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The impact of differing audience sizes on referees and team performance from a North American perspective

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ABSTRACT

The COVID-19 pandemic provides a natural experimental framework to comprehensively test the effect of crowds on both referees and players. We examine this from a North American perspective, using data from three major leagues: the National Basketball Association (NBA), National Football League (NFL) and National Hockey League (NHL). In all three leagues in the 2020–2021 season, matches were played either in empty stadiums or before diverse audience sizes. We find that the lockdown affects NBA and NFL results, by lowering the prospects of winning and the expected scoring points of the home team, when games are played without an audience. Conversely, the lockdown does not substantially influence the outcomes of NHL games. We also examine the effect of audience size on game outcomes using historical observations from the past decade, when no lockdown measures were in force. Interestingly, a larger audience size increases the chance of winning and the expected scoring points of the visiting team for NFL games. No significant effect of the audience size on match outcomes is observed for NBA or NHL games. Regarding referee decisions, spectators do not significantly influence referee calls of NHL matches. As for NBA and NFL, the lockdown significantly increases the total number of referee calls but does not prompt more biased decisions towards either of the teams. Finally, a larger audience leads to referee calls more favourable to the visiting team for NFL games. These results extend the literature regarding crowd pressure on the behaviour of players and officials, with an indication that the specific sports activity has a pivotal role in the response to a cheering audience.

1. Introduction

An individual's decision-making is affected by social forces, according to psychologists, economists, and social scientists (Akerlof & Kranton, 2000; Becker & Murphy, 2009; Bernheim, 1994). As social groups often penalize individuals who flout social norms, decision-making can be biased by a crowd. Therefore, most people follow conformist behaviour to gain necessary social acceptance.

The prevalence of biased behaviour has already been extensively studied in the context of different sports before the emergence of the COVID-19 pandemic. Particularly for professional soccer, Garicano et al. (2005) and Dawson et al. (2007) have claimed that referees systematically favour the home team by making biased decisions due to the presence of a supporting crowd. This notion can be supported by the phenomenon of referees being subconsciously affected by the cheering crowd, leading them to satisfy the supporters of the home team. These studies argue that referee bias in soccer is observable in terms of stoppage time, penalties awarded, and yellow or red cards. Boyko et al. (2007) in particular showed that in the English Premier League football, even the crowd size affects referee decisions, through the award of significantly fewer yellow cards to the home team when the crowds are large. In related research, Unkelbach and Memmert (2010) asserted that in German Bundesliga games, crowd density correlates with the magnitude of referee bias. Buraimo et al. (2010) considered the effect of playing in stadiums with or without a running track for German Bundesliga games and found that playing in stadiums with a running track increases the number of referee calls sanctioned to the home team. In a pre-COVID-19 study, Pettersson-Lidbom and Priks (2010) also considered one-off games when soccer matches were played behind closed doors, finding that referees make much fairer decisions under this special circumstance. Due to the small sample size (21 games), it is unclear whether the driver behind the findings is the unfamiliarity with the events or the removal of social pressure. This study has been extended by Reade et al. (2020b), who analyzed 160 games from the beginning of the 2002/03 European season until the emergence of COVID-19, revealing that referees cautioned visiting teams significantly less often behind closed doors; they also found that playing behind closed doors did not significantly lower the match scores of the home and away teams. Due to

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an unusual event when the Argentinian government banned supporters of the visiting team in August 2013 from first division games, Colella et al. (2021) examined 591 soccer games where only home supporters were allowed to be in the stadiums. They discovered that the visiting teams' winning chances were reduced by about 20% without their supporters; nonetheless, this ban did not significantly influence referees' decisions. Regarding other popular sports in North America, Price and Wolfers (2010) suggested the existence of referee bias based on racial discrimination for the NBA[1], while Levitt (2002) argued that adding a second referee for NHL[2] games has little impact on the probability of detecting offenses.

After the emergence of the COVID-19 pandemic, a large number of papers exploited the natural experiment offered by the COVID-19 regulations that limited or banned fans from attending matches and extensively examined possible deviations, compared to pre-COVID-19 games. These papers aimed to investigate the effects of crowd support on the performance of the home and visiting teams and the decision-making of the referees. In the process, they could also contribute to the large literature on home advantage. Home advantage refers to the widely accepted and well-documented phenomenon of teams performing substantially better in sports leagues when playing at the home court, compared to being the visiting team (Courneya & Carron, 1992). The possible reasons for home advantage have been debated (Pollard, 2008). Three potential reasons have been proposed: crowd support, familiarity, and travel fatigue. Before the emergence of the COVID-19 pandemic, researchers had only a limited sample of games to examine the underlying reasons due to the lack of controlled environments where attendance at sports events is restricted. The advent of the COVID-19 pandemic therefore also yields the unique opportunity to better understand the mechanism behind home advantage by investigating the extent of social pressure on referees and players on a large scale. Considering soccer matches in different European leagues, the causal effect of crowd absence on referee bias and home-court advantage has been investigated *inter alia* by Cueva (2020), Bryson et al. (2021), Scoppa (2021), McCarrick et al. (2021), Reade et al. (2020a) and Benz and Lopez (2021). The methodology and the considered dataset of these papers reveal some variation; consequently, the results of these papers are mixed. Some of these papers (Cueva, 2020; Reade et al., 2020a) provide empirical evidence of home advantage dropping significantly behind closed doors, besides referee decisions being much more balanced without a crowd and significantly fewer cards being awarded to the away team in empty stadiums. Bryson et al. (2021) concluded that the absence of crowd has no effect on the final match score-lines, but away teams are still sanctioned with significantly fewer cards. Benz and Lopez (2021) point to substantial heterogeneity in the 17 considered professional soccer leagues; in some leagues, home advantage significantly decreases without fans, whereas in some others, it might have actually risen without supporters. McCarrick et al. (2021) argued that referee bias might actually be more intricate than previously examined and the defensive or offensive style of the teams are important factors to be considered and when controlling for the attacking dominance of the teams, referee bias is diluted. On a related note, Dagaev et al. (2021) found evidence that the nationality of the referees and the two teams also influences referee bias.

To our knowledge, the present paper is a pioneering effort to comprehensively examine the relation of home advantage and attendance size, considering three North American (NFL[3], NBA, NHL) sports leagues, including referee calls. The rationale of this research is to assess how the findings of studies concerning European football translate to other globally popular sports. Through this study, we also aim to compare the fairness of sports in terms of the magnitude of potential referee bias; we also seek to understand the extent of the home advantage that can be attributed to the presence of fans in different sports activities. Compared to soccer, the literature on other sports, considering post-COVID-19 games, is relatively scarce. McHill and Chinoy (2020) studied NBA games from the perspective of travel impact on teams' performances. They claimed that without having to travel for the visiting team, the home teams' winning percentage is significantly lower, compared to normal matches. It should be acknowledged though that this paper does not consider any heterogeneities among the matches. Higgs and Stavness (2021), focusing on NFL, NBA, NHL, and Major League Baseball, used a Bayesian type Negative binomial regression model to estimate the game results by considering the relative team strength. They asserted that for NBA and NHL games, the home advantage was significantly hindered during the playoffs in the COVID-19-afflicted seasons, whereas for NFL, there was no significant difference of home advantage in the COVID-19 afflicted seasons, *vis-a-vis* normal seasons. Losak and Sabel (2021) compared the 2019 and 2020 Major League Baseball seasons and found no statistically significant difference in the magnitude of home advantage between the two seasons. None of the previous papers considered referee calls.

