Effectiveness of non-pharmaceutical interventions in nine fields of activity to decrease SARS-CoV-2 transmission (Spain, September 2020 - May 2021)

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Abstract

Background

We estimated the association between the level of restriction in nine different fields of activity and SARS-CoV-2 transmissibility in Spain, from 15 September 2020 to 9 May 2021.

Methods

A stringency index (0 to 1) was created for mobility, social distancing, commerce, indoor and outdoor bars and restaurants, culture and leisure, worship and ceremonies, indoor and outdoor sports, for each Spanish province (n = 50) daily. The logarithmic return (LR) of the weekly percentage variation of the 7-days COVID-19 cumulative incidence was used to measure COVID-19 transmission, lagged 12 days behind the stringency index. A hierarchical multiplicative model was fitted, and the median of coefficients across provinces (with 95% bootstrap confidence intervals) was used to quantify the effect of increasing one standard deviation (1SD) in the stringency index in each field.

Results

Highest levels of restriction were seen in mobility, sports and restaurants, particularly indoors. The increase in restrictions overall reduced SARS-CoV-2 transmission by 22% (RR = 0.78; one-sided 95%CI: 0,0.82) in one week, with highest effects for culture and leisure 14% (0.86; 0,0.98), social distancing 13% (0.87; 0,0.95), indoor restaurants 10% (0.90; 0,0.95) and indoor sports 6% (0.94; 0,0.98). In a reduced model with seven fields, culture and leisure no longer had a significant effect while ceremonies decreased transmission by 5% (0.95; 0,0.96). Models R^2 was around 70%.

Conclusion

Increased restrictions decreased COVID-19 transmission. Limitations include remaining collinearity between fields, and somewhat artificial quantification of qualitative restrictions, so the exact attribution of the effect to specific areas must be done with caution.

Introduction

The rapid expansion of the COVID-19 epidemic by March 2020, forced many countries to implement stringent restrictions and lockdowns, which managed to control transmission(1–3). Studies in this first wave assessed effectiveness of different non-pharmaceutical interventions (NPIs), finding as key interventions curfews, lockdowns, and closure of places where people gather extended periods of time, including schools(1, 3–6). Cancelling public gatherings was effective when allowed for less than 10 persons(1, 5, 6), while evidence regarding internal movement restrictions was contradictory, possibly because other measures already reduced mobility to a large extent(1, 7).

The translation of evidence into recommendations during the following waves was challenging. First, the high temporal correlation in the implementation of measures made causal attribution to a particular intervention likely spurious, and the robustness of these results has been questioned(8–10). Second, the effectiveness in the first wave was measured against a pre-pandemic scenario, with no use of facemasks, no awareness nor behavioural adaptations, which could make the marginal benefit of restrictions lower. Third, very restrictive NPIs had a high economic, social and mental health cost, resulted in increased social and gender inequalities(11, 12), and were difficult to maintain in a longer time-frame. As a result of the lack of solid evidence, despite important coordination efforts, there was wide variability in the NPIs typology and intensity.

In the second and successive epidemic waves, most countries in Europe have implemented NPIs with geographical granularity, more fine-tuned intensity guided by epidemiological indicators and alert levels, and targeting different fields of activity, shaped by economic, political and sociocultural preferences(10, 13). In parallel, some evidence has been generated on the effectiveness of such tiered levels systems and on specific NPIs within those systems(10, 13–15). The more time-spaced implementation of NPIs and the varying intensity in these waves allows to better disentangle the effects and provide more detailed evidence. Cultural factors may determine different number and intensity of social contacts in different venues, such as bars and restaurants, commercial or cultural activities or religious temples, across the different contexts, making it relevant to investigate the effect of NPI in varied settings.

