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Assessment and Mitigation of Infection Risk Caused by a Coughing Person

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Abstract. The recent COVID-19 pandemic has increased public awareness of the importance of clean indoor air. Many studies have been conducted on how virus-like particles propagate in indoor environments, and how their spreading could be constrained. In this study, we assessed how the infection risk caused by a coughing person behaves in a meeting room. We analysed how well different protective measures (face masks, visors, air purifiers, partitions) can reduce the risk. The room had a floor area of 21 m^2 and was furnished with a conference table with seating for six people. The room was equipped with a mixing ventilation system providing fresh air at a rate of 36 l/s, or 1.7 l/s·m^2. The supply air temperature was 17°C and the room air temperature 23°C. The coughing person was realized by a cough/sneeze machine Ch3st developed by CH Technologies, USA. Paraffin oil was aerosolized with a BLAM nebulizer from the same company and released in bursts by the cough machine to emulate real coughs. A breathing thermal manikin (PT Teknik, Denmark) was used as the exposed person. Two TSI 3330 OPS optical particle sizers were used to assess the particle concentrations. There were 14 test cases in total. A case with no protective equipment was used as the reference. During each measurement, 21 coughs were released into the test room and the particle concentrations were monitored at one-second intervals from the exposed person's breathing zone and from the infector's workstation. Each cough reaching the exposed person produced a sharp peak in the particle concentration and the number of these peaks was used to assess the effectiveness of each protection measure. The distance between the opposite workstations was 120 cm. The results indicate that masks and visors on the infected person, and partitions, are effective protective measures against cough-based pathogens. Air purifiers and personal protection on the exposed person had little effect.

1 Introduction

Coughing, along with sneezing, are two major routes for an infected person to spread pathogens. Coughs, both from real people and from an artificial "cough boxes", have been investigated in laboratory environments in various studies [1-9]. Some of these studies [1-7] have focused on the coughs themselves whereas others have taken an approach to investigate strategies for preventing the infection spread [8,9]. In the wake of the recent COVID-19 pandemic, the assessment and prevention of aerosol-based disease transmission has become an even greater priority.

During a cough, a distribution of mucosalivary droplets of varying sizes is released, and these droplets may carry pathogens if the coughing person is infected [1-3,10,11]. The largest (> 100 µm) droplets, often referred to as large respiratory droplets, tend to fall quickly on surfaces. Small respiratory droplets between 5 and 100 µm can, depending on their size, stay airborne for a while whereas the smallest ones (< 5 µm), also called droplet nuclei, can persist in the air even for long periods of time. Since the mucus and water in the respiratory droplets evaporate in air, droplets may shrink in size and eventually become droplet nuclei. From an infection risk point of view, the droplet nuclei are problematic as pathogens bound to them can be present in indoor air even after the infected person has already left the space.

While there are plenty of studies on coughing and its consequences, experimental investigations of how a coughing person affects the infection risk of others in an office environment are lacking. Chao et al. [1], Yang et al. [2], and Zayas et al. [3] focused on determining the characteristics and droplet distributions of coughs with particle sizing methods in their experimental studies. Gupta et al. [4], Gao et al. [5], Bouroiba et al. [6], and Zhang et al. [7] studied the trajectories of cough jets with velocity measurements, visualization techniques and CFD simulation. Ronen et al. [8] and Tang et al. [9] investigated face shields and masks as protective measures, respectively, but in both studies the focus was on a single coughing person. Shang et al. [10], and Mariam et al. [11] studied the transmission of cough droplets in indoor environments, but both with numerical methods.

In this study, the main objective was to assess the infection risk caused to an exposed person by a coughing person opposite to him/her in an office environment. The research aimed to find an answer to how the

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infection risk behaves, and how various active filtration and structural measures could be used to reduce it. The study was conducted as an experimental investigation and was part of the larger SUOJAILMA project that aims to find effective and cost-efficient methods for protecting office workers against airborne pathogens. The focus of this conference paper is on the different protective measures and their effect when the exposed person is sitting opposite to the infected one.

2 Methodology

2.1 Test room

The measurements were conducted in the test room of the HVAC laboratory at Aalto University. The room's dimensions were 5.5 x 3.8 x 3.6 m (L x W x H), and it was a well-insulated and airtight thermal chamber.

The room was equipped with a mixing ventilation system. Fresh air was provided with a perforated duct diffuser (diameter 0.2 m) at a rate of 36 l/s, or 1.7 $l/s \cdot m^2$. The supply air temperature was 17 ± 0.5°C and the room temperature 23 ± 0.5°C.

