Impact of self-imposed prevention measures and short-term government intervention on mitigating and delaying a COVID-19 epidemic

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Abstract

Background: With new cases of COVID-19 surging around the world, many countries have to prepare for moving beyond the containment phase. Prediction of the effectiveness of non-case-based interventions for mitigating, delaying or preventing the epidemic is urgent, especially for countries affected by the ongoing seasonal influenza activity.

Methods: We developed a transmission model to evaluate the impact of self-imposed prevention measures (handwashing, mask-wearing, and social distancing) due to the spread of COVID-19 awareness and of short-term government-imposed social distancing on the peak number of diagnoses, attack rate and time until the peak number of diagnoses.

Findings: For fast awareness spread in the population, self-imposed measures can significantly reduce the attack rate, diminish and postpone the peak number of diagnoses. A large epidemic can be prevented if the efficacy of these measures exceeds 50%. For slow awareness spread, self-imposed measures reduce the peak number of diagnoses and attack rate but do not affect the timing of the peak. Early implementation of short-term government interventions can only delay the peak (by at most 7 months for a 3-month intervention).

Interpretation: Handwashing, mask-wearing and social distancing as a reaction to information dissemination about COVID-19 can be effective strategies to mitigate and delay the epidemic. We stress the importance of rapidly spreading awareness on the use of these self-imposed prevention measures in the population. Early-initiated short-term government-imposed social distancing can buy time for healthcare systems to prepare for an increasing COVID-19 burden.

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Keywords: SARS-CoV-2, COVID-19, mathematical model, prevention measures, mitigation, epidemic control, disease awareness, social distancing, handwashing, mask-wearing

Research in context

Evidence before this study

Evidence to date suggests that containment of SARS-CoV-2 using quarantine, travel restrictions, isolation of symptomatic cases, and contact tracing may need to be supplemented by other interventions. Given its rapid spread across the world and immense implications for public health, it is urgent to understand whether non-case-based interventions can mitigate, delay or even prevent a COVID-19 epidemic. One such strategy is a broader-scale contact rate reduction enforced by governments which was used during previous outbreaks, e.g., the 1918 influenza pandemic and the 2009 influenza A/H1N1 pandemic in Mexico. Alternatively, governments and media may stimulate self-imposed prevention measures (handwashing, mask-wearing, and social distancing) by generating awareness about COVID-19, especially when economic and societal consequences are taken into account. Both of these strategies may have a significant impact on the outbreak dynamics. Currently, there are no comparative studies that investigate their viability for controlling a COVID-19 epidemic.

Added value of this study

Using a transmission model parameterized with current best estimates of epidemiological parameters, we evaluated the impact of handwashing, mask-wearing, and social distancing due to COVID-19 awareness and of government-imposed social distancing on the peak number of diagnoses, attack rate, and time until the peak number of diagnoses. We show that a short-term (1-3 months) government intervention initiated early into the outbreak can only delay the peak number of diagnoses but neither alters its magnitude nor the attack rate. Our analyses also highlight the importance of spreading awareness about COVID-19 in the population, as the impact of self-imposed measures is strongly dependent on it. When awareness spreads fast, simple self-imposed measures such as handwashing are more effective than short-term government intervention. Self-imposed measures do not only diminish and postpone the peak number of diagnoses, but they can prevent a large epidemic altogether when their efficacy is sufficiently high (above 50%). Qualitatively, these results will aid public health professionals to compare and select interventions for designing effective outbreak control policies.

Implications of all available evidence

Our results highlight that dissemination of evidence-based information about effective prevention measures (handwashing, mask-wearing, and self-imposed social distancing) can be a key strategy for mitigating and postponing a COVID-19 epidemic. Government interventions (e.g., closing schools and prohibiting mass gatherings) implemented early into the epidemic and lasting for a short-time can only buy time for healthcare systems to prepare for an increasing COVID-19 burden.

Introduction

As of March 18, 2020, the novel coronavirus (SARS-CoV-2) has spread to more than 140 countries and has caused over 200,000 confirmed cases of COVID-19, starting with the detection of the outbreak in China on December 31, 2019.[1] On March 11, the World Health Organization officially declared the COVID-19 outbreak a pandemic.[1] Several approaches aimed at the containment of SARS-CoV-2 in China were unsuccessful. Airport screening of travelers was hampered by a potentially large number of asymptomatic cases and the possibility of pre-symptomatic transmission.[2,3,4] Quarantine of fourteen days combined with fever surveillance was insufficient in containing the virus due to the high variability of the incubation period.[5]

Now that SARS-CoV-2 has spread to Europe, it is evident that many European countries face a real possibility of a large COVID-19 epidemic.[6] Until recently, the policy regarding COVID-19 prevention was mainly limited to reporting cases, strict isolation of severe symptomatic cases, home isolation of mild cases, and contact tracing.[7] However, due to potential asymptomatic spread, these case-based interventions have a significant impact on the transmission of SARS-CoV-2 only if they are highly effective.[8,9] Given the current risk evaluation and expected developments in the next few weeks, temporary social distancing measures aiming to reduce the contact rate in the population and, subsequently, transmission were assessed to be necessary.[6] Governments can impose social distancing by closing schools or public places, cancelling mass events, and promoting remote work.[10,11,12] Previous studies showed that the timing and magnitude of such mandated interventions had a profound influence on the 1918 influenza pandemic. However, when poorly timed, the impact of short-term interventions might be limited, with a high risk of epidemic resurgence.[13,14,15,16]

Self-imposed prevention measures such as handwashing, mask-wearing, and social distancing could also contribute to slowing down the epidemic.[17,18] Alcohol-based sanitizers are effective in removing the SARS coronavirus from hands[19] and handwashing with soap may have a positive effect on reducing the transmission of respiratory infections.[20] Surgical masks, often worn for their perceived protection, are not designed nor certified to protect against respiratory hazards, but they can stop droplets being spread from infectious individuals.[21,22] Information dissemination and official recommendations about COVID-19 can create awareness and motivate individuals to adopt such measures. Previous studies emphasized the importance of disease awareness for changing the course of an epidemic.[23,24,25] Depending on the rate and mechanism of awareness spread, the awareness process can reduce the attack rate of an epidemic or prevent it completely,[23] but it can also lead to undesirable outcomes such as the appearance of multiple epidemic peaks.[24,25] It is essential to assess under which conditions, spread of disease awareness that instigates self-imposed measures can be a viable strategy for COVID-19 control.

