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The effect of COVID-19 on home advantage in high- and low-stake situations: Evidence from the European national football competitions

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ABSTRACT

The Covid-19 pandemic has significantly altered the way sporting events are observed. With the absence or limited presence of spectators in stadiums, the traditional advantage enjoyed by home teams has diminished considerably. This underscores the notion that the support of home fans can often be considered a key factor of the home advantage (HA) phenomenon, wherein teams perform better in front of their own supporters. However, the impact of reduced attendance on games with higher stakes, as opposed to low-stakes friendly matches, remains uncertain. In this study, we investigate the recently concluded European football championship (EURO 20), wherein several teams had the advantage of playing at home in high-stakes games with only one-third of the stadium capacity filled. Firstly, we demonstrate that the Covid-19 restrictions, leading to reduced fan attendance, resulted in a nearly 50% decrease in HA compared to the HA exhibited by the same teams during the qualification stage preceding EURO 20, even after accounting for team strength. Secondly, we show that while low-stakes friendly matches generally exhibit a smaller overall HA compared to high-stakes games, the absence of fans led to a similar reduction in HA during the low-stakes matches. Utilizing the recently developed Home Advantage Mediated (HAM) model (Bilalić, Gula, & Vaci, 2021, Scientific Reports, 21558), we were able to attribute the reduction in both high- and low-stakes games to poorer team performance, with no significant contribution from referee bias.

1. Introduction

Covid-19 pandemic has changed the way we live our lives but also how we watched sports. Instead of full stadiums, the competitions were taking place with either significantly reduced capacity or in completely empty stadiums. The absence of fans has paradoxically enabled a natural experiment when it comes to one of the significant contributors to the home advantage (HA) phenomenon. Namely, it has long been theorized that the better performance of home teams is down to the support they receive from the home fans (Carron, Loughhead, & Bray, 2005). It is indeed the case that the HA has been significantly reduced across different (league) competitions (Leitner, Daumann, Follert, & Richlan, 2022).[1] We do not know, however, the extent to which the absence of fans impacts the high-stake games where, for example, only the winner gets to progress further, and how it compares to the absence of fans in the low-stake games. Here we investigate the recently finished UEFA European Championship (EURO 20) where several teams enjoyed the support of fans, but that support was diminished due to COVID-19 restrictions and partially filled stadiums.

We first show that in the games where every loss can be the last one, the HA is markedly reduced compared to the home performance of the same teams in the UEFA Qualifications for the European Championship

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[1] Some North American sports, such as Baseball (MLB) and American Football (NFL), did not show any reduction during their pandemic season (Higgs & Stavness, 2021; Zimmer, Snyder, & Bukenya, 2021). Their Covid-related restrictions were, however, considerably milder than those in other North American sports, such as Basketball (NBA) and Hockey (NHL) (Higgs & Stavness, 2021).

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(QUALI 19) that took place just a couple of years earlier. We then demonstrate that the HA is significantly smaller in national friendly, low-stake games than in the competitive high-stake games (EURO 20 and QUALI 19), but that the absence of fans leads to a similar HA reduction in low-stake games as in high-stake games. In both cases, we use the Home Advantage Mediated (HAM) model to demonstrate that the reduction is almost completely caused by the worse team performance at the competition with no or limited fans present. The referee bias was minimal and did not influence the outcome.

1.1. The HA mechanism and Home Advantage Mediated (HAM) model

The better performance of home teams can be attributed to multiple factors. Home teams benefit from familiarity with the field and environment as they frequently play in those conditions (Leite, Giardina, Almeida, & Pollard, 2022; Loughead, Carron, Bray, & Kim, 2003; Pollard, 2002; Schwartz & Barsky, 1977). Additionally, the travel required for away teams can induce fatigue, potentially contributing to the home advantage (McHill & Chinoy, 2020; Pollard, Silva, & Medeiros, 2008). It is widely suggested that the presence of fans is a significant factor in the home advantage, although this claim warrants further examination. While fans do not directly participate in the game, their passionate support is believed to influence the main protagonists. Coaches may employ more daring tactics and formations due to their awareness of the home advantage (Staufenbiel, Lobinger, & Strauss, 2015). Furthermore, players' physiological and mental states may be altered in ways that enhance their performance during home games (Bray, Jones, & Owen, 2002; Carré, Campbell, Lozoya, Goetz, & Welker, 2013). The influence of the fans may extend to match officials as well, potentially affecting their impartiality through the influence of crowd noise (Nevill, Balmer, & Williams, 2002; Unkelbach & Memmert, 2014). However, it is important to consider that factors other than fan presence may also contribute to the observed effects, such as the overall experience of playing at home.

Previous research has investigated the HA factors such as referee bias and team performance separately (Goumas, 2017; Park, Choi, Bang, & Park, 2016; Reade, Schreyer, & Singleton, 2022) or without regard to their interdependence (Boyko, Boyko, & Boyko, 2007; Bryson, Dolton, Reade, Schreyer, & Singleton, 2021; Sors, Grassi, Agostini, & Murgia, 2021; Wunderlich, Weigelt, Rein, & Memmert, 2021). This is problematic as one factor may nullify the influence of the other. For example, the referees may issue more official warnings to the away team not because they were influenced by the home crowd cheering, but rather because the away team was defending most of the time and had to revert to fouling in order to prevent dangerous game-situations (Carmichael & Thomas, 2005; Goumas, 2014a). We have recently proposed a model which simultaneously considers the most important HA factors (Bilalić et al., 2021). The Home Advantage Mediated (HAM) model (see Figure 1) uses the classical HA theories (Carron et al., 2005; Courneya & Carron, 1992) which implicitly assume that the home venue influences how both the team and the referees will perform, which in turn affects the outcome.

The HAM model postulates these relations explicitly: the root of the HA, the Venue factor, influences the outcome through the team performance and referee bias. In other words, the home venue's influence on the outcome is mediated by team performance and referee bias. At the same time, the referee bias is affected by the team performance, as better, more dominant teams receive fewer official warnings (Goumas, 2014a). The inclusion of all factors and their interrelations simultaneously allows for a complete unbiased estimation of the individual factors. We can, therefore, explicitly say whether the HA mechanism is indeed related to the mediations through team performance and referee bias, as well as determine the extent of their influence on the overall HA. For example, in our recent study on the European football leagues (Bilalić et al., 2021) we found out that the HA reduction of 37% due to the absence of fans is mostly (67%) related to the worse team performance by the home sides and only to some extent (19%) to the decreased referee bias.[2]

1.2. The effect of COVID-19 on HA

One way to measure the impact of the fans on the HA is to check how much it differs depending on the number of fans present during the games. Indeed, the HA is larger the more fans are present (Armatas & Pollard, 2014; Goumas, 2014b), especially when the stadium capacity (Agnew & Carron, 1994) and how close to the pitch the fans are (Unkelbach & Memmert, 2010) have been accounted for. The ultimate test is, however, the situation where there is no audience at all (Mill, 1906; Popper, 2005). Previous research on "ghost games" has been greatly hampered by the small number of such instances (Moore & Brylinsky, 1993; Pettersson-Lidbom & Priks, 2010; Van de Ven, 2011). The current pandemic has provided a unique opportunity for a prolonged natural experiment (Dunning, 2012). Meanwhile, there are numerous studies on the effect of the absent (or drastically reduced) audience in various sports (for a review in soccer, see Leitner et al., 2022).

In (association) football, or soccer, the most relevant sport for our study, home teams won around between 2% and 3.8% fewer games during the COVID-19 period than before (Bilalić et al., 2021; Bryson et al., 2021; Cueva, 2020). While this does not sound like much, the HA reduction due to empty stadiums, when we compare it with full stadiums, is around 37% (Bilalić et al., 2021). More specifically, home teams won between 0.15 and 0.24 points less during the COVID-19 period than before (Cueva, 2020; Scoppa, 2020; Wunderlich, Weigelt, et al., 2021) and score on average between 0.08 and 0.15 goals fewer per game (Bryson et al., 2021; Scoppa, 2020). Similar findings are found for referee bias as the advantage in the number of fouls (how many more were given to the away team) was reduced from 0.66 to 0.88 fouls (Bilalić et al., 2021; Cueva, 2020; Scoppa, 2020; Wunderlich, Weigelt, et al., 2021), yellow cards from 0.36 to 0.50 (Bilalić et al., 2021; Bryson et al., 2021; Cueva, 2020; Scoppa, 2020; Wunderlich, Weigelt, et al., 2021), and red cards from 0.03 to 0.05 (Bilalić et al., 2021; Bryson et al., 2021; Cueva, 2020; Scoppa, 2020; Wunderlich, Weigelt, et al., 2021).

1.3. The effect of COVID-19 on HA in high- and low-stake games

Previous research has mostly focused on the effect of COVID-19 on the HA in league games, where teams play several games during a season (Bilalić et al., 2021; Cueva, 2020; Scoppa, 2020; Wunderlich, Weigelt, et al., 2021). These games are significant, but not as crucial as high-stake games such as those at the UEFA European Championship (EURO 20) where an unfortunate result may lead to immediate elimination. Research on the impact of COVID-19 on international friendlies (Sors, Grassi, Agostini, & Murgia, 2022), considered low-stake games compared to EURO 20, exists, but direct comparisons between high- and low-stake situations are lacking.

Representing their country in national team games may increase players' motivation, potentially resulting in more effort and focus. Coupled with media attention and fan support, the HA may be magnified in high-stake games where the winner takes it all (House, Power, & Alison, 2014). In contrast, national friendly games, which lack these

[2] The home teams performed 0.57 SD better than away team with fans before Covid-19, but the HA dropped to 0.36 of a SD when there were no fans during Covid-19. The HA reduction of a 0.21 SD (0.57–0.36) equals 37% of the previous HA. The reduction of 0.21 SD is made of 0.14 SD reduction in Team Performance when teams played with and without fans (0.14/0.21 = 0.67) and of 0.04 SD reduction in Referee Bias going from playing with and without fans (0.04/0.21 = 0.19). While these reductions are based on standardised model estimates, they are similar if we use raw number of points won and goals scored with and without fans present.

