was observed at all (e.g., Tilp &

**Figure 2** Illustration of the TOST test for home advantage and referee bias variables. The plot shows the observed mean differences, 95% confidence interval bars, and the equivalence bounds expressed in raw scores units. If the 95% confidence interval does not include the equivalence bounds, statistical equivalence is reached.

Full-size DOI: 10.7717/peerj.13681/fg-2
Thaller, 2020). These apparently conflicting results can be attributed to the different leagues examined, to the unbalanced home/away schedule of the matches considered in the analyses (as only a portion of the season was played behind closed doors), and to the relatively limited number of matches. In the present study, we tried to overcome these issues, analyzing almost 4,000 matches from 10 complete leagues from five different countries. In accordance with the majority of previous studies, our results confirm a reduction of the home advantage. Similar to Sors et al. (2021), we found that the home-away difference of gained points decreases from around 20% points (roughly 60–40% with spectators) to around 10% points (roughly 55–45% with attendance restrictions). As for the performance-related home advantage variables, the analyses revealed significant differences in favor of the home teams also in absence of spectators, however these differences are mainly due to the large sample size. Indeed, the TOST analyses revealed meaningless effect sizes for four out of five variables, with the exception of total shots, for which a small effect size was observed and the statistical equivalence hypothesis was rejected. Overall, the results indicate that, in absence of spectators, the advantage for the home teams is reduced, however a certain degree of home advantage still persists.

Among the factors driving the home advantage, in normal conditions the referee bias plays an important role. However, the absence of spectators seems to eliminate this bias, with a substantial to decisive evidence in favor of null effects for fouls, yellow and red cards, and less clear results (but still non-significant home-away differences) for penalties and extra time. Similar to previous studies on matches behind closed doors (e.g., Bryson et al., 2021; Hill & Van Yperen, 2021; McCarrick et al., 2021; Scoppa, 2021; Sors et al., 2021), the absence of the social pressure normally exerted by spectators seems to influence referees in a positive way, making them fairer and less prone to make disparities between home and away teams. Consequently, the absence of referee bias is likely to contribute to the reduction of the home advantage observed when comparing matches with and without spectators, while the remaining quota of home advantage still observed in matches with attendance restrictions should be explained as the consequence of other factors.

The factors determining the home advantage have been summarized by Courneya & Carron (1992). According to their model, the game location factors (crowd, learning, travel, and rules) would affect the critical psychological states of competitors, coaches and officials, and consequently their behaviors and performances. Applying this model to our study, it is reasonable to hypothesize that the absence of the crowd—which would determine an absence of support for the home teams and a reduced pressure for the away teams—affect the psychological states of players and coaches (empirical support to this hypothesis was recently provided by Leitner & Richlan, 2021b). Similarly, the absence of pressure exerted by the crowd would influence the psychological states of the referees as well. Consequently, the critical behaviors of home and away teams’ members would be negatively vs. positively affected by crowd absence, respectively; in addition, the behavior (i.e., decisions) of the referees would be fairer (thus less advantageous for the home teams). Then, the combination of these effects would determine a reduction of the home advantage in absence of spectators, compared to regular matches with spectators. Notably, the
remaining quota of home advantage in matches behind closed doors is not surprising and should be attributed to the other game location factors described in the model, in particular learning and travel. This is consistent with the observation that in national teams matches—in which learning and travel factors are comparable for home and away players—the home advantage disappears in absence of spectators (Sors et al., in press).

When investigating for potential effects of country and league level (first vs. second division), no meaningful differences emerged for any of the home advantage and referee bias variables included in the study. This indicates that the observed results are quite stable among the investigated countries, as well as between the first and second divisions within them. Although these results seem quite reliable, their validity cannot be generalized to all countries. Indeed, the present study focused on a limited number of countries, and future studies should therefore investigate the same phenomena also in different ones. In this regard, it would be of particular interest to examine whether similar effects occurred also in other continents, as well as in specific regions such as the Balkan area, where it is known that the home advantage is higher than the average (e.g., Pollard & Gomez, 2014).