Spain is a highly decentralised 47 million people country, divided into 17 Autonomous Communities (17 AC, further divided into 50 Provinces), and 2 Autonomous Cities. In the first COVID-19 wave, a first state of alarm imposed a total lockdown on 14 March 2020 (16). From 4 May to 21 June 2020, restrictions were progressively relaxed (17), until the only measures were compulsory use of facemasks, general hygiene and ventilation measures and minimum interpersonal distance of 1,5 metres at work, commerce and restaurants (18). By mid-August cases started rising and a second epidemic wave became widespread by mid-September. A national risk assessment framework with alert levels and tiered restrictions was agreed by all AC on 22 October (19). However, it was adopted as a voluntary guideline. On 25 October, the Government declared a second state of alarm(20), with a minimum curfew between 00:00 and 5:00, restrictions to movements between AC, and prohibition of groups over six persons (except household members). AC were free to adapt these measures based on their context. As a result, AC Governments ruled very differently, providing a natural experiment of NPIs in 50 territories.

The objective of this work is to analyse the effectiveness of NPIs implemented in nine different fields of activity to decrease SARS-CoV-2 transmission in Spain from 15 September 2020 (beginning of the second epidemic wave) to 9 May 2021 (end of the second state of alarm).

Methods

NPIs data and creation of a stringency index

We reviewed all 17 AC Official Bulletins, extracted and coded a pre-defined list of NPIs (Appendix I), together with the days of start and end, at the Province level, weighting by the proportion of population affected when the measure did not affect the entire Province. Some measures were not included due to lack of variability in the period (closure of nightclubs, recommendations to work from home, compulsory facemasks, or measures in schools and kindergartens, which remained open) or because they were not ruled centrally (semi-present education at Universities).

NPIs were grouped in nine fields of activity: Indoor sports (INSP, maximum capacity, number of persons in a group, public events, or closure of installations), Outdoor sports (OUTSP, similar to INSP but outdoors), Culture and leisure venues (CULT, maximum capacity or closure of museums, monuments, cinemas theatres, zoos, amusement parks), Ceremonies and religious celebrations (CERE, maximum capacity or cancellation of funerals, weddings and baptisms, and activities in religious temples), Commerce (COMM, maximum capacity, opening hours or closure of retail services, close-contact activities, malls and/or street markets), Indoor bars and restaurants (INRE, maximum capacity, persons per table, prohibition to use the bar, opening hours, or total closure of indoor spaces), Outdoor bars and restaurants (OUTRE, similar to INRE but outdoors), Social distance (DIST, number of persons in gatherings or non-household members in public and/or private spaces, need for authorisation or cancellation of events, recommendations to stay at home or mandatory home-confinement) and Mobility (MOBI, curfew and perimeter exit/entry restriction).

Intensity of each NPI was graded as low, medium or high, respectively assigning values of 0.2, 0.5 and 1, to make the scale more sensitive to more stringent measures. NPIs in the same field were combined using weights (Appendices II and III), agreed by the expert panel of project collaborators. The result was one stringency index from 0 to 1 per field of activity, day and province. The codified measures and stringency indices are available at the project website (21).

Case data and specification of the outcome variable

Confirmed COVID-19 cases (diagnosed by Polymerase-Chain Reaction or Rapid Antigen Test) by day and province were extracted from the national surveillance database(22). Compulsory notification and exhaustive surveillance was in place throughout the study period. We computed 7-day cumulative incidence (IA7) as number of COVID-19 cases over the previous 7 days per 100,000 inhabitants, to smooth week seasonality.

The growth ratio (GR) is typically used to represent the relative variation in IA7 in a week timeframe. Considering $IA7_t$ the IA7 at day t, we define $GR_t = (IA7_{t-7} - IA7_t) / IA7_{t-7} = IA7_t / IA7_{t-7} - 1$. GR is not expected to behave symmetrically, since its smallest possible value is -1, while it does not have an upper limit. Just to use a symmetric analogue of GR, the logarithmic return (LR) was also considered, defined as $LR_t = \log(IA7_t / IA7_{t-7}) = \log(1 + GR_t)$. For moderate values of GR (e.g. between −20% and 20%) GR and LR are almost identical.

Functional boxplots(23) were used to show the tendency of GR, LR, IA7 over time in the 50 provinces (Fig. 1) helping to assess the use of IA7, GR and LR to measure SARS-CoV-2 transmission. IA7 shows a general overview on the pandemic evolution, with main pandemic waves (October-November 2020 and January-February 2021) clearly shown in the functional median (solid black line). Heterogeneity in provinces and time is evidenced by the width variation of the coloured bands. In comparison, local maxima (peaks) of the functional median for GR and LR appear a few days after the long weekends of 12 October and early December 2020, and after Christmas and New Year. The coloured band width shows more variability for GR than for LR. Also, the functional median is more symmetrical in LR than GR. Based on these facts, LR was considered better suited for analysing the impact of NPIs in SARS-CoV-2 transmission.