The comparison of the effectiveness of early implemented short-term government-imposed social distancing and self-imposed prevention measures on reducing the transmission of SARS-CoV-2 are currently missing but are of crucial importance in the attempt to stop its spread. Moreover, if a COVID-19 epidemic cannot be prevented, it is important to know how to effectively diminish and postpone the epidemic peak to give healthcare professionals more time to prepare and react effectively to an increasing health care burden. For affected areas like Europe, where the outbreak runs concurrently with the influenza season, the importance to identify such interventions is profound.

Using a transmission model we evaluated the impact of self-imposed measures (handwashing, mask-wearing, and social distancing) due to awareness about COVID-19 and of a short-term government-imposed social distancing intervention on the peak number of diagnoses, attack rate, and time until the peak number of diagnoses since the first case. We provide a comparative analysis of these interventions and assess the range of intervention efficacies for which a large COVID-19 outbreak can be prevented.

Methods

Baseline transmission model

We developed a deterministic compartmental model describing SARS-CoV-2 transmission in a population stratified by disease status (Figure 1). In this baseline model, individuals are classified as susceptible (S), latently infected (E), infectious with mild or no symptoms (I_M), infectious with severe symptoms (I_S), diagnosed and isolated (I_D), and recovered after an infection with mild and severe symptoms (R_M and R_S, respectively). Susceptible individuals (S) can become latently infected (E) through contact with infectious individuals (I_M and I_S) with the force of infection dependent on the fractions of the population in I_M and I_S. A proportion of the latently infected individuals (E) will go to the I_M compartment, and the remaining E individuals will go to the I_S compartment. We assume that infectious individuals with mild symptoms (I_M) do not require medical attention, recover undiagnosed and are not conscious of having contracted the infection (R_M). Individuals with severe symptoms (I_S) are diagnosed and know their disease status when they are detected. After detection, they are kept in isolation (I_D) until recovery (R_S). Diagnosed individuals are assumed to be perfectly isolated, and, hence, neither contribute to transmission nor to the contact process. Recovered individuals (R_M and R_S) cannot be reinfected. The infectivity of individuals with mild symptoms is lower than the infectivity of individuals with severe symptoms. Natural birth and death processes are neglected as the time scale of the epidemic is short compared to the mean life span of individuals. However, severely symptomatic patients in isolation may be removed from the population due to disease-associated mortality.

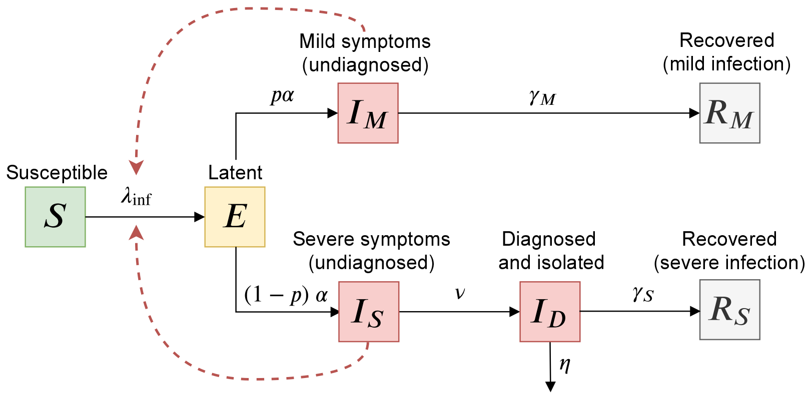

Figure 1. Schematic of the baseline transmission model. Black arrows show epidemiological transitions. Red dashed arrows indicate the compartments contributing to the force of infection. Susceptible persons (S) become latently infected (E) with the force of infection λ_{inf} via contact with infectious individuals in two infectious classes (I_M and I_S). Individuals leave the E compartment at rate α. A proportion p of the latently infected individuals (E) will go to the I_M compartment, and the proportion $(1-p)$ of E individuals will go to the I_S compartment. Infectious individuals with mild symptoms (I_M) recover undiagnosed (R_M) at rate γ_M. Individuals with severe symptoms (I_S) are diagnosed and kept in isolation (I_D) at rate ν until they recover (R_S) at rate γ_S or die at rate η. Table 1 provides the description and values of all parameters.

Transmission model with disease awareness

In the extended model with disease awareness, the population is stratified not only by the disease status but also by the awareness status into disease-aware (S^a, E^a, I^a_M, I^a_S, I^a_D, and R^a_M) and disease-unaware (S, E, I_M, I_S, I_D, and R_M) (Figure 2 A). Disease awareness is a state that can be acquired as well as lost. Disease-aware individuals are distinguished from unaware individuals in two essential ways. First, infectious individuals with severe symptoms who are disease-aware (I^a_S) get diagnosed faster (I^a_D), stay in isolation for a shorter period of time and have lower disease-associated mortality than unaware individuals. Disease-aware individuals recognize the symptoms on average faster than disease-unaware individuals and receive treatment earlier which leads to a better prognosis of I_D individuals. Second, disease-aware individuals are assumed to use self-imposed measures such as handwashing, mask-wearing and self-imposed social distancing that can lower their susceptibility, infectivity and/or contact rate. Individuals who know their disease status (I_D and R_S) do not adapt any such measures since they know that they cannot contract the disease again. Hence, they are excluded from the awareness transition process and we assume that their behaviour in the contact process is identical to disease-unaware individuals.