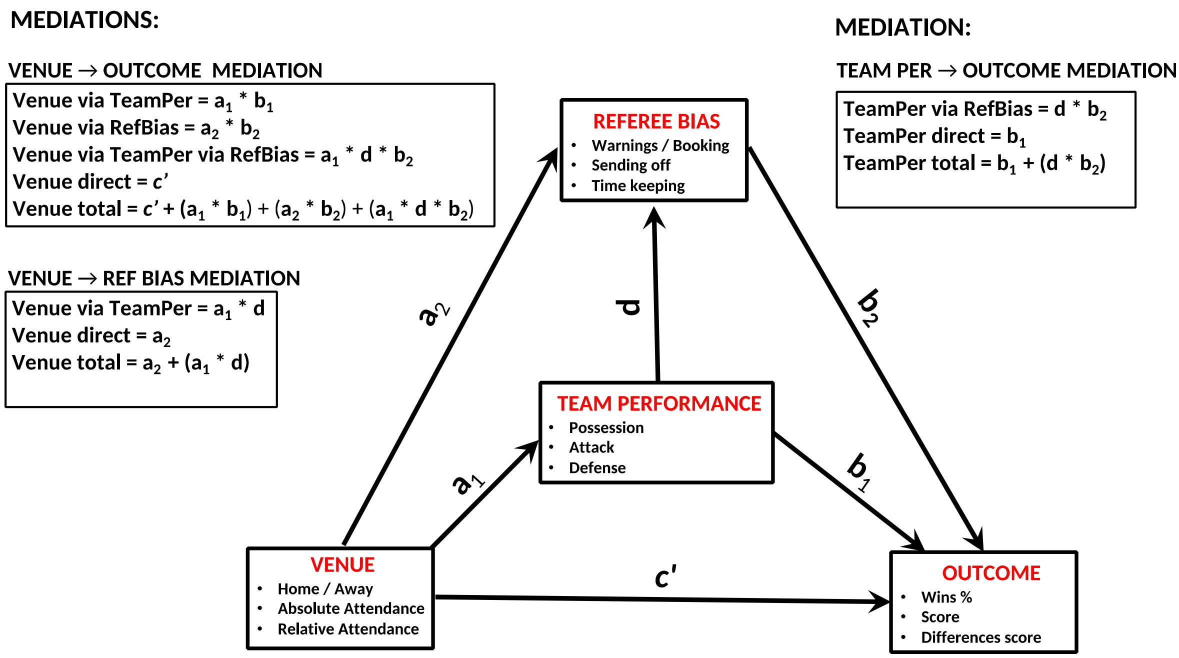

Figure 1. HAM model. Venue is mediated directly through Team Performance and Referee Bias (mediations specified in the left boxes). The Team Performance is mediated through the Referee Bias (mediation specified in the right box). The relations between concepts are labelled by small letters and are then used to express the manipulations for calculating the mediation and total effects (see results).

factors, might lead to less intense performances and more tactical experimentation. High-stake games might also experience more referee bias due to the combination of occasion magnitude and crowd pressure, factors absent in low-stake games.

The Covid-19 related absence or considerable reduction of fans should impact team performance and referee bias, considerably reducing the HA. This effect could be particularly pronounced in high-stake situations, where HA is, arguably, closely associated with fan support. It is, however, unclear whether the HA mechanism, and its related reduction due to the absence of fans, works the same way on high-and low occasions. Similarly, it is unclear what is the extent of the HA reduction in such instances.

1.4. Current study – European national championship and friendly games

We use the games played at European Championships as the example of high-stake games, while we treat international friendlies as the low-stake games. More specifically, for the high-stake games, we focus on the recent EURO 20, comparing host team games, played with reduced fan presence, with 1) the games of the same host teams in the UEFA Qualifications for the European Championship (QUALI 19), and 2) the home games played in the 15 previous European Championships (from 1960 to 2016; EURO 60-16), where there were no fan restrictions.

For the low-stake games, we use the Nations League, a biennial international football (European) competition, which is primarily treated as a series of slightly more serious friendly games. Most of the teams have not much to gain and are mostly experimenting and preparing for the official international competitions. We compare the 2018-19 edition, played with fan presence, with the 2020-21 edition, played under COVID-19 attendance restrictions.

In all instances, we employ the HAM model to disentangle the effect of individual factors on the HA. We expect the HA to be considerably smaller during the last EURO 20, which was played in partially filled stadiums, compared to the qualifications and previous editions of the European Championships, which were played under no Covid-19 restrictions. The reduction should be a direct product of suppressed team performance due to the lack or reduction of crowd support. The low-stake games most likely should follow the same HA mechanisms as high-stake games, but their overall HA, and therefore HA reduction due to the absence of fans, should be smaller.

2. Methods

2.1. Design

We were interested in the impact of two factors: Stake and Covid-19 related attendance on HA (see Table 1). As presented in Table 1, one could argue that we have a 2 x 2 design where the Covid factor (presence vs. absence of fans) is crossed with the Stakes factor (high- and low-stakes). For the high-stake situation with reduced or absent crowds, we used the recently finished EURO 20. Unlike previous editions, EURO 20 was conducted in several countries, allowing several teams to host games. All games were played in front of a considerably reduced number of fans (around ¼ of capacity), and most, if not all, games had great significance for further progression in the tournament.

For the comparison with EURO 20, as the high-stake situation with full crowd presence, we used the games from the UEFA Qualifications for the European Championship (QUALI 19), which took place only a short period before EURO 20. The same teams that hosted games at EURO 20 were also hosts in several games during QUALI 19. Given the similar timeframe between the two competitions, as well as the almost identical players in the teams, this comparison arguably makes sense (especially if we account for the differing strengths of the opponents, which we do here - see below Method). The advantage of using recent QUALI 19 games is that we also possess enough additional data on team performance and referee bias besides the outcome. Therefore, we can apply the HAM model to both sets of data, which allows us to examine not only whether the HA in both competitions followed the same mechanisms but also the differences between the two settings (Bilalić et al., 2021; Sors et al., 2022).

The other logical comparison, the 15 previous UEFA European Championships (from 1960 to 2016), is not possible to model with HAM because for most of the games, at least those before 2004, we do not possess additional statistics for team performance and referee bias. Therefore, we use a two-step approach to supplement the EURO 20 vs. QUALI 19 analysis: 1) we model EURO 04-16 games with HAM and

Table 1
Design and data sets. Overview of data sets used and their characteristics.

Competition	Year	Stakes	Fan presence	Games	Fans	Density	Home Elo Difference	Home Points	Home Goal Difference
European Championship (EURO 20)	2021	High	Reduced	27	23,336	33%	67 (.22 SD)	62% (57%)	+0.59
Quaification for EURO 20 (QUALI 19)	2019	High	Present	41	37,642	77%	280 (.93 SD)	83% (82%)	+1.6
Nations League (Nations 20)	2020–2021	Low	Absent	133	<50	<1%	−3 (.01 SD)	50% (46%)	+0.16
Nations League (Nations 18)	2018–2019	Low	Present	133	17,592	42%	7 (.02 SD)	61% (56%)	+0.48

Note. Density = Percentage of the stadium filled with fans; Home Elo Difference = Home Elo - Away Elo with how many SD is the difference (Elo SD is around 300 points); Home Points = Home points/(Home points + Away points), in the brackets is the percentage of points won by the home team out of all possible points; Home Goal Difference = Home goals - Away goals, i.e. how many goals the home team scored on average per match.

compare them to EURO 20, and 2) we compare EURO 20 with EURO 60-16 only on the outcome variables - points won and goals scored (these analyses are presented in the Supplementary Material (SM), Section 3).

For low-stake games, we use the Nations League, which was recently introduced as a substitute for international friendly matches. European teams are divided into four groups/leagues based on rankings and play a home-and-away round-robin schedule. The top four teams then play a knockout stage to determine the title. Although the Nations League provides a backdoor qualification path to the European Championship, the majority of national teams treat it as an opportunity to experiment with different formations and players. We use the 2018-19 edition, which was played with the presence of fans, and the 2020-21 edition, which was played almost exclusively without fans.

2.2. Sample

2.2.1. High-stake games

EURO 20. The latest European Football Championship, that of 2021 (EURO 20), was the main focus. EURO 20 was played at different countries in front of reduced numbers of fans. There were 27 matches (and 54 data points) where one side enjoyed the home ground advantage. Altogether, there were 10 teams who played home matches during EURO 20. The average attendance for these 27 matches was 23,336 (*SD* = 3367). When compared to the stadium capacity, the relative capacity was on average only $^{1/3}$ (*M* = 33%; *SD* = 4%). The information about the home games during EURO 20 was taken from the official UEFA website: https://www.uefa.com/uefaeuro/history/seasons/2020/.

QUALI 19. We compared EURO 20 with two samples of games. The first set of games were from the European Qualifiers held mostly in 2019 (here designated QUALI 19) with no restrictions on attendance. The same 10 teams who were hosts at EURO 20 had to qualify for EURO 20. We have taken their home games during QUALI 19 as the first comparison with their home games during EURO 20. Altogether there were 41 games, played in front of on average 37,642 fans (*SD* = 2937), or in relative terms ¾ of the stadium capacity (*M* = 77%; SD = 3). The data on the QUALI 19 games were obtained from the professional football reference website: https://www.fbref.com.

2.2.2. Low-stake games

Nations 2018-19. The Nations League is divided into four leagues (A, B, C and D) based on the UEFA national team coefficients. Each league is further split into four groups of three or four teams. The teams play each other home and away in a round-robin format. The group winners of League A qualify for the Nations League Finals, where they compete for the trophy. The group winners of Leagues B, C and D are promoted to the next league, while the last-placed teams of Leagues A, B and C are relegated to the lower league. The Nations League also offers a backdoor qualification for the World Cup and the European Championship. Two places in each tournament are reserved for the best-ranked Nations League teams that have not qualified directly through the conventional qualifying groups. These teams enter a play-off system, where they are drawn into single-leg semi-finals and a final. The winner of each play-off path qualifies for the final tournament.

During the 2018-19 Nations League, a total of 142 matches unfolded. For the purposes of this study, however, a set of nine matches was systematically excluded from consideration following a similar procedure by Sors et al. (2022). Five of these games were subjected to penalties that resulted in them being played in the absence of spectators. Furthermore, the final knockout stage games - four in number - were also dismissed due to their distinct nature. Consequently, our analysis focused on the remaining 133 matches, which were characterized by a varied range of spectator presence - from a sparse gathering of 736 individuals to a bustling crowd of 81,392, with an average tally at 17,592 ± 18,787. The relative capacity was on average almost 1/2 (*M* = 42%; *SD* = 50%). The data on the Nations 2018-19 games were obtained from Sors et al. (2022), supplemented by Elo ratings (obtained at the website eloratings.net), and were double checked using https://www.fbref.com.

Nations 2020-21. In the subsequent 2020-21 edition, there were originally 164 matches under consideration. As in Sors et al. (2022), we also dismissed nine matches from the set - five were hosted on neutral grounds, and once more, the four final knockout stage matches were excluded. With the remaining 155 matches, a decision was made to include the matches played behind closed doors and those with less audience than the lowest attendance from the previous edition. This decision left us with a refined selection of 133 matches from the 2020-21 edition. Among these, 115 were marked by the total absence of spectators, whereas the remaining 18 attracted audiences ranging from a modest 60 spectators to a relatively larger group of 696. The average attendance for these games stood at 299 ± 214. The data on the Nations 2020-21 games were obtained from Sors et al. (2022), supplemented by Elo ratings (obtained at the website eloratings.net), and were double checked using https://www.fbref.com.

2.2.3. Comparisons

The freely available data includes the scores, goals for each team, shots, shots on target, corners, fouls, yellow and red cards, and several other indicators (which are of no interest here) for each individual game. The exceptions to this are the games for the European Championships before 2004 where only the final score (and, from 1992, official warnings) were available. Consequently, we compare EURO 20 with QUALI 19 on outcome, team performance, and referee bias variables. The Nations 2019-20 is compared to Nations 2020-21 also on the outcome, team performance, and referee bias variables. However, EURO 60-16 is compared only on the outcome indicators (i.e., points won based on the 90 minutes and goals scored) to EURO 20. The four European Championships from 2004 to 2016 were compared to EURO 20 on the outcome, team performance, and referee bias variables. The last two additional analyses were presented in the SM (Section 3).

