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Assessment of effectiveness of optimum physical distancing phenomena for COVID-19

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ABSTRACT

Currently, COVID-19 is a global pandemic that scientists and engineers around the world are aiming to understand further through rigorous testing and observation. This paper aims to provide safe distance recommendations among individuals and minimize the spread of COVID-19, as well as examine the efficacy of face coverings as a tool to slow the spread of respiratory droplets. These studies are conducted using computational fluid dynamics analyses, where the infected person breathes, coughs, and sneezes at various distances and environmental wind conditions and while wearing a face-covering (mask or face shield). In cases where there were no wind conditions, the breathing and coughing simulations display 1–2 m physical distancing to be effective. However, when sneezing was introduced, the physical distancing recommendation of 2 m was deemed not effective; instead, a distance of 2.8 m and greater was found to be more effective in reducing the exposure to respiratory droplets. The evaluation of environmental wind conditions necessitated an increase in physical distancing measures in all cases. The case where breathing was measured with a gentle breeze resulted in a physical distancing recommendation of 1.1 m, while coughing caused a change from the previous recommendation of 2 m to a distance of 4.5 m or greater. Sneezing in the presence of a gentle breeze was deemed to be the most impactful, with a recommendation for physical distancing of 5.8 m or more. It was determined that face coverings can potentially provide protection to an uninfected person in static air conditions. However, the uninfected person's protection can be compromised even in gentle wind conditions.

I. INTRODUCTION

Throughout history, mankind has always been faced with plagues and illnesses that have threatened the well-being of society.[1] It has always been the aim of scientists, engineers, and researchers to work toward creating innovative solutions to overcome diseases and other issues.[2] Most recently, the world is in the midst of combating COVID-19, a global outbreak.[3] COVID-19 is a zoonotic disease caused by a new strain of coronavirus that began in December 2019. Symptoms from the virus include fever, shortness of breath, nausea, congestion, and a multitude of others.[4] Similar to other pathogenic respiratory coronaviruses such as severe acute respiratory syndrome (SARS) and the Middle East respiratory syndrome (MERS), the effects of COVID-19 can be fatal, given its 3% mortality rate.[5] The virus can also cause severe, long-lasting health complications such as inflammation of the heart, referred to as myocarditis and pericarditis. While cases of myocarditis are uncommon among young people, it can still occur.[6] Presently, cases of the virus have been reported in more than 200 countries, with outbreaks occurring in hospitals, old age care facilities, prisons, and hospitals.[7]

During the preliminary stages of COVID-19 research, it was believed that human to human transmissions of the virus was relatively limited and posed no imminent threat. However, as further research on the virus continued, it was established that the virus was being transmitted from human to human.[5] As recent as April 2020, scientists were able to determine that the primary mode of transmission of the virus is attributed to respiratory droplets when the unprotected individuals are in close proximity with an infected person.[8–10] Additional evidence suggests that the virus can be found in blood and human stool and can exist on surfaces.[8]

In order to stop and mitigate the transmission of COVID-19, health care professionals recommend practicing hand hygiene, maintaining physical distancing, wearing masks and face coverings, and using cleaning or disinfectant supplies.[11] Of the methods listed, wearing a mask and other face coverings is the most logical method to stop of sneezing without a breeze and without a face covering were used as a baseline to compare the results of sneezing in the direction of a gentle wind while wearing an N95 face covering and a face shield. As expected, the release of respiratory droplets at a high velocity and wind blowing in the direction of the exhalation has the potential to drastically worsen the situation. However, wearing a face covering has the potential to improve the situation. It is evident that in both the N95 and face shield, the simulations achieve a final particle position of 1.62 m and 1.53 m. Therefore, a minimum safe distance recommendation of 1.62 m and 1.53 m can be made in these scenarios. The distance traveled is attributed to respiratory droplets under the influence of the environment after they leave the covering, therefore causing them to be blown forward. Whereas when someone sneezes in static air without the influence of wind, a much larger minimum safe distance recommendation of 2.77 m must be made.

Based on the analysis conducted, it was identified that sneezing produced the most volatile results with and without the influence of wind. This is displayed in the dispersion of particles and the final position of particles. However, it is also acknowledged that these circumstances are somewhat unique and can be considered more extreme. Therefore, breathing analyses in the presence of wind at different velocities and directions were conducted. Figure 11 provides a visual comparison between various scenarios where the infected person is breathing in static air, and in the same direction as a gentle and moderate wind. Finally, the results of the infected person breathing in the opposite direction of a gentle breeze were compared.