A limitation of the present study is that a direct comparison with previous seasons was made exclusively for the distribution of matches outcomes, but not for the performance-related and referee bias variables; future studies should consider extending the comparison also to these variables, to gain further insights on the two phenomena. Another limitation of the study is that it consists in a “natural experiment”, which did not allow to control/manipulate the variables. Indeed, there was a small number of matches with a (very) limited attendance. We decided to include all matches in the analyses, as it was fundamental to have a fully balanced home/away schedule; we cannot exclude that the results may be even stronger excluding matches with a limited attendance. Another variable that was not possible to control is the video assistant referee (VAR). Indeed, during the period analyzed in the present study, the VAR was introduced in different seasons depending on the country/league (and French second division does not have it yet). Although we did not compare the referee bias in matches with and without attendance restrictions, we cannot exclude that, when comparing the home advantage in matches with and without such restrictions, the referee bias might have differently contributed to the home advantage depending on the absence/presence of the VAR. Finally, the expression “referee bias”, although normally used to describe the favoritism of referees towards the home teams, might also reflect the behaviors of home and away players in presence of spectators (e.g., more offensive attitude of home players, aggressive reaction of away players to booing). Thus, the observed absence of the referee bias in matches with attendance restrictions might be due not only to the absence of social pressure on the referees (Sors et al., 2019; Unkelbach & Memmert, 2010), but also to potential differences in players’ behaviors.

The results of the present study further highlights the relevant contribution of spectators to matches outcomes. From a practical perspective, football clubs should be aware of the significant impact of their fans, and should therefore adopt effective marketing strategies to maximize—obviously net of restrictions—the attendance at the home venue (e.g., discounts for bringing a friend/relative). Moreover, other strategical initiatives could be...
proposed to motivate fans to attend also away matches (e.g., free/discounted transportation), in order to at least partially contrast the influence of the opposite fans.

**CONCLUSIONS**

In conclusion, the COVID-19 pandemic and its related restrictions gave us the chance to investigate how the absence of spectators modify the outcomes of football matches, as well as performance parameters and referees’ behaviors. In normal conditions, the home teams have a clear advantage due to several factors, including the support of their fans and the referee bias in their favor. Our findings demonstrate that the absence of spectators significantly reduces the home advantage and eliminates the referee bias, providing more solid evidence compared to previous literature. The persistence of the home advantage—although significantly reduced—indicates that other factors such as the familiarity with local conditions and the travel fatigue play an important role and somehow influence the players’ behavior and the subsequent outcomes. Conversely, the absence of referee bias suggests that it mainly derives from the pressure normally exerted by spectators.

**ACKNOWLEDGEMENTS**

We thank Silvano Suban, Alberto Mariconda, Filippo Maria Bernardi, Valnea Glavaš, Giorgia Scheriani, Nicolaus Pagnanelli, Jessica Mecchia, Sara Veritti, Dena Riva, Emma Benini, and Marco Pedronetto for their precious contribution to data collection.

**ADDITIONAL INFORMATION AND DECLARATIONS**

**Funding**

The authors received no funding for this work.

**Competing Interests**

Fabrizio Sors is an Academic Editor for PeerJ.

**Author Contributions**

- Fabrizio Sors conceived and designed the experiments, performed the experiments, prepared figures and/or tables, authored or reviewed drafts of the article, and approved the final draft.
- Michele Grassi conceived and designed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the article, and approved the final draft.
- Tiziano Agostini conceived and designed the experiments, authored or reviewed drafts of the article, and approved the final draft.
- Mauro Murgia conceived and designed the experiments, authored or reviewed drafts of the article, and approved the final draft.

**Data Availability**

The following information was supplied regarding data availability:
The raw data is available in the Supplemental File.

Supplemental Information
Supplemental information for this article can be found online at http://dx.doi.org/10.7717/peerj.13681#supplemental-information.

REFERENCES
Almeida CH, Werlayne SL. 2021. Professional football in times of COVID-19: did the home advantage effect disappear in European domestic leagues? Biology of Sport 38(4):693–701 DOI 10.5114/biolsport.2021.104920.

Balmer NJ, Nevill AM, Lane AM, Ward P, Williams AM, Fairclough SH. 2007. Influence of crowd noise on soccer refereeing consistency in soccer. Journal of Sport Behavior 30(2):130–145.

Benz LS, Lopez MJ. 2021. Estimating the change in soccer’s home advantage during the COVID-19 pandemic using bivariate Poisson regression. AStA–Advances in Statistical Analysis 66(2):6 DOI 10.1007/s10182-021-00413-9.