Similarly to Perra et al[24], disease-unaware individuals acquire disease awareness at a rate proportional to the rate of awareness spread and to the current number of diagnosed individuals (I_D and I^a_D) in the population (Figure 2 B). We assume that awareness fades and individuals return to the unaware state at a constant rate. The latter means that they no longer use self-imposed measures. For simplicity, we assume that awareness acquisition and fading rates are the same for individuals of type S, E, I_M, and R_M. However, the rate of awareness acquisition is faster and the fading rate is slower for infectious individuals with severe symptoms (I_S) than for the remaining disease-aware population.

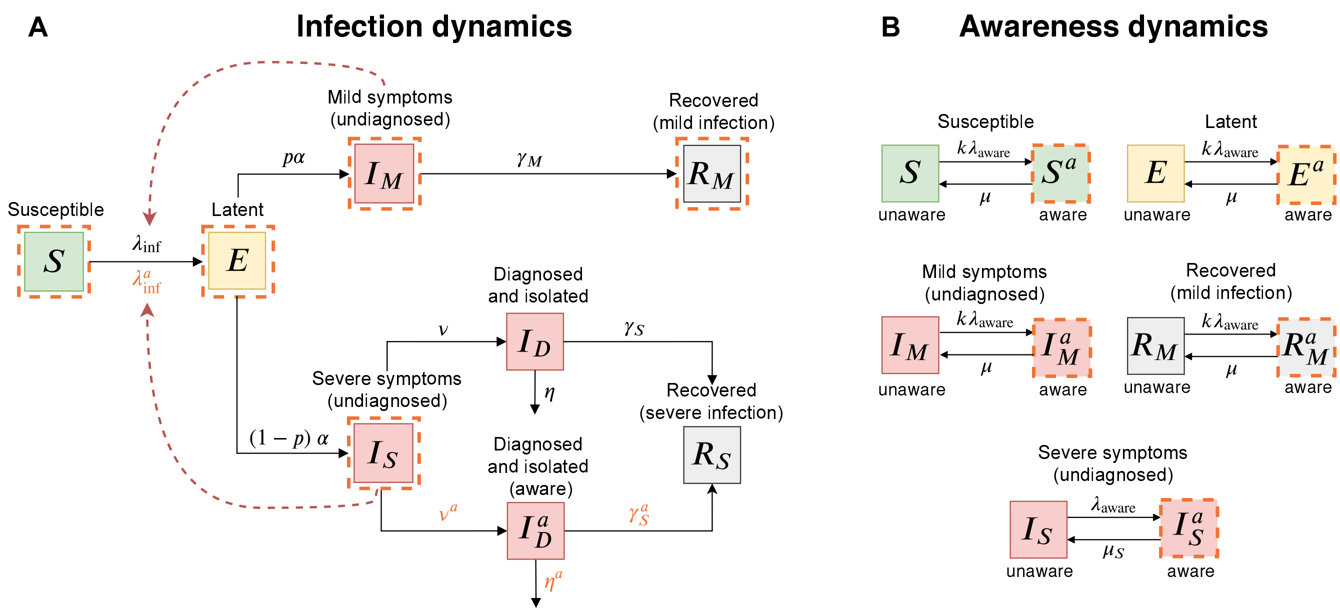

Figure 2. Schematic of the transmission model with disease awareness. (A) shows epidemiological transitions in the transmission model with awareness (black arrows). The orange dashed lines indicate the compartments that participate in the awareness dynamics. The red dashed arrows indicate the compartments contributing to the force of infection. Disease-aware susceptible individuals (S^a) become latently infected (E^a) through contact with infectious individuals (I_M, I_S, I^a_M, and I^a_S) with the force of infection λ^a_{inf}. Infectious individuals with severe symptoms who are disease-aware (I^a_S) get diagnosed and are kept in isolation (I^a_D) at rate ν^a, recover at rate γ^a_S and die from disease at rate η^a. (B) shows awareness dynamics. Infectious individuals with severe symptoms (I_S) acquire disease awareness (I^a_S) at rate λ_{aware} proportional to the rate of awareness spread and to the current number of diagnosed individuals (I_D and I^a_D) in the population. As awareness fades, these individuals return to the unaware state at rate μ_S. The acquisition rate of awareness ($k\lambda_{\text{aware}}$) and the rate of awareness fading (μ) are the same for individuals of type S, E, I_M, and R_M, where k is the reduction in susceptibility to the awareness acquisition compared to I_S individuals. Table 1 provides the description and values of all parameters.

Prevention measures

We considered short-term government intervention aimed at fostering social distancing in the population and a suite of measures self-imposed by disease-aware individuals, i.e., mask-wearing, hand washing, and self-imposed social distancing.

