Combating Toronto's COVID-19 Second Wave: Effectiveness of Non-pharmaceutical Interventions in Reducing Infections

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Keywords: COVID-19, non-pharmaceutical interventions, agent-based simulation, infection rates, compliancy

Abstract

Since the outbreak of the novel coronavirus, also referred to as COVID-19, countries around the world have implemented a range of preventive measures to limit the risk of transmission, such as personal protective equipment (PPE) and social distancing. Currently, many studies have focused solely on the usage of PPE in healthcare facilities; yet, there remains a lack of scientific data available to assess the outcomes of non-pharmaceutical interventions in the general population. The purpose of this study was to determine the effectiveness of handwashing, masks, and gloves in minimizing community transmission of COVID-19 when 30% and 50% of the population abides with each of these precautions. Complexity and Organized Behavior within Environmental Bounds (COBWEB) 2D, an agent-based simulation software, was used to model the transmission rate of the virus in the city of Toronto, Canada. Multiple rounds of simulations revealed that mask wearing was the most effective at lowering COVID-19 infection rates when compliance rates were 30% ($R^2 = 0.752$, $p < 0.05$). Nevertheless, hand washing became the most effective method in preventing further contamination when adherence levels increased to 50% ($R^2 = 0.922$, $p < 0.05$), thus resulting in decreased infection rates. Solely wearing gloves proved to be ineffective in reducing the spread of COVID-19 ($R^2 = 0.944$, $p < 0.05$). As a vaccine has yet to be discovered, the findings of the study can address the lack of information on effective physical interventions. More importantly, by presenting a credible and evidence-based model, this study could potentially assist public health officials in making informed decisions on necessary protocols and establishing strategies required for the phased resumption of normal activities throughout the province, and in different countries.

Introduction

Originating in Wuhan, China, a novel coronavirus known as the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) emerged in early December 2019, giving rise to the global COVID-19 pandemic[1]. In the span of several months, this contagious disease has infected individuals around the world, creating surges in sickness and challenges to healthcare systems. Healthcare policies such as self-isolation and social distancing have been enforced, drastically hindering economies and livelihoods as the pandemic underwent its first wave. With governments around the world proceeding to reopen businesses and workplaces while relaxing constraints on public gatherings, there is a possibility of a virus resurgence. This is speculated from an observation of the second wave of Severe Acute Respiratory Syndrome (SARS) in hospitals, months after it was introduced to Canada in 2003[2]. Similar cases occurred in countries such as Japan and South Korea, which are currently undergoing a post-lockdown resurgence of COVID-19[3]. It is believed that transmission occurred primarily via varying viral RNA load from cough and sneeze droplets of various sizes[4]. Hence, the method of social distancing is heavily advocated for. However, this method may become restricted as the Canadian government advances with the second phase of reopening and even further.

Through this inquiry, the application of practical non-pharmaceutical interventions in reducing virus transmission, specifically when the continuation of physical distancing protocols in public spaces is not feasible, was investigated and analyzed. By modeling the spread of COVID-19 with the use of COBWEB 2D and secondary data, this research attempted to answer the question of: "Which preventive measure is most effective in preventing SARS-CoV-2 transmission within the city of Toronto, Ontario, in terms of medical masks, handwashing, and gloves with regard to the second wave". These interventions were selected due to their common presence in the general public, as well as their potential in mitigating the spread of respiratory viruses during epidemics[5]. As discussed above, respiratory droplet transmission serves as the main mode of transmission of SARS-CoV-2; yet, the World Health Organization (WHO) recently acknowledged that RNA aerosol transmission may also be possible in populated and poorly ventilated indoor spaces[6]. An additional experimental study revealed that aerosols could be created via talking and coughing by a healthy individual[7]. Consequently, the use of medical-grade, non-reusable masks by healthcare workers and the general population have been heavily advocated for. Furthermore, WHO has recommended vigorous handwashing with commercial soap as a practice for coronavirus infection prevention[8]. Still, commercial hand rubs and sanitizers are frequently used in public settings to allow hygienic hand disinfection, as handwashing is seen as impractical in outdoor environments. There have been different claims with the effectiveness of hand sanitizers compared to handwashing: the Centre for Disease Control and Prevention stated that handwashing with soap and water was most effective against disseminating SARS-CoV-2, and that hand sanitizers were ineffective when used for the aforementioned purpose[9]. Conversely, a

March 2020 study done by Swiss and German scientists concluded that WHO's recommended formulation 1 consisting of increased levels of ethanol (80% (vol/vol)), and formulation 2 containing increased levels of 2-propanol (75% (vol/vol)), efficiently inactivated SARS-CoV-2 when used for 30 seconds[10]. In view of these conflicting statements, this study aimed to actively demonstrate the competency of hand washing in the general public. Similarly, when observing the use of medical gloves, there has not been significant scientific evidence proving its effectiveness against coronavirus transmission. It is currently perceived that gloves provide some protection against the transmission of pathogens, but it does not completely prevent hand contamination[11]. Due to the lack of research on the effectiveness of gloves against communicable diseases, this investigation was used to provide a realistic elucidation for the efficacy of gloves against COVID-19 in a given population.

