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# USING GENDER DISPARITIES TO MEASURE THE EURO 2020 MATCH-INDUCED EFFECT ON COVID-19 CASES IN SELECTED EUROPEAN COUNTRIES

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## Abstract

## Introduction

Growing levels of immunity against SARS-CoV-2 (through vaccination programs and post-infection [1, 2]) and potential effects of seasonality in the northern hemisphere [3, 4] promote a sustained re-opening in the COVID-19 pandemic. In the coming months, non-essential activities, such as sports events with spectators, are expected to increase [5]. However, social and economic pressure to restore a pre-COVID level of activities might lead to lifting restrictions too fast, thus risking further epidemic waves featuring variants of SARS-CoV-2 [1, 2, 6–8]. Consequently, it is critical to quantify the impact that these events might have on the spreading dynamics of COVID-19 [9, 10] and to detect subtle signatures of potential super-spreading events associated with them [11].

COVID-19 super-spreading events have been reported in different settings, mostly related to mass gatherings and closed settings [12–17]. Even though in-field and in-stadium preventive measures are in place for sports like football and rugby [18–20], popular matches that achieve country-scale engagement also influence uncontrolled settings (e.g., private gatherings, open-air bars, watching parties) to extents that are challenging to predict. Furthermore, the presence of in-stadium spectators (promoted mainly for economic reasons [5]) might have a synergistic effect on the engagement of TV watchers [21, 22] and on the peer pressure to participate in gatherings or watching parties [23]. Experiences of 2020, where some non-pharmaceutical interventions remained in place, pointed to a minor effect of local and country-scale matches on the community transmission

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of COVID-19 [24, 25]. However, international tournaments, such as the 2020 UEFA European Football Championship (EURO 2020, 11 June to 11 July 2021), might have a noticeable impact on the spreading dynamics of COVID-19 in the countries involved, especially in the context of restrictions being steadily lifted.

Here, we investigate the effect that independent matches of the EURO 2020 championship had on the spreading dynamics of COVID-19 across Europe, and quantify their contribution to spread in a Bayesian framework. We model the matches as singular interventions that affect the effective reproduction number. We compare the dynamics observed in every country after the match, using those eliminated in the qualifying tournament as control.

## Results

### Some countries show a significant effect of the championship on case numbers

Local news outlets and early reports alerted about increased COVID-19 incidence after EURO2020 matches [26–29]. This increased incidence was not only linked to in-stadium attendance, but also to public gatherings and mass celebrations [29]. To assess such effect, we analysed case numbers and the gender ratio among them for four European countries taking part in the EURO2020 championship: Germany, France, Scotland, and England (Fig. 1). We observe that not every country had an evident effect noticeable by naked-eye. However, countries like Scotland and England have marked deviations from the baseline trend in the gender ratio concurrent to EURO2020 matches in which they were involved, thus probably explained by them.

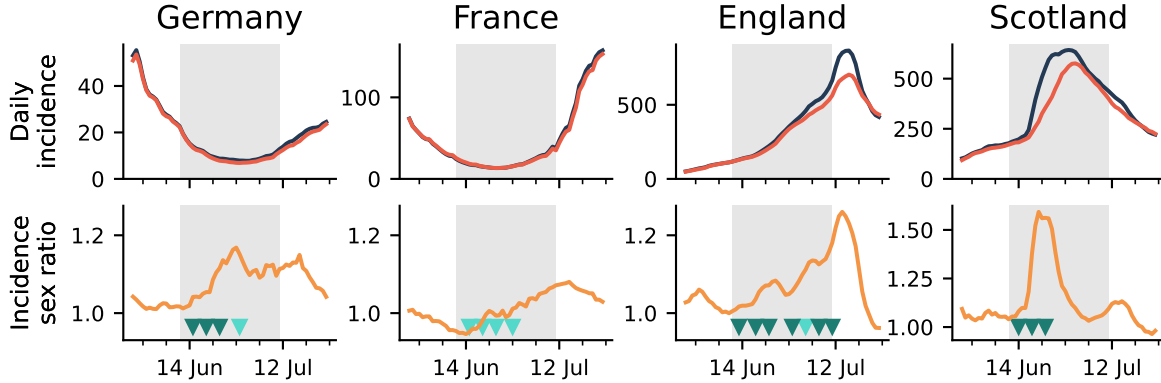


Figure 1: **UEFA 2020 football matches caused an increased COVID-19 incidence among men in several countries.** A–D: (upper) gender-resolved COVID-19 daily new cases per 1 million people and (lower) male/female gender ratio for Germany (A), France (B), England (C), and Scotland (D). The EURO2020 period is highlighted in grey, matches are marked with triangles. Trends have been averaged on a centered 7-day moving window to remove weekly modulation. On the one hand, countries as Germany, France and England show a slight —but notorious— trend shift in the gender ratio of COVID-19 incidence during the EURO2020 championship. On the other hand, there was a significant increase in the gender ratio of COVID-19 incidence upon single games as the finals in the English data and the away game versus England in the Scottish data.