Analytical methods

Since the effect of NPIs on SARS-CoV-2 transmission is not instantaneous, the series of NPI indices at day t (NPI_t) and the lagged LR series k days ahead (LR_{t+k}) were considered. Systematic fits of regression models for LR_{t+k} using NPI_t were performed for k values between 0 and 30. Most models gave the largest R^2 values for $k = 12$. Therefore, lagged LR values 12 days ahead (LR_{t+12}) was considered as response variable (Y). The explanatory variables were the stringency indices for INSP (X_1), OUTSP (X_2), CULT (X_3), CERE (X_4), COMM (X_5), INRE (X_6), OUTRE (X_7), DIST (X_8) and MOBI (X_9). NPI indices were normalised to obtain the effect of varying the index in 1 standard deviation.

Multiple linear regression models (MLR) and generalised additive models (GAM) for every province, mixed models (with random intercept, depending on the province, and fixed slope) and multiple linear and log-linear hierarchical models were used. The most satisfactory model in terms of R^2 was the hierarchical multiple linear model (adjusted $R^2 = 0.7049$):

$$Y = \boldsymbol{\beta}_0 + \boldsymbol{\beta}_1 \cdot X_1 + \cdots + \boldsymbol{\beta}_9 \cdot X_9 + \boldsymbol{\varepsilon}$$

where $Y = LR_{t+12}$, $\boldsymbol{\beta}_0, \ldots, \boldsymbol{\beta}_9$ are random effects at province level, associated to the intercept and to the nine indices: $X_1, \ldots, X_9$. Since $LR_t = \log(IA7_t / IA7_{t-7})$ the model can be rewritten in terms of the weekly IA7 ratio, thus obtaining an estimation of the Risk Ratio ($RR = IA7_t / IA7_{t-7}$):

$$RR = \boldsymbol{\alpha}_0 \cdot \boldsymbol{\alpha}_1^{X1} \cdot \cdots \cdot \boldsymbol{\alpha}_9^{X9} \cdot \boldsymbol{\tau}$$

where $\boldsymbol{\tau} = \exp(\boldsymbol{\varepsilon})$ is a multiplicative error term and $\boldsymbol{\alpha}_0 = \exp(\boldsymbol{\beta}_0), \ldots, \boldsymbol{\alpha}_9 = \exp(\boldsymbol{\beta}_9)$ are positive random effects at province level. This hierarchical multiplicative model (HMM) accounts for province variability (the coefficients $\boldsymbol{\alpha}_i$ are random, since they depend on the province) and the NPI indices enter the model in a simple way (the X_i is just the exponent of $\boldsymbol{\alpha}_i$). If $\boldsymbol{\alpha}_i < 1$, an increase in the stringency index, X_i, would imply a reduction in the mean of the cumulative incidence weekly ratio. So $\boldsymbol{\alpha}_i < 1$ (or equivalently $\boldsymbol{\beta}_i < 0$) implies that the NPIs summarised in X_i are associated to COVID-19 incidence reduction. Since the HMM depends on 500 parameters (10 coefficients for 50 provinces), significance of the estimated parameters have to be done with caution, avoiding multiple testing problems. Methods for controlling the FWER, family-wise error rate (24), and FDR, false discovery rate(25), have been used for p-value correction due to multiple testing.

To summarise the effect of every NPI index in the model, median values, along provinces, for every coefficient, α_i, were estimated. The significance of the hypotheses Median(α_i) < 1, i = 1,...,9, were examined using the bootstrap method, which was also used to derive one-sided 95% confidence intervals (95% CI).