By creating an agent-based simulation, a comparison of the effects of different physical interventions, based on varying levels of conformity, has proved to be a reliable outlook for Toronto, Canada. It was conjectured that the use of all three of the preventive measures would correlate to a decrease in the coronavirus infection rates within the population to be simulated. Moreover, it was hypothesized that increasing adherence in populations will correlate to decreased COVID-19 disease prevalence. In particular, the most effective intervention in combating COVID-19 during the presence of a second wave would be handwashing. This interference was based on comparing contact transmission rates between various precautions, which exemplified that handwashing had the lowest contact transmission rate, discussed further in the next section. As this investigation confirmed many conflicts within the different claims made about certain PPE and its efficacies as well as the use of PPE in the general population, it has the potential to be applied to other common communicable diseases such as common cold and flu. It could also be referred to in the event of future diseases and viruses to serve other densely populated municipalities.

Methods

Research Design

COBWEB 2D was used in this investigation to create simulations modeling varying population adherence to COVID-19 preventive measures in the city of Toronto, Canada. The software was designed to examine how interaction systems adapt to changes in the environment over time, through the manipulation of multiple parameters within the software. For this study, certain modifications were made under several tabs, specifically those named as Environment, Resources, Agents, Disease, and Toxins. Other settings were left identical to the default data, as addressed further in this section. The three independent variables in this study were the efficacies of non-sterile disposable gloves, medical-grade face masks, and proper handwashing (at least 20 seconds with water and regular soap) in diminishing the risk of SARS-CoV-2 transmission. An absence of all preventive measures, denoted by the baseline transmission rate of SARS-Cov-2, acted as the control variable. The dependent variable measured was the rate of infection for each varying percentage of the population (30%, 50%) that followed one of the protective measures mentioned above. This was based on published data concluding that 54.1% of individuals abided with all community preventive measures, such as wearing masks outdoors and preventing socializing outside of home[12]. In order to amplify ramifications of the measures tested when less obeyance may occur, rates in increments below this percentage were utilized. Altogether, six simulations, as illustrated in Table 1, were set up and run.

Simulation Environment

The width and height of the simulation grid were adjusted to 86 and 42 squares respectively, and it was assumed that each small square within the simulation represented 1 m^2. The approximate dimensions of Toronto (a maximum east-west distance of 43 000 meters, and a maximum length of 21 000 meters from north to south[13]) were each reduced by a factor of 500 to obtain these two values. By decreasing the size of the simulation environment, a smaller number of agents could be used, allowing the simulation to run smoothly. Agents - organisms in an ecosystem - are presented in COBWEB 2D as isosceles triangles with apexes directed towards their path of movement. For this simulation, agent types were set to two. Agent 1 represented the portion of the population that abode by the preventive measure being experimented, while agent 2 portrayed the other portion of the population that did not follow the same precaution. The movement of these agents were obstructed by black squares known as blocking stones. To depict physical obstacles such as infrastructure which exists in the locally dense region of Toronto, the total number of stones was set to 500. This value was most suitable in respect of emulating Toronto's population density, which was 230.71244 people per square metre[14], as multiple trials on COBWEB 2D demonstrated that 500 random stones can best simulate the motility of people in the city. The likelihood and allocation of resources in particular areas of the environment were limited by random seeds. Based on a randomized generation by the software, the amount of random seeds was set to a value of 95,577. This randomized feature allowed an estimate of the average density across the simulation environment since many different population densities across the city were present. Under the Resources tab, the initial amount of food resources that could be consumed by the agents was regulated to 100.

Agent Characteristics

Each simulation represented a population of 500 agents that was composed of agent 1 and agent 2. As seen in Figure 1, the initial counts for both agent types were adjusted based on the compliance rate. Moreover, the initial energy was set to 1000, while other food energy, rock bump energy, agent bump energy, and mutation rate were all adjusted to zero. All of the above modifications were made in the Agents tab. For the disease parameters, the initially infected fraction was altered for both agents, also displayed in the Figure 1, so that every simulation and every agent type started with an approximately equal number of infected agents. To simulate the ability of SARS-Cov2 to spread between people, the options "Transmit to 1" and "Transmit to 2" were enabled for both agents. Furthermore, all toxin parameters under the Toxin tab were set to 0, so that the percentage of those who contracted the disease, rather than death rates, were determined. These settings ensured that the agents in the simulation would not disappear, which represented death.