### Gender-resolved Bayesian model quantifies EURO2020 impact on transmission

Aiming to quantify the impact of individual EURO 2020 matches on the country-level spread of COVID-19, we proposed a Bayesian model. Our model simulates the spread in each country using a discrete renewal process [30, 31], which has also a gender resolution for community contagion. The disease spreads with an

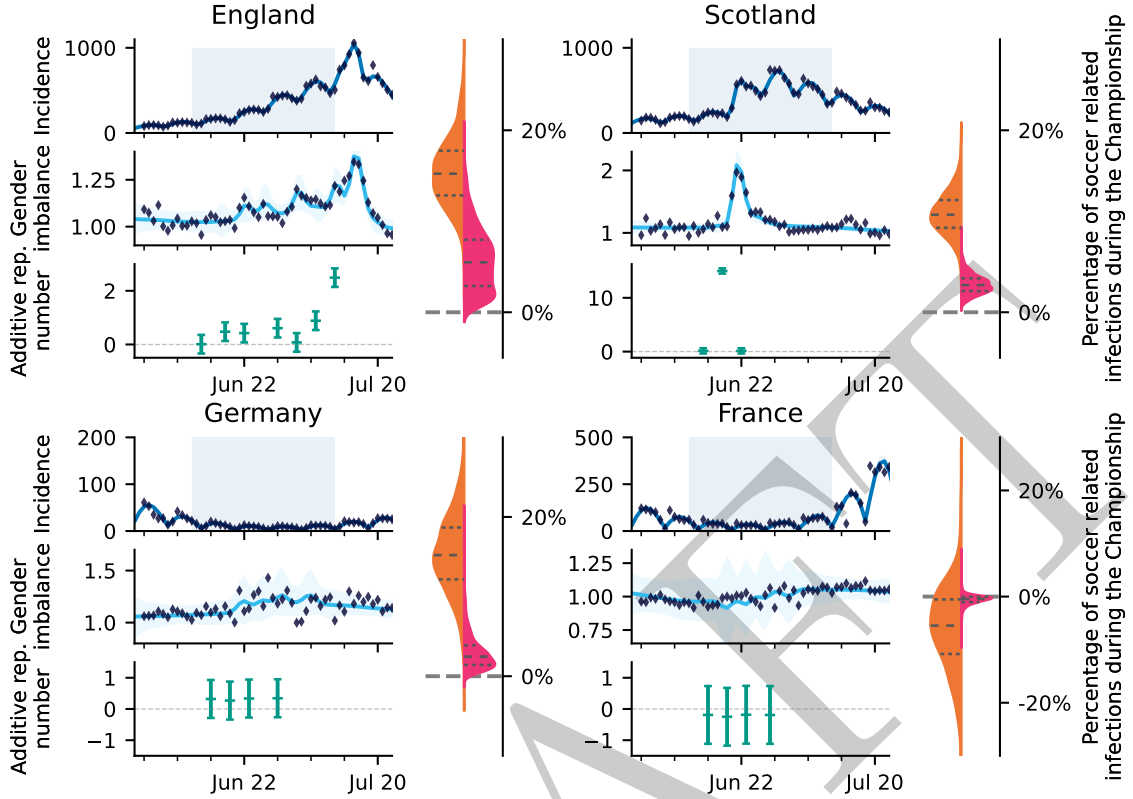


Figure 2: **Using a Bayesian model we can infer the effect size of the Championship in several countries.** The gender imbalance of the incidences (male incidence/female incidence) can be well explained by assuming that on the day of football matches, additional infections occurred mainly in the male population. This is here modelled by the additive reproduction number.

inferred time-dependent effective reproduction number  $R_c$  [32], which was allowed to increase when matches took place. We then quantify the strength of the effect induced by the match, analyzing the gender-related difference in case numbers after the event, as men are likelier to attend the stadium and sport-related events [33]. We assumed that contagion can occur in two modii, depending on whether the contact was with peers of the same biological gender or not. Consistently, in football or football-induced events, contagion was more likely to occur between men, and the trend would be corrected with a delay as they subsequently interact with men and women more equally.

Under the assumption that changes in the incidence gender ratio was mainly driven by soccer games, even if the effect of individuals games are not significant, we find evidence in three out of 4 countries, that a significant proportion of the total infection during the UEFA cup was due to gatherings related to the games. In details, in our model we find that for England that 15% of the male infections during the duration of the UEFA cup [are likely due to the cup] (CI: [8%, 23%]), for Scotland 10% (CI: [6%, 15%]) and for Germany 15% (CI: [2%, 25%]). We find no effect for France (mean -5%, CI: [-23%, 8%]). Note that in England, Scotland and France the incidence of COVID-19 cases increased significantly over the course of the EURO 2020.