2.3. Analysis

2.3.1. Descriptive statistics

We operationalized the Venue as a factor variable with two levels: home (coded 1) and away (coded 0). Points won and goals scored were used to produce the Outcome, the Referee Bias consisted of fouls plus yellow and red cards, while the Team Performance was measured by corners, shots, and shots on target. The categorization of the individual indicators into these groups not only makes sense from the theoretical standpoint, but also from the empirical perspective as the indicators form an independent latent construct which can be obtained by factor analytical procedures (Bilalić et al., 2021).

2.3.2. HAM model for the EURO 20 vs. QUALI 19 comparison (high-stakes pre-vs. during covid)

The measures of the Outcome, Team Performance, and Referee Bias were obtained by regressing the weights of the individual variables in the factor analysis to produce latent standardized variables (with the mean 0 and standard deviation 1). The approach of collapsing variables into a single latent concept is shown to improve concept validity (Conway et al., 2005; Foster et al., 2015). It also has the practical effect of simplifying the statistical model (Kline, 2015) (e.g. one analysis instead of three separate ones).

For our HAM model we used a game-pairs framework where a single game with its indicators (e.g. goals, points, team or referees' performance) was in the analysis for both home and away teams (for similar approaches, see Goumas, 2017; Ponzo & Scoppa, 2018; Van Damme & Baert, 2019). The game-paired framework has the advantage of telling us the cause of the difference: whether fewer shots when playing in front of a reduced audience are the product of reduced performance by home teams, increased performance by away teams, or a combination of both. We would not be able to do this by using other approaches, such as using the difference between home and away teams (Armatas & Pollard, 2014; Bryson et al., 2021; Cueva, 2020).

The specified model was then analyzed using conditional mixed-effects process analysis (Hayes, 2017; Shipley, 2016) in the Bayesian framework (Kruschke, 2011) for testing the indirect effect of Venue on Outcome through Team Performance and Referee Bias. These indirect effects, or mediations, can tell us how much of the overall advantage of the home ground is through better team performance and how much it is a consequence of referee bias (Bilalić et al., 2021). It is also possible to make a binary comparison between EURO 21 and QUALI 19, as one can incorporate the influence of the partial presence of the fans (Covid factor) in the path analysis by checking the interaction of the Covid factor with individual path relations – also known as moderated mediation (Hayes, 2017).

To control for possible differences in the teams' strengths between EURO 20 and QUALI 19, we used the World Football Elo Ratings (obtained at the website eloratings.net), which is a modification of the Elo rating from chess (Elo, 1978). It considers several football-specific factors such as the margin of victory, the importance of the match, and the home ground advantage. It has been shown to have the highest predictive capability among a number of other rating systems, including FIFA's own (Lasek, Szlávik, & Bhulai, 2013; Xiong, Yang, Zin, & Iida, 2016). On average, the Elo rating for the European teams is around 1600 with a standard deviation of around 300. The best teams have an Elo rating of around 2000 and more. For the analysis, we have taken the Elo rating for the teams in the month that the competition started (June 2021 for EURO 20, January 2019 for QUALI 19, and usually the June of the year when the European Championships were taking place between 1960 and 2016). We used the Elo ratings before the actual competition began and the Elo rating was standardized ($M = 0$ and $SD = 1$) to be comparable to the standardized rating from the study we used to establish priors for the Bayesian analysis (see the section on the Bayesian analysis below). The Elo was included in the HAM model as a predictor of all three concepts (Outcome, Team Performance, and Referee Bias), as well as interaction with Venue and Covid factors. The results are reported in detail in the Supplemental Material (SM, Section 2) but were not depicted in the main text for the sake of simplicity and readability.

Given that all variables in the model have been standardized (i.e., $M = 0$, $SD = 1$), the coefficients presented in the figures and tables are standardized regression coefficients. For instance, a coefficient of 0.51 in Table 2 and Figure 3, representing the relationship between Team Performance and Outcome (for QUALI 19), means that a 1 SD increase in Team Performance results in a 0.51 SD increase in the Outcome, while holding other variables in the model (Referee Bias, Venue, and Rating) constant. The Venue variable is a binary variable, and in this case, a coefficient of 0.98 for the relationship between Venue and Team Performance indicates that the Team Performance of home teams (referenced as 1) is 0.98 SD better compared to the Team Performance of away teams (referenced as 0).

2.3.3. HAM model for Nations 2019-20 vs. Nations 2020–21 (low-stakes)

Finally, we also conducted a comparison between Nations 2019-20 and Nations 2020-21 using the HAM model. The same procedure as in the EURO 20 vs. QUALI 19 comparison mentioned above was applied. We created measures for the Outcome (based on points and goals), Team Performance (derived from corners and shots), and Referee Bias (assessed through cards and fouls). These measures were utilized in a mediation model, alongside Elo ratings of team strengths as a control covariate (obtained from World Football Elo: eloratings.net). The analysis and interpretation of the results followed the same approach as the EURO 20 vs. QUALI 19 comparison discussed earlier.

2.3.4. Bayesian analysis information

The Bayesian framework was chosen for its flexibility, which enabled us to conduct all analyses within a single framework, as well as its ability to provide rich information about the model and its parameters (Kruschke, 2011). Here we provide a brief overview of the main options in the Bayesian analysis. The full information on every aspect of the analysis is available in the SM (Section 1), while we also provide the data and the code for the analysis (https://osf.io/wjqma/).

The HAM model for both comparisons (EURO 20 vs. QUALI 19 and Nations 19 vs. Nations 20) was modeled using the Gaussian function as the outcome variables (Outcome, Team Performance, and Referee Bias) most closely resembled a normal distribution (see Figure S7 in SM). We used three different priors. The first one was an un-informative prior for all coefficients that followed the normal distribution with mean centered around 0 and standard deviation 1. This prior covered the whole range of plausible possibilities, with those between 1 and -1 being most probable (i.e. 68% of all possibilities), as all coefficients in our model were standardized (i.e. z-scale between −3 and 3). The second prior was a strong prior as we used the previous study (Bilalić et al., 2021), which compared club teams across European leagues in the 2019-20 season, as the template study. The previous study had the same design, including one period when the games were played under no restrictions and another when there were full or partial restrictions. The exact coefficients (i.e. Ms and SDs) for the individual relations were also taken as the priors for the current study. Finally, we used informative priors which were half the estimated coefficients from the previous study, with SD defined as such that $M + 1SD$ reached the full estimate (e.g., if the coefficient was +0.50, the prior was $M = 0.25$ with $SD = 0.25$). This was done because the use of the exact estimates (e.g. M and SD) as in the strong priors would bias the current estimates to an unhealthy extent (Dienes, 2021).

We provide the results of the model with the informative priors in the main text. The results of the models with the un-informative and strong priors, as well as other details about the priors, are presented in the SM within the sensitivity analysis (Section 4).

The estimated coefficients (i.e. reported central tendencies) were supplemented by four different indicators of existence and significance

(Makowski, Ben-Shachar, Chen, & Lüdecke, 2019). We first provide the credible intervals (CrI) of the posterior distribution. Here we use the 89% CrI as suggested by some researchers (Kruschke, 2011; McElreath, 2018) and used in previous research (Bilalić et al., 2021; Vaci, Cocić, Gula, & Bilalić, 2019). The coefficients that do not encompass zero within the CrI are highlighted in the figures (with an asterisk). The other measure of effect existence, probability of direction (pd), is also provided. The pd measure indicates how much the effect/coefficient is greater (or smaller if negative) than zero. More precisely, it presents the proportion of the posterior distribution that is of the same sign as the mean estimate and is a Bayesian equaling of the p measure in the frequentist statistics (Makowski et al., 2019).

Besides the two measures of consistency of an effect in one particular direction (CrI and pd), we present two measures of significance, that is how important the estimates are: Regions Of Practical Equivalence (ROPE) and Bayes Factor (BF). The ROPE indicates that the values within the CrI are important by defining the region of unimportance and testing how much of the posterior distribution falls within that region of practical equivalence. BF is the degree by which the probability mass has shifted away from or toward the null value, after observing the data. Unlike the measures of existence, ROPE and BF can tell us not only whether the effect exists, but also whether the effect does not exist. The percentage of ROPE would be rather high (e.g. 95%) and BF can be expressed in two measures, one for the significance of effect (BF_{10}) and the other for the significance of the null effect (BF_{01}).

2.3.5. Additional analyses

The SM presents additional analyses which feature different statistical and analytical approaches. First, we provide supplemental analyses for the EURO 20 vs QUALI 19 comparison. We use the previous four European Championships (from 2004 to 2016; EURO 04-16) with available Team Performance and Referee Bias statistics to compare them to EURO 20 in the HAM model (SM, Section 3). We also use all 15 previous European Championships (from 1960 to 2016; EURO 60-16) to compare them to EURO 20 on the outcome variables such as points and goals (SM, Section 3). We then use non-Bayesian approaches, for example conditional path analysis (SM, Section 5.1), to demonstrate that they produce a largely identical pattern of results. Similarly, a different statistical technique, Structural Equation Modeling (SEM), where all the indicators of the concepts were incorporated directly in a single model, also produces essentially the same results (SM, Section 5.2). The frequentist zero-inflated Poisson regression also confirms the results of the Bayesian analyses for points and goals in the comparison between EURO 20 and EURO 60-16 (SM, Section 5.3).

3. Results

3.1. High-stake games (EURO 2020 vs. Qualifications 2019)

3.1.1. Descriptive analysis

The home teams performed well during QUALI 19 in front of full stadiums (see the top row of Figure 2). They won more points (2.4 vs. 0.54) and scored more goals (3.5 vs. 0.80) than the away teams. Their home advantage was considerably smaller when they faced the away teams during EURO 20 in front of reduced crowds. They still won more points (1.7 vs. 1) and scored more goals (1.6 vs. 0.96) but the advantage was only 38% and 22% of the initial home advantage for goals and points, respectively. As well as the reduced crowds, one of the reasons for this drastic drop is certainly the strength of away teams at the two competitions. The home teams were considerably better than the away teams during QUALI 19 as measured by the Elo rating for national teams (almost 300 rating points difference, which is almost one SD; for more details, see Method). During EURO 20, this advantage was reduced to just 66 Elo points.

The Outcome measures are most likely a consequence of team performance. Team performance can be measured by indicators related to created opportunities to score, such as corners, shots, and shots on target (Armatas & Pollard, 2014; Castellano, Casamichana, & Lago, 2012). Figure 2 (middle panel) illustrates that there is a marked drop in home teams' performance going from QUALI 19 to EURO 20. Home teams won fewer corners (−2.80) when they played with only a fraction of fans present than when they played with fans, created fewer shots (−18.1), and fewer of these shots landed on target (−3.2). In contrast, away teams' performance suffered only slightly when the games were played with reduced attendance (+0.24, −11.3, and 0.7 for corners, shots, and shots on target, respectively).