The objective of this study is two-fold. We aim to answer the following two research questions:

- *RQ1*: Does lockdown have a statistically significant effect on the magnitude of home advantage and the referee decisions, for NBA, NHL, and NFL?
- *RQ2*: In general, does the natural variation of audience size statistically affect the magnitude of home advantage and the referee decisions for NBA, NHL, and NFL significantly?

Considering the referee calls and match outcomes, and controlling for several variables, we will conduct a comprehensive study by analysing the corresponding NFL, NBA, and NHL games from Season 2011–2012.

The rest of the paper is organised as follows. In Section 2, we discuss the data for the three sports leagues and present descriptive statistics. In Section 3, we detail our methods and show the corresponding results. In Section 4, we conclude. The appendix contains some complementary results that strengthen the robustness of the findings.

2. Material and methods

In this work, we examined three major North American professional sports leagues, namely the NBA, NFL, and NHL. We consider observations from the beginning of Season 2011–2012 till the end of Season 2020–2021. This comprises 12581 NBA games, 2672 NFL games, and 12279 NHL games. To answer *RQ1,* we included only games from the last one, two, or three seasons in the analysis, whereas to answer *RQ2,* we included games from all ten seasons with a positive recorded attendance. We treated the analysis separately for the three different sports. To perform this study, we focused on match outcomes along with the points scored by the two teams and match attendance. We also examined referee calls in terms of penalties sanctioned to the home and away teams.

The NBA match outcomes along with the size of the audience were sourced from www.basketball-reference.com and NBA penalty data for both teams for all the games from www.nba.com/stats/teams/boxscores. The NFL match outcomes along with the size of the audience were taken from www.pro-football-reference.com and NFL penalty data for both teams for all the games from www.nflpenalties.com. The NHL match outcomes along with the size of the audience and penalty data were sourced from www.hockey-reference.com. As indicated, we used two sources for NBA and NFL leagues to gather all the necessary data. Once all data were extracted, we merged the two sources to obtain a unique data frame containing all the variables for each game. Regarding NHL, we extracted data from multiple tables from the same

[1] NBA: National Basketball Association
[2] NHL: National Hockey League
[3] NFL: National Football League

website, again needing to merge different sources. All data manipulation and subsequent work were performed through software R. We checked that no matches were missing from the samples of the three considered leagues. The dataset obtained for each of the three leagues is available online at https://github.com/davidzoltanszabo/NorthAmericanHomeAdvantage. Attendance data is precisely reported for all the considered games, but as a caveat, as Schreyer (2019) pointed out, and as discussed by Reade and Singleton (2021), and Reade et al. (2021), there can be differences between the actual and reported attendances. To the best of our knowledge, attendance data reflect the tickets sold for all three considered sports, and many fans may occasionally choose not to use their tickets purchased in advance. This behaviour might have been more prevalent at the beginning of the COVID-19 outbreak, as both NHL and NBA were halted on 11 March 2020. Nonetheless, as we have no data available on the difference between the tickets sold and people going through the turnstiles, we have to rely on the attendance data available in the public domain.

Referee calls are sport-specific; for NBA, we treated variable penalty as the sum of personal fouls of all the players of a team during the match, while for NFL, we treated variable penalty as the sum of different penalties that a team committed during the match and for NHL, we treated variable penalty as the total assessed length of penalties each player of a team accrued during the game. With this approach, we aimed to quantitatively capture potentially subjective referee decisions towards the two teams. As for NBA, exceeding the limit on personal fouls results in disqualification for the remainder of the game for the player, and for NFL, penalties result in a loss of yardage, while for NHL, for the length of the penalty, the team of the punished player will be short-handed. In agreement with the yellow and red cards of soccer, these referee decisions can substantially affect the flow and score-line of the games.

We considered some additional features based on which we can further categorize matches. Our dataset not only contains the number of spectators who attended each match but also features whether or not the game was played in the regular or playoff part of the season, the exact date of the game, and its location.

Of these three leagues, only NFL games can end in a draw, as all NHL and NBA games are decided over overtime, in case the two teams are level after the regular time. Over the ten NFL seasons considered, only nine games were tied, which were excluded from the study. Further, as this work focuses on the relationship between home-court advantage and match attendance, we disregarded games played at neutral venues. Regularly, 4–5 games in each season, and each of the three leagues were played overseas before the emergence of the COVID-19 pandemic, without having a proper home and away teams. After the COVID-19 outbreak in March 2020, the remainder of NBA and NHL games for Season 2019–2020 was postponed. The resumption of the 2019–2020 NBA season followed after a five-month hiatus in a bubble at a neutral site called Walt Disney World in Bay Lake, with no spectators. We excluded all these post-resumption games for Season 2019–2020 from the analysis due to the lack of home-court for any of the teams. Likewise, the resumption of the 2019–2020 NHL season after a five-month hiatus happened with a modified format of a 24-team playoff tournament behind closed doors. These games were played at Scotiabank Arena, the home venue of the Toronto Maple Leafs, or Rogers Place, the home venue of the Edmonton Oilers. We further cleaned the dataset by excluding most of the post-resumption games for Season 2019–2020 due to the lack of home and away teams leaving in just nine NHL games when one of the teams was either Toronto Maple Leafs or Edmonton Oilers, which were played at their regular home venue. We note that all postponed games for Season 2019–2020 for NHL and NBA were played behind closed doors. Unlike NBA and NHL, the 2019–2020 NFL Season could finish uninterrupted due to its timings before the COVID-19 outbreak.

The 2020–2021 season in all three leagues started behind closed doors and, depending on the league and the state policies of the home team, some of the games were held in stadiums with a certain open capacity, as the season progressed. Moreover, some games near the end of the 2020–2021 season witnessed their previous regular attendance. On the left of Figure 1, we can see Kernel density estimates of audience size for the three different leagues, while on the right, we can find the Kernel density estimates of score difference between home and away teams for the three different leagues using the same time partition. This is displayed by distinguishing the ten different seasons. We calculated for each game the difference between the points scored by the home team and those of the away team to acquire this score difference variable. As we can see in Figure 1, there was some natural variation in each season in reported attendance even before the emergence of the COVID-19 pandemic for all three leagues. Regarding NHL, the league regularly scheduled at least one outdoor game per year with a significantly greater-than-usual crowd size; thus, we can see an unexpectedly large number on the right of the X-axis in the corresponding graph. In Season 2020–2021, 580 out of the 1171 NBA games were played behind closed doors, as were 148 out of 266 NFL games and 573 out of NHL 950 games.

2.1. Descriptive statistics

Having excluded all games without a proper home venue and nine tied NFL games, we finally considered 12390 NBA games, 2624 NFL games, and 12126 NHL games. We first calculated match results and referee calls mean statistics for the three different groups; thereafter, we statistically compared two of these groups. The first group comprises all the games from Season 2011–2012 until the outbreak of COVID-19, which can be considered as a normal pre-COVID-19 period. The second group consists of all the games since the emergence of COVID-19 when any positive number of supporters were present during the game, and the third group comprises all the games since the emergence of COVID-19, with strictly zero attendance. In Table 1, we can see the mean values for different game characteristics for the three groups, along with the sample sizes. [4]These characteristics are: share of wins of home teams among all games, points scored by the home team, points scored by the away team, difference of points scored by home and away teams, sum of points scored by home and away teams, penalties awarded to the home team, penalties awarded to the away team, difference of penalties awarded to home and away teams, and the sum of penalties awarded to the home and away teams. As for the last column of Table 1, similar to Bryson et al. (2021), we invoked a two-sided unpaired *t*-test with unequal variances (Welch-test) to test whether the corresponding means of the second and third groups are significantly different. We also reported the corresponding Cohen's-d effect sizes for these means. The choice of the second and third groups enabled us to compare samples of around the same size. Further, there might be significant trends in some of the characteristics over the last decade, and hence we could substantially distort this comparison by including games from earlier seasons.