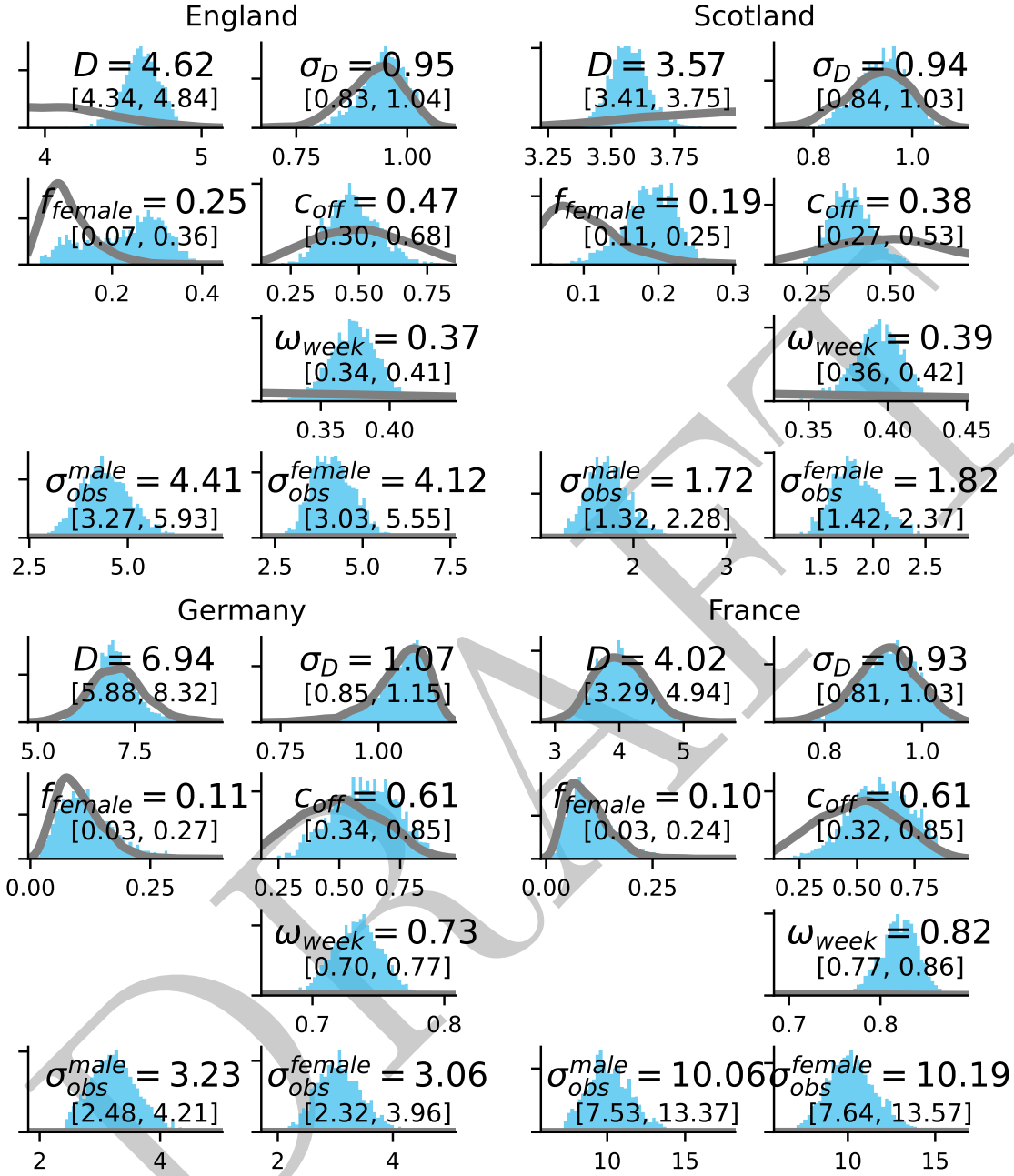


Figure 3: Distributions for additional model parameters

## Discussion

### Limitation of the chosen approach and model comparison

Our model allows us to decouple none-pharmaceutical interventions (NPIs), seasonality, vaccinations and other known or unknown effects from the effects of EURO 2020 single matches in the spreading dynamics of COVID-19. This is due to the use of the gender-ratio in the observed COVID-19 cases, and the separation of the modelling of gender-asymmetric transmission during championship-related fan gatherings from the

subsequent gender-symmetric transmission in all other contact situations. This allows to model all EURO-2020 independent effects with an underlying slowly modifying base transmission dynamics, while the gender-asymmetry in the observed and modelled cases allows to extract both the gender asymmetry and a measure of COVID-19 transmission directly attributed to fan events. Furthermore, the known date of games allows to correlate spikes in the gender asymmetry of observed cases to inferred transmission dates. Mass events like this pose the unique opportunity to compare measurements of the overall average delay between infection and detection under the current testing and tracing regime from tracing of individual transmissions [] to an ensemble measurement.