Finally, the average stringency index, $X_{av} = (X_1 + \cdots + X_9) / 9$, was computed to explore the overall effect of NPIs. We described its correlation with LR_{t+12} and performed scatterplots X_{av}-LR_{t+12} for each province and total Spain. X_{av} was then introduced in a HMM similar to the one described above, to estimate its effect on LR_{t+12}. The degree to which the effect for X_{av} approximates the sum of the individual effects for $X_1 + \cdots + X_9$ depends on the correlation between them; therefore the comparison of the effects estimated for the average index and for the individual components is not straightforward.

Results

Description of the stringency index

The evolution of the daily stringency index for each field of activity in each Province can be accessed and downloaded at the project website(21) and is summarised in the functional boxplots in Figure 1. Static boxplots for the distribution of the median and interquartile range of the nine stringency indexes can be found in Supplementary Appendix IV.

The fields with highest stringency index across the study period and the 50 Provinces were MOBI (mean index=0.4808), INSP (0.4784), INRE (0.4509) and OUTSP (0.4187); while mean stringency index was lower in DIST (0.3531), CERE (0.2997), OUTRE (0.2879), COMM (0.2346) and CULT (0.1680) (Table 1; Supplementary Appendix IV). Most mean indices lay below 0.5, showing that restrictions were more frequently of medium intensity, compared to the theoretical maximum. Since ceremonies were never prohibited, nor cult places closed, nor home-confinement imposed, some fields such as CERE and DIST never reached an index above 0.5-0.6. AC most often fine-tuned NPIs by increasing or decreasing restrictions in INRE, OUTRE, INSP and OUTSP, while other fields were more constant over time.

Results show high heterogeneity in the intensity and type of NPIs imposed in the different Provinces (Appendix V). For example, provinces in Castilla-La Mancha had the highest restrictions in INSP, OUTSP, CULT and CERE, but the lowest in COMM, INRE, OUTRE and DIST, while others such as Murcia or the Balearic Islands, mainly imposed restrictions in INRE, OUTRE and DIST. The Provinces in Catalonia experienced very high stringency in most fields except DIST and CULT, while Madrid scored equally low in all nine fields. High correlation is found between specific fields, such as INSP and OUTSP sports and INRE and OUTRE, with correlation profiles varying by province (Appendix VI).

Effect of NPIs on SARS-CoV-2 transmission

Scatter plots for the mean stringency index versus the logarithmic 12-day return for 7-day cumulative incidence (LR_{t+12}) by province assess visually the association between making NPIs more stringent and decreasing SARS-CoV-2 transmission (Appendix VII). There is high variation across provinces, with illustrative cases included in Figure 2. The corresponding correlation coefficients are included in Table 3. While Madrid (ρ =0.13) and Guadalajara (ρ =-0.14) exhibit slightly positive or very moderate negative association, Granada (ρ =-0.73), Soria (ρ =-0.72) and Valencia (ρ =-0.72) show an important negative association. For total Spain the association is negative and quite relevant (ρ =-0.58).

The estimated coefficients of the hierarchical multiplicative model (HMM) for each province are shown in Appendix VIII. In order to summarise the effect of every NPI, median values across provinces, for every coefficient α_i, along with one-sided bootstrap 95% confidence intervals (95% CI) have been collected in Table 1. For a one-dimensional model, with just the average stringency index, the effect of NPIs is significant in the median across provinces, with estimated SARS-CoV-2 transmission reduction of 22% while, with 95% confidence, the reduction is, at least, of 18% (RR= 0.78; 95% CI:0, 0.82). In the full model, a significant effect of restrictions on SARS-CoV-2 transmission was found for CULT (RR=0.86 ; 95% CI: 0, 0.98)), DIST (RR=0.87 ; 95% CI: 0, 0.95), INRE (RR=0.90 ; 95% CI: 0, 0.95) and INSP (RR= 0.94; 95% CI: 0, 0.98). Of note, the effect of the average stringency index was higher than the effect of any single field of activity, but lower than the total sum of their effects; as previously explained, the degree to which the effect of the average approximates the sum of the effect of the individual components depends on the correlation between them and the comparison is not straightforward. Using FWER and FDR methods for p-value correction to handle multiple testing, we computed the percentage of significant coefficients (α_i <1) (Appendix IX). For the significance level α =0.05 and using FRD, these percentages are in the range 45% - 70%.