The results displayed in Table 1 reveal that for the five characteristics, there is a difference between games played with and without a crowd for NBA games at a 5% significance level, and for four characteristics, the difference is significant even at a 1% significance level. That said, the home teams' winning share is significantly greater with a crowd, while the away score increases without an audience. The home score is not significantly affected by a crowd, but the difference of scores between the two teams is significantly lower without a crowd. The number of home penalties is significantly higher without a crowd, while away penalties are unaffected by a crowd; therefore, the penalty difference between the home and away teams also significantly decreases without a crowd. Regarding NHL games, the only significantly different

[4] As mentioned, 9 games after the resumption of 2019–2020 NHL Season were played with the existence of a home team. This accounts for the difference between the 573 games considered earlier in Figure 1 and the sample size of 582 games in Table 1.

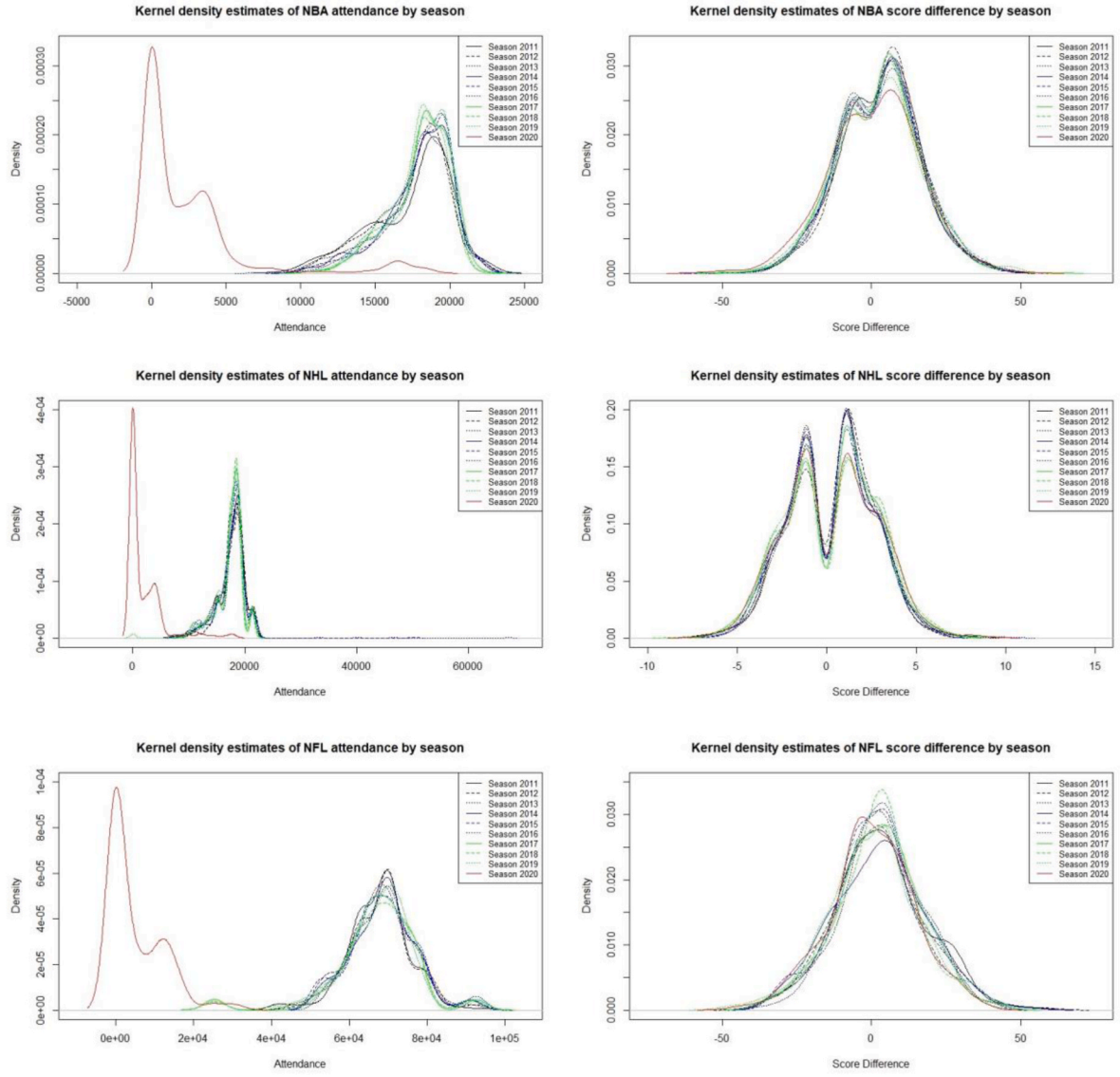

Figure 1. Kernel density estimates of attendance for the different leagues on the left and of score difference between home and away teams for the different leagues on the right. For estimation, we used Gaussian Kernel and the rule-of-thumb bandwidth estimator given by Scott (2015).

characteristic with and without crowds is the score difference, and that too only at a 5% significance level. The home team scores significantly more points than the away team when playing before an audience. The other eight characteristics are not significantly influenced by the presence of a crowd. Regarding NFL games, we do not have any characteristics that would be significantly influenced by the presence of crowds even at a 5% level.

It is to be noted that this previous comparison does not deal with the possible heterogeneity among the observations; instead, it treats all matches of the same kind. Some of the results might be affected by within-season variation in the respective sports leagues. We have also not accounted for the strength of the two teams, besides the possibility of the match-up of the games without a crowd being different from that of the games played in front of spectators. This suggests the idea of controlling for some characteristic variables to better understand the mechanism behind potential referee bias and home advantage. Therefore, we proceed to the next section, where we consider the longitudinal observations as panel data and fix some model parameters for the regressions.

2.2. Panel regression

As discussed, the descriptive statistics do not consider possible within-season variation. Further, the change in the scheduling of the leagues before and after the lockdown is not captured by the mean differences in Table 1. Besides, we also want to answer *RQ2,* which requires additional work. Thus, to provide an accurate answer to *RQ1* and to answer *RQ2*, we built a framework following the ones widely used in sports economics in European football (Bryson et al., 2021; Cueva, 2020; Scoppa, 2021). That said, we proceeded by building a panel regression separately for each of the three leagues. To answer *RQ1,* we estimated the following, using ordinary least squares (OLS):

$$yi,j,k,l,m = \beta 1 CDi,j,k,l,m + hsi + asj + dk + rpl + \varepsilon i,j,k,l,m \quad (1)$$

and to answer *RQ2,* we estimated the following using OLS:

Table 1
Sample means for different match outcomes and referee calls.