Table 1. Parameter values for the transmission model with and without awareness

		Value*	Source
Epidemiological parameters			
Basic reproduction number	R_0	2.5	Li et al[5]
Probability of transmission per contact with I_S	ϵ	0.048	From $R_0 = \beta\left[p\sigma/\gamma_M + (1-p)/\nu\right]$
Transmission rate of infection via contact with I_S	β	0.66 per day	$\beta = c\epsilon$
Average contact rate (unique persons)	c	13.85 persons per day	Mossong et al[26]
Relative infectivity of mildly infected (I_M)	σ	50%	Assumed
Proportion of mildly infected (I_M)	p	82%	Wu et al[9], Anderson at al[18]
Latent period	$1/\alpha$	4 days	Shorter than incubation period[5,27]
Delay from onset of infectiousness to diagnosis for I_S	$1/\nu$	5 days	Li et al[5]
Recovery period of mildly infected (I_M)	$1/\gamma_M$	7 days	Li Xingwang[†]
Delay from diagnosis to recovery for diagnosed unaware (I_D)	$1/\gamma_S$	14 days	WHO[28]
Relative infectivity of isolated (I_D)		0%	Assuming perfect isolation
Case fatality rate of unaware diagnosed (I_D)	f	1.6%	Althaus et al[29]
Disease-associated death rate of unaware diagnosed (I_D)	η	0.0011 per day	$\eta = \gamma_S f/(1-f)$
Awareness parameters			
Rate of awareness spread (slow, fast and range)	δ	5×10^{-5}, 1 (10^{-6}–1) per year	Assumed[‡]
Relative susceptibility to awareness acquisition for S, E, I_M, and R_M	k	50% (0–100%)	Assumed[‡]
Duration of awareness for S^a, E^a, I_M^a, and R_M^a	$1/\mu$	30 (7–365) days	Assumed[‡]
Duration of awareness for I_S^a	$1/\mu_S$	60 (7–365) days	Longer than $1/\mu$[‡]
Delay from onset of infectiousness to diagnosis for I_S^a	$1/\nu^a$	3 (1–5) days	Shorter than $1/\nu$[‡]
Delay from diagnosis to recovery of diagnosed aware (I_D^a)	$1/\gamma_S^a$	12 days	Shorter than $1/\gamma_S$
Case fatality rate of aware diagnosed (I_D^a)	f^a	1%	Smaller than f
Disease-associated death rate of aware diagnosed (I_D^a)	η^a	0.0008 per day	$\eta = \gamma_S^a f^a/(1-f^a)$
Prevention measure parameters			
Efficacy of mask-wearing (reduction in infectivity)		0–100%	Varied
Efficacy of handwashing (reduction in susceptibility)		0–100%	Varied
Efficacy of self-imposed contact rate reduction		0–100%	Varied
Efficacy of government-imposed contact rate reduction		0–100%	Varied
Duration of government intervention		3 (1–3) months	Assumed[‡]
Threshold for initiation of government intervention		10 (10–1000) diagnoses	Assumed[‡]

*Mean or median values were used from literature; range was used in the sensitivity analyses.
[†] Expert at China's National Health Commission
[‡] Sensitivity analyses

Mask-wearing

Mask-wearing does not reduce the individual's susceptibility because laypersons, i.e., not medical professionals, are unfamiliar with correct procedures for its use and may often engage in face-touching and mask adjustment.[30] Therefore, we assume that mask-wearing only lowers the infectivity of disease-aware infectious individuals (I_M^a and I_S^a) with an efficacy ranging from 0% (zero efficacy) to 100% (full efficacy).[22]

Handwashing

Since infectious individuals may transmit the virus to others without direct physical contact, we assume that handwashing only reduces one's susceptibility. The efficacy of handwashing is described by the reduction in susceptibility (i.e., probability of transmission per single contact) of susceptible disease-aware individuals (S^a) which ranges from 0% (zero efficacy) to 100% (full efficacy).

Self-imposed social distancing

Disease-aware individuals may also practice social distancing, i.e., maintaining distance to others and avoid congregate settings. As a consequence, this measure leads to a change in mixing patterns in the population. The efficacy of social distancing of disease-aware individuals is described by the reduction in their contact rate which is varied from 0% (no social distancing or zero efficacy) to 100% (full self-isolation or full efficacy).

Short-term government-imposed social distancing

Governments may decide to promote social distancing policies through interventions such as school and workplace closures or by issuing a ban on large gatherings. These policies will cause a community-wide contact rate reduction, regardless of the awareness status. Here, we assume that the government intervention is initiated if the number of diagnosed individuals exceeds a certain threshold (10–1000 persons) and terminates after a fixed period of time (1–3 months). As such, the intervention is implemented early into the epidemic. The efficacy of government-imposed social distancing is described by the reduction of the average contact rate in the population which ranges from 0% (no distancing) to 100% (complete quarantine of the population).

Model output

The model outputs are the peak number of diagnoses, attack rate (a proportion of the population that recovered or died after severe infection) and the time to the peak number of diagnoses since the first case. We compared the impact of different prevention measures on these outputs by varying the reduction in infectivity of disease-aware infectious individuals (mask-wearing), the reduction in susceptibility of disease-aware susceptible individuals (handwashing), the reduction in contact rate of disease-aware individuals only (self-imposed social distancing) and of all individuals (government-imposed social distancing). We refer to these quantities as the efficacy of a prevention measure and vary it from 0% (zero efficacy) to 100% (full efficacy) (Table 1). The main analyses were performed for two values of the rate of awareness spread that corresponded to scenarios of slow and fast spread of awareness in the population (Table 1). For these scenarios, the proportion of the aware population at the peak of the epidemic was 40% and 90%, respectively. In the main analyses, government-imposed social distancing was initiated when 10 individuals got diagnosed and was lifted after 3 months.