Transmission Rate

The contact and child transmission rate under the Disease tab were both determined based on transmission characteristics and mechanisms of each precaution. This could ensure that transmission was not affected by other confounding variables and the subsequent effects of each physical intervention could be differentiated. In this simulation, the value 0.25 was used as a control transmission rate for SARS-Cov-2. This was the transmission rate for SARS, a pandemic that infected 8,437 individuals worldwide as of July 11th, 2003[15]. Both SARS and SARS-Cov-2 are part of the SARS-associated coronavirus family, possessing similar transmission characteristics. SARS was spread through a transfer of viral load onto others' eyes, nose or mouth by an infected individual's respiratory droplets and aerosols[16], similar to the droplet and airborne transmission route of COVID-19 as stated previously.

According to a 2017 study, the use of gloves in care settings portrayed that cross-contamination occurred 50% of the time while accounting for various human factors[17].

Therefore, Agent 1 for the gloves simulation was assumed to have a contact transmission rate of 12.5%, reducing the baseline transmission of SARS-CoV-2 by 50%. It was assumed that Agent 2 did not partake in any use of protective measures; therefore, it had a contact transmission rate of 25%.

Determining contact transmission rates of mask use by evaluating their filtration efficacy would best simulate the effects of mask wearing in a population. Agent 1, depicting a fraction of the population wearing masks, was assigned a transmission rate of 5% based on a study that analyzed the approaches of handwashing versus mask wearing in defense of avian influenza virus, as a stand-in for SARS-Cov-2[18]. Agent 2 was assigned an approximate contact transmission rate of 17% according to a literature review and meta-analysis of observational studies that compared the effectiveness of N95/surgical masks versus no mask wearing[19].

The contact transmission rate of handwashing was predicated on previous studies that contrasted its effectiveness to medical grade masks and disposable gloves. Possessing the lowest transmission rate, Agent 1 was set as 2% in accordance to the same study referenced for Agent 1 of mask use[18]. Agent 2 was attributed a contact transmission rate of 16%, which represented the relative risk percentage of respiratory infections when handwashing protocols were not followed[20]. This includes opting for hand sanitizer or alcohol-based hand rubs over handwashing, and failure to clean with soap and water for a minimum of 20 seconds.

Simulation Period

The simulation was run for 3000 ticks, also understood as the number of time steps for which the output data was collected. According to epidemiological reports for Toronto, the majority of COVID-19 cases occurred during a 3-month period, from March 11th, 2020 to approximately June 11th, 2020. At the end of this 3-month interval, a plateau in the curve began to form[21]. A similar plateau was demonstrated by a graph that illustrated the total number of cases versus the total number of ticks in the simulation. Thus, on an estimate, 3000 ticks corresponded to a time period of 3 months, or approximately 33 ticks per day.

Statistical Analysis

The data compiled from the COBWEB 2D simulations was used to create graphical representations of COVID-19 disease prevalence in 30% and 50% compliant populations. This was executed through the Microsoft Excel software; the two categories of graphs emulated were the infection rates and total percent infected for each individual protective measure. Statistical analysis was performed using R Studio, in which nonlinear regression was tested to identify a statistically significant correlation between the simulation model and a Gompertz Curve fitting. The 3 coefficients of the Gompertz Curve equation (Equation 1) were determined before modelling the best line of fit: coefficient "a" was evaluated by plotting the specific curve and estimating the y-value where a plateau is evident. Coefficient "b", the displacement from 0 (x-value), was determined by examining the same graph. The slope of the curve's initial fast growth was used to estimate coefficient "c", the growth rate. Approximate values allowed the actual parameters to be ascertained by the Gompertz Curve function in R Studio. The statistical level of significance for this model was chosen as 0.05.

Results

30% Compliance Rate

As depicted in Figure 2, all curves resulted in a plateau at the end of the simulation duration. The use of no preventive measures as displayed by the curve labelled Agent 2 Gloves resulted in approximately 11 out of 50 agents, or as conveyed, 22% of the population, to be infected by the termination of the 3-month period. Conversely, the data curve of Agent 1 Masks demonstrated that mask wearing reduced the percent infected of the population to 8%, signifying 4 out of 50 infected agents. Furthermore, the plotted line for ineffective or absence of regular handwashing (Agent 2 Handwashing) was characterized by an initial, slow growth, followed by a sharp, rapid incline of cases, ultimately surpassing the curve for Agent 1 Gloves. This indicated that inadequate handwashing practices led to a greater infection risk than glove wearing. In general, the absence of all physical interventions (Agent 2 Gloves) was observed to be least effective ($R^2 = 0.909$, $p < 0.05$), while mask wearing (Agent 1 Masks) was shown to be most effective ($R^2 = 0.8213$, $p < 0.05$). Data validity was measured via nonlinear regression fitting and contained statistically significant, greater and positive r-squared values.