(a) Match Results and referee calls mean statistics for NBA games

	Pre (N = 11219)	$Post_{Yes}$ (N = 591)	$Post_{No}$ (N = 580)	Mean difference between $Post_{Yes}$ and $Post_{No}$	
Home Win	0.587	0.584	0.509	0.075**	(p = 0.01, Cohen's d = 0.151)
Home Score	104.813	112.834	112.279	0.555	(p = 0.539, Cohen's d = 0.044)
Away Score	102.047	110.442	112.341	−1.9**	(p = 0.01, Cohen's d = −0.159)
Score Difference	2.766	2.393	−0.062	2.455**	(p = 0.006, Cohen's d = 0.162)
Total Scores	206.86	223.276	224.621	−1.345	(p = 0.249, Cohen's d = −0.067)
Home Penalties	19.963	18.873	19.543	−0.67**	(p = 0.004, Cohen's d = −0.171)
Away Penalties	20.609	19.565	19.566	0	(p = 0.999, Cohen's d = 0)
Penalty difference	−0.646	0.692	−0.022	−0.67*	(p = 0.02, Cohen's d = −0.137)
Total Penalties	40.572	38.438	39.109	−0.67	(p = 0.077, Cohen's d = −0.104)

(b) Match Results and referee calls mean statistics for NHL games

	Pre (N = 11167)	$Post_{Yes}$ (N = 377)	$Post_{No}$ (N = 582)	Mean difference between $Post_{Yes}$ and $Post_{No}$	
Home Win	0.547	0.562	0.512	0.05	(p = 0.127, Cohen's d = 0.101)
Home Score	2.955	3.199	2.967	0.232	(p = 0.051, Cohen's d = 0.129)
Away Score	2.678	2.695	2.826	−0.132	(p = 0.219, Cohen's d = -0.082)
Score Difference	0.277	0.504	0.141	0.363*	(p = 0.029, Cohen's d = 0.144)
Total Scores	5.633	5.894	5.794	0.1	(p = 0.511, Cohen's d = 0.044)
Home Penalties	9.436	8.292	8.11	0.182	(p = 0.694, Cohen's d = 0.027)
Away Penalties	10.061	8.777	8.009	0.769	(p = 0.089, Cohen's d = 0.117)
Penalty difference	−0.625	−0.485	0.101	−0.587	(p = 0.063, Cohen's d = -0.124)
Total Penalties	19.497	17.069	16.119	0.95	(p = 0.268, Cohen's d = 0.076)

(c) Match Results and referee calls mean statistics for NFL games

	Pre (N = 2358)	Post $_{Yes}$ (N = 118)	$Post_{No}$ (N = 148)	Mean difference between $Post_{Yes}$ and $Post_{No}$	
Home Win	0.574	0.542	0.473	0.069	(p = 0.262, Cohen's d = 0.139)
Home Score	23.963	26.144	23.878	2.266	(p = 0.056, Cohen's d = 0.238)
Away Score	21.526	24.949	24.439	0.51	(p = 0.691, Cohen's d = 0.049)
Score Difference	2.437	1.195	−0.561	1.756	(p = 0.319, Cohen's d = 0.124)
Total Scores	45.489	51.093	48.318	2.776	(p = 0.109, Cohen's d = 0.2)
Home Penalties	6.295	5.28	5.399	−0.119	(p = 0.667, Cohen's d = -0.053)
Away Penalties	6.712	5.568	5.77	−0.202	(p = 0.517, Cohen's d = -0.08)
Penalty difference	−0.417	−0.288	−0.372	0.083	(p = 0.831, Cohen's d = 0.026)
Total Penalties	13.007	10.847	11.169	−0.321	(p = 0.466, Cohen's d = -0.09)

Notes: 'Pre' refers to the games played from Season 2011–2012 until the emergence of COVID-19, '$Post_{Yes}$' refers to the games since the emergence of COVID-19, where any positive number of fans was present during the match, '$Post_{No}$' refers to the games since the emergence of COVID-19, where no fans were present during the match. 'N' refers to the number of games in each sample. The last column shows the mean differences between the latter two sample groups along with its significance level. We also present the Cohen's d effect size. ***, **; * indicate significance from zero at 0.1%, 1%, and 5% levels, respectively. We used two-sided unpaired t-tests with unequal variances.

$$y_{i,j,k,l,m} = \beta 1 ATT_{i,j,k,l,m} + hsi + asj + dk + rpl + \varepsilon i,j,k,l,m \quad (2)$$

where y denotes the outcome variable, taken from one of the nine characteristics indicated in Table 1. *CD* is a dummy variable taking value 1 if the match was played behind closed doors, and 0 otherwise. *ATT* is a variable that measures the number of spectators. The rest of the variables are fixed effects, *hs* is home team-season fixed effect, *as* is away team-season fixed effect, *d* is the day of the week fixed effect and *rp* is a dummy fixed effect that captures whether the match was played in the regular or playoff part of the season.

By controlling for these fixed effects, we can indeed capture possible individual heterogeneities. Though the teams that play in these leagues do not vary from season to season, their actual strength and playing style might change over time; we hence interacted the home team and season variables to obtain a home team-season fixed effect. We likewise obtained an away team-season fixed effect. We could thus fix the team strength and their proneness to referee sanctions for an entire season, but we let them change from season to season. The day of the week fixed effect is to address possible differences in game features played on different days. As pointed out by Goller and Krumer (2020), games played on non-frequent days can be substantially different, compared to those played on frequent days, in European football. We also considered the regular/playoff fixed effect, which can address some within-season variation by separating games played during the regular part or the playoff part of the season.

We incorporated one-one regressor in the two models. Equation 1 will be considered for the period when COVID-19 onset was imminent or was already present. With the *CD* regressor, we can clearly distinguish games played with and without crowds and check their significance. Conversely, Equation 2 will be considered for the entire ten seasons when fans were allowed to attend. We can thus check the significance of the *ATT* regressor variable to ascertain whether the sheer number of reported spectators significantly influences any of the nine characteristics considered–in other words, to understand whether the natural variation of attendance influences either the referee's decisions or the match outcomes.

3. Results and discussion

In this section, we present and discuss the results to provide answers

[5] Model specification has been conducted for the nine variables and for all three leagues. Neither adding a squared attendance term to the regression nor considering the logarithm of attendance variable improves the results in terms of Adjusted-R Squared values or the statistical significance of the explanatory variables.

to both *RQ1* and *RQ2*, with regression results furnished separately for Equations 1 and 2.

Table 2 displays the results of the nine corresponding regressions of Equation 1 for the three sports considering data of Seasons 2019–2020 and 2020–2021. We can see only a statistically significant *CD* regressor variable for NBA and NFL. For both NBA and NFL, the home teams' winning share significantly drops without having supporters, their score is significantly smaller without crowds, the total number of referee calls are significantly higher. On the other hand, the higher overall penalty decisions are not entangled with an increased referee bias towards any of the teams, as the individual penalty calls and the penalty difference between the two teams do not change significantly due to playing in empty stadiums. Regarding NHL, we can see that none of the nine variables is significantly affected by the presence of an audience. Supporters do not significantly influence referee decisions, meaning that the number of penalties sanctioned to either team does not substantially increase or decrease due to the presence of spectators. Further, unlike NBA and NFL, the performance of the home NHL teams does not improve significantly when playing before spectators. We checked the robustness of these results by altering the considered seasons in Tables A1–A2 in the Appendix. By running the regressions of Equation 1 for the games in Season 2020–2021 alone and for the games in Seasons 2018–2019, 2019–2020, and 2020–2021, we can confirm the robustness of the aforementioned results only with some minor changes. As for NBA and NFL, the home teams' winning share and score significantly decrease without the presence of supporters in all corresponding tables. Considering Season 2020–2021 alone, the number of total penalties does not increase significantly for NFL games; otherwise, there is no difference in significance in the corresponding tables for NFL and NBA. Regarding NHL, there is one occurrence of a significant variable. Considering the games in Seasons 2018–2019, 2019–2020, and 2020–2021, the number of total scores significantly decreases without crowds. We note that this variable is not related to home advantage or any sort of referee bias. Apart from this, we do not observe any significant changes for any of the nine corresponding characteristics for NHL games. By selecting games from the last one, two, or three seasons alone, we could ensure samples where the number of games played behind closed doors or before an audience is of the same magnitude.