Estimates of epidemiological parameters were obtained from most recent literature (Table 1). We used contact rates for the Netherlands, but the model is appropriate for other Western countries with similar contact patterns. A detailed mathematical description of the model can be found in the Appendix. The model was implemented in Mathematica 10.0.2.0. The code reproducing the results of this study is available at `https://github.com/lynxgav/COVID19-mitigation`.

Role of the funding source

The funders of the study had no role in study design, data collection, data analysis, data interpretation, writing of the manuscript, or the decision to submit for publication. All authors had full access to all the data in the study and were responsible for the decision to submit the manuscript for publication.

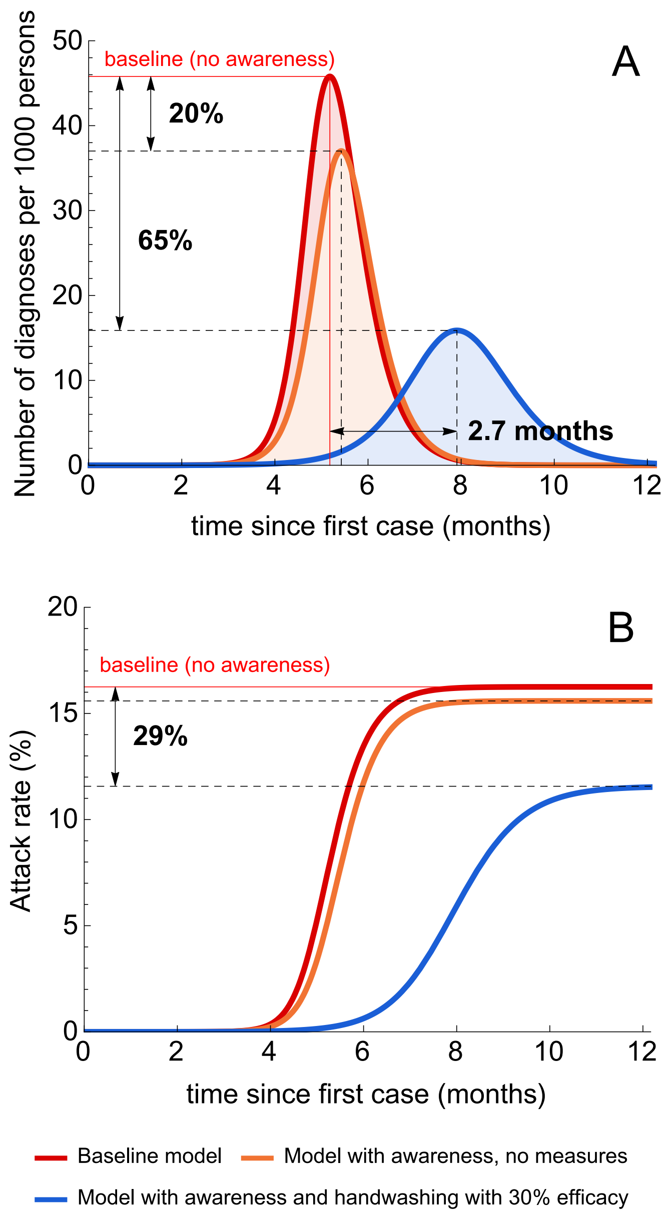

Figure 3. Illustrative simulations of the transmission model. (A) and (B) show the number of diagnoses and the attack rate during the first 12 months after the first case under three model scenarios. The red lines correspond to the baseline transmission model. The orange lines correspond to the model with a fast rate of awareness spread and no interventions. The blue lines correspond to the latter model where disease awareness induces the uptake of handwashing with an efficacy of 30%.

Results

Our analyses show that disease awareness spread has a significant effect on the model predictions. We first considered the epidemic dynamics in a disease-aware population where handwashing is promoted, as an example of self-imposed measures (Figure 3). Then, we performed a systematic comparison of the impact of different prevention measures on the model output for slow (Figure 4) and fast (Figure 5) rate of awareness spread.

Epidemic dynamics

All self-imposed measures and government-imposed social distancing have an effect on the COVID-19 epidemic dynamics. The qualitative and quantitative impact, however, depends strongly on the prevention measure and the rate of awareness spread. The baseline model predicts 46 diagnoses per 1000 individuals at the peak of the epidemic, an attack rate of about 16% and the time to the peak of about 5.2 months (red line, Figure 3 A and B). In the absence of prevention measures, a fast spread of disease awareness reduces the peak number of diagnoses by 20% but has only a minor effect on the attack rate and peak timing (orange line, Figure 3 A and B). This is expected, as disease-aware individuals with severe symptoms seek health care sooner and therefore get diagnosed faster causing fewer new infections as compared to the baseline model. Awareness dynamics coupled with the use of self-imposed prevention measures has an even larger impact on the epidemic. The blue line in Figure 3 A shows the epidemic curve for the scenario when disease-aware individuals use handwashing as self-imposed prevention measure. Even if the efficacy of handwashing is modest (i.e., 30% as in Figure 3 A) the impact on the epidemic can be significant, namely we predicted a 65% reduction in the peak number of diagnoses, a 29% decrease in the attack rate, and a delay in peak timing of 2.7 months (Figure 3 A and B).

The effect of awareness on the disease dynamics can also be observed in the probability of infection during the course of the epidemic. In the model with awareness and no measures, the probability of infection is reduced by 4% for all individuals. Handwashing with an efficacy of 30% reduces the respective probability by 14% for unaware individuals and by 29% for aware individuals. Note that the probability of infection is highly dependent on the type of prevention measure. The detailed analysis is given in the Appendix.