Since the correlation between INSP and OUTSP, and INRE and OUTRE, is large for the majority of provinces (Appendix VI), they were combined to avoid heavy collinearity in the model: SP=(INSP+OUTSP)/2 and RE=(INRE+OUTRE)/2. Results for this new HMM, just considering seven fields, are shown in Table 2. In this model RE (indoor or outdoor) still had a significant effect (RR=0.88; 95% CI: 0, 0.94) but not SP (indoor or outdoor; RR=0.97; 95% CI: 0, 1.04). Also DIST consistently showed association with a significant reduction in SARS-CoV-2 transmission (RR= 0.91; 95% CI: 0, 0.99) and a small magnitude effect was found for CERE (RR= 0.95; 95% CI: 0, 0.96).

Discussion

Our results show that non-pharmaceutical interventions were effective in decreasing transmission, with an overall estimated decrease in the 7-day cumulative incidence of 22% in one week, starting 5 days after an increase in restrictions of 1 standard deviation. Our models assigned the highest and most consistent effects to interventions in social distance and bars and restaurants, particularly indoors, which each decreased incidence by 9–13%, depending on the model. Inconsistent associations with decreased COVID-19 transmission were found for culture and leisure venues, ceremonies and religious celebrations, and indoor sports, possibly explained by a certain collinearity remaining in the model. For any model, no effect of outdoor sports, commerce or mobility restrictions was found in decreasing transmission.

Our study has some limitations. First, the definition of a quantitative index entails discretionary decisions. For example, restrictions in bars and restaurants included different measures, some of them qualitative, such as the prohibition of using the bar or stay standing-up, limitations to number of persons per table, to the capacity or in opening hours. Further, the resulting scale is being compared to NPI applied, for example, to sport activities. Decisions were taken by a panel of expert collaborators and are documented and freely available. Moreover, NPIs were graded from a theoretical maximum that in some cases was not achieved. Indexes were normalised to improve comparability, but still, an increase of one standard deviation may not have an equivalent meaning in all fields. Second, there was important correlation between different fields, meaning that they tended to increase or decrease together. This could difficult identifiability of individual effects (8, 26). The attribution of effect to NPIs in specific fields should be done with caution, as it could be sensitive to analytical choices and model specification. Third, we analysed official restrictions, but not adherence to them, nor precautions decided by individuals on top of existing recommendations. Some studies point to difficulties of the population in understanding complex and changing norms(27, 28), while others show how people may increase precautions and decrease mobility by their own decision(29). Pandemic fatigue may have further decreased compliance throughout the study period. Finally, we left our some NPIs to avoid noise in the index. For example, measures in betting and gaming venues, or in swimming pools were overlooked, considered to represent a small fraction of interactions in the field. Any effect of these measures would be spuriously attributed to restrictions implemented simultaneously, for example, in bars and restaurants or in sports facilities in general.

As a strength, the study was conducted over a long period of 8 months and three epidemic waves, with on and off measures at different points in time across 50 territories, providing a rich natural experiment with sufficient variability. Of note, there were no significant changes in the testing and surveillance recommendations in this period, making the time series reliable within each territory. Moreover, many cultural, socioeconomic factors and other contextual variables are shared by the territories, being more homogeneous than international comparisons, facilitating the attribution of differences to different levels of NPIs(13, 30).

Some previous studies have estimated the effectiveness of NPIs in the second and successive COVID-19 epidemic waves. A study in 114 regions of 7 European countries using subnational data and analysing 17 different NPIs found a combined effect of all NPIs of 66% reduction in the (instantaneous) reproduction number Rt(10). However, it evaluated strict measures, such as closure of leisure and entertainment venues, gastronomy, retail and close-contact services, night clubs or educational institutions. Therefore it is expected that the impact on SARS-CoV-2 transmission is larger than the one estimated in our study, where softer restrictions are considered. More in line with our results, in Italy, implementation of the less stringent “yellow” tier was associated to decreases in Rt after 3 weeks of 13–19%, the “orange” tier, including closure of restaurants and restrictions to intra-municipality mobility to 27–38% and the strictest “red” tier to 36–45%(15). However, in countries such as Italy or the UK, measures were implemented in tiered levels with fixed combinations of NPIs, making it more difficult to evaluate the relative contribution of the different types of NPIs(13–15).