We continue by presenting the results to Equation 2. Table 3 displays the results of the nine corresponding regressions for the three sports, considering all games played without closed doors since Season 2011–2012. In other words, we excluded from consideration only those games where the *CD* dummy variable would be 1. We can see only statistically significant *ATT* regressor variables for NFL and NBA. Regarding NFL, visiting teams' winning share and score significantly increase along with the audience size. Further, the score difference between the home and away teams gets significantly smaller and the penalty difference between the two teams significantly higher along with the size of the audience. Regarding NBA, the number of home penalties is significantly lower when the games are played before a larger audience. Regarding NHL, we can see that none of the nine variables is significantly affected by the number of spectators. Playing before more supporters does not substantially affect the performance of NHL teams, measured with the scored points or with the outcome of the game. Besides, referees' decisions in terms of issued referee calls are also unaffected by the number of spectators. We check the robustness of these results in Tables A3–A4 in the Appendix. Clearly, one can argue that the post-COVID-19 games, even with fan attendance, were essentially different compared to the matches of the previous normal seasons. Mask-wearing was required for spectators at games, leading to potentially different spectator behaviour during the game. We proceeded to repeat the previous analysis as presented in Table A3 by considering only games before the emergence of the COVID-19 pandemic. We can thus assess the impact of audience size on game outcomes under normal circumstances. The results of this table are fundamentally identical to those of Table 3, with some minor differences in terms of significant variables. The *ATT* regressor variable alone significantly affects the NFL and NBA game outcomes. Regarding NFL, home teams' winning share significantly decreases along with the size of the audience, the visiting teams' score is significantly higher, the score difference between the home and away teams is significantly lower and the penalty difference between them is significantly higher when playing in front of more spectators. Regarding NBA, the total number of scores significantly increases along with the size of the audience, the number of penalties sanctioned to the home team, and the total number of penalties sanctioned to both teams significantly decreases when playing before more spectators. Next, we also want to address the fact that not all stadiums have the same capacity. Regarding NBA stadiums, the capacity is

Table 2
Estimated effects of playing games behind closed doors on match results and referee decisions considering all games in Seasons 2019–2020 and 2020–2021 with a home court.

(a) NBA, N = 2139										
		Home win	Home Score	Away Score	Score Diff.	Total Scores	Home Pen.	Away Pen.	Pen. Diff.	Total Pen.
Closed doors	$\widehat{\beta}_1$	−0.09**	−2.144**	0.039	−2.182	−2.105*	0.466	0.294	0.171	0.76*
	SE	0.031	0.745	0.891	1.313	0.988	0.32	0.205	0.412	0.346
	p	0.004	0.004	0.966	0.097	0.033	0.146	0.15	0.678	0.028
Adjusted R^2		0.164	0.177	0.166	0.201	0.155	0.162	0.144	0.125	0.167
(b) NHL, N = 2035										
		Home win	Home Score	Away Score	Score Diff.	Total Scores	Home Pen.	Away Pen.	Pen. Diff.	Total Pen.
Closed doors	$\widehat{\beta}_1$	0.019	−0.088	−0.244	0.156	−0.332	0.535	0.432	0.103	0.967
	SE	0.067	0.136	0.192	0.281	0.178	0.592	0.554	0.254	1.119
	p	0.779	0.516	0.204	0.579	0.063	0.366	0.436	0.685	0.387
Adjusted R^2		0.053	0.046	0.069	0.083	0.025	0.048	0.072	0.03	0.065
(c) NFL, N = 526										
		Home win	Home Score	Away Score	Score Diff.	Total Scores	Home Pen.	Away Pen.	Pen. Diff.	Total Pen.
Closed doors	$\widehat{\beta}_1$	−0.116*	−2.296*	1.921	−4.217**	−0.375	0.002	0.389	−0.388	0.391*
	SE	0.058	1.033	2.098	1.345	3.021	0.21	0.345	0.542	0.18
	p	0.046	0.027	0.36	0.002	0.901	0.993	0.259	0.475	0.03
Adjusted R^2		0.179	0.184	0.193	0.26	0.113	0.085	0.123	0.079	0.123

Notes: The panel regression corresponds to Equation 1, 'N' refers to the sample size. ***, **; * indicate significance from zero at 0.1%, 1%, and 5% levels, respectively, two-sided tests. Standard errors (SE) are corrected for heteroskedasticity and robust to two-way clustering (day of week, regular/playoff).

Table 3
Estimated effects of playing games before various audience sizes on match results and referee decisions considering all games since Season 2011–2012 with a home court and without closed doors.

(a) NBA, N = 11810										
		Home win	Home Score	Away Score	Score Diff.	Total Scores	Home Pen.	Away Pen.	Pen. Diff.	Total Pen.
Attendance	$\widehat{\beta}_1$	−0.03	0.008	0.038	−0.03	0.046	−0.038*	−0.027	−0.012	−0.065
in (1000s)	SE	0.004	0.085	0.077	0.137	0.087	0.017	0.026	0.025	0.036
	p	0.443	0.924	0.622	0.827	0.597	0.022	0.305	0.635	0.069
Adjusted R^2		0.166	0.317	0.311	0.21	0.355	0.176	0.186	0.171	0.187
(b) NHL, N = 11544										
		Home win	Home Score	Away Score	Score Diff.	Total Scores	Home Pen.	Away Pen.	Pen. Diff.	Total Pen.
Attendance	$\widehat{\beta}_1$	0.003	0.017	−0.006	0.023	0.011	0.016	−0.04	0.057	−0.024
in (1000s)	SE	0.003	0.01	0.009	0.012	0.015	0.04	0.055	0.055	0.079
	p	0.222	0.096	0.514	0.069	0.473	0.683	0.463	0.301	0.764
Adjusted R^2		0.041	0.044	0.05	0.053	0.041	0.074	0.068	0.016	0.08
(c) NFL, N = 2476										
		Home win	Home Score	Away Score	Score Diff.	Total Scores	Home Pen.	Away Pen.	Pen. Diff.	Total Pen.
Attendance	$\widehat{\beta}_1$	−0.012***	−0.044	0.207***	−0.251***	0.163*	0.016	−0.026	0.042**	−0.01
in (1000s)	SE	0.002	0.057	0.027	0.059	0.067	0.016	0.014	0.014	0.027
	p	$9.2 \cdot 10^{-13}$	0.444	$1.8 \cdot 10^{-14}$	$2.09 \cdot 10^{-5}$	0.015	0.304	0.066	0.002	0.723
Adjusted R^2		0.174	0.187	0.207	0.246	0.143	0.083	0.076	0.075	0.084

Notes: The panel regression corresponds to Equation 2, 'N' refers to the sample size. ***, **; * indicate significance from zero at 0.1%, 1%, and 5% levels, respectively, two-sided tests. Standard errors (SE) are corrected for heteroskedasticity and robust to two-way clustering (day of week, regular/playoff).

between 16867 and 20917, for NHL stadiums between 15321 and 21302, and NFL stadiums, between 61500 and 82500. Hence, we can calculate for each game the relative reported attendance or reported crowd density to measure the proportion of stadium seats filled for the different matches. Though this crowd density variable has a strong positive correlation with the attendance variable, it can still control inequalities between the facilities available for the different teams. Using this crowd density as the regressor variable instead of *ATT* in Equation 2, we reran the panel regression considering all games played without closed doors since Season 2011–2012. The corresponding Table A4 again echoes the previously obtained results. The results in terms of significance are identical to Table 3 for NBA games, Table A3 for NFL games, and to both Table 3 and Table A3 for NHL games. We considered a final robustness test for Equations 1 and 2. We invoked a probit model for all three leagues in which for the home teams' winning share binary outcome variable, a probit regression was applied. The results can be seen in Table A5tblA5 in the Appendix. These results are perfectly in line with our previous findings, for, NBA and NFL games played behind closed doors lower the probability of the home teams' winning and do not significantly affect the home teams' winning prospects for NHL games, whereas playing before a larger audience significantly lowers the probability of home teams' winning in NFL games and does not significantly affect the home teams' winning prospects for NBA and NHL games.