Figure 3 portrayed a larger increase in infections over a 3-month period when gloves were used in favor of masks and hand washing, with 2 out of 50 initially infected (4% of the population) spiking to 11 out of 50 (22% of the population) after 1 month. Overall trends in masks illustrated a slower rate of increase in infections, where 12% of the simulated population became infected after the same month. In addition, handwashing rates remained fairly constant with a very slow increase, resulting in 8% of the agent population infected. Culminating cases at the end of 3 months resulted from approximately 16 out of 50 individuals that were using gloves ($R^2 = 0.911$, $p < 0.05$), 9 out of 50 using masks ($R^2 = 0.752$, $p < 0.05$) and 6 out of 50 following handwashing practices ($R^2 = 0.953$, $p < 0.05$). In general, an overall 30% compliance in mask use was most useful while gloves were the least ideal method to contain cases. 30% preventive measure adherence significantly correlates to an increase in cases with minimum deviation between the fitted line and the observed trends.

50% Compliance Rate

As evidenced by Figure 4, which compared the utilization of preventive measures at 50% adherence, most infection rates decreased with increasing compliance. The number of infected agents lowered to 6, in other words, 12% of the population. This was also discerned for the data curve of Agent 2 Handwashing, where 6% of the population, or 3 out of 50 agents were infected. Contrarily, the percentage of infections for mask use (Agent 1 Masks) increased from 4% to 8% of the population. With a 50% compliance rate overall, Agent 1 Handwashing was shown to be most effective ($R^2 = 0.816$, $p < 0.05$), while Agent 2 Gloves remained least effective ($R^2 = 0.945$, $p < 0.05$) against suppressing the number of COVID-19 cases. Non-linear regression line fitting showed minimum variance between the months elapsed and the prevalence of COVID-19 infection for all preventive measures tested.

According to Figure 5, glove utilization led to 12 out of 50 infected agents ($R^2 = 0.944$, $p < 0.05$), the largest number of cases within all tested interventions. Compared to Figure 3, increasing mask compliance reduced infections from 9 out of 50 agents at the two-and-a-half-month mark to 8 out of 50 agents at the end of 3 months ($R^2 = 0.948$, $p < 0.05$). In addition, hand washing indicated an overall slower climb in infections, with an end result of 5 out of 50 cases, denoting 10% of the population ($R^2 = 0.922$, $p < 0.05$). All in all, handwashing was the most effective approach in flattening the number of positive cases in a 50% compliant population. Indicated is a relatively small variation between observed and fitted data, while there is a large positive correlation between months elapsed and percentage infected according to efficacies of gloves, masks, and handwashing. Data and prediction validity were confirmed via coefficient of determination values approaching 1, thus most of the variation is accounted for by the regression line. A summary of all statistical findings for each figure is shown in Table 2.

Discussion

The findings from this study suggested that mask wearing is the most efficient when compliance rates are low ($R^2 = 0.752$, $p < 0.05$), whereas handwashing remains the most effective precaution when levels of compliance are high ($R^2 = 0.922$, $p < 0.05$). The results also implied that the use of preventive measures, particularly during increased adherence, decreases COVID-19 disease prevalence. This indicates that proper handwashing as a main SARS-CoV-2 prevention measure would possibly have an enhanced effect on reducing second wave SARS-CoV-2 cases in Toronto. Due to the high availability of soap and other strong microbial agents in developed cities such as Toronto, handwashing can be a definitive solution to mitigate the transmission of COVID-19. However, as various papers including those done in hospital settings have proposed, virus transmission mainly occurs through droplet and aerosol routes[4,6]; thus, handwashing as a sole prevention measure may not be adequate enough in order to stop the spread of the virus in light of reduced compliance. On the other hand, the inefficacy of glove use is strongly supported through previous literature. All data obtained and visualized through graphical methods have demonstrated that sole glove use will propagate a major increase in infection rates amongst the Toronto population. One article indicated that glove surfaces are easily contaminated and can proliferate the spread of pathogens[22]; another study evaluating the misuse of gloves found that the failure to remove or change contaminated gloves was a major contributor to poor hand hygiene and microbial transmission[23]. Such literature can be reasonably applied to Toronto where solely gloving cannot suppress the rates of COVID-19 infection with frequent daily human interaction.