The referee's decision-making was also impacted by the reduced number of fans present during EURO 20 compared to QUALI 19. Figure 2 (lower panel) demonstrates that fouls by home teams were penalized more by referees when they played without spectators (+2.3) than when they played with the fans present, not unlike the away teams who were also whistled more often for infringements (+3.38). Home teams were punished more with yellow cards in the during-than in the pre-Covid period (+0.14), whereas the away teams received fewer official warnings (−0.24) when the games were played in front of a reduced crowd. Finally, the use of the most severe punishment, the red card, was also influenced by the presence of fans – home teams received on average fewer red cards in the during-Covid period (−0.02) while away teams were punished more often (+0.01).

3.1.2. The Home Advantage Mediated (HAM) model

Unlike the descriptive analysis presented above, the HAM model takes into consideration the interrelations between the factors. Moreover, it addresses the significant difference in the quality of the away opponents in EURO 20 and QUALI 19 by controlling for team strength through the inclusion of the Elo measure in the mediation model.

Figure 3 presents the results of the HAM model for QUALI 19 and EURO 20. When we consider the results for QUALI 19 (blue coefficients in Figure 2), we can see that Team Performance is the strongest predictor of the Outcome (0.52). Venue (0.09) and Referee Bias (−0.03) were not particularly related to the Outcome. Playing at home did, however, heavily influence the Team Performance (0.90) and in that way indirectly the Outcome (mediation Venue → Team Performance → Outcome was 0.47 – see the top left box in Figure 3). Home teams were also on the receiving end of fewer official warning (−0.10), similarly to the better performing teams (−0.10).

The results for EURO 20 (red coefficients in Figure 3) followed a similar pattern in that the Team Performance (0.51) was the strongest predictor, whereas Venue (0.07) and Referee Bias (−0.03) were not that relevant. Similarly, the referee bias was also predicted by the team performance (−0.12). The biggest difference between EURO 20 and QUALI 19 was that playing at home now resulted in a) the reduction in the association with better team performance (now 0.48 instead of 0.90) and b) the reverse (albeit weak) association with the referee bias as the home teams now were receiving more official warnings (0.03 instead of −0.10).

These differences also resulted in the decreased overall influence of playing at home on the outcome. The indirect influence (i.e., mediation) of Venue on Outcome through Team Performance was present and significant for QUALI 19 (0.47), but was not present for EURO 20 (0.25). The overall influence of playing at home, which included both mediations through Team Performance and Referees' Decisions, as well as the direct influence on the Outcome, was also almost halved when the fans were partially present during EURO 20 (0.32) compared with when they

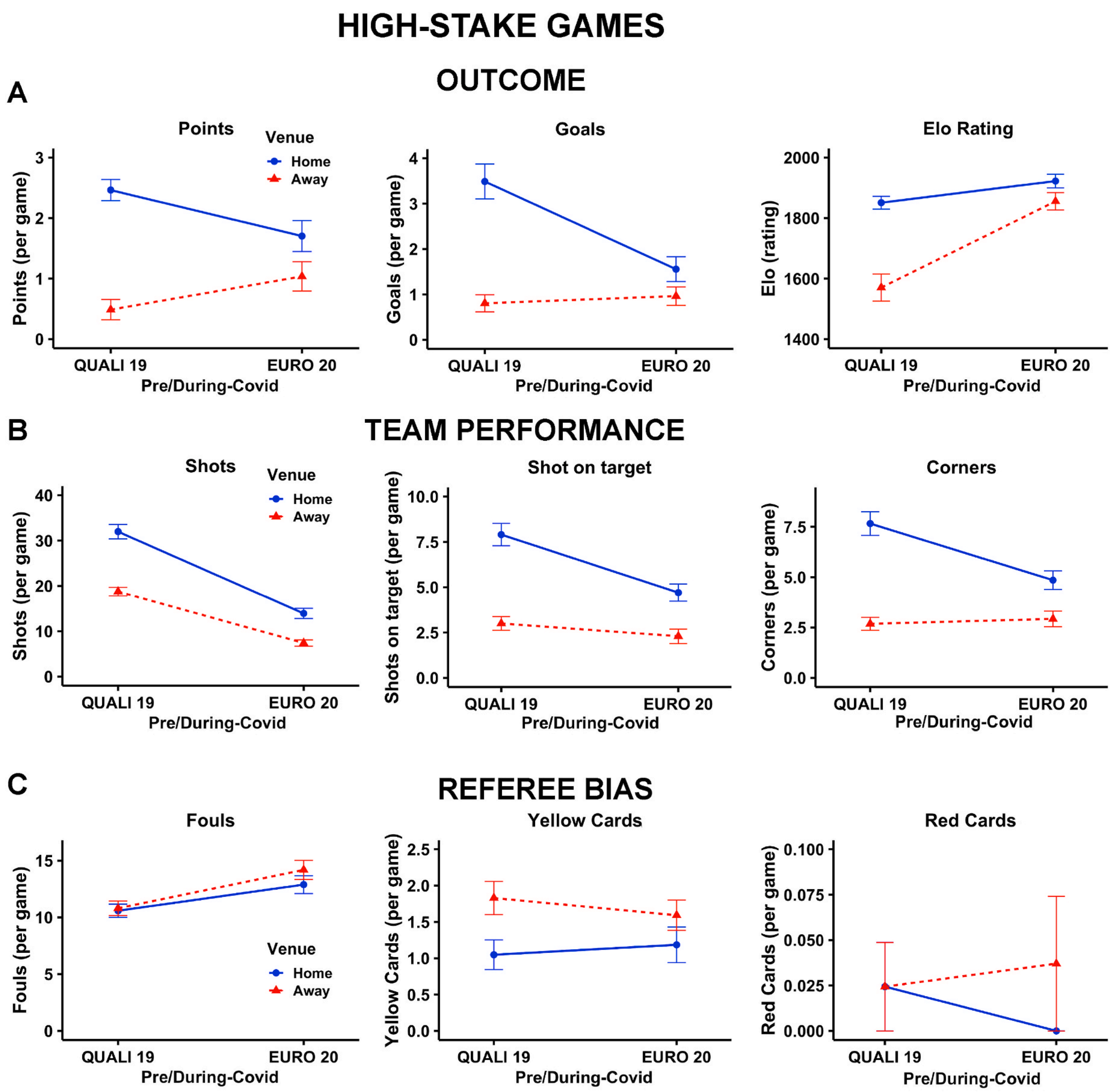

Figure 2. Descriptive Statistics for Venue x Covid interaction in High-stake Games (QUALI 19 vs. EURO 20). A) Outcome variables of average number of points won per game (left), average number of goals scored per game (middle), and Elo rating (right). B) Team Performance variables of corners per game (left), shots per game (middle), and shots on target per game (right); C) Referee Bias variables of fouls per game (left), yellow cards per game (middle), and red cards per game (right). Error bars represent +/− 1 standard error of the mean.

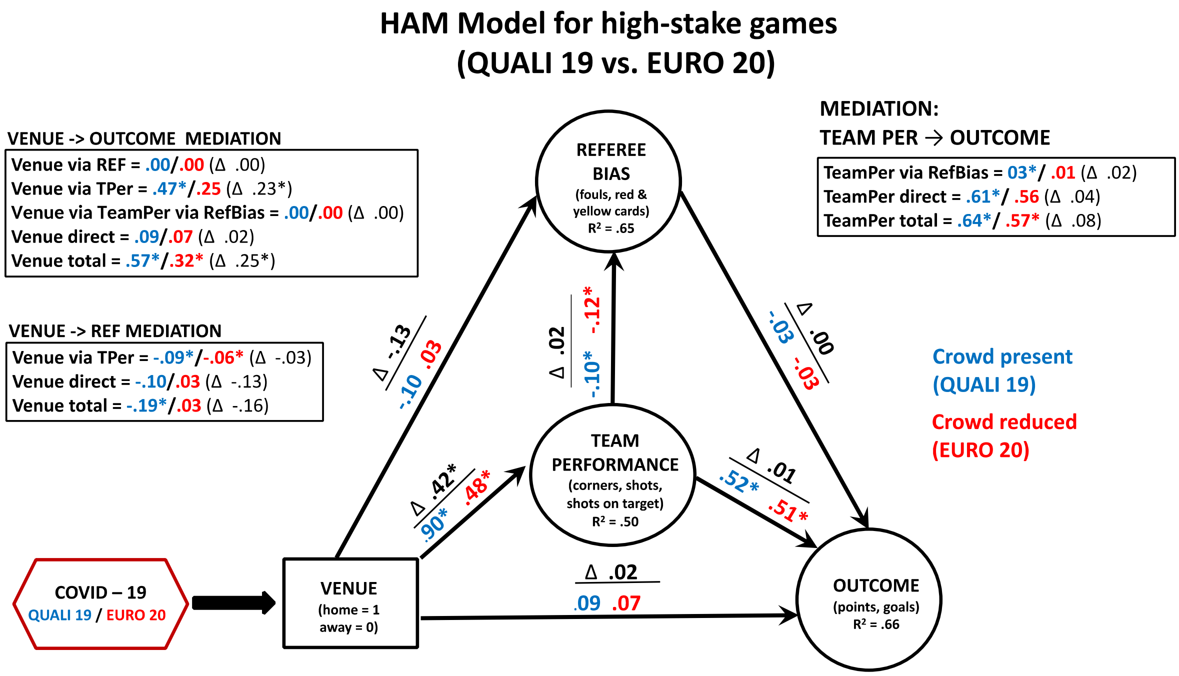

Figure 3. HAM Model – Bayesian (mixed-effects) conditional process analysis of HA. The interplay between Venue, Team Performance, Referees' Decisions, and Outcome (the circular shape denotes latent variables, with the individual variables listed within the boxes). Lines with single-end arrows indicate the direction of influence. The numbers on the line are path model coefficients. The pre-Covid path coefficients are in blue, the during-Covid coefficients are in red, while their differences, indicated by Δ, are in black. The statistically significant coefficients (95% credible intervals do not encompass 0) are indicated with *. The difference between the pre- and during-Covid path coefficients, delta (Δ), is indicated above the individual coefficients (* when 95% credible intervals do not encompass 0 and ns when they do). The indirect influence of Venue on Outcome through Team Performance and Referees' Decisions is formally tested in a mediation model (upper left box). The indirect influence of Venue on Referees' Decision through Team Performance is also formally tested by mediation (lower left box). R^2 is Bayesian full model coefficient of determination, which includes both fixed (COVID, Venue, Referees' Decisions, Team Performance, Importance, and Rating) and random (league and team) effects. The control variable of Elo rating was not presented here for the sake of conciseness (see SM, Section 2).

Table 2
HAM model detailed statistics for high-stake games. Individual estimates for QUALI 19 and EURO 20, as well as their difference.