With the previous analysis, we can answer both *RQ1* and *RQ2*. Regarding *RQ1*, we found evidence that lockdown reduces the performance of the home team for NBA and NFL but does not affect the performance of the home team or the visiting team for NHL. Besides, lockdown influences only the referee decisions in terms of lowering the total number of sanctioned penalties for NBA and NFL, but does not influence referee decisions towards the two individual teams and has thus no impact on referee bias. Regarding *RQ2*, we found evidence that a growing audience size improves the performance of visiting teams for the NFL, but does not affect the performance of the home team or the visiting team for NBA and NHL. Besides, audience size influences referee decisions for NFL and NBA, resulting in fewer calls towards the home team for NBA and towards the visiting teams for NFL, when games are played before more spectators. Contrary to NBA, for NFL games, even the penalty difference is significantly influenced by the number of spectators, indicating the strong existence of biased referee decisions. There is no evidence of referee bias for NHL due to lockdown or audience size.

These findings indicate that home advantage and referee bias are rather intricate phenomena and related to each other differently for the three North American sports leagues. In light of the above, we can compare these findings with the numerous articles concerning the change of referees' decisions due to the lockdown for soccer games. These studies observed the reduction of yellow cards for away teams relative to home teams, by considering games without spectators. This behavioral change can be the consequence of the removal of elevated social pressure on the referees (Benz & Lopez, 2021; Scoppa, 2021) or the change in the attacking tendency of the home team when playing without spectators (McCarrick et al., 2021). Conversely, when controlling for the seasonal characteristics of home and away teams, due to the lockdown, we do not find a reduction or growth of penalties awarded to the home or visiting teams for any of the three (NFL, NBA, NHL) leagues; the total number of referee calls alone might be significantly affected by empty stadiums. This inconsistency can be attributed to the generally widespread reliance on Video Assistant Referee (VAR) in the North American sports leagues. As discussed by Chen and Davidson (2021), NFL and NBA have adopted video technology years earlier to the professional leagues of soccer and the usage of this system is in a more advanced phase. Coach challenge has already been introduced in the NFL, NBA, and NHL (Chen & Davidson, 2021; Rosen, 2019), whereby head coaches of the teams are given the opportunity to initiate a video review of some referee calls by executing a challenge. Nonetheless, the size of the audience still significantly affects referee decisions for NBA and NFL matches, and interestingly, the direction of potential referee bias is opposite for the two leagues. On the other hand, penalty difference as the most appropriate variable to measure referee bias is significantly affected only by the size of the audience for NFL matches, by increasingly favouring the visiting teams for games played before a larger audience.

Regarding match outcomes, the presence of lockdown significantly lowers the performance of the home team for NBA and NFL, with substantially fewer points being scored and fewer games won, when playing without spectators. No such effect is found for NHL. Having eliminated the possibility of referee bias due to lockdown for the three leagues, we

still find that crowds can influence match outcomes for NBA and NFL. One possible interpretation is that the presence of home supporters offers a morale boost for the home NBA and NFL teams, who therefore perform better and score more points. Basketball is an indoor sport, with the sound reverberating in the arena, which can increase the performance of the home team players. This sound can also affect the work of the referees, who try to satisfy the supporters by awarding fewer penalties to the teams when played before supporters or when attendance is higher. Penalty difference is not significantly affected by lockdown or the number of supporters; thus, referee decisions due to social pressure do not ultimately affect the final scorelines of NBA games. Ice hockey is an indoor sport as well, but we can argue that the requirement that the ice rink be surrounded by a wooden or fiberglass barrier imposes a physical and mental distance between the players, referees, and fans. Hence, hockey players and hockey referees might be able to distance themselves from the voice of the supporters, reducing the consequent effect on their play and work. NFL is a rather unique sport, as lockdown reduces the winning ratio of home teams, but games played before a larger audience result in a lower chance of the home team's success. A possible explanation for this somewhat surprising finding is that there is a general core supporting group, possibly season ticket holders, without whose presence home teams underperform. Additional spectators on top of this cohort might be neutral sports fans or supporters of the away team. When playing before unfamiliar supporters in their own stadiums, their performance might deteriorate and they may concede more points. These non-core supporters also influence the work of the officials, leading to more penalty decisions favourable to the visiting team, as the characteristics of the supporters get increasingly diluted. We can alternatively argue that playing before an exceedingly large number of spectators puts additional pressure on the players of the home team, whose performance crumbles under the elevated pressure. The playing style and offensive/defensive tendency of the two teams might be different in front of more supporters, thus also affecting referee decisions.

Comparing these results with the studies on soccer, we find most soccer articles suggesting a decrease in home advantage due to the lockdown; nonetheless, as shown by Benz and Lopez (2021) in some leagues, home teams' performance may have actually risen after the emergence of COVID-19. The result for NBA and NFL due to lockdown is mostly in line with the literature on soccer; on the other hand, the result of NFL concerning the negative impact of audience size on home teams' performance is not completely unprecedented either. We also compare the results of this study with those of the short literature concerning the relationship of home advantage of North American sports and COVID-19. McHill and Chinoy (2020) considered pre-COVID-19 games by reckoning the number of time zones the away team has to travel and also examined the 176 NBA games played at Walt Disney World in Bay Lake, to understand the importance of travel fatigue as a contributing factor to home advantage. They concluded that the winning percentages of the home and away teams significantly differed when traveling across time zones, but also found that circadian effects and travel cannot fully account for home and away differences. This finding is in accordance with the current study, in the sense that we have found evidence of the presence of fans also substantially influencing home and away differences for NBA games; thus, travel fatigue cannot be the only factor corresponding to home advantage. Higgs and Stavness (2021) suggested that home advantage is negatively impacted by the COVID-19 in the NBA and NHL considering playoff games, whereas there is no such impact on the home advantage in the NFL. They considered games from Season 2015–2016 to Season 2019–2020 and accounted for team strengths. The findings concerning NBA correspond to our findings. The best explanation for the differing results regarding NHL is the different datasets we used, vis-a-vis the one used by Higgs and Stavness (2021). They represented the lockdown period by considering only the playoff part of Season 2019–2020 for NHL, during which games were played in bubbles and we only left in nine NHL games from this sample. Regarding NFL, the best explanation for the differing results is the fact that we distinguished games in Season 2019–2020 depending on the presence of supporters, whereas Higgs and Stavness (2021) considered all these games similarly, without considering whether the games were played behind closed doors.