Our model contains some limitations in simulating the second wave of COVID-19 in Toronto. Only three types of preventive measures were modeled: handwashing, medical mask use, and disposable glove use. This was done to measure the separate efficacies of each method but realistically, more than one method is employed. Additionally, there is a lack of literature that determines the actual transmission rate for SARS-CoV-2, posing a limitation on the predicted percentage of infected individuals. COBWEB 2D can only allow a limited number of agents and AI behaviors, hindering the practical aspect of the simulation. Environmental factors such as emigration and immigration, as well as varying levels of individual agent movements were not accounted for. Nonetheless, the model was able to provide various trends from which one can deduce the effectiveness of each PPE. Moreover, this study could act as a basis for future research that relates to the transmission of airborne diseases in populated areas. To illustrate, the population density could be modified through various settings in the Environment tab to simulate that of other Ontario cities. Additional studies could be performed to evaluate the effectiveness of various PPE combinations, which more realistically represents the current state of compliance in the general population. These are just some of the plethora of ways that this investigation could be utilized to explore additional research topics.

Acknowledgements

Our deepest gratitude to Sizhen Wu for her helpful guidance and suggestions regarding the statistical analysis component of our study.

Competing Interests

No competing interests declared.

Data Availability

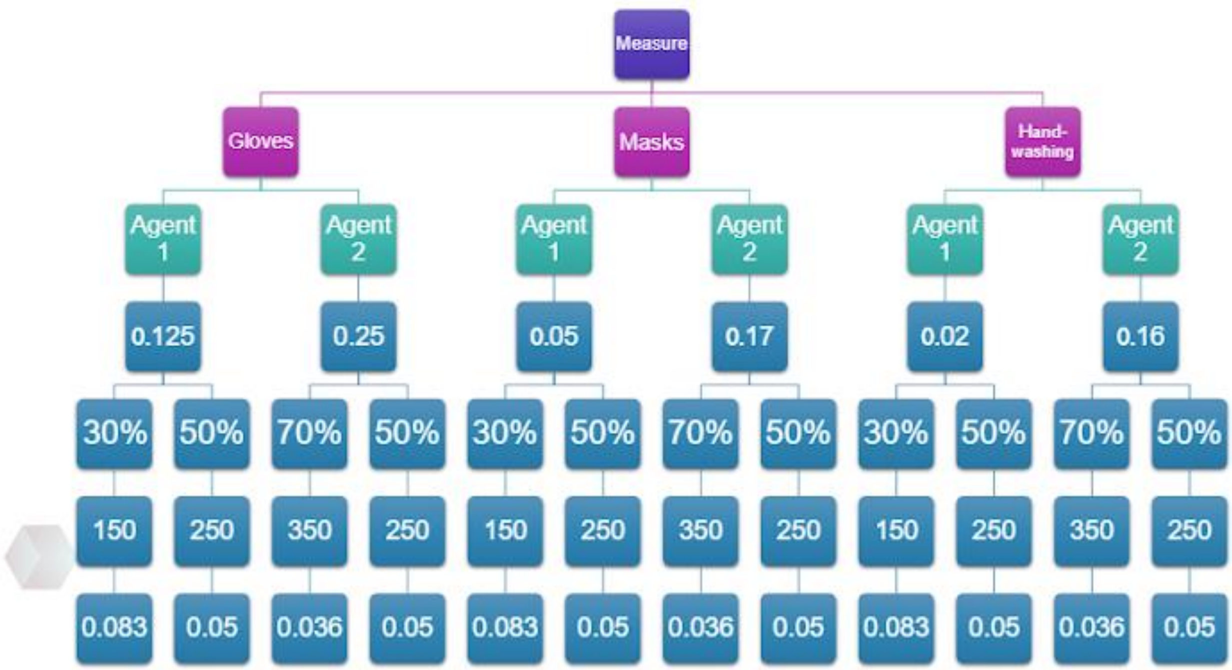
The data that support the findings of this study are openly available in [OSF] at [https://osf.io/a475j], identifier [doi: 10.17605/osf.io/kztx7]

TABLE 1

Preventive Measure	30% Compliance	50% Compliance
Medical Masks	30% compliance for mask use	50% compliance for mask use
Non-medical, disposable gloves	30% compliance for glove use	50% compliance for glove use
Hand washing	30% compliance for hand washing	50% compliance for hand washing

Summary of simulation types in the investigation.
Each separate preventive measure simulation utilizes the same transmission rate proven through previous literature. Agent numbers vary with adherence rates.