#	Relation		Est.	CrI low - high	pd	ROPE %	BF01	BF10
A.	*Main Effects*							
1	Venue → Outcome	QUALI 19	0.09	−0.01 – 0.19	0.93	24	0.65	1.5
		EURO 20	0.07	−0.05 – 0.20	0.84	32	1.01	1.0
		DIFF	0.02	−0.06 – 0.10	0.65	67	0.98	1.0
2	Team Performance → Outcome	QUALI 19	0.52	0.43 – 0.62	1.00	0	0.00	>1000
		EURO 20	0.51	0.41 – 0.62	1.00	0	0.00	>1000
		DIFF	0.01	−0.07 – 0.09	0.59	69	1.01	1.0
3	Referee Bias → Outcome	QUALI 19	−0.03	−0.06 – 0.00	0.96	81	0.38	2.6
		EURO 20	−0.03	−0.11 – 0.04	0.76	60	0.97	1.0
		DIFF	0.00	−0.07 – 0.07	0.50	74	1.11	0.9
4	Venue → Team Performance	QUALI 19	0.90	0.68 – 1.12	1.00	0	0.00	>1000
		EURO 20	0.48	0.23 – 0.74	1.00	0	0.02	61.1
		DIFF	0.42	0.24 – 0.60	1.00	0	0.00	589
5	Venue → Referee Bias	QUALI 19	−0.10	−0.22 – 0.02	0.91	23	0.74	1.4
		EURO 20	0.03	−0.18 – 0.23	0.58	29	1.12	0.9
		DIFF	−0.13	−0.30 – 0.05	0.88	19	0.94	1.1
6	Team Performance → Referee Bias	QUALI 19	−0.10	−0.19 – −0.02	0.97	17	0.37	2.7
		EURO 20	−0.12	−0.23 – 0.00	0.95	16	0.41	2.4
		DIFF	0.02	−0.06 – 0.09	0.63	67	0.98	1.0

Note. Est. = path coefficient, CrI = Credible Intervals 89%, pd = Proportion of Direction, ROPE% = % in the Region of Practical Equalence (−0.05 to +0.05), BF = Bayes Factor, → = direction of influence.

were fully present during QUALI 19 (0.57).

The other factor that displayed a different pattern of results due to the absence of fans was the referees' decisions (see lower left box in Figure 3). There was a reversal of the direct trends in official warnings between home and away teams for the QUALI 19 (−0.07) and EURO 20 (+0.05) periods. Home teams were, however, considerably less dominant in EURO 20 than in the QUALI 19 period (0.90 vs. 0.48), which indirectly weakened their influence on the referee bias (the mediation between Venue and Referee Bias through Team Performance was −0.10 vs. +0.03, for QUALI 19 and EURO 20, respectively). This all resulted in a total effect of Venue on Referee Bias being three times greater when the fans were present during QUALI 19 (−0.19) than when the games were played in front of a handful of fans during EURO 20 (0.03). The home teams, which usually enjoyed fewer official warnings when the fans were present, were suddenly punished more when there was only a partial audience.

Table 3
HAM model detailed statistics for mediations for high-stake games. Individual estimates for the mediations for QUALI 19 and EURO 20, as well as their difference.

#	Relation		Est.	CrI low - high	pd	ROPE %	BF01	BF10
B.	*Mediation: Venue → Outcome*							
7	Indirect/mediated Team Performance [4 x 2]	QUALI 19	0.47	0.34 – 0.62	1.00	0	0.00	>1000
		EURO 20	0.25	0.11 – 0.40	1.00	1	0.00	392
		DIFF	0.23	0.12 – 0.34	1.00	0	0.00	505
8	Indirect/mediated Referee Bias [5 x 3]	QUALI 19	0.00	0.00 – 0.01	0.88	100	0.44	2.3
		EURO 20	0.00	−0.01 – 0.01	0.54	100	1.08	0.9
		DIFF	0.00	−0.01 – 0.02	0.77	100	0.77	1.3
9	Direct Venue [1]	QUALI 19	0.09	−0.01 – 0.19	0.93	24	0.65	1.54
		EURO 20	0.07	−0.05 – 0.20	0.84	32	1.01	0.99
		DIFF	0.02	−0.06 – 0.10	0.65	67	0.98	1.02
10	Total Venue [1 + (5 x 3) + (4 x 2)]	QUALI 19	0.57	0.41 – 0.74	1.00	0	0.00	>1000
		EURO 20	0.32	0.14 – 0.51	1.00	1	0.02	47
		DIFF	0.25	0.12 – 0.38	1.00	1	0.01	120
C.	*Mediation: Venue → Referees*							
11	Indirect/mediated Team Performance [6 x 4]	QUALI 19	−0.09	−0.18 – −0.01	0.97	21	0.05	18.8
		EURO 20	−0.06	−0.13 – 0.00	0.95	48	0.11	9.2
		DIFF	−0.03	−0.09 – 0.02	0.83	65	0.28	3.6
12	Direct Venue [5]	QUALI 19	−0.10	−0.22 – 0.02	0.91	23	0.74	1.35
		EURO 20	0.03	−0.18 – 0.23	0.58	29	1.12	0.90
		DIFF	−0.13	−0.30 – 0.05	0.88	19	0.94	1.06
13	Total Venue [5 + (6 x 4)]	QUALI 19	−0.19	−0.33 – −0.05	0.99	5	0.16	6.1
		EURO 20	−0.03	−0.24 – 0.18	0.58	28	1.14	0.9
		DIFF	−0.16	−0.34 – 0.02	0.92	13	0.67	1.5

Note. Est. = path coefficient, CrI = Credible Intervals 89%, pd = Proportion of Direction, ROPE% = % in the Region of Practical Equivalence (−0.05 to +0.05), BF = Bayes Factor, → = direction of influence. Terms in the squared parenthesis in sections B and C specify how the particular mediation was obtained.

It should be noted that the model controlled for the different strength of the away teams in QUALI 19 and EURO 20 by including the national team rating (Elo) as a mediator variable in all possible relations. As expected, the rating had a big and reliable effect on the Outcome (0.30) and Team performance (0.15) and was not affected by the presence or absence of fans (see SM, Section 2). We do not present all the relations in Figure 3 to avoid cluttering, but we present all model coefficients depicted in Figure 3. The estimated for mediations are presented in Table 2 and Table 3.

3.2. Low-stake games (Nations 18 vs. Nations 20)

3.2.1. Descriptive analysis

In the low-stake games, for which we take the Nations League games in 2018-19 and 2020–21, the outcome variables were affected by the presence/absence of fans. The home teams performed well during Nations 18 in front of full stadiums (see the top row of Figure 4). They won more points (1.68 vs. 1.09) and scored more goals (1.47 vs. 0.98) than the away teams. Their home advantage was considerably smaller when they faced the away teams during Nations 20 in front of reduced crowds. They did not win any more points (1.37 home teams vs. 1.37 away teams) but did score more goals (1.24 vs. 1.08), producing the advantage of only 6% and 14% of the initial home advantage for goals and points, respectively. Unlike between QUALI 19 and EURO 20 comparison, there were hardly any differences in team strength between home and away teams in either of the two Nations League competitions.

Figure 4 (middle panel) illustrates that there is a marked drop in home teams' performance going from Nations 18 to Nations 20. Home teams won fewer corners (−1) when they played with only without fans present than when they played with fans, created fewer shots (−2.04), and fewer of these shots landed on target (−0.62). In contrast, away teams' performance suffered only slightly when the games were played with reduced attendance (−0.06, −0.78, and +0.14 for corners, shots, and shots on target, respectively).

The referee's decision-making was also impacted by the reduced number of fans present during Nations 20 compared to Nations 18. Figure 4 (lower panel) demonstrates that fouls by home teams were penalized more by referees when they played without spectators (+0.29) than when they played with the fans present, not unlike the away teams who were also whistled more often for infringements (+0.51). Home teams were punished more with yellow cards in the during-than in the during-Covid period (+0.47), whereas the away teams received somewhat fewer official warnings (−0.15) when the games were played in front of a reduced crowd. Finally, the red cards were also influenced by the presence of fans – home teams received on average more red cards in the during-Covid period (+0.11) while away teams were punished to a similar degree (−0.01).

3.2.2. The Home Advantage Mediated (HAM) model

Next, we put the game indicators into a HAM model (see Figure 5). For Nations 18, depicted in blue coefficients within Figure 5, Team Performance emerged as the primary predictor of Outcome with a coefficient of 0.40. Conversely, Venue and Referee Bias showed relatively minimal correlation to the Outcome, with coefficients of 0.09 and −0.03 respectively. The influence of the home venue significantly correlated with Team Performance (0.49), indirectly impacting the Outcome. A mediation effect was discerned between Venue, Team Performance, and Outcome (0.20). Furthermore, home teams received fewer official warnings (−0.13), akin to teams performing better (−0.13).

In contrast, the Nations 20 results (red coefficients in Figure 5) followed a comparable pattern. Team Performance retained its position as the strongest predictor with a coefficient of 0.43, while Venue and Referee Bias remained less significant with coefficients of 0.07 and −0.05 respectively. Team performance also predictably influenced referee bias (−0.18). The prominent difference between Nations 18 and Nations 20 was the decreased correlation of playing at home with better team performance (0.20 versus 0.49), and a mild reversal in correlation with referee bias, with home teams now receiving more official warnings (0.08 instead of −0.13).

These variances led to a reduced overall impact of home venue on the outcome. For Nations 18, the indirect influence of Venue on Outcome through Team Performance was evident and significant at 0.20. Although this influence was also significant for Nations 20, it diminished considerably to 0.09. The total effect of the home venue on the Outcome, incorporating mediation through Team Performance and Referees' Decisions, as well as direct influence, nearly halved in the absence of fans