While the present study produced a comprehensive analysis, we also acknowledge the limitations of the methods applied. We did not control for the identity of the referee crews due to the shortage of data. However, to our knowledge, officials were not allocated differently before and during COVID-19. One could also extend this study by considering the playing style (defensive, offensive) of the teams, potential changes in training schedules due to COVID-19 and the distance travelled by the away team. This study could be repeated with more data for lower leagues, and the corresponding basketball, ice hockey, and American football leagues of other countries. A future study could also consider women's games to test which of the findings are gender-specific. This provides interesting future work that might confirm the results of this study or shed light on heterogeneities between leagues or even reveal some other variables that need to be considered.

In conclusion, we can assert that social pressure on agents' behaviour can be very different depending on the type of activity. The causes of the generally observed home advantage and the relation between home advantage and referee bias are sports-specific.

4. Conclusion

It has long been observed that while social pressure potentially changes behaviour and decision-making, individuals tend to seek conformist behaviour.

The COVID-19 pandemic offers a rare opportunity to study social pressure in a sports context. Numerous papers have exploited the naturally exogenous change in the crowd size to better understand referee bias and its causal relationship with home and away teams' performances, in European football. This is the first paper that contributes to this growing literature by investigating the mechanism behind the home advantage for three major American sports leagues (NBA, NFL, NHL), considering audience sizes and referee decisions. The articles studying European football games provided different explanations as to why referee bias favouring the home team significantly decreases without a partisan crowd, and though mostly they observed a reduction of home advantage without this crowd, counter-examples have been offered for some leagues, revealing the existence of substantial heterogeneity even within the same sport.

For the three considered sports of this study, we have obtained different results regarding how penalty decisions are affected by spectators; the match score-lines too show relations substantially different from the variation in the number of supporters. NHL referee decisions and match outcomes are unaffected by supporters. Playing behind closed doors significantly reduces the winning prospects and the scored points of the home team for NBA and NFL games; the overall number of awarded penalties is also higher behind closed doors without the implication of an increased or decreased referee bias. Playing without closed doors, the size of the audience has a significant positive impact on the winning chance and scored points of the visiting teams for NFL games; at the same time, referees make decisions that increasingly favour the visiting team. Regarding NBA, we have obtained evidence that the number of spectators can affect match outcomes, but none of the outcomes linked to home advantage or referee bias.

The potential causes of these results have been discussed. Some key factors in our explanation are that NBA is an indoor sport, the ice rink for NHL games is physically cordoned off from the spectators, and an increased NFL audience size is associated with the greater presence of non-home supporters. We compared the results of this paper to the extensive literature concerning the relation of COVID-19 and home advantage for European football, and to the few published articles on North American sports. Due to the absence of considered referee calls in

the articles considering North American leagues and due to the difference in the examined games, while the results cannot fully be compared, still, the exclusion of travel fatigue as the sole factor contributing to the phenomenon of home advantage in NBA in McHill and Chinoy (2020) and the heterogeneous results among the different leagues due to the absence of a crowd in Higgs and Stavness (2021), are in accordance with this study.

In sum, we have extended the literature corresponding to home advantage and referee bias, also providing evidence that the effect of social pressure even in sports contexts is activity-specific. The evidence shown that for NBA and NFL games, psychological factors substantially contribute to match results and to referee decisions, provides important feedback for sports psychologists. They can address in their work the outlined reasons that reduce the performance of players and affect the work of the officials. In the process, they can help players and referees to improve their performance. Future studies can address the limitations of this study to confirm whether the findings are specific to the league, sport, or gender.

Declaration of competing interest

The authors have no affiliation with any organization with a direct or indirect financial interest in the subject matter discussed in the manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.psychsport.2022.102162.

Appendices.

See Tables A1–A5.

Table A.1
Estimated effects of playing games behind closed doors on match results and referee decisions considering all games in Season 2020–2021 with a home court

(a) NBA, N = 1171										
		Home win	Home Score	Away Score	Score Diff.	Total Scores	Home Pen.	Away Pen.	Pen. Diff.	Total Pen.
Closed doors	$\widehat{\beta}_1$	−0.089**	−2.142**	−0.033	−2.109	−2.174*	0.456	0.282	0.174	0.738*
	SE	0.03	0.749	0.869	1.298	0.973	0.321	0.209	0.418	0.346
	P	0.004	0.004	0.97	0.105	0.026	0.156	0.178	0.678	0.033
Adjusted R^2		0.133	0.165	0.17	0.184	0.158	0.149	0.132	0.097	0.165
(b) NHL, N = 950										
		Home win	Home Score	Away Score	Score Diff.	Total Scores	Home Pen.	Away Pen.	Pen. Diff.	Total Pen.
Closed doors	$\widehat{\beta}_1$	0.036	−0.064	−0.273	0.209	−0.336	0.258	0.312	−0.054	0.57
	SE	0.066	0.128	0.208	0.278	0.206	0.638	0.607	0.249	1.221
	P	0.583	0.62	0.191	0.452	0.103	0.686	0.608	0.83	0.641
Adjusted R^2		0.081	0.046	0.085	0.106	0.01	0.078	0.1	0.029	0.098
(c) NFL, N = 266										
		Home win	Home Score	Away Score	Score Diff.	Total Scores	Home Pen.	Away Pen.	Pen. Diff.	Total Pen.
Closed doors	$\widehat{\beta}_1$	−0.126*	−2.739**	1.728	−4.467**	−1.011	−0.06	0.414	−0.474	0.354
	SE	0.06	0.876	1.996	1.439	2.726	0.173	0.333	0.472	0.242
	P	0.038	0.002	0.388	0.002	0.711	0.731	0.214	0.317	0.144
Adjusted R^2		0.208	0.211	0.159	0.234	0.13	0.057	0.024	0.035	0.041

Notes: The panel regression corresponds to Equation 1, 'N' refers to the sample size.
***, **; * indicate significance from zero at 0.1%, 1%, and 5% levels, respectively, two-sided tests. Standard errors are corrected for heteroskedasticity and robust to two-way clustering (day of week, regular/playoff)

Table A.2
Estimated effects of playing games behind closed doors on match results and referee decisions considering all games in Season 2018–2019, Season 2019–2020 and in Season 2020–2021 with a home court

(a) NBA, N = 3448										
		Home win	Home Score	Away Score	Score Diff.	Total Scores	Home Pen.	Away Pen.	Pen. Diff.	Total Pen.
Closed doors	$\widehat{\beta}_1$	−0.084**	−2.171**	−0.181	−1.99	−2.352*	0.466	0.273	0.192	0.739*
	SE	0.031	0.779	0.877	1.301	1.028	0.305	0.213	0.387	0.355
	p	0.007	0.005	0.837	0.126	0.022	0.127	0.199	0.62	0.037
Adjusted R^2		0.16	0.178	0.172	0.205	0.16	0.174	0.163	0.12	0.192
(b) NHL, N = 3388										
		Home win	Home Score	Away Score	Score Diff.	Total Scores	Home Pen.	Away Pen.	Pen. Diff.	Total Pen.
Closed doors	$\widehat{\beta}_1$	0.021	−0.09	−0.25	0.16	−0.34*	0.482	0.436	0.046	0.918
	SE	0.066	0.136	0.191	0.285	0.17	0.574	0.543	0.28	1.081

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Table A.2 (*continued*)

(a) NBA, N = 3448										
		Home win	Home Score	Away Score	Score Diff.	Total Scores	Home Pen.	Away Pen.	Pen. Diff.	Total Pen.
	p	0.748	0.51	0.19	0.573	0.045	0.401	0.422	0.87	0.396
Adjusted R^2		0.041	0.055	0.053	0.066	0.04	0.042	0.054	0.026	0.053
(c) NFL, N = 787										
		Home win	Home Score	Away Score	Score Diff.	Total Scores	Home Pen.	Away Pen.	Pen. Diff.	Total Pen.
Closed doors	$\widehat{\beta}_1$	−0.126*	−2.455**	2.05	−4.505**	−0.405	0.02	0.373	−0.353	0.393*
	SE	0.06	0.941	2.15	1.528	2.946	0.203	0.346	0.534	0.191
	p	0.036	0.009	0.341	0.003	0.891	0.92	0.282	0.51	0.04
Adjusted R^2		0.176	0.201	0.203	0.26	0.151	0.059	0.086	0.058	0.083

Notes: The panel regression corresponds to Equation 1, 'N' refers to the sample size.
***, **; * indicate significance from zero at 0.1%, 1%, and 5% levels, respectively, two-sided tests. Standard errors are corrected for heteroskedasticity and robust to two way clustering (day of week, regular/playoff).