Through the separation of the underlying gender-symmetric transmission dynamics from the gender-asymmetric fan events, our approach is insensitive to all other changes not directly attributed to fan events. Indirect effects like an average reduced self-imposed contact restriction through observation of game-related festivities would contribute to the base reproduction measurement of our model and not be attributed directly to the EURO 2020. Also, potentially increased travel between European countries is not explicitly modelled.

### **Sensitivity and reliability of the results**

We study the sensibility of our model to uncertainties in the parameters we explore, ...

### **Discussion of results**

Football matches in the EURO 2020 can be understood as singular perturbations to the dynamical state of the system. In that way, a stable (or meta-stable) system can see its stability compromised by the effect of the match, or case numbers would grow steeper if the system were already unstable. The dynamical state of the system, i.e., whether case numbers are controlled around a somewhat stable level or steadily growing, is determined by the balance between stabilising and destabilising contributions. In these endeavours, very strong contributions weigh each side of the balance, making it even more challenging to detect subtle, early hints of the effect of separate matches on COVID-19 dynamics [10]. Stabilising contributions are seasonality [3], the progress of vaccination [1], better hygiene and distancing concepts in stadiums and hospitality. The destabilising contributions of single matches of the EURO 2020 relate to the i) live audience and in-stadium spectators – which, besides exposing themselves, induce a larger engagement of people broadcasting the events [22, 23], ii) the broad international viewership of the contest, iii) the great heterogeneity among participant teams (in demographics, control of COVID-19, and culture), iv) incentives for going to the stadium or viewing parties among countries with low case numbers [34], and v) variants partially escaping immune response currently circulating. Furthermore, some of the factors act synergistically; a live audience in stadiums increases the interest among viewers and the total viewership [22] —which also increases the peer pressure for individuals to participate [23]—, and the referee decision bias, thus triggering emotional reactions that might endanger containment.

### **Explicit comparison to other results not using observables optimised for the study target**

Previous studies aiming to evaluate the impact of football matches on the spread of COVID-19 were not conclusive on whether there was an effect. For instance, the study of Fischer [24] pointed to a minor impact of German premier league matches; only after three weeks, communities hosting a game would observe an increase in the daily incidence between 0.52 and 0.91 cases per 100.000 inhabitants — which could easily

fall within the inherent noise in the observable. Furthermore, the weekly incidence on the day of the match (around 25 cases per week) modulates the match’s impact on the community transmission. In contrast to ongoing premier league matches, the EURO 2020 is characterised by a significant increase of fan activity outside stadiums and an increase in international travel, which both are expected to boost the impact on COVID-19 transmission. In addition, the use of a more sensitive observable – the gender ratio – in addition to the overall case numbers allows to extract effects which otherwise are within statistical uncertainty.

In different settings at high COVID-19 incidence, large gatherings with poor preventive measures (as Trump rallies) were found to increase cumulative cases by 250 cases per 100.000 inhabitants ten weeks after the protest took place. Toumi et al. [25] studied the effect of matches of the US National Football League (NFL) on the increase of COVID-19 cases. The authors concluded no significant effect, as two weeks after the match, the county-level daily incidence did not increase more than 5 cases per 100.000 inhabitants, which would translate to a weekly incidence of 35 cases — a very generous upper bound when compared to the previously discussed studies. Furthermore, delays between contagion, testing, and identification of new cases within the community, can further delay the point when the effect would be noticeable.

Understanding how mass events with a high engagement and international viewership affect the spreading dynamics of COVID-19 can help us design better strategies for not endangering novel outbreaks. The general mechanisms reported in this article may help gain insights on the reasons why hygienic concepts proposed for the EURO2020 [29] and the Tokyo 2020 Summer Olympics [35] were not 100% effective.

## Methods

The methods might not be totally up to date but should still give you a rough overview of our model!

## 1 Model

### 1.1 Spreading dynamics

To estimate the effect of the championship across countries we build a hierarchical Bayesian model, which simulates the spread of COVID-19 in each country separately using a discrete renewal process [30, 31, 36]. We infer a time-dependent effective reproduction number  $R_c(t)$  [32] for each country  $c$ , with the addition that the reproduction number of each country is increased on the days of a match.