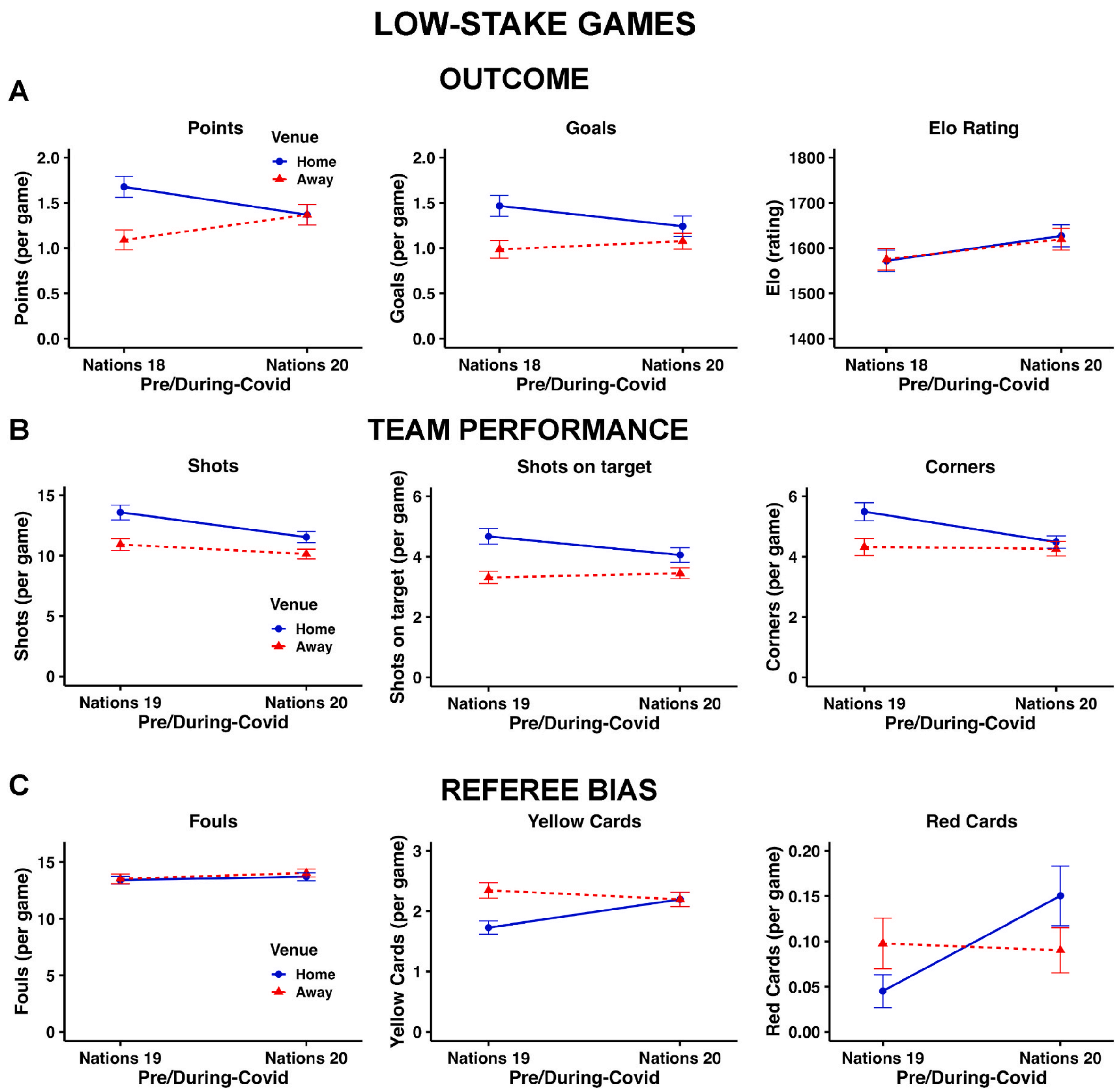

Figure 4. Descriptive Statistics for Venue x Covid interaction in Low-stake Games (Nations 19 vs. Nations 20). A) Outcome variables of average number of points won per game (left), average number of goals scored per game (middle), and Elo rating (right). B) Team Performance variables of corners per game (left), shots per game (middle), and shots on target per game (right); C) Referee Bias variables of fouls per game (left), yellow cards per game (middle), and red cards per game (right). Error bars represent +/− 1 standard error of the mean.

during Nations 20 (0.16) compared to their full presence during Nations 18 (0.29).

The Referee Bias exhibited a distinct trend due to the absence of fans, as illustrated in the lower left box of Figure 5. A contrast in the trajectory of official warnings for home and away teams was identified between the Nations 18 (−0.13) and EURO 20 (+0.08) periods. The dominance of home teams during Nations 20 was considerably less pronounced than in the Nations 20 period, exhibiting coefficients of 0.20 and 0.49, respectively. This consequently attenuated the impact on referee bias. Specifically, the mediation effect between Venue and Referee Bias via Team Performance was measured at −0.07 for Nations 18 and -0.04 for Nations 20. Therefore, the aggregate influence of Venue on Referee Bias was considerably larger during the Nations 18 edition (−0.21) when compared to the same edition without fans, Nations 20 (0.04). Interestingly, the home teams, who typically benefited from fewer official warnings during fan-attended matches, encountered an increase in penalties in the absence of fans.

As in the high-stake games analysis, the rating relations were not presented in Figure to avoid cluttering. We present all rating-related coefficients, as well as all model coefficients, in Table 4. The estimated for mediations are presented in Table 5.

3.3. Comparing high and low stake games pre- and during-covid

One of the advantages of the Bayesian approach is that it provides posterior distributions, which represent the updated uncertainty or belief about parameters or hypotheses after observing the data. These distributions allow us to directly compare the estimates. In our study, we have a 2 x 2 factorial design with two factors: “stakes” (high vs. low, referring to EURO/QUALI vs. Nations) and “Covid” (pre- and during-Covid, with and without fans). We can calculate the main effects of these factors, as well as their interaction.

For example, we can examine the total effect of the Venue factor, which represents the overall home advantage. Figure 6A illustrates that when we combine the posterior distributions of games with and without fan presence, regardless of high or low stakes (Nations 18 + QUALI 19 vs. EURO 20 + Nations 20), the distributions differ significantly and do not overlap much. This indicates that the overall home advantage effect

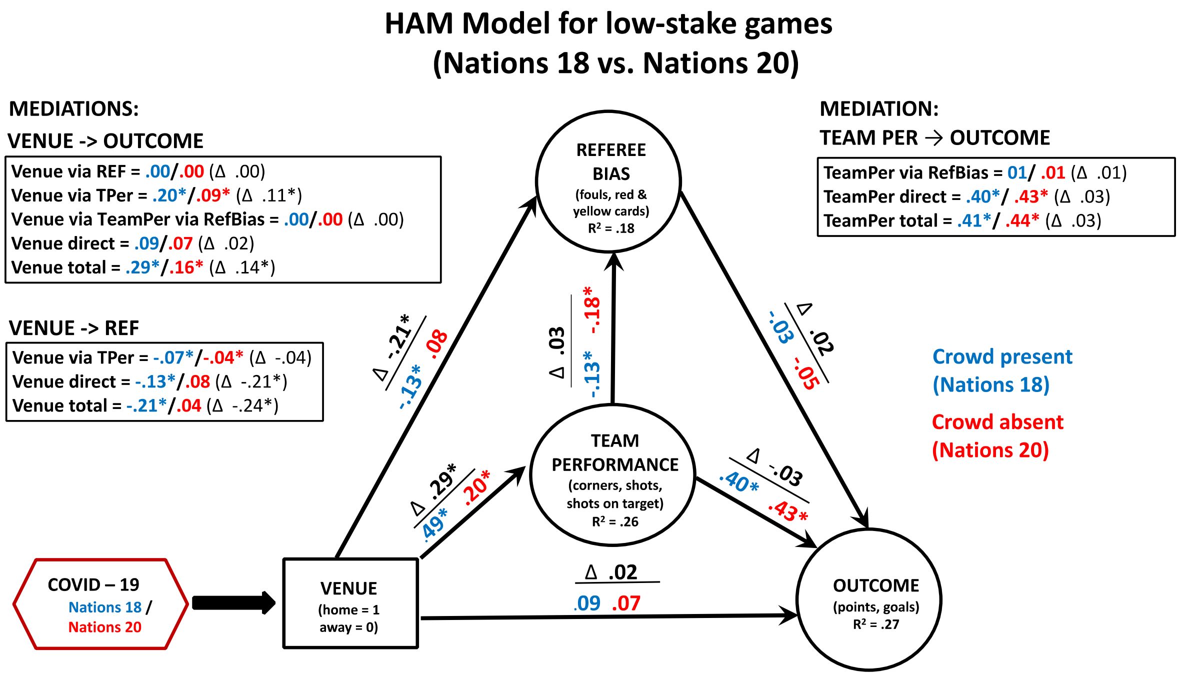

Figure 5. HAM Model – Bayesian (mixed-effects) conditional process analysis of HA. The interplay between Venue, Team Performance, Referees' Decisions, and Outcome (the circular shape denotes latent variables, with the individual variables listed within the boxes). Lines with single-end arrows indicate the direction of influence. The numbers on the line are path model coefficients. The pre-Covid path coefficients are in blue, the during-Covid coefficients are in red, while their differences, indicated by Δ, are in black. The statistically significant coefficients (95% credible intervals do not encompass 0) are indicated with *. The difference between the pre- and during-Covid path coefficients, delta (Δ), is indicated above the individual coefficients (* when 95% credible intervals do not encompass 0 and ns when they do). The indirect influence of Venue on Outcome through Team Performance and Referees' Decisions is formally tested in a mediation model (upper left box). The indirect influence of Venue on Referees' Decision through Team Performance is also formally tested by mediation (lower left box). R^2 is Bayesian full model coefficient of determination, which includes both fixed (COVID, Venue, Referees' Decisions, Team Performance, Importance, and Rating) and random (league and team) effects. The control variable of Elo rating was not presented here for the sake of conciseness (see SM, Section 2).

Table 4
HAM model detailed statistics for low-stake games. Individual estimates for Nations 19 and Nations 20, as well as their difference.

#	Relation		Est.	CrI low - high	pd	ROPE %	BF01	BF10
A.	*Main Effects*							
1	Venue → Outcome	Nations 18	0.09	−0.01 – 0.19	0.96	21	0.49	2.1
		Nations 20	0.07	−0.05 – 0.19	0.88	33	0.95	1.1
		DIFF	0.02	−0.07 – 0.11	0.67	69	1.05	1.0
2	Team Performance → Outcome	Nations 18	0.40	0.32 – 0.48	1.00	0	0.00	>1000
		Nations 20	0.43	0.34 – 0.53	1.00	0	0.00	>1000
		DIFF	−0.03	−0.12 – 0.05	0.78	63	0.83	1.2
3	Referee Bias → Outcome	Nations 18	−0.03	−0.07 – 0.00	0.95	86	0.41	2.4
		Nations 20	−0.05	−0.12 – 0.03	0.88	54	0.72	1.4
		DIFF	0.02	−0.06 – 0.09	0.65	77	1.20	0.8
4	Venue → Team Performance	Nations 18	0.49	0.33 – 0.65	1.00	0	0.00	>1000
		Nations 20	0.20	0.04 – 0.37	0.99	4	0.21	4.9
		DIFF	0.29	0.13 – 0.44	1.00	0	0.01	158
5	Venue → Referee Bias	Nations 18	−0.13	−0.25 – −0.02	0.99	8	0.19	5.3
		Nations 20	0.08	−0.09 – 0.24	0.82	32	1.22	0.8
		DIFF	−0.21	−0.37 – −0.05	0.99	3	0.10	9.8
6	Team Performance → Referee Bias	Nations 18	−0.15	−0.22 – −0.07	1.00	0	0.00	>1000
		Nations 20	−0.18	−0.27 – −0.09	1.00	0	0.00	937
		DIFF	0.03	−0.05 – 0.12	0.77	64	0.92	1.1

Note. Est. = path coefficient, CrI = Credible Intervals 89%, pd = Proportion of Direction, ROPE% = % in the Region of Practical Equalence (−0.05 to +0.05), BF = Bayes Factor, → = direction of influence.

is greater when fans are present compared to when they are absent (or significantly reduced), regardless of the stakes involved. Similarly, Figure 6 shows that high-stake games consistently produce larger overall home advantage effects compared to low-stake games.

We can also investigate whether there is an interaction between the stake and Covid factors, meaning whether the impact of fan presence/absence on home advantage differs depending on the stakes of the games. In a factorial design, this can be tested by examining the difference in differences, specifically comparing the difference between pre- and during-Covid in high-stake games (QUALI 19 vs. EURO 20) with the difference between pre- and during-Covid in low-stake games (Nations 18 vs. Nations 20). Figure 6A suggests that there is no significant difference in the overall home advantage effect. The reduction in home advantage due to the absence of fans is greater in high-stake games compared to low-stake games, but this difference is not statistically significant.

Table 5
HAM model detailed statistics for mediations for low-stake games. Individual estimates for the mediations for Nations 19 and Nations 20, as well as their difference.