FIGURE 1



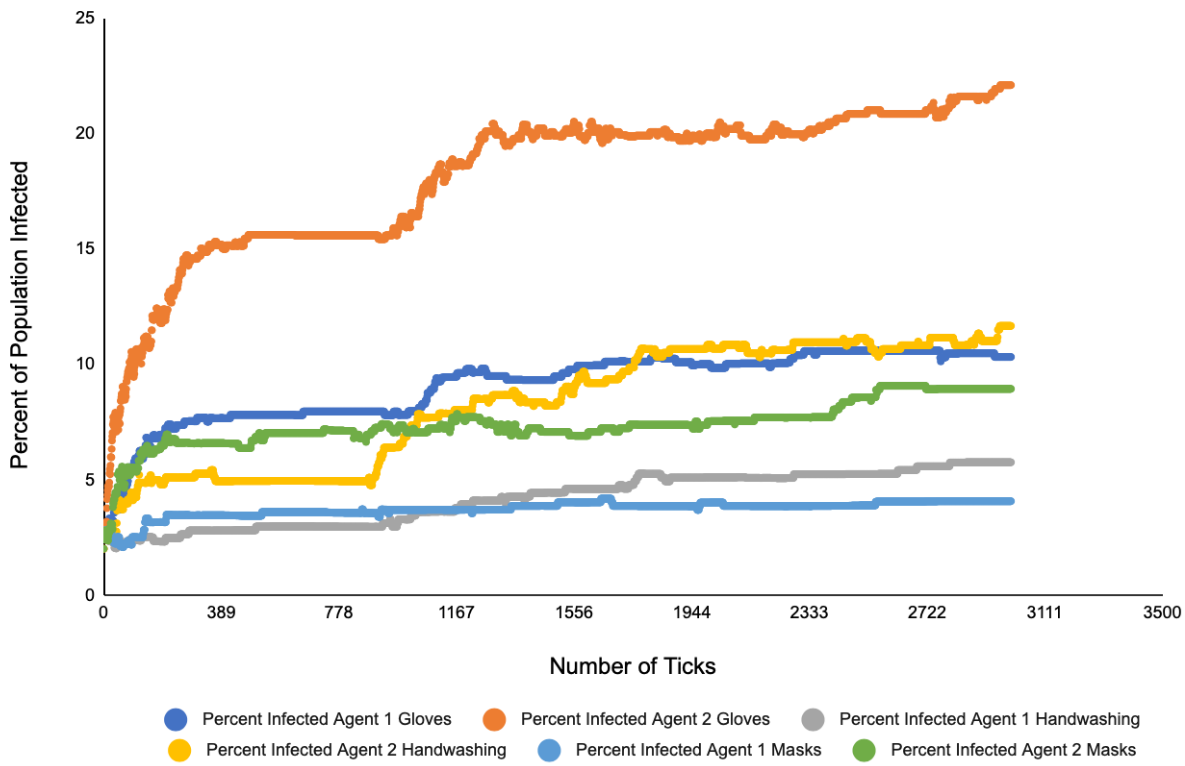
Summary of various parameters in each simulation.
A scheme for each simulation, six in total. The 4th row represents the contact transmission rate for each agent type, while the 5th row shows the percent of the total population that conforms with Agent 1 or 2 behavior. The 6th and 7th row illustrates the number of agents in each agent type population and the initially infected fraction respectively. All agent type populations have an initially infected population of 2.4%±0.26 to emulate a total of 25 infected individuals per 500 population.