Using the typical notation, i.e. susceptible pool  $S$ , infectious pool  $E$ , population size  $N$ , and country subscript  $c$  the spreading dynamics read as:

$$E_c(t) = \frac{S_c(t)}{N_c} R_c(t) \sum_{\tau=0}^{10} E_c(t-1-\tau) g(\tau) \quad (1)$$

$$S_c(t) = S_c(t-1) - E_c(t-1) \quad (2)$$

$$g(\tau) = \text{Gamma}(\tau; \mu = m, \sigma = 0.4) \quad (3)$$

$$m \sim \text{Normal}(\mu = 4, \sigma = 1). \quad (4)$$

We assume the generation interval  $g$  to stay the same for each country i.e. the time delay between infections of a primary case and its secondary case is country independent.

## 1.2 Gender differences in spreading

Even though female participation in soccer has increased in the last decades [37], football (soccer) fans are predominantly male [33]. Integrating this information into the model together with gender separated case numbers, allows a better inference of the effect of the championship in individual countries. To this end, we modulate equations (1) – (4) by a gender factor  $f$ , denoting the female and male population. We then model the spreading dynamics of COVID-19 in each country  $c$  separately for males and females, where infections between male and females are parameterized by an effective contact matrix  $\mathbf{C}$ :

$$E_{c,f}(t) = \frac{S_c(t)}{N_c} \sum_{f'=1}^2 \mathbf{C}_{c,f,f'}(t) \sum_{\tau=0}^{10} E_{c,f'}(t-1-\tau)g(\tau), \quad (5)$$

$$S_{c,f}(t) = S_{c,f}(t-1) - E_{c,f}(t-1), \quad (6)$$

$$g(\tau) = \text{Gamma}(\tau; \mu = m, \sigma = 0.4), \quad (7)$$

$$m \sim \text{Normal}(\mu = 4, \sigma = 1), \quad (8)$$

$$(9)$$

As prior we assume that females are only 10% as likely to get infected. To account for non-soccer related contacts we introduce a base contact matrix  $C_{\text{base}}$ , which assumes an evenly likely infection on both male and females.

$$\mathbf{C}_{c,f,f'} = R_{\text{base},c} C_{\text{base},c,f,f'} + R_{\text{soccer},c}(t) C_{\text{soccer},c,f,f'} \quad (10)$$

$$\mathbf{C}_{\text{base},c} = \begin{pmatrix} 1 - c_{\text{off},c} & c_{\text{off},c} \\ c_{\text{off},c} & 1 - c_{\text{off},c} \end{pmatrix} \quad (11)$$

$$\mathbf{C}_{\text{soccer},c} = \begin{pmatrix} 1 - \omega_{\text{female},c} & \omega_{\text{female},c} \\ \omega_{\text{female},c} & \omega_{\text{female},c}^2 \end{pmatrix}. \quad (12)$$

$$c_{\text{off},c} \sim \text{Beta}(\alpha = 4, \beta = 4) \quad \forall c \quad (13)$$

$$\omega_{\text{female},c} \sim \text{Gamma}(k = 4, \theta = 1/40) \quad \forall c \quad (14)$$

The soccer related infections can occur from public or private soccer viewing in the home country (parameterized by  $\alpha^\dagger$ ) or because of infections happening in stadiums (parameterized by  $\beta^\dagger$ ). Both of these can have different effects on each country  $c$  and each game  $g$ . To this end we further define the soccer related additive reproduction number:

$$R_{\text{soccer},c}(t) = \exp \left( \sum_g (\alpha_{c,g} + \beta_{c,g}) \cdot \delta(t_g - t) \right) - 1.0 \quad (15)$$

$$(16)$$

We assume the effect of each game to only be effective in a small timeframe centered around each game, thus we apply a delta function  $\delta(t_g - t)$ . [Add sentence about normalization of delta]

## 1.3 Soccer related hierarchical effect

We distinguish between the effect size of each game and the overall effect of soccer games onto the spreading of COVID-19. For the effect associated to public or private soccer viewing in the home country  $\alpha$  we introduce

one base effect and differentiate between each countries and their played games. We do this by typical hierarchical modeling:

$$\alpha_{c,g} = \alpha_{\text{prior},c,g} (\alpha_{\text{mean}} + \Delta\alpha_c + \Delta\alpha_g) \quad (17)$$

$$\alpha_{\text{mean}} \sim \mathcal{N}(0, 1), \quad (18)$$

$$\Delta\alpha_c \sim \mathcal{N}(0, \sigma_{\alpha,c}) \quad (19)$$

$$\Delta\alpha_g \sim \mathcal{N}(0, \sigma_{\alpha,g}) \quad (20)$$

$$\sigma_{\alpha,c} \sim \text{HalfNormal}(0.5) \quad \forall c \quad (21)$$

$$\sigma_{\alpha,g} \sim \text{HalfNormal}(0.5) \quad \forall g. \quad (22)$$

The same applies to the effect  $\beta$  induced by infections happening in stadiums. We apply the same hierarchy with the difference of a weighting factor  $W_c$ , which weights the effect of the a game in a country depending on the population these and the number of people allowed in the stadium. It is defined as  $W_c = \frac{\text{people in stadium}}{\text{population of country } c}$  since in stadium infections can only affect fans inside the stadium.