#	Relation		Est.	CrI low - high	pd	ROPE %	BF01	BF10
B.	*Mediation: Venue → Outcome*							
7	Indirect/mediated Team Performance [4 x 2]	Nations 18	0.20	0.13 – 0.27	1.00	0	0.00	>1000
		Nations 20	0.09	0.02 – 0.17	1.00	16	0.04	27
		DIFF	0.11	0.03 – 0.18	1.00	6	0.01	93
8	Indirect/mediated Referee Bias [5 x 3]	Nations 18	0.00	0.00 – 0.01	0.88	100	0.24	4.2
		Nations 20	0.00	−0.02 – 0.01	0.54	100	1.00	1.0
		DIFF	0.01	0.00 – 0.02	0.77	100	0.42	2.4
9	Direct Venue [1]	Nations 18	0.09	−0.01 – 0.19	0.96	21	0.49	2.05
		Nations 20	0.07	−0.05 – 0.19	0.88	33	0.95	1.05
		DIFF	0.02	−0.07 – 0.11	0.67	69	1.05	0.96
10	Total Venue [1 + (5 x 3) + (4 x 2)]	Nations 18	0.29	0.17 – 0.42	1.00	0	0.00	>1000
		Nations 20	0.16	0.02 – 0.30	1.00	7	0.19	5
		DIFF	0.14	0.02 – 0.25	1.00	7	0.08	13
C.	*Mediation: Venue → Referees*							
11	Indirect/mediated Team Performance [6 x 4]	Nations 18	−0.07	−0.12 – −0.03	0.97	15	0.00	>1000
		Nations 20	−0.04	−0.08 – −0.01	0.95	78	0.05	19.1
		DIFF	−0.04	−0.08 – 0.01	0.83	75	0.16	6.2
12	Direct Venue [5]	Nations 18	−0.13	−0.25 – −0.02	0.99	8	0.19	5.31
		Nations 20	0.08	−0.09 – 0.24	0.82	32	1.22	0.82
		DIFF	−0.21	−0.37 – −0.05	0.99	3	0.10	9.82
13	Total Venue [5 + (6 x 4)]	Nations 18	−0.21	−0.33 – −0.08	0.99	1	0.01	115.6
		Nations 20	0.04	−0.13 – 0.20	0.58	40	1.59	0.6
		DIFF	−0.24	−0.41 – −0.08	0.92	1	0.04	25.3

Note. Est. = path coefficient, CrI = Credible Intervals 89%, pd = Proportion of Direction, ROPE% = % in the Region of Practical Equivalence (−0.05 to +0.05), BF = Bayes Factor, → = direction of influence. Terms in the squared parenthesis in sections B and C specify how the particular mediation was obtained.

The majority of the overall venue effect can be attributed to the mediation of venue on outcome through team performance. It is not surprising that the mediation of venue on outcome through team performance follows the same pattern as the overall home advantage/venue effect. Both the Covid and Stakes factors have a significant impact, indicating that games with fans lead to larger mediation effects of team performance compared to games without fans, regardless of the stakes involved (Figure 6B). Additionally, high-stake games produce larger mediation effects than low-stake games, irrespective of fan presence. Similar to the overall home advantage effect, the interaction between the two factors is negligible, as the absence of fans affects the mediation process in both low and high-stake games to a similar extent.

The same analysis can be applied to Referee Bias. Figure 6C demonstrates that the (home) Referee Bias is significantly higher when (home) fans are present compared to when they are absent, regardless of the game stakes. However, there are no differences between high- and low-stake games. The absence of fans has a similar impact on both high- and low-stake games when considering the total effect of Venue on Referee Bias (interaction of Covid x Stakes).

The total Referee Bias is influenced by both the direct effect of Venue and the mediating effect of Venue on Referee Bias through Team Performance. Figure 6D indicates that the mediation may differ from zero and vary depending on the Covid and Stakes factors, as well as their interaction. In other words, the difference in Referee Bias before and during Covid can be directly attributed to the effect of Venue on Referee Bias.

3.4. Model assessment and additional analyses

All models involved had a good to excellent fit (see SM, Section 6). We supplement the analyses presented here with an additional HAM model which compares EURO 20 with the previous four European Championships (2004, 2008, 2012, and 2016) for which we have enough freely available statistics to construct the team performance and referee bias constructs (SM, Section 3). EURO 20 was also compared on goals and points in separately with all 15 previous European Championships (EURO 60-16; SM, Section 3). Similarly, we use non-Bayesian approaches, such as path analysis (SM, Section 5.1), and different statistical techniques, such as Structural Equations Modeling (SEM; SM, Section 5.2). Finally, the frequentist zero-inflated Poisson regression for points and goals in the comparison between EURO 20 and EURO 60-16 was conducted (SM, Section 5.3). In all instances, the additional results corroborate the main conclusions from the results presented here.

4. Discussion

The exceptional circumstances of the Covid-19 pandemic, which resulted in either no fans or limited attendance in stadiums, provided a unique opportunity to gain insights into the mechanisms behind the well-established and robust home advantage phenomenon. Our findings suggest that the reduction in fan presence diminishes the home advantage during high-stakes games, as evidenced by the poorer performance of home teams at EURO 20 compared to their performance in the qualifying matches leading up to the championship just a few years prior. Similarly, the absence of fans had a detrimental effect on the home advantage during low-stakes games, as indicated by the weaker performance of home teams in the Nations League when games were played without spectators. The diminished home advantage, regardless of the stakes of the games, seems to suggest a crucial role of fans in shaping the atmosphere, influencing player performance, and therefore, the game outcome. While high-stakes games exhibited a larger overall home advantage than low-stakes games, both categories of games were similarly impacted by the absence of fans.

4.1. The impact of absence of fans on high- and low-stake games

One of the advantages of the HAM model is its ability to tentatively quantify the overall home advantage effect. This overall home advantage may then be utilized to calculate the reduction resulting from the absence of fans and compare it between high-stakes and low-stakes games. For example, the HA reduction due to fans absence seemed considerable in the high-stake games. The overall influence of the home venue was 44% smaller during EURO 20 than for the home matches of the same teams during QUALI 19. Whereas the home field advantage produced more than half of the SD (positive) change in the outcome during the qualifications (Venue Total = 0.57 – see Figure 3, upper left

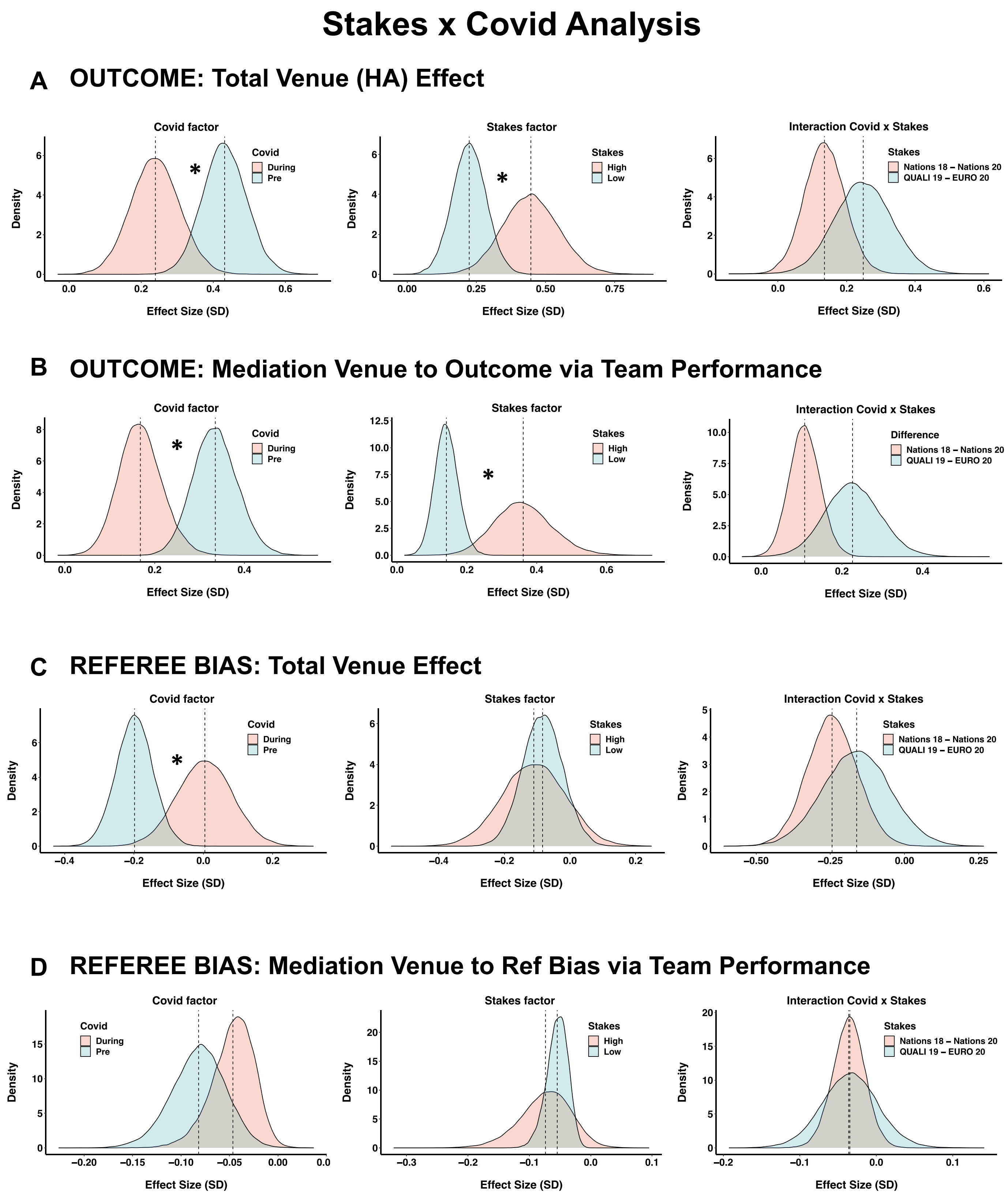

Figure 6. HAM model posterior distributions Covid x Stakes. A) Posterior distributions of the overall effect of Venue on the Outcome dependent on Covid (left panel), Stakes (middle), and their interaction (right). **B)** Posterior distributions of the mediation effect of Venue on the Outcome through Team Performance dependent on Covid (left panel), Stakes (middle), and their interaction (right). **C)** Posterior distributions of the overall effect of Venue on the Referee Bias dependent on Covid (left panel), Stakes (middle), and their interaction (right). **D)** Posterior distributions of the mediation effect of Venue on the Referee Bias through Team Performance dependent on Covid (left panel), Stakes (middle), and their interaction (right).

box), the HA resulted only in one third of the SD in the outcome during the latest European Championship (Venue Total = 0.32 – see Figure 3, upper left box).