A mock-up of a typical office with two workplaces was built into the room. Each workplace was equipped with a laptop computer and a chair. A breathing thermal manikin (PT Teknik, Denmark) was used as the exposed person. The infected person was realized by a heated dummy with the atomizer fitted into its mouth. The experimental setup is shown in Fig. 1.

Figure 1. The experimental setup with the infected person on the right and the exposed person on the left.

2.2 Cough generation

For generating coughs, a Ch3st sneeze/cough machine (CH Technologies, USA) was used. The cough machine was connected to a Blaustein atomizer (BLAM) from the same company, and paraffin oil was used as the aerosol source. The obtained particle distribution was in accordance with previous studies [1,2], with most generated droplets being in the sub-0.7 µm and 1-2 µm ranges. The cough duration was 1 second and the peak velocity was set to 10 ± 1 m/s according to a review of cough studies [12]. A controllable syringe pump was utilized to supply paraffin oil into the atomizer at a constant rate of 66 µl/min during the coughs.

2.3 Aerosol measurement

The particle concentration produced by the coughing was monitored at two locations with TSI 3330 OPS optical particle sizers. The devices had a 100% counting efficiency for particles larger than 0.3 µm and the upper detection limit was 10 µm. The sampling flow rate was 1.0 (± 5%) l/min.

The first measurement location was 30 cm above the table, and 40 cm away from and 10 cm below the mouth of the infected person. This location was used to monitor the cough generation and ensure that the cough machine was working properly, and the particle distribution was as designed. The second measurement location was in the breathing zone of the exposed person, two centimeters to the side from the mouth so that the manikin's breathing did not interfere with the sample collection. Samples were collected from both locations at a one-second interval.

2.4 Test cases

In this work, the effectiveness of a total of seven different protection methods (surgical mask, FFP2 mask, plexiglass visor, personal air purifier, room air purifier, partitions of two different heights) were studied. The specifications of the protection methods are shown in Table 1. The first four were investigated on both the infected and the exposed persons, and each mask type also with both persons wearing them at the same time. Hence, the total number of cases was 14 and a breakdown of them can be found in Table 2. For each case, a total of 21 coughs at a one-minute interval were recorded.

Table 1. Studied protective measures

Name	Type	Information
Surgical mask	Active	CE certified, EN 14683:2019 + AC:2019
FFP2 mask	Active	CE certified, EN 149:2001+A1:2009
Visor	Structural	-
Personal air purifier	Active	4 filters (HEPA + UV + nanocoating + ionizer), airflow 2.4 m^3/h at max speed
Room air purifier	Active	2 filters (HEPA + sterilizer), CADR 310 m^3/h at max speed, sterilization rate >99.9% for Staphylococcus Albus
Low partition	Structural	Polyurethane sheet, height 40 cm
High partition	Structural	Polyurethane sheet, height 80 cm

Table 2. Test cases.

Case	Protection method
1	None
2	Surgical mask on infected
3	Surgical mask on exposed
4	Surgical mask on both
5	FFP2 mask on infected
6	FFP2 mask on exposed
7	FFP2 mask on both
8	Visor on infected
9	Visor on exposed
10	Personal air purifier on infected
11	Personal air purifier on exposed
12	Room air purifier (CADR 90 l/s, 2.5 x supply air)
13	Low partition (40 cm)
14	High partition (80 cm)

3 Results

The results from cases 1, 7 and 8 are shown in Figs. 2-4. These three cases were selected to present the three different data patterns obtained from the experiments. Only the number of peaks measured at the exposed person is assessed in this paper, and further concentration analysis will be done in a later study. It can be noted that the background concentration increased slightly in all the test cases and the nonlinearity of the increase is explained by the total particle number of each individual cough being different.

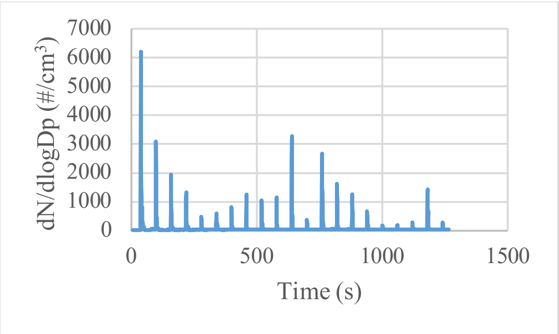

Figure 2. Total particle number concentration at the exposed person in case 1 (no protection)