A comparison of prevention measures

Figure 4 shows the impact of all considered self-imposed measures as well as of the government-imposed social distancing on the peak number of diagnoses, attack rate, and the time to the peak for slow rate of awareness spread. In this scenario, the model predicts progressively larger reductions in the peak number of diagnoses and in the attack rate as the efficacy of the self-imposed measures increases. In the limit of 100% efficacy, the reduction in the peak number of diagnoses is 23% to 30% (Figure 4 A) and the attack rate decreases from 16% to 12-13% (Figure

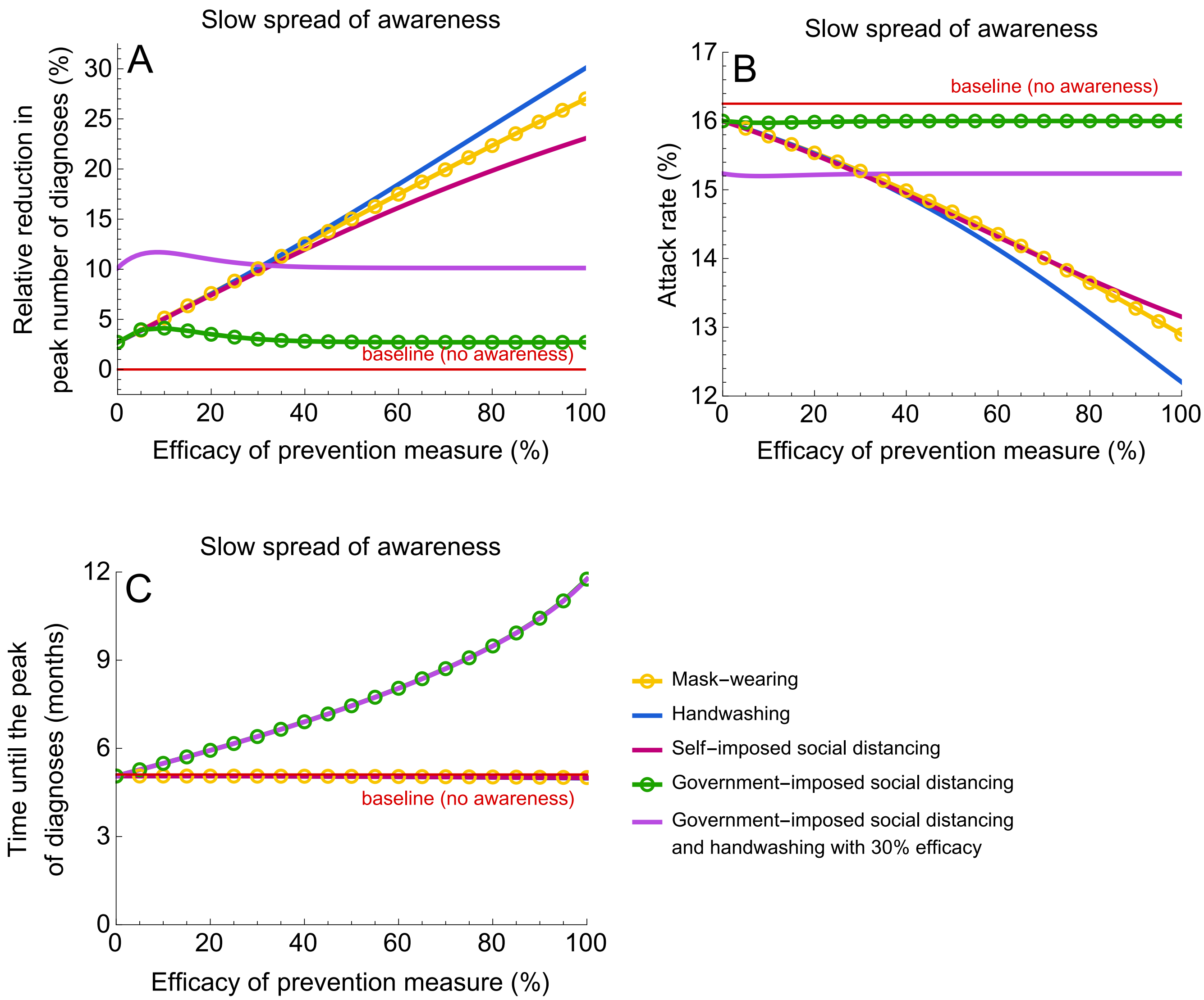

Figure 4. Impact of prevention measures on the epidemic for a slow rate of awareness spread. (A), (B) and (C) show the relative reduction in the peak number of diagnoses, the attack rate (proportion of the population that recovered or died after severe infection) and the time until the peak number of diagnoses. The efficacy of prevention measures was varied between 0% and 100%. In the context of this study, the efficacy of social distancing denotes the reduction in the contact rate. The efficacy of handwashing and mask-wearing are given by the reduction in susceptibility and infectivity, respectively. The simulations were started with one case. Government-imposed social distancing was initiated after 10 diagnoses and lifted after 3 months. For parameter values, see Table 1.

4 B). The efficacy of the self-imposed measures has very little impact on the peak timing when compared to the baseline, i.e., no awareness in the population (Figure 4 C). Since the proportion of aware individuals who change their behavior is too small to make a significant impact on transmission, self-imposed measures can only mitigate but not prevent an epidemic. When awareness spreads at a slow rate, a 3-month government intervention has a contrasting impact. The time to the peak number of diagnoses is longer for more stringent contact rate reductions. For example, at 100% efficacy (full quarantine) the government can postpone the peak by almost 7 months but its magnitude and attack rate are unaffected. Similar predictions are expected, as long as government-imposed social distancing starts early (e.g, after tens to hundreds cases) and is lifted few weeks to few months later (Appendix). This type of intervention halts the epidemic for the duration of intervention, but, because of a large pool of susceptible individuals, epidemic resurgence is expected as soon as social distancing measures are lifted. Finally, when government-imposed social distancing is combined with self-imposed prevention measures, the model predicts that the relative reduction in the peak number of diagnoses and attack rate are determined by the efficacy of the self-imposed measure, while the timing of the peak is determined by the efficacy of government intervention. This is demonstrated in Figure 4 (light purple line), where we used a combination of handwashing with 30% efficacy and government-imposed social distancing with efficacy ranging from 0% to 100% (shown on the x-axis).