Regarding the effectiveness of NPIs in particular fields of activity, in Switzerland, business closures, recommendations to work from home and restrictions on gatherings were particularly effective (31). In 7 European countries(10), the highest effect was found for closing non-essential business, which decreased COVID-19 transmission by 35%, including night clubs, restaurants, retail and close-contact services and, to a smaller extent, closing leisure and entertainment venues (theatres, museums and zoos) which only contributed 3% of the total effect). Limiting gatherings to 2 people also had a very important effect, reducing COVID-19 transmission by 26%. Curfew alone decreased transmission by 13%. As indicated before, these were more stringent interventions than in our study, therefore a higher impact in transmission is expected. For example, our estimated effect for bars and restaurants (combined indoors and outdoors) was 12% reduction in 7-day cumulative incidence in 1 week, and restrictions in culture and leisure venues were only significant in one of the two models, reducing incidence by 14%. We did not evaluate measures in nightclubs, since they were closed in the entire study period. Contrary to the findings in the mentioned study, we did not find any effect for restrictions in commerce, although in Spain total closure was seldom applied, and restrictions in capacity or opening hours were more common. We also did not find any effect of mobility restrictions, including curfew, possibly because it was in place in the vast majority of the study period, with only variations in hours affected. A study in Spain in 7 provinces during a shorter period, also found no effect of regional mobility restrictions but found that more strict curfews were associated with increased transmission(32). However, the range of NPIs included was limited, making spurious associations a greater threat, as argued in the limitations section. This same study found an effect of limiting gatherings, the intervention that is found associated with decreased transmission more consistently (in our study, social distance decreased transmission between 9% and 13%).

In conclusion, our results estimate that increasing restrictions had a considerable effect in decreasing COVID-19 transmission, with interventions in social distance, bars and restaurants having the higher and more consistent effect. Our results can contribute to the corpus of evidence that will help inform future decisions in response to COVID-19 resurgence or to future pandemics. This must include, not only studies in effectiveness of NPI, but also in their cost-effectiveness and potential negative effects. Continued partnership and collaboration between epidemiologists in the public administration and scientists, particularly mathematicians and data scientists, is crucial to ensure adequate and timely analysis of data that can be used for evidence-based recommendations.

Declarations

Conflicts of interest: The authors have no relevant financial or non-financial interests to disclose.

Contributions: RC, SM, DGU, MJS and SV conceived the idea and initiated the study. SFB, BV, SM and members of the collective author defined the NPI coding book, and operationally defined the stringency index. SFB, SM and members of the collective author collected and validated the NPI data. IB and DP analysed the data under the supervision of RC and DGU. RC, IB and SM wrote the first draft with inputs from DP and DGU. All authors participated in the interpretation of results and critically reviewed the content of the manuscript. All authors read and approved the final version of the manuscript.

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Tables

Table 1. Results of the HMM for the effect of the stringency index overall and in nine fields of activity over the Logarithmic Return (LR_{t+12}) of the weekly COVID-19 incidence growth rate. Results interpretable as Risk Ratio (RR) for the cumulative incidence in the current day vs. one week ago for a change in one standard deviation in the stringency index.

Field of activity	Mean index value	Standard Deviation	RR (Median(α_i))	One-sided bootstrap 95% Confidence Interval
All fields combined*	0.35	0.17	0.78	(0,0.82)
OUTSP	0.42	0.24	1.12	(0, 1.32)
INSP	0.48	0.28	0.94	(0, 0.98)
CULT	0.17	0.19	0.86	(0, 0.98)
CERE	0.30	0.13	0.97	(0, 1.19)
COMM	0.23	0.16	0.93	(0, 1.02)
INRE	0.45	0.32	0.90	(0, 0.95)
OUTRE	0.29	0.25	0.92	(0, 1.02)
DIST	0.35	0.11	0.87	(0, 0.95)
MOBI	0.48	0.29	1.02	(0, 1.07)

*Simple mean across fields of activity. OUTSP= Outdoor sports; INSP= Indoor sports; CUL= Culture; CERE= Ceremonies; COMM= Commerce; INRE= Indoor bars and restaurants; OUTRE= Outdoor bars and restaurants; DIST=Social distance; MOBI= Mobility. For every province, in the HMM model, the coefficients $\alpha_i = \exp(\beta_i)$.