Bryson A, Dolton P, Reade JJ, Schreyer D, Singleton C. 2021. Causal effects of an absent crowd on performances and refereeing decisions during COVID-19. Economics Letters 198(6):109664 DOI 10.1016/j.econlet.2020.109664.

Buraimo B, Forrest D, Simmons R. 2010. The 12th man? Refereeing bias in English and German soccer. Journal of the Royal Statistical Society: Series A (Statistics in Society) 173(2):431–449 DOI 10.1111/j.1467-985X.2009.00604.x.

Buraimo B, Simmons R, Maciaszczyk M. 2012. Favoritism and referee bias in European soccer: evidence from the Spanish League and the UEFA Champions League. Contemporary Economic Policy 30(3):329–343 DOI 10.1111/j.1465-7287.2011.00295.x.

Carron AV, Loughhead TM, Bray SR. 2005. The home advantage in sport competitions: Courneya and Carron’s, 1992 conceptual framework a decade later. Journal of Sports Sciences 23(4):395–407 DOI 10.1080/02640410400021542.

Correia-Oliveira CR, Andrade-Souza VA. 2021. Home advantage in soccer after the break due to COVID-19 pandemic: does crowd support matter? International Journal of Sport and Exercise Psychology 25(1):1–12 DOI 10.1080/1612197X.2021.1934716.

Courneya KS, Carron AV. 1992. The home advantage in sport competitions: a literature review. Journal of Sport and Exercise Psychology 14(1):13–27 DOI 10.1123/jsep.14.1.13.

Cross J, Uhrig R. 2020. Do fans impact sports outcomes? A COVID-19 natural experiment. SSRN Electronic Journal 7(2):181 DOI 10.2139/ssrn.3705085.

Cueva C. 2020. Animal spirits in the beautiful game: testing social pressure in professional football during the COVID-19 lockdown. Available at https://osf.io/hczkj/.

Dilger A, Vischer L. 2020. No home bias in ghost games. EconStor–Discussion Paper of the Institute for Organisational Economics, No. 7/2020, Westfälische Wilhelms-Universität Münster. Available at http://hdl.handle.net/10419/223208.

Dohmen T, Sauermann J. 2016. Referee bias. Journal of Economic Surveys 30(4):679–695 DOI 10.1111/joes.12106.

Downward P, Jones M. 2007. Effects of crowd size on referee decisions: analysis of the FA Cup. Journal of Sports Sciences 25(14):1541–1545 DOI 10.1080/02640410701275193.

Endrich M, Gesche T. 2020. Home-bias in referee decisions: evidence from ghost matches during the COVID-19-pandemic. Economics Letters 197(3–4):109621 DOI 10.1016/j.econlet.2020.109621.
Ferraresi M, Gucciardi G. 2020. Team performance and audience: experimental evidence from the football sector. Available at https://EconPapers.repec.org/RePEc:ipu:wpaper:94.

Ferraresi M, Gucciardi G. 2021. Who chokes on a penalty kick? Social environment and individual performance during COVID-19 times. Economics Letters 203(5):109868 DOI 10.1016/j.econlet.2021.109868.

Fischer K, Haucap J. 2020. Does crowd support drive the home advantage in professional soccer? Evidence from German ghost games during the COVID-19 Pandemic. EconStor – DICE Discussion Papers, No. 344 (2020), Düsseldorf Institute for Competition Economics (DICE). Available at http://hdl.handle.net/10419/222278.

Goumas C. 2014. Home advantage and referee bias in European football. European Journal of Sport Science 14(Suppl. 1):S243–S249 DOI 10.1080/17461391.2012.686062.

Gómez-Ruano MA, Pollard R. 2022. The home advantage phenomenon in sport: history and development. In: Gómez-Ruano MA, Pollard R, Lago-Peñas C, eds. Home Advantage in Sport: Causes and the Effect on Performance. New York: Routledge, 3–12.

Hill Y, Van Yperen NW. 2021. Losing the home field advantage when playing behind closed doors during COVID-19: change or chance? Frontiers in Psychology 12:658452 DOI 10.3389/fpsyg.2021.658452.