Since the government intervention reduces the contact rate of all individuals irrespective of their awareness status, it has a comparable impact on transmission for scenarios with fast and slow rate of awareness spread (compare Figure 4 and Figure 5). However, the impact of self-imposed measures is drastically different when awareness spreads fast. All self-imposed measures are more effective than short-term government intervention. These measures not only reduce the attack rate (Figure 5 B), diminish and postpone the peak number of diagnoses (Figure 5 A and C), but they can also prevent a large epidemic altogether when their efficacy is sufficiently high (about 50%). Note that when the rate of awareness is fast, as the number of diagnoses grows, the population becomes almost homogeneous, with most individuals being disease-aware. It can be shown that in such populations prevention measures yield comparable results if they have the same efficacy. Furthermore, the effect of combinations of self-imposed measures is additive (see Appendix). This means that a large outbreak can be prevented by, for example, a combination of handwashing and self-imposed social distancing each with an efficacy of around 25% (or other efficacies adding up to 50%). As before, for combinations of self-imposed measures and government intervention, the reduction in the peak number of diagnoses and attack rate are determined by the efficacy of the self-imposed measure (Figure 5 A and B) but the peak timing is now determined by the efficacies of both interventions (Figure 5 C). Note, that for fast spread of awareness, a combination of highly efficacious government intervention and handwashing with an efficacy of 30% could postpone the time to the peak number of diagnoses by nearly 10 months (light purple line in Figure 5 C).

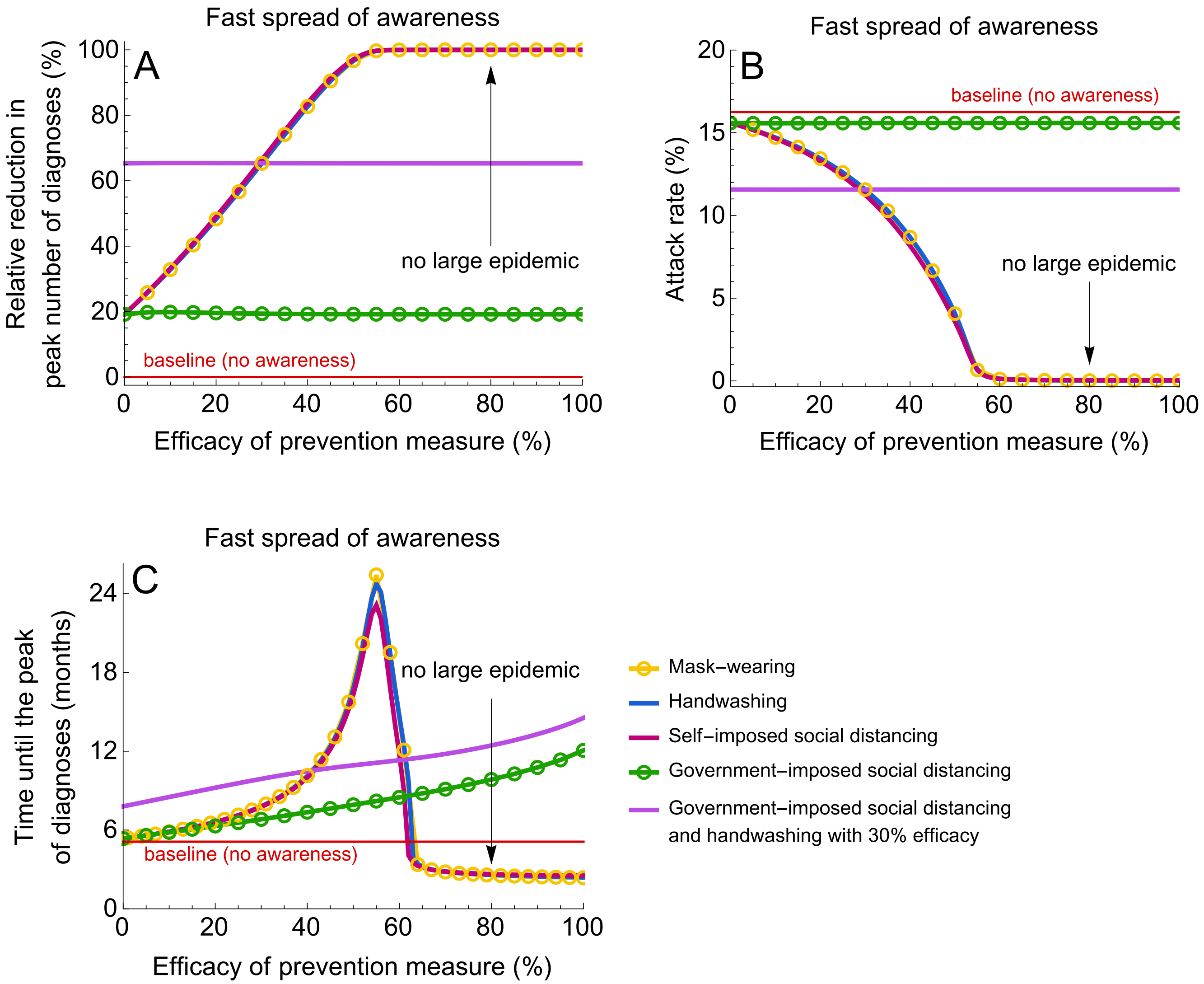

Figure 5. Impact of prevention measures on the epidemic for a fast rate of awareness spread. Same description as in Figure 4 but for a fast rate of awareness spread. For parameter values, see Table 1.