$$\beta_{c,g} = \beta_{\text{prior},c,g} W_c (\beta_{\text{mean}} + \Delta\beta_c + \Delta\beta_g) \quad (23)$$

$$\beta_{\text{mean}} \sim \mathcal{N}(0, 1), \quad (24)$$

$$\Delta\beta_c \sim \mathcal{N}(0, \sigma_{\beta,c}) \quad (25)$$

$$\Delta\beta_g \sim \mathcal{N}(0, \sigma_{\beta,g}) \quad (26)$$

$$\sigma_{\beta,c} \sim \text{HalfNormal}(0.1) \quad \forall c \quad (27)$$

$$\sigma_{\beta,g} \sim \text{HalfNormal}(0.1) \quad \forall g. \quad (28)$$

$\alpha_{\text{prior},c,g}$  is a matrix that encodes the prior expectation of the effect of a game on the reproduction number. If a country didn't participate in a game, the entry is put to 0. Countries which have historically a higher soccer enthusiasm and viewership are encoded with higher entries, and games of later phases of the tournament are rated higher.

$\beta_{\text{prior},c,g}$  is matrix that encodes where a game took place and eventual priors that encodes whether effective hygiene concepts were implemented during the game.

#### 1.4 Non-soccer related reproduction number

To account for effects not related to the soccer games, e.g. non-pharmaceutical interventions, vaccinations, seasonality or variants, we introduce a slowly changing reproduction number  $R_{\text{base}}(t)$ , which is identical for both genders and should map all other not specifically modelled effects.

$$R_{\text{base},c}(t) = R_{0,c} \exp \left( \sum_w \gamma_{c,w}(t) \right) \quad (29)$$

$$R_{0,c} \sim \text{Gamma}(k = 3, \theta = 0.5) \quad \forall c. \quad (30)$$

This base reproduction number is defined as a superposition of logistical change point  $\gamma(t)$  every  $[X]$  days, which are parameterized by the length of the change points  $l$  and the date of the change point  $d$ . The subscripts  $n$  denotes the discrete enumeration of the change points.

$$\gamma_{c,n}(t) = \frac{1}{1 + e^{-4/l_{c,n} \cdot (t - d_{c,n})}} \cdot \Delta\gamma_{c,n} \quad (31)$$



$$\Delta\gamma_{c,n} = \Delta\gamma_n + \delta\gamma_n \quad (32)$$

$$\Delta\gamma_n \sim \mathcal{N}(0, \sigma_{\Delta\gamma}) \quad \forall n \quad (33)$$

$$\sigma_{\Delta\gamma} \sim \text{Halfnormal}(0.1) \quad (34)$$

$$\delta\gamma_{c,n} \sim \mathcal{N}(0, \sigma_{\delta\gamma}) \quad \forall c, n \quad (35)$$

$$\sigma_{\delta\gamma} \sim \text{Halfnormal}(0.05). \quad (36)$$

## Author Contributions

## Data availability

The used data and source code are available online on GitHub [https://github.com/Priesemann-Group/covid19\\_soccer](https://github.com/Priesemann-Group/covid19_soccer). The daily case numbers originate from the local health authorities.

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## References

- [1] Simon Bauer, Sebastian Contreras, Jonas Dehning, Matthias Linden, Emil Iftekhar, Sebastian B Mohr, Álvaro Olivera-Nappa, and Viola Priesemann. Relaxing restrictions at the pace of vaccination increases freedom and guards against further COVID-19 waves in Europe. *arXiv preprint arXiv:2103.06228*, 2021.
- [2] Joao Viana, Christiaan H van Dorp, Ana Nunes, Manuel C Gomes, Michiel van Boven, Mirjam E Kretzschmar, Marc Veldhoen, and Ganna Rozhnova. Controlling the pandemic during the SARS-CoV-2 vaccination rollout: a modeling study. *Nature communications*, 12(3674):1–15, 2021.
- [3] Tomáš Gavenčiak, Joshua Teperowski Monrad, Gavin Leech, Mrinank Sharma, Sören Mindermann, Jan Marcus Brauner, Samir Bhatt, and Jan Kulveit. Seasonal variation in sars-cov-2 transmission in temperate climates. *medRxiv*, 2021.
- [4] Yiqun Ma, Sen Pei, Jeffrey Shaman, Robert Dubrow, and Kai Chen. Role of meteorological factors in the transmission of sars-cov-2 in the united states. *Nature Communications*, 12(1):1–9, 2021.
- [5] Thomas Horky. No sports, no spectators—no media, no money? the importance of spectators and broadcasting for professional sports during covid-19. *Soccer & Society*, 2020.
- [6] Sebastian Contreras and Viola Priesemann. Risking further COVID-19 waves despite vaccination. *The Lancet Infectious Diseases*, 2021.
- [7] Salim S Abdool Karim and Tulio de Oliveira. New sars-cov-2 variants—clinical, public health, and vaccine implications. *The New England journal of medicine*, 2021.
- [8] Viola Priesemann, Rudi Balling, Melanie M Brinkmann, Sandra Ciesek, Thomas Czypionka, Isabella Eckerle, Giulia Giordano, Claudia Hanson, Zdenek Hel, Pirta Hotulainen, et al. An action plan for pan-european defence against new SARS-CoV-2 variants. *The Lancet*, 397(10273):469–470, 2021.