Table A.3
Estimated effects of playing games behind various audience sizes on match results and referee decisions considering all games from Season 2011–2012 until the emergence of COVID-19 with a home court and without closed doors

(a) NBA, N = 11219										
		Home win	Home Score	Away Score	Score Diff.	Total Scores	Home Pen.	Away Pen.	Pen. Diff.	Total Pen.
Attendance	$\widehat{\beta}_1$	0	0.108	0.054	0.054	0.162*	−0.048*	−0.044	−0.004	−0.093*
in (1000s)	SE	0.006	0.096	0.09	0.167	0.082	0.023	0.028	0.035	0.038
	P	0.984	0.264	0.547	0.749	0.049	0.033	0.118	0.905	0.014
Adjusted R^2		0.166	0.311	0.304	0.211	0.345	0.175	0.187	0.175	0.184
(b) NHL, N = 11167										
		Home win	Home Score	Away Score	Score Diff.	Total Scores	Home Pen.	Away Pen.	Pen. Diff.	Total Pen.
Attendance	$\widehat{\beta}_1$	0.004	0.013	−0.008	0.021	0.005	0.041	−0.03	0.071	0.01
in (1000s)	SE	0.003	0.008	0.009	0.012	0.012	0.038	0.055	0.059	0.074
	P	0.121	0.093	0.4	0.076	0.694	0.284	0.582	0.227	0.888
Adjusted R^2		0.039	0.043	0.048	0.05	0.04	0.074	0.066	0.017	0.079
(c) NFL, N = 2358										
		Home win	Home Score	Away Score	Score Diff.	Total Scores	Home Pen.	Away Pen.	Pen. Diff.	Total Pen.
Attendance	$\widehat{\beta}_1$	−0.013***	−0.024	0.243***	−0.267***	0.218***	0.025	−0.024	0.048***	0.001
in (1000s)	SE	0.002	0.054	0.016	0.058	0.055	0.016	0.013	0.014	0.025
	P	2.3•10-16	0.651	<2.2•10-16	4.2•10-6	7.3•10-5	0.114	0.067	3.9•10-4	0.983
Adjusted R^2		0.175	0.188	0.205	0.245	0.142	0.082	0.079	0.082	0.079

Notes: The panel regression corresponds to Equation 2, 'N' refers to the sample size. ***, **; * indicate significance from zero at 0.1%, 1%, and 5% levels, respectively, two-sided tests. Standard errors are corrected for heteroskedasticity and robust to two way clustering (day of week, regular/playoff).

Table A.4
Estimated effects of playing games behind various crowd densities on match results and referee decisions considering all games since Season 2011–2012 with a home court and without closed doors

(a) NBA, N = 11810										
		Home win	Home Score	Away Score	Score Diff.	Total Scores	Home Pen.	Away Pen.	Pen. Diff.	Total Pen.
Crowd density	$\widehat{\beta}_1$	−0.062	0.218	0.619	−0.401	0.837	−0.697*	−0.494	−0.203	−1.191
	SE	0.084	1.55	1.476	2.53	1.661	0.312	0.481	0.479	0.655
	P	0.46	0.888	0.675	0.874	0.614	0.026	0.304	0.671	0.069
Adjusted R^2		0.166	0.317	0.311	0.21	0.355	0.176	0.186	0.171	0.187
(b) NHL, N = 11544										
		Home win	Home Score	Away Score	Score Diff.	Total Scores	Home Pen.	Away Pen.	Pen. Diff.	Total Pen.
Crowd density	$\widehat{\beta}_1$	0.061	0.288	−0.114	0.402	0.174	0.332	−0.685	1.018	−0.353
	SE	0.05	0.175	0.166	0.215	0.264	0.724	0.969	0.997	1.39
	P	0.227	0.099	0.493	0.062	0.51	0.646	0.479	0.307	0.8
Adjusted R^2		0.041	0.044	0.05	0.053	0.041	0.074	0.068	0.016	0.08
(c) NFL, N = 2476										
		Home win	Home Score	Away Score	Score Diff.	Total Scores	Home Pen.	Away Pen.	Pen. Diff.	Total Pen.
Crowd density	$\widehat{\beta}_1$	−0.903***	−4.366	14.932***	−19.298***	10.566*	1.105	−1.905	3.01**	−0.8

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Table A.4 (*continued*)

(a) NBA, N = 11810

		Home win	Home Score	Away Score	Score Diff.	Total Scores	Home Pen.	Away Pen.	Pen. Diff.	Total Pen.
	SE	0.122	3.97	2.188	4.144	4.891	1.082	1.071	0.928	1.943
	p	2.2•10-13	0.272	1.2•10-11	3.4•10-6	0.031	0.307	0.075	0.01	0.681
Adjusted R^2		0.175	0.187	0.207	0.246	0.143	0.083	0.076	0.075	0.084

Notes: The panel regression corresponds to Equation 2 by replacing the regressor *ATT* with the 'Crowd density' variable, 'N' refers to the sample size. ***, **; * indicate significance from zero at 0.1%, 1%, and 5% levels, respectively, two-sided tests. Standard errors are corrected for heteroskedasticity and robust to two way clustering (day of week, regular/playoff).

Table A.5

Estimated effects of playing games behind closed doors and various audience sizes on home teams' winning share for the three different leagues using Probit estimates. On the left, we consider all games in Seasons 2019–2020 and 2020–2021 with a home court, and on the right, all games since Season 2011–2012 with a home court and without closed doors.

(a) Games with a home court

		NBA	NHL	NFL
Closed doors	$\widehat{\beta}_1$	−0.276**	0.063	−0.554**
	SE	0.087	0.195	0.197
	p	0.002	0.746	0.005
N		2139	2035	526
Pseudo R^2		0.172	0.087	0.347

(b) Games with a home court and without closed doors

		NBA	NHL	NFL
Attendance	$\widehat{\beta}_1$	−0.009	0.01	−0.05***
in (1000s)	SE	0.014	0.008	0.007
	p	0.493	0.223	$1.2•10^{-12}$
N		11810	11544	2476
Pseudo R^2		0.17	0.069	0.365

Notes: The panel regression corresponds to Equation 1 on the left panel and to Equation 2 on the right panel, 'N' refers to the sample size. ***, **; * indicate significance from zero at 0.1%, 1%, and 5% levels, respectively, two-sided tests. Standard errors are corrected for heteroskedasticity and robust to two-way clustering (day of week, regular/playoff)

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