Discussion

For many countries around the world, the focus of public health officers in the context of COVID-19 epidemic has shifted from containment to mitigation and delay. Our study provides new insights for designing effective outbreak control strategies. We show that hand-washing, mask-wearing, and social distancing adopted by disease-aware individuals are all viable strategies for delaying the epidemic peak, flattening the epidemic curve and reducing the attack rate. We show that the rate at which disease awareness spreads has a strong impact on how self-imposed measures affect the epidemic. For a slow rate of awareness spread, self-imposed measures have little impact on transmission, as not many individuals adopt them. However, for a fast rate of awareness spread, their impact on the magnitude and timing of the peak increases with increasing efficacy of the respective measure. For all measures, a large epidemic can be prevented when the efficacy exceeds 50%. Moreover, the effect of combinations of self-imposed measures is additive. In practical terms, it means that SARS-CoV-2 will not cause a large outbreak in a country where 90% of the population adopt handwashing and social distancing that are 25% efficacious (i.e., reduce susceptibility and contact rate by 25%, respectively).

Although the effects of self-imposed measures on mitigating and delaying the epidemic are similar (see Figure 4 and Figure 5), not all explored efficacy values may be achieved for each measure. For instance, handwashing with soap or using alcohol-based sanitizers may remove the virus completely leading to 100% efficacy.[19] For surgical masks, their filtration efficiency has a wide range (0%–84%) and thus their actual efficacy is difficult to quantify.[21] For this reason, the promotion of handwashing might become preferable. Thus, for a fair comparison between measures, realistic efficacy values of a specific measure should be taken into consideration.

We contrasted self-imposed measures stimulated by disease awareness with mandated social distancing. Our analyses show that short-term government-imposed social distancing that is implemented early into the epidemic, can delay the epidemic peak but does not affect its magnitude nor the attack rate. For example, a 3-month government intervention imposing community-wide contact rate reduction that starts after tens to hundreds diagnoses in the country can postpone the peak by about 7 months. If this intervention is combined with a self-imposed measure, then the delay can be even longer (up to 10 months for handwashing with 30% efficacy). Such an intervention is highly desirable, when a vaccine is being developed or when healthcare systems require more time to treat cases or increase capacity.

Since for many countries the COVID-19 epidemic is still in its early stages, government-imposed social distancing was modeled as a short-term intervention initiated when the number of diagnosed individuals was relatively low. Our sensitivity analyses showed that government intervention introduced later into the epidemic and imposed for a longer period of time not only delays the peak of the epidemic but also reduces it for intermediate efficacy values (see Appendix). Previous studies suggested that the timing of mandated social distancing is crucial for its viability in controlling a large disease outbreak.[13,14,16] As discussed by Hollingsworth et al[16] and Anderson et al,[18] a late introduction of such interventions may have a significant impact on the epidemic peak and attack rate. However, the authors also showed that the optimal strategy is highly dependent on the desired outcome. A detailed analysis of government interventions with different timings and durations that also takes into account the economic and societal consequences, and the cost of SARS-CoV-2 transmission is a subject for future work.

Our study provides the first comparative analysis of a suite of self-imposed measures and of short-term government-imposed social distancing as strategies for mitigating and delaying a COVID-19 epidemic. In our analyses, we explored the full efficacy range for all prevention measures and different durations of early-initiated government intervention. Our results allow to draw conclusions on which combination of prevention measures can be most effective in diminishing and postponing the epidemic peak when realistic values for the measure's efficacy are taken into account. We showed that spreading disease awareness such that highly efficacious preventive measures are quickly adopted by individuals can be crucial in reducing SARS-CoV-2 transmission and preventing large outbreaks of COVID-19.

Our model has several limitations. It does not account for stochasticity, demographics, heterogeneities in contact patterns, spatial effects, inhomogeneous mixing and imperfect isolation. Our conclusions can, therefore, be drawn on a qualitative level. Detailed models will have to be developed to design and tailor effective strategies in particular settings. To take into account the uncertainty in SARS-CoV-19 epidemiological parameters, we performed sensitivity analyses to test the robustness of the model predictions. As more data become available, our model can be easily updated. In addition, our study assumes that individuals become disease-aware with a rate of awareness acquisition proportional to the number of currently diagnosed individuals. Other forms for the awareness acquisition rate that incorporate, e.g., the saturation of awareness, may be more realistic and would be interesting to explore in future studies.

In conclusion, we provide the first empirical basis of how stimulating the uptake of effective prevention measures, such as handwashing, can be pivotal to achieve control over a COVID-19 epidemic. While information on the rising number of COVID-19 diagnoses reported by the media may fuel anxiety in the population, wide and intensive promotion of self-imposed measures with proven efficacy by governments or public health institutions may be a key ingredient to tackle COVID-19.

Contributors

AT, TMP, NGG, MK, MCJB and GR developed the conceptual framework of the study. AT, TMP, NGG and GR developed the model. AT and GR performed the model analyses. GR produced the results for the main text and conducted sensitivity analyses. NGG conducted the literature search. NGG, AT, TMP and GR wrote the manuscript. AT wrote the appendix. MCJB and MK contributed to interpretation of the results and provided critical review of the manuscript. All authors approved its final version.

Declaration of interests

We declare that we have no conflicts of interest.

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