EQUATION 1

ft= ae-be-ct

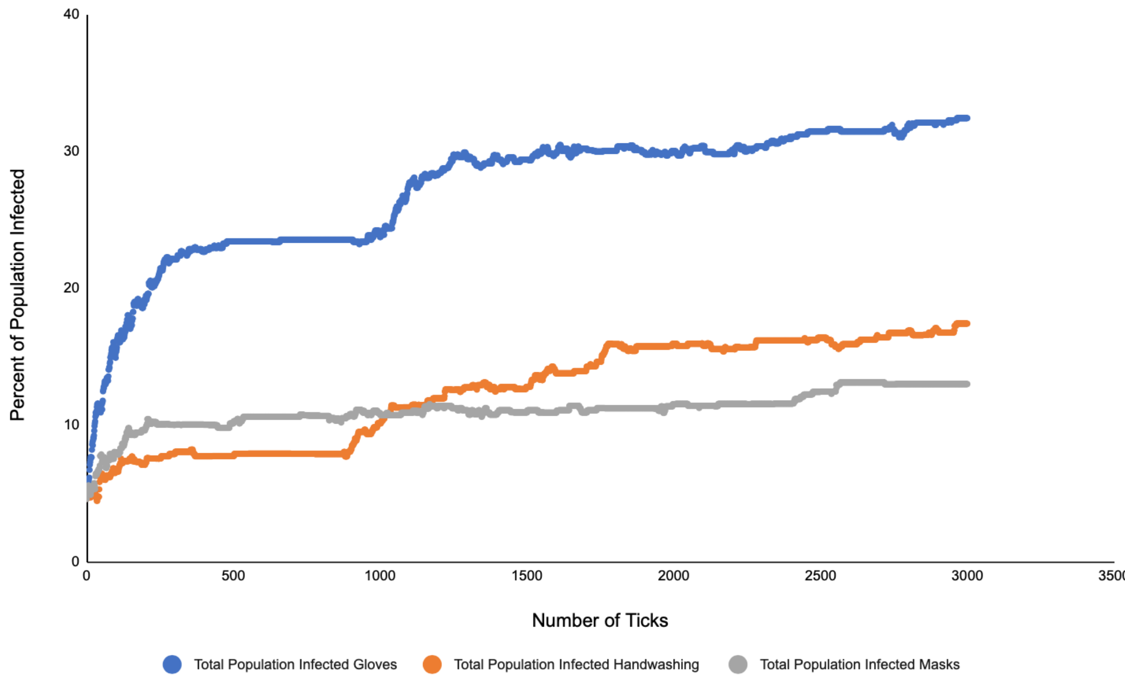
Gompertz Equation
This is a sigmoidal-type growth model used to determine the COVID-19 disease prevalence for each PPE parameter.

FIGURE 2



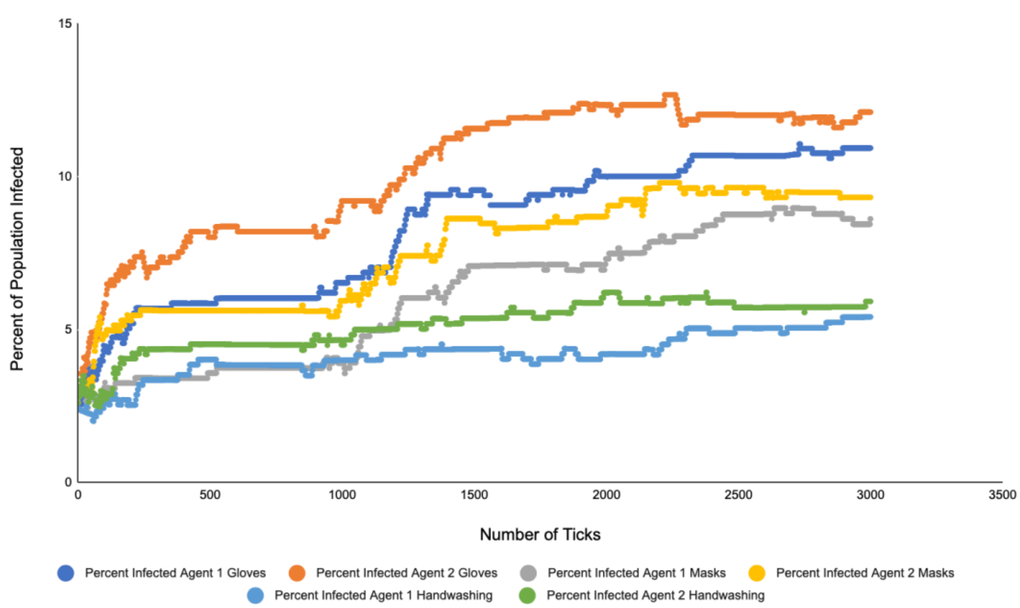
SARS-CoV-2 cases induced by agent populations with a 30% compliance rate.
This comparative graph displays the various efficacies of preventive measures, as tested in simulations that characterize 30% population abidance to these precautions over a 3-month period. To measure effectiveness, percentages of a population infected with COVID-19 are used. These values are calculated based on a fraction of the number of agents infected over the total number of agents in each respective population type. Parameter manipulation, such as the selection of agent type infected, is consistent for all simulations of 30% compliance.