Jamieson JP. 2010. The home field advantage in athletics: a meta-analysis. Journal of Applied Social Psychology 40(7):1819–1848 DOI 10.1111/j.1559-1816.2010.00641.x.

Jarosz AF, Wiley J. 2014. What are the odds? A practical guide to computing and reporting Bayes factors. The Journal of Problem Solving 7(1):2–9 DOI 10.7771/1932-6246.1167.

Jimenez Sanchez A, Lavin JM. 2021. Home advantage in European soccer without crowd. Soccer & Society 22(1–2):152–165 DOI 10.1080/14660970.2020.1830067.

Konaka E. 2021. Home advantage of European major football leagues under COVID-19 pandemic. Available at https://arxiv.org/abs/2101.00457v2.

Krawczyk M, Strawinski P. 2020. Home advantage revisited. Did COVID level the playing fields? Available at https://EconPapers.repec.org/RePEc:war:wpaper:2020-36.

Lago-Peñas C, Gómez-Ruano MA. 2022. How does playing without an audience affect the home advantage? In: Gómez-Ruano MA, Pollard R, Lago-Peñas C, eds. Home Advantage in Sport: Causes and the Effect on Performance. New York: Routledge, 85–95.

Lakens D. 2017. Equivalence tests: a practical primer for t tests, correlations, and meta-analyses. Social Psychological and Personality Science 8(4):355–362 DOI 10.1177/1948550617697177.

Lakens D. 2018. Two one-sided tests (TOST) equivalence testing. Version 0.3.4 [software]. Available at https://CRAN.R-project.org/package=TOSTER.

Leite W, Pollard R. 2018. International comparison of differences in home advantage between level 1 and level 2 of domestic football leagues. German Journal of Exercise and Sport Research 48(2):271–277 DOI 10.1007/s12662-018-0507-2.

Leitner MC, Daumann F, Follert F, Richlan F. 2022. The cauldron has cooled down: a systematic literature review on home advantage in football during the COVID-19 pandemic from a socio-economic and psychological perspective. Management Review Quarterly 25(1–2):53 DOI 10.1007/s11301-021-00254-5.

Leitner MC, Richlan F. 2021a. No fans-no pressure: referees in professional football during the COVID-19 pandemic. Frontiers in Sports and Active Living 3:720488 DOI 10.3389/fspor.2021.720488.
Leitner MC, Richlan F. 2021b. Analysis system for emotional behavior in football (ASEB-F): matches of FC Red Bull Salzburg without supporters during the COVID-19 pandemic. *Humanities and Social Sciences Communications* 8(1):14 DOI 10.1057/s41599-020-00699-1.

Link D, Anzer G. 2021. How the COVID-19 pandemic has changed the game of soccer. *International Journal of Sports Medicine* 43(1):83–93 DOI 10.1055/a-1518-7778.

Matos R, Amaro N, Pollard R. 2020. How best to quantify home advantage in team sports: an investigation involving male senior handball leagues in Portugal and Spain. *RICYDE–Revista Internacional de Ciencias del Deporte* 16(59):12–23 DOI 10.5232/ricyde2020.05902.

Matos R, Monteiro D, Antunes R, Mendes D, Botas J, Clemente J, Amaro N. 2021. Home-advantage during COVID-19: an analysis in Portuguese football league. *International Journal of Environmental Research and Public Health* 18(7):3761 DOI 10.3390/ijerph18073761.

McCarrick D, Bilalic M, Neave N, Wolfson S. 2021. Home advantage during the COVID-19 Pandemic: analyses of European football leagues. *Psychology of Sport and Exercise* 56(1):102013 DOI 10.1016/j.psychsport.2021.102013.

Morey RD, Rouder JN. 2018. BayesFactor: computation of Bayes factors for common designs. R package. Version 0.9.12-4.2. [Available at](https://CRAN.R-project.org/package=BayesFactor).

Nevill AM, Balmer NJ, Williams AM. 2002. The influence of crowd noise and experience upon refereeing decisions in football. *Psychology of Sport and Exercise* 3(4):261–272 DOI 10.1016/S1469-0292(01)00033-4.

Page K, Page L. 2010. Alone against the crowd: individual differences in referees’ ability to cope under pressure. *Journal of Economic Psychology* 31(2):192–199 DOI 10.1016/j.joep.2009.08.007.