- [9] M Murakami, T Yasutaka, M Onishi, W Naito, N Shinohara, T Okuda, K Fujii, K Katayama, and S Imoto. Living with COVID-19: Mass gatherings and minimising risk. *QJM: An International Journal of Medicine*, 06 2021. hcab163.
- [10] Matthew Harris, J Kreindler, A. El-Osta, A El-Osta, T Esko, and Azeem Majeed. Safe management of full-capacity live/mass events in covid-19 will require mathematical, epidemiological and economic modelling. *Journal of the Royal Society of Medicine*, 2021.
- [11] Morgan P Kain, Marissa L Childs, Alexander D Becker, and Erin A Mordecai. Chopping the tail: How preventing superspreading can help to maintain covid-19 control. *Epidemics*, 34:100430, 2021.
- [12] Vincent Chi-Chung Cheng, Kitty Sau-Chun Fung, Gilman Kit-Hang Siu, Shuk-Ching Wong, Lily Shui-Kuen Cheng, Man-Sing Wong, Lam-Kwong Lee, Wan-Mui Chan, Ka-Yee Chau, Jake Siu-Lun Leung, Allen Wing-Ho Chu, Wai-Shan Chan, Kelvin Keru Lu, Kingsley King-Gee Tam, Jonathan Daniel Ip, Kenneth Siu-Sing Leung, David Christopher Lung, Herman Tse, Kelvin Kai-Wang To, and Kwok-Yung Yuen. Nosocomial outbreak of COVID-19 by possible airborne transmission leading to a superspreading event. *Clinical Infectious Diseases*, 04 2021. ciab313.
- [13] Nguyen Van Vinh Chau, Nguyen Thi Thu Hong, Nghiem My Ngoc, Tran Tan Thanh, Phan Nguyen Quoc Khanh, Lam Anh Nguyet, Le Nguyen Truc Nhu, Nguyen Thi Han Ny, Dinh Nguyen Huy Man, Vu Thi Ty Hang, et al. Superspreading event of sars-cov-2 infection at a bar, ho chi minh city, vietnam. *Emerging infectious diseases*, 27(1):310, 2021.
- [14] Bert Douglas Bernheim, Nina Buchmann, Zach Freitas-Groff, and Sebastián Otero. The effects of large group meetings on the spread of covid 19 the case of trump rallies preprint. *social science research network*, 2020.
- [15] Liang Wang, Xavier Didelot, Jing Yang, Gary Wong, Yi Shi, Wenjun Liu, George F Gao, and Yuhai Bi. Inference of person-to-person transmission of covid-19 reveals hidden super-spreading events during the early outbreak phase. *Nature communications*, 11(1):1–6, 2020.
- [16] Dhaval Dave, Drew McNichols, and Joseph J Sabia. The contagion externality of a superspreading event: The sturgis motorcycle rally and covid-19. *Southern economic journal*, 87(3):769–807, 2021.
- [17] Quentin J Leclerc, Naomi M Fuller, Lisa E Knight, Sebastian Funk, Gwenan M Knight, CMMID COVID-19 Working Group, et al. What settings have been linked to sars-cov-2 transmission clusters? *Wellcome open research*, 5, 2020.
- [18] Ben Jones, Gemma Phillips, Simon Kemp, Brendan A.I. Payne, Brendan A. I. Payne, B. R. Hart, Matthew J Cross, and Keith Stokes. Sars-cov-2 transmission during rugby league matches: do players become infected after participating with sars-cov-2 positive players? *British Journal of Sports Medicine*, 2021.
- [19] Yorck Olaf Schumacher, Montassar Tabben, Khalid Hassoun, Asmaa Al Marwani, Peter V. Coyle, Ahmed Khellil Abbassi, Hani Taleb Ballan, Abdulaziz Al-Kuwari, Karim Chamari, and Roald Bahr. Resuming professional football (soccer) during the covid-19 pandemic in a country with high infection rates: a prospective cohort study. *British Journal of Sports Medicine*, 2021.
- [20] Florian Egger, Oliver Faude, Sebastian Schreiber, Barbara Gärtner, and Tim Meyer. Does playing football (soccer) lead to sars-cov-2 transmission? - a case study of 3 matches with 18 infected football players. *null*, 2021.