Table 2. Results of the HMM for the effect of the stringency index overall and in seven fields of activity over the Logarithmic Return (LR_{t+12}) of the weekly COVID-19 incidence growth rate. Results interpretable as Risk Ratio (RR) for the cumulative incidence in the current day vs. one week ago for a change in one standard deviation in the stringency index.

Field of activity	Mean index value	Standard Deviation	RR (Median(α_i))	One-sided bootstrap 95% Confidence Interval
All fields combined*	0.34	0.15	0.77	(0,0.82)
SP	0.45	0.25	0.97	(0, 1.04)
CULT	0.17	0.19	1.01	(0, 1.18)
CERE	0.30	0.13	0.95	(0, 0.96)
COMM	0.23	0.16	0.89	(0, 1.01)
RE	0.37	0.26	0.88	(0, 0.94)
DIST	0.35	0.11	0.91	(0, 0.99)
MOBI	0.48	0.29	1.02	(0, 1.07)

*Simple mean across fields of activity. SP= Indoor and outdoor sports; CUL= Culture; CERE= Ceremonies; COMM= Commerce; RE= Indoor and outdoor bars and restaurants; DIST=Social distance; MOBI= Mobility. For every province, in the HMM model, the coefficients $\alpha_i = \exp(\beta_i)$.

Table 3. Correlation between the variable (LR+12) and the mean stringency index for every province and for the total of Spain. Results interpretable as Risk Ratio (RR) for the cumulative incidence in the current day vs. one week ago for a change in one standard deviation in the stringency index.

Province	Cor(LR+12, Mean strigency index)
Álava	-0.31
Albacete	-0.29
Alicante	-0.66
Almería	-0.5
Asturias	-0.61
Ávila	-0.53
Badajoz	-0.63
Illes Balears	-0.31
Barcelona	-0.71
Bizkaia	-0.52
Burgos	-0.66
Cáceres	-0.61
Cádiz	-0.51
Cantabria	-0.51
Castellón	-0.62
Ciudad Real	-0.32
Córdoba	-0.37
A Coruña	-0.66
Cuenca	-0.29
Girona	-0.66
Granada	-0.73
Guadalajara	-0.14
Guipuzkoa	-0.54
Huelva	-0.57
Huesca	-0.57
Jaén	-0.65
León	-0.69
Lleida	-0.64
Lugo	-0.6
Madrid	0.13
Málaga	-0.46
Murcia	-0.69
Navarra	-0.62
Ourense	-0.49
Palencia	-0.57

Las Palmas	-0.21
Pontevedra	-0.61
La Rioja	-0.51
Salamanca	-0.59
Santa Cruz de Tenerife	-0.42
Segovia	-0.61
Sevilla	-0.61
Soria	-0.72
Tarragona	-0.67
Teruel	-0.32
Toledo	-0.29
Valencia	-0.72
Valladolid	-0.68
Zamora	-0.57
Zaragoza	-0.48
Spain	-0.58

Figures

Figure 1

Functional plots for the 7-day COVID-19 incidence growth rate (GR), the 7-day COVID-19 logarithmic return of the incidence growth rate (LR), the 7-day COVID-19 cummulative incidence (IA7) and the daily stringency indices, in the 50 Spanish Provinces between 15 September 2021 and 9 May 2022. The black curve in the plot corresponds to the median function along the provinces. The dark magenta colored area in the plot represents the region that contains the central 25% of the curves along Spanish provinces. The magenta colored area includes the central 50% of the curves, while the pink area corresponds to the central 75% of the curves.The upper and lower blue solid lines account for the curve envelope, i.e. the most extreme values (minima and maxima) in the curves.

Figure 2

Scatter plots for the mean strigency index and the 7-day COVID-19 logarithmic return of the incidence growth rate 12 days delayed (LRt+12R) in Granada, Soria, Valencia, Guadalajara, Madrid and Spain. For the total of Spain consecutive data are joined with segments to show evolution in time.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryAppendix.pdf