Pettersson-Lidbom P, Prik M. 2010. Behavior under social pressure: empty Italian stadiums and referee bias. *Economics Letters* 108(2):212–214 DOI 10.1016/j.econlet.2010.04.023.

Pollard R. 1986. Home advantage in soccer: a retrospective analysis. *Journal of Sports Sciences* 4(3):237–248 DOI 10.1080/02640418608732122.

Pollard R. 2006. Home advantage in soccer: variations in its magnitude and a literature review of the inter-related factors associated with its existence. *Journal of Sport Behavior* 29(2):169–189.

Pollard R, Gomez MA. 2009. Home advantage in football in South-West Europe: long-term trends, regional variation, and team differences. *European Journal of Sport Science* 9(6):341–352 DOI 10.1080/17461390903009133.

Pollard R, Gomez MA. 2014. Components of home advantage in 157 national soccer leagues worldwide. *International Journal of Sport and Exercise Psychology* 12(3):218–233 DOI 10.1080/1612197X.2014.888245.

Pollard R, Pollard G. 2005. Home advantage in soccer: a review of its existence and causes. *International Journal of Soccer and Science* 3(1):28–44.

Ponzo M, Scoppa V. 2018. Does the home advantage depend on crowd support? Evidence from same-stadium derbies. *Journal of Sports Economics* 19(4):562–582 DOI 10.1177/1527002516665794.

R Core Team. 2020. *R: a language and environment for statistical computing*. Vienna: The R Foundation for Statistical Computing. [Available at](https://www.R-project.org/).

Ramchandani G, Millar R. 2021. Investigating the “Twelfth Man” effect in five European domestic football leagues: a COVID-19 induced natural experiment. *Journal of Global Sport Management* 36(6):1–15 DOI 10.1080/24704067.2021.1951614.

Rovetta A, Abate A. 2021. The impact of cheering on sports performance: comparison of serie a statistics before and during COVID-19. *Cureus* 13(8):e17382 DOI 10.7759/cureus.17382.
Santana HAP, Bettega OB, Dellagrana RA. 2021. An analysis of Bundesliga matches before and after social distancing by COVID-19. *Science and Medicine in Football* 5(Suppl. 1):17–21 DOI 10.1080/24733938.2021.1903540.

Schwartz B, Barsky SF. 1977. The home advantage. *Social Forces* 55(3):641–661 DOI 10.2307/2577461.

Scoppa V. 2021. Social pressure in the stadiums: do agents change behavior without crowd support? *Journal of Economic Psychology* 82(4):102344 DOI 10.1016/j.joep.2020.102344.

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. *European Journal of Sport Science* 21(12):1597–1605 DOI 10.1080/17461391.2020.1845814.

Sors F, Grassi M, Agostini T, Murgia M. 2021. The influence of spectators on home advantage and referee bias in national teams matches: insights from UEFA Nations League. *International Journal of Sport and Exercise Psychology* (in press) 30(2):1–16 DOI 10.1080/1612197X.2022.2044367.

Sors F, Tomé Lourido D, Parisi V, Santoro I, Galmonte A, Agostini T, Murgia M. 2019. Pressing crowd noise impairs the ability of anxious basketball referees to discriminate fouls. *Frontiers in Psychology* 10:2380 DOI 10.3389/fpsyg.2019.02380.

Sutter M, Kocher MG. 2004. Favoritism of agents—the case of referees’ home bias. *Journal of Economic Psychology* 25(4):461–469 DOI 10.1016/S0167-4870(03)00013-8.

Tilp M, Thaller S. 2020. COVID-19 has turned home-advantage into home-disadvantage in the German Soccer Bundesliga. *Frontiers in Sports and Active Living* 2:593499 DOI 10.3389/ispor.2020.593499.

Unkelbach C, Memmert D. 2010. Crowd noise as a cue in referee decisions contributes to the home advantage. *Journal of Sport and Exercise Psychology* 32(4):483–498 DOI 10.1123/jsep.32.4.483.

van de Ven N. 2011. Supporters are not necessary for the home advantage: evidence from same-stadium derbies and games without an audience. *Journal of Applied Social Psychology* 41(12):2785–2792 DOI 10.1111/j.1559-1816.2011.00865.x.

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 DOI 10.1371/journal.pone.0248590.