The overall home advantage for low-stakes games is considerably smaller compared to high-stakes games (refer to Figure 6A). For instance, in Nations 19 games with fans, the home advantage effect was modest (Venue Total = 0.29, as shown in Figure 5, upper left box), which is approximately half the size of the equivalent effect in high-stakes games (0.57 in QUALI 19). However, the absence of fans had a similar impact on the home advantage in both low-stakes and high-stakes games, reducing the overall home advantage by 48% (from 0.29 with fans to 0.15 without fans, as depicted in Figure 5, upper left box). In other words, it seems that the higher the stakes, the more pronounced the home advantage. Similarly, the absence or even a mere reduction of fans seemed to result in a decreased overall home advantage. Nonetheless, there was no interaction between the Stake and Covid-19 factors, indicating that the absence of fans may have affected both high-stakes and low-stakes games to a similar extent. This uniform HA reduction in the absence of fans, irrespective of the stakes of the game, underscores the fans critical contribution to the HA.

Our findings tentatively provide empirical support for a long-held assumption that the home advantage is particularly pronounced in important games. European championships occur every four years, featuring only a limited number of games, each of which holds significant importance, potentially being the last one for teams. This stands in stark contrast to the friendly nature of the games in the Nations League, where very little is at stake. This comparison adds another layer of understanding to the HA mechanisms because it points out the interaction between the psychological pressure associated with high-stakes games and the supportive role of fans presence.

It can be speculated that the presence of fans, with their visual and acoustic support, may act as an amplifier of the home advantage in high-stakes games. While fans are also present in low-stakes games, their impact may not be as influential due to the lesser intensity of those matches. Surprisingly, the reduction in home advantage due to the absence of fans is similar in both high-stakes and low-stakes games. While it is unclear which factors may be at play here (e.g. similar psychological and atmosphere impact regardless of stakes), the observed similarity in the reduction of home advantage in the absence of fans potentially highlights the significant role that fan presence plays in influencing game outcomes.

It should be noted that the HA reduction in the high-stake games (from 0.57 at QUALI 19 to 0.36 at EURO 20) appears similar to the decrease we estimated using the same HAM model for the completely empty stadium for the European leagues in the 2019/20 season (Bilalić et al., 2021). Actually, the reduction we found during the European championship (44%) is even larger than in the elite club football (37%), which is particularly remarkable when we consider that the HA was not as severe when the clubs were allowed to play in partially filled stadiums (Bilalić et al., 2021; Bryson et al., 2021; Higgs & Stavness, 2021). This seems to contradict previous research suggesting that the home advantage (HA) increases with crowd size only up to a certain threshold, typically around 20,000 spectators, beyond which further increases in fan presence have minimal impact on the HA (Goumas, 2014b).

One possible explanation of the size of the HA reduction due to partially filled stadiums might be the importance of the games. Unlike the national leagues where teams usually play every other week at home, the European championship happens every four years. There are commonly dozens of home games in a season, whereas there are only a few at the European championships, with each one possibly being the last one. It is a fair assumption that a single game at the European championship should be much more important to players than a single game for their clubs. Similarly, one could assume that the presence of the fans, with all the accompanying visual and acoustic support, serves as the amplifier of the HA. In other words, having your fans present matters more when the stakes are high than in a random club match in February. Obviously, these speculations need further empirical backing.

The disparity in the quality of teams faced by home teams during the qualifications and the European championship is a significant factor to consider. At EURO 20, the away teams were inevitably stronger compared to QUALI 19 since weaker teams did not qualify. Team strength is undeniably one of the most influential variables, strongly predicting both Team Performance and Outcome (0.30 for Outcome and 0.15 for Team Performance, se detailed overview in SM, Section 2). Hence, it is important to approach raw descriptive statistics in Figure 2 cautiously. However, we address this by controlling for team strength in all our HAM models through the inclusion of Elo team ratings. The HA estimates presented here already account for the rating disparity. It could be argued that no control can fully account for such a significant disparity. Nevertheless, our supplementary analyses demonstrate that even when there is no disparity in team strength, considering the previous four European Championships (2004–2016) or all previous Championships from 1960 to 2016, EURO 20 still exhibits a reliably reduced HA due to the reduced presence of fans (see SM, Section 3). Despite these findings, they are derived from a very particular context and hence their generalizability may be somewhat restricted.

4.2. The HA mechanism

The HAM model offers the advantage of estimating all significant relationships simultaneously, allowing us to differentiate the possible direct impact of the home venue on the outcome from the potential indirect influence through team performance and referee bias (refer to Figure 3 and 5). Consistent with our previous study (Bilalić et al., 2021), team performance emerges as the largest contributor to the home advantage, mediating the relationship between the home venue and the outcome. This mediation is affected by both the absence of fans and the stakes involved: reduced fan presence inevitably leads to a reduction in the mediation through team performance, and the mediation through team performance is more pronounced in high-stakes games compared to low-stakes games (see Figure 6B). It is important to note that the mediation through team performance remains substantial in high-stakes games, whether with fans present (82% or 0.47 out of 0.57) or with reduced fan presence (78% or 0.25 out of 0.32), as well as in low-stakes games, whether with fans present (69% or 0.20 out of 0.29) or with reduced fan presence (56% or 0.09 out of 0.16). In contrast, the home venue itself does not emerge as a significant and consistent predictor. Rather, the presence of fans motivates the players towards improved performance, which subsequently translates into better results. The fact that even partial fan presence fails to replicate this mechanism, exhibiting a considerable diminishment and statistical inconsistency, underscores the significance of the Venue → Team Performance mechanism in shaping the home advantage phenomenon.

However, as we contemplate the broader application of these results, it's essential to recognize the potential variability in these relationships across different contexts. Unlike in the previous analysis with club teams, when the referees' decisions contributed significantly to the HA (around 20%), there was little evidence of referee bias during the national team games, either high- or low-stakes (see Figure 3 and 5, as well as Table 2 and 4). Although the impact of Referee Bias on the outcome was found to be minimal, home teams consistently received more favorable treatment, even when playing in front of full stadiums, irrespective of the stakes involved. However, it is notable that the positive Referee Bias towards home teams appears to dissipate (as depicted in Figure 6C) in games with no fans present. The stakes of the game did not influence this finding, as the absence of Referee Bias was observed in both high-stakes and low-stakes games.

It became evident that team performance, as a potential mechanism to explain the difference in Referee Bias with and without fan presence, is probably not a suitable explanation. Although the mediation through team performance played a substantial and reliable role, the majority of the Referee Bias was directly attributed to the Venue itself (as depicted in Figure 3 and 5). The referees tended to penalize away teams more frequently than home teams when fans were present, regardless of the stakes involved or the team performances. The inclusion of Video Assisted Referees (VAR) is likely to be one of the contributing factors to this specific pattern (Wunderlich, Seck, & Memmert, 2021; Wunderlich, Weigelt, et al., 2021). Notably, VAR was not utilized in QUALI 19 and Nations 18, the competitions in which fans were present, whereas VAR was implemented in EURO 20 and Nations 20, the competitions used to analyze the absence (or reduction) of fans.

4.3. Limitation

Even in controlled laboratory experiments, achieving perfection is challenging, and this is even more true for natural experiments like the one we conducted due to Covid-19 pandemic. Given these realities, we must carefully consider the generalizability of our results. While our study provides valuable insights into specific relationships within our sample, the applicability of these insights to different settings and populations may be limited. For example, while the low-stake games in the two editions of the Nations League in 2018 and 2020 had a clear design of fan presence versus absence, the same cannot be said for the high-stakes games in EURO 20. In EURO 20, there was only a reduced presence of fans, rather than a complete absence, which made the 2 x 2 factorial design imperfect. It is important to acknowledge that the impact of the Covid-19 pandemic extended beyond just reduced fan attendance. It also affected various rules (such as the number of substitutes and water breaks) and had potential implications for the mental health of players, among other factors. Although our study does not address these factors, it is important to recognize their existence and complexity. Operationalizing, measuring, and including these factors in the model would have presented significant challenges.

EURO 20 was also hosted by several different countries, which ensured that several different national teams enjoyed the home advantage, unlike the previous editions where at most two countries shared the hospitality. Yet, there were only 10 teams that played only 27 home matches, a far cry from the ten thousand used in previous analyses on club competitions. The small sample size problem has been alleviated here using Bayesian statistics (Gelman et al., 2021; Kruschke, Aguinis, & Joo, 2012; Smid, McNeish, Miočević, & van de Schoot, 2020; van de Schoot et al., 2021), particularly the informative priors which proved sensitive enough (see SM, Section 4, for the sensitivity analysis).

The disparity in the opponents' strength during EURO 20 and QUALI 19 has been dealt with by the inclusion of Elo ratings in the model. It is unclear, however, whether it is possible to completely offset the rating discrepancy through statistics. One indication of the HA reduction through the absence of the fans is the historical comparison with the previous European championships (see SM, Section 3). Yet, one can point out that the HA has been declining throughout the years (Beckmann, 2022; Pollard & Pollard, 2005; Wunderlich, Weigelt, et al., 2021) and that even this rating-balanced historical comparison is imperfect. Although we recognize these facts, it remains uncertain whether more suitable data or real-world experiments are available.

Besides these external context-related inadequacies, there are internal, model-related limitations. An HAM model, being a mediation model, relies on accounting for all potential confounding variables. It is crucial to consider external variables that may directly influence the mediator and the outcome (Fiedler, Schott, & Meiser, 2011; Judd & Kenny, 1981; Rohrer, Hünermund, Schmukle, & Elson, 2022). For instance, in the context of football, team strength can impact Team Performance and Outcome, irrespective of whether the game is played at home or away. Similarly, referee decisions may be influenced by the dominance of a team rather than solely the venue. In our analyses, we included these potential confounders, incorporating team strength through Elo rating and team dominance through Team Performance.

Additional confounding variables or factors of interest can be added to the model, as demonstrated in our previous work (Bilalić et al., 2021), where we incorporated crowd factors (e.g., absolute size, density, proximity to the playing field), team performance factors (e.g., defense, attack), and fatigue (e.g., travel). The comprehensive nature of the HAM model, with its inclusion of important HA factors such as team performance, referee bias, and venue, along with control variables, allows us to isolate their direct and indirect individual effects. However, it should be noted that no model is exhaustive, and certain situational or individual factors, such as the significance of individual matches, individual referees' preferences or seasonal effects have not been included in the HAM model. Furthermore, as currently conceptualized, the model requires multiple observations and may not capture the dynamics within a single game, where referees (Raab, Avugos, Bar-Eli, & MacMahon, 2021), players, and coaches may react dramatically to specific positive or negative circumstances.

4.4. Conclusions

In conclusion, our study highlights that both high-stakes games and the absence of fans significantly influence the home advantage (HA). Importantly, the absence of fans impacts the reduction of HA similarly in both high-stakes and low-stakes games. The intensity and significance of European championship games serve to amplify the home advantage, resulting in even the partial absence of the 12th man having a comparable, if not greater, impact than the complete absence. These findings underscore the crucial role played by fans in shaping the HA and emphasize the lasting impact of the Covid-19 pandemic on sporting events. We do, however, recognize that our findings provide a specific snapshot in time, shaped by unique circumstances, and further research is needed to fully understand the dynamics of home advantage across a wider range of settings.

Declaration of competing interest

The authors declare no competing interests.

Data availability

Preregistration, data, and code for the analyses can be found here: https://osf.io/wjqma.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.psychsport.2023.102492.

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