FIGURE 3



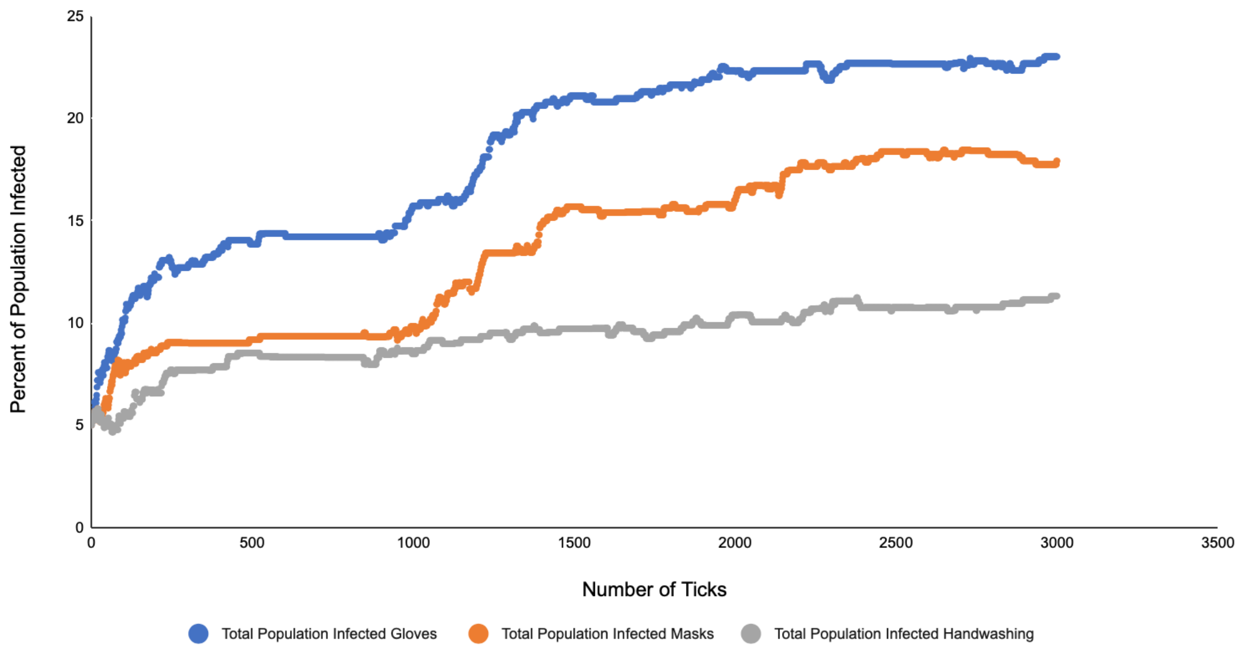
Total SARS-CoV-2 cases induced by agent populations with a 30% compliance rate. This graph portrays the total percentage of infected individuals in each simulated population, where the intervention abidance level over a 3-month period is 30%. The effectiveness of precautions is compared. All simulations of 30% compliancy contain identical parameters for consistency.

FIGURE 4



SARS-CoV-2 cases induced by agent populations with a 50% compliance rate.
This contrastive graph is emulated from simulations that depict 50% of the population following a physical intervention over a 3-month period. The effectiveness of different preventive measures is denoted as percentages of a population infected with COVID-19, which are computed by dividing the number of agents infected over the total number of agents. Parameter manipulation is consistent for all 50% compliant simulations.

FIGURE 5



Total SARS-CoV-2 cases induced by agent populations with a 50% compliance rate.
This graph exhibits the total percentage of infected individuals in each simulated population, where the intervention compliance level over a 3-month period is 30%. The effectiveness of precautions is compared. All simulations of 50% compliancy contain identical parameters for consistency.

TABLE 2

Figure 2 Agents	Coefficient of Determination (R^2)	Figure 3 Agents	Coefficient of Determination (R^2)
Agent 1 Gloves	0.894*	Agent 1 Gloves	0.947*
Agent 2 Gloves	0.909*	Agent 2 Gloves	0.923*
Agent 1 Hand Washing	0.966*	Agent 1 Hand Washing	0.816*
Agent 2 Hand Washing	0.938*	Agent 2 Hand Washing	0.899*
Agent 1 Masks	0.821*	Agent 1 Masks	0.957*
Agent 2 Masks	0.715*	Agent 2 Masks	0.919*
Figure 4 Agents	**Coefficient of Determination (R^2)**	**Figure 5 Agents**	**Coefficient of Determination (R^2)**
Total Infected Masks	0.752*	Total Infected Masks	0.948*
Total Infected Hand Washing	0.953*	Total Infected Hand Washing	0.922*
Total Infected Gloves	0.911*	Total Infected Gloves	0.944*

Coefficient of Determination values for Agent COVID-19 disease prevalence for all figures.

Note. The nonlinear regression model (Gompertz Curve) was used to determine the variance between the fitted line and the observed trend. The asterisk (*) indicates statistical significance ($p < 0.05$).

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