As expected, breathing in the same direction of the wind greatly impacts the distance that the respiratory droplets were able to reach. However, the opposite occurred when breathing opposed the direction of a gentle breeze.

The particles' positions from Fig. 11 over time were analyzed in greater detail in Fig. 12. As stated previously, the scenarios presented with greater wind speeds were able to produce further particle positions. This is evident in the fact that breathing in static air produced a final particle position of 0.33 m, whereas breathing in the direction of a moderate wind produced a final particle position 1.67 m. Furthermore, if a gentle breeze blows in the opposite direction of the infected person, the particle position was approximately -2.33 m. The negative particle position implies that the respiratory droplets moved in the opposite direction, and that people behind the person exhaling is primarily at risk as opposed to the person in front.

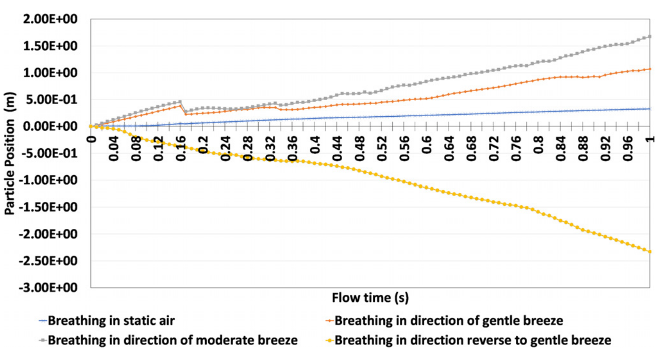

FIG. 12. Comparison between sneezing and various face coverings at different views.

Additional analyses were conducted to identify if individuals would still be at risk in more volatile scenarios. To do this, the study compared the results of coughing, breathing, and sneezing in the direction of a gentle breeze with sneezing in static air conditions. Figure 13 provides a graphical representation of the particle's position within the first second of the simulation. Unlike previously conducted studies where the human models were positioned 2 m apart, Fig. 13 increased the position between human models to adjust for environmental conditions and high respiratory particle launch velocities.

Based on the results presented, breathing in the direction of a gentle breeze presents the least risk, given that the particle's final position is 1.18 m at the end of 1 s, whereas sneezing in the direction of a gentle breeze without any face-covering presents a much greater risk, given its maximum particle position of 5.73 m. However, coughing in the direction of a gentle breeze provided a lower level of risk, given its final particle position of 1.78 m. This was likely attributed to the higher velocity of a sneeze compared to a cough. The prevailing notion from the results of Fig. 13 is that physical distance must drastically be increased to adequately protect individuals from the transmission of respiratory droplets, if they are released at a high velocity and in the same direction as a gentle breeze. A minimum safe distance recommendation of 5.73 m can be made if an infected person sneezed in the direction of a gentle breeze.

An overall score was also assigned to the various simulations presented within the study. This overall score, referred to as the COVID-19 risk factor, falls within the range of 0 to 1, where 1 represents the normalized worst-case scenario of sneezing in the same direction as a gentle breeze and 0 represents breathing, coughing, or sneezing opposite to the direction of a gentle breeze while wearing no face covering(s). This COVID-19 risk factor score of 0 represents relatively no risk to the other person positioned in front of the exhaling person. Figure 14 serves as a representation that compares the COVID-19 risk factor of the various scenarios.

As seen in Fig. 14, sneezing in the direction of a gentle breeze while wearing no face covering produced the worst results. Therefore, all values were normalized relative to this scenario. The results depict that wearing a face-covering can be highly beneficial to mitigate the spread of respiratory droplets. This is illustrated when comparing the COVID-19 risk factor of the subject sneezing in static air without a face covering, with the results of the subject sneezing in the direction of gentle breeze while wearing a face-covering (mask or face shield). Sneezing in the direction of a gentle breeze was considered to be

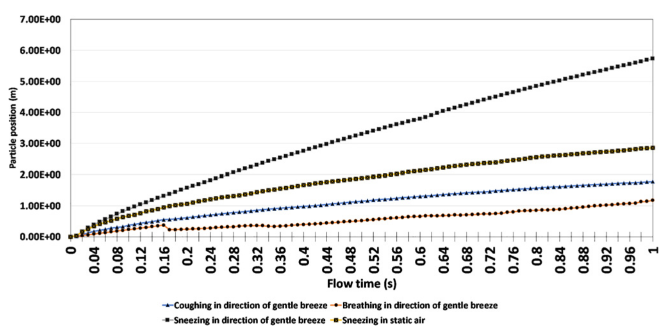

FIG. 13. Comparison between sneezing, coughing and breathing with increased physical distance.