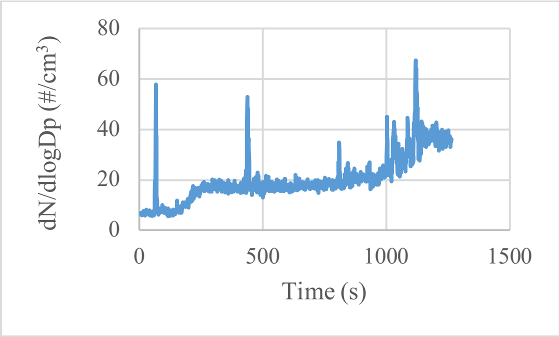

Figure 3. Total particle number concentration at the exposed person in case 8 (visor on infected person)

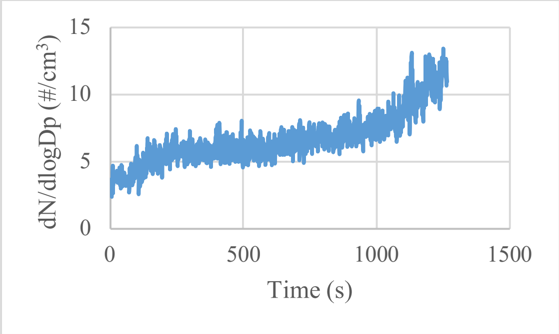

Figure 4. Total particle number concentration at the exposed person in case 7 (FFP2 mask on both persons)

Fig. 2, corresponding to the reference case with no protection, shows 21 peaks of varying heights. The variation in peak height is not assessed here but it is a combination of differences between individual coughs, differences in the fraction of cough particles reaching the exposed person, and the short duration of the cough event itself. The number of peaks indicates that each of the coughs has reached the exposed person. The second example from case 8 in Fig. 3 shows three peaks clearly higher than the background, meaning that some coughs reached the exposed person and the solution offered partial protection. Finally, the example from case 7 in Fig. 4 shows full protection where no peaks are present and only a small increase in the background concentration can be observed. All the 14 measured cases can be categorized with one of these patterns and an overview of the results is shown in Table 2.

Cases 4,5,7 and 14 produced no peaks at all, showing that FFP2 mask on the infected person, any mask on both persons, and the high partition were the best protective measures against particles originating from a cough. Cases 2,8 and 13 corresponding to surgical mask and visor on the infected person, and the low partition each had less than five peaks and thus were also rather effective. The rest of the cases i.e., masks/visor only on the exposed person and the air purifiers, offered no protection at all.

Table 3. Overview of the protection efficiencies in each test case based on the amount of cough peaks observed at the exposed person

Case	Protection efficiency
1	Low
2	Medium
3	Low
4	High
5	High
6	Low
7	High
8	Medium
9	Low
10	Low
11	Low
12	Low
13	Medium
14	High

The results were mostly according to our hypotheses that direct flow obstructions would be beneficial against coughing whereas secondary effects via indoor air would not help much. An interesting find was that protecting the exposed person with a mask, or a visor did not help when the infected one was left unprotected. This suggests that these measures are good at disrupting the cough jet but offer little protection against a burst of pathogens entering the breathing zone from elsewhere.

4 Summary

In this study, we assessed how different protective measures (air purifiers, face masks, visors, partitions) can help to prevent cough-originated cross-infection in an office environment. Laboratory measurements with paraffin oil -based aerosol were performed and particles were counted from the exposed person's breathing zone. The results indicate that methods which directly obstruct the flow of the cough (mask, partition, visor) were good in protecting the exposed person from infection whereas air purifiers were not effective. The exception to this were masks or visor worn by the exposed person which had very little effect if the infected person wore no protection.

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References

1. C.Y.H. Chao et al., J. Aerosol. Sci., **40**, 122-133 (2009)
2. S. Yang et al., J. Aerosol. Med., **20**, 484-494 (2007)
3. G. Zayas et al., BMC Pulm. Med., **12**, 11 (2012)
4. J.K. Gupta, C.-H. Lin, Q. Chen, Indoor Air, **19**, 517-525 (2009)
5. G. Cao, S. Liu, B.E. Boor, A. Novoselac, J. Occup. Environ. Hyg., **14**, 618-631 (2017)
6. L. Bourouiba, E. Dehandschoewercker, J.W.M. Bush, J. Fluid Mech., **745**, 537-563 (2014)
7. B. Zhang et al., Indoor Built Environ., **30**, 1546-1567 (2021)
8. A. Ronen et al., J. Occup. Environ. Hyg., **18**, 72-83 (2021)
9. J.W. Tang, T.J. Liebner, B.A. Craven, G.S. Settles, J. R. Soc. Interface, **6**, 727-736 (2009)
10. Y. Shang et al., J. Aerosol. Sci., **162**, 105943 (2022)
11. Mariam et al., ACS Omega, **6**, 16876-16889 (2021)
12. Z.T. Ai, A.K. Melikov, Indoor Air, **28**, 500-524 (2018)