- [21] Taeyeon Oh, Hojun Sung, and Kisung Dennis Kwon. Effect of the stadium occupancy rate on perceived game quality and visit intention. *International Journal of Sports Marketing and Sponsorship*, 2017.
- [22] Elisa Herold, Felix Boronczyk, and Christoph Breuer. Professional clubs as platforms in multi-sided markets in times of covid-19: The role of spectators and atmosphere in live football. *Sustainability*, 2021.
- [23] Brian H. Yim, Kevin K. Byon, Thomas A. Baker, and James J. Zhang. Identifying critical factors in sport consumption decision making of millennial sport fans: mixed-methods approach. *European Sport Management Quarterly*, 2020.
- [24] Kai Fischer and Kai Fischer. Thinning out spectators: Did football matches contribute to the second covid-19 wave in germany? *social science research network*, 2021.
- [25] Asmae Toumi, Haoruo Zhao, Jagpreet Chhatwal, Benjamin P Linas, and Turgay Ayer. The effect of nfl and ncaa football games on the spread of covid-19 in the united states: An empirical analysis. *medRxiv*, 2021.
- [26] Syed Ahmar Shah, Emily Moore, Chris Robertson, Jim McMenamin, Srinivasa Vittal Katikireddi, Colin R Simpson, Ting Shi, Uktarsh Agrawal, Colin McCowan, Sarah Stock, et al. Predicted covid-19 positive cases, hospitalisations, and deaths associated with the delta variant of concern, june–july, 2021. *The Lancet Digital Health*, 2021.
- [27] Kimberly Marsh, Emily Griffiths, Johanna J Young, Carrie-Anne Gibb, and Jim McMenamin. Contributions of the euro 2020 football championship events to a third wave of sars-cov-2 in scotland, 11 june to 7 july 2021. *Eurosurveillance*, 26(31):2100707, 2021.
- [28] Steven Riley, Oliver Eales, David Haw, Haowei Wang, Caroline E Walters, Kylie EC Ainslie, Christina Atchison, Claudio Fronterre, Peter J Diggle, Deborah Ashby, et al. React-1 round 13 interim report: acceleration of sars-cov-2 delta epidemic in the community in england during late june and early july 2021. *medRxiv*, 2021.
- [29] Philippa Roxby. Covid: Watching euros may be behind rise in infections in men, Jul 2021.
- [30] Seth Flaxman, Swapnil Mishra, Axel Gandy, H Juliette T Unwin, Thomas A Mellan, Helen Coupland, Charles Whittaker, Harrison Zhu, Tresnia Berah, Jeffrey W Eaton, and Others. Estimating the effects of non-pharmaceutical interventions on COVID-19 in Europe. *Nature*, pages 1–8, 2020.
- [31] Jan M. Brauner, Sören Mindermann, Mrinank Sharma, David Johnston, John Salvatier, Tomáš Gavenčíak, Anna B. Stephenson, Gavin Leech, George Altman, Vladimir Mikulik, Alexander John Norman, Joshua Teperowski Monrad, Tamay Besiroglu, Hong Ge, Meghan A. Hartwick, Yee Whye Teh, Leonid Chindelevitch, Yarin Gal, and Jan Kulveit. Inferring the effectiveness of government interventions against COVID-19. *Science*, 2020.
- [32] Jonas Dehning, Johannes Zierenberg, F Paul Spitzner, Michael Wibral, Joao Pinheiro Neto, Michael Wilczek, and Viola Priesemann. Inferring change points in the spread of COVID-19 reveals the effectiveness of interventions. *Science*, 2020.
- [33] Susan Lagaert and Henk Roose. The gender gap in sport event attendance in europe: The impact of macro-level gender equality. *International Review for the Sociology of Sport*, 53(5):533–549, 2018.
- [34] J James Reade and Carl Singleton. Demand for public events in the covid-19 pandemic: a case study of european football. *European Sport Management Quarterly*, pages 1–15, 2020.
- [35] Kiyoshi Takenaka and Elaine Lies. Factbox: Coronavirus cases at the tokyo olympics, Aug 2021.

- [36] Christophe Fraser. Estimating Individual and Household Reproduction Numbers in an Emerging Epidemic. *PLoS ONE*, 2(8), August 2007.
- [37] Henk Erik Meier, Bernd Strauss, and Dennis Riedl. Feminization of sport audiences and fans? evidence from the german men's national soccer team. *International Review for the Sociology of Sport*, 52(6):712–733, 2017.

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