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What is the risk of airborne (aerosol) SARS-CoV-2 transmission in gyms and how can it be reduced?

Independent, rapid, scientific report

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1 Background

Because of the COVID-19 pandemic, most European governments have introduced mitigation measures such as "stay-at-home" lockdowns and business closures (Imperial-College-COVID-19-Response-Team, 2020). These measures have reduced the rate of transmission as measured by reproduction number R_0 from above 2 to less than 1 so that, at present, infections, hospitalisations and death rates in most of Europe are in decline. Gyms have been asked to close in most countries, too. After the closures, gyms in the USA have started to resume their operation at the end of April. On the 11.05.2020, gyms have re-opened in the state of North Rhine-Westfalia in Germany and gyms are scheduled to open in Italy on the 25.05.2020 (BBC & Der Spiegel, 16.05.2020). Even though gyms operate in a similar fashion elsewhere, the dates for gym re-openings vary greatly within Europe with no discernable scientific base for such variation.

In the Netherlands, the re-opening of gyms is currently scheduled for the 01.09.2020 subject to discussion. Such a long period of closure causes major economic problems for these facilities. Currently, one remaining issue is a query by the advisory body about SARS-CoV-2 transmission via aerosols in the particular environment of gyms. As the Dutch gym federation cannot answer this question itself, it has commissioned the present, rapid, independent scientific report prior to an advisory board meeting on the 26.5.2020, where an earlier reopening of gyms will be discussed.

Aim of this report: The aim of the proposed project is to write by the 25.5.2020 an independent, rapid, scientific report that estimates the risk of airborne (aerosol-mediated) SARS-CoV-2 infections in gyms and recommends measures that reduce such risk.

2 Recommendation: What is the risk of airborne (aerosol) SARS-CoV-2 transmission in gyms and how can it be reduced?

There is indirect scientific evidence for airborne (i.e. aerosol-mediated) SARS-CoV-2 transmission indoors. The risk of an airborne SARS-CoV-2 infection is generally high in all small indoor venues with poor ventilation that are frequented by many people that talk or sing. A gym-specific risk is high intensity exercise (e.g. spinning classes, Tabata/HIIT, Zumba) as intensive exercise increases the minute ventilation of the lung which is the amount of air inhaled and exhaled per minute. To minimize the risk of airborne SARS-CoV-2 infections specifically in gyms we recommend (see also **Figure 1** below):

- **Building ventilation measures**: Ensure high air exchange rates (AER) via the building's ventilation system or if the building has no ventilation system by regular natural ventilation achieved by opening doors and windows. Also there should be 15 min breaks between classes which is time during which exercise venues are ventilated and when aerosol can be removed. We recommend an AER value of 2 h^{-1} or window opening twice per hour and after each class as this is the probably most effective measure to reduce airborne SARS-CoV-2 transmissions. In small gyms with poor opportunities for ventilation, portable consumer air cleaning devices may be an alternative.
- **Limit the number of people per m^2.** Fewer people per area means a lower chance that an infected individual is present and fewer people will be infected if an infected individual is present. We recommend an area of at least 7 m^2 per person (this value is used in North Rhine-Westfalia). We also recommend to consider a maximum total number of 200 people in any gym at any time.
- **Limit the number of people per m^2.** Fewer people per area means a lower chance that an infected individual is present and also if there is SARS-CoV-2 in the room then fewer people will become infected. Moreover, limiting the number of people in a venue lowers the risk of droplet infections as distancing is easier. We recommend an area of at least 7 m^2 per person. This value was used in North Rhine-Westfalia.
- **Prohibit high intensity exercise**: The minute ventilation of the lung can increase from 5-10 L/min to above 100 L/min during maximal exercise. During intensive exercise such as spinning, Tabata/HIIT or Zumba, each individual will inhale more air (equating to more exposure if there is SARS-CoV-2 in the room) and exhale more air (therefore infected individuals will deliver more SARS-CoV-2 into the room). This presents a risk specific to gyms which must be mitigated. We therefore recommend to prohibit initially highly intensive exercise sessions such as spinning, HIIT/Tabata or Zumba classes whilst there is a significant SARS-CoV-2 infection risk in a region. Resistance exercise/weight lifting, Yoga, Pilates classes only moderately increase lung ventilation and should therefore be allowed.

- **Gym instructors should** use a microphone, speak/shout less and quieter than usual as talking or singing is particularly associated with aerosol production.
- **Shield risk groups.** Lawmakers and gym owners should plan special safety measures to shield older individuals and individuals with co-morbidities such as diabetes, coronary heart disease or treatment that results in immune suppression. This can e.g. be achieved by further reducing group sizes, by offering special times or classes solely for affected individuals. Such shielding will further reduce the risk of a severe course of COVID-19 or even fatalities as a consequence of a visit to a gym.

Conclusion. Most risk factors for airborne SARS-CoV-2 infections in gyms are little different from those in hair dressers, banks or churches. The risk of airborne SARS-CoV-2 infections in gyms can effectively be reduced by a high air exchange rate, by limiting the number of people per m^2 and by prohibiting high intensity exercise. If these measures are put in place then there is in our opinion no evidence-based argument to keep gyms closed whilst other outlets with similar risk profiles are open, such as hair dressers, banks, shops, churches or those in the hospitality sector.

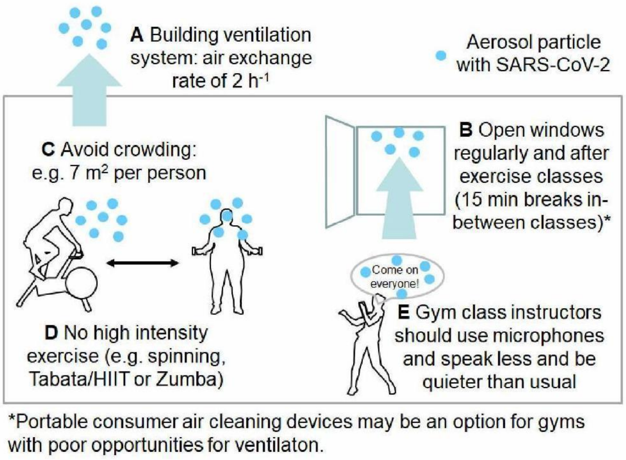

Figure 1. Schematical of the recommendations to prevent airborne SARS-CoV-2 infections in gyms. This can be achieved **A** buy a building ventilation system or alternatively **B** by regular window opening. **C** Crowding can be avoided by space-per-person rules. High aerosol generation and uptake can be avoided by **D** prohibiting high intensity exercise and **E** by limiting the speaking and shouting of gym instructors.

3 Scientific evidence for the recommendations

3.1 Can SARS-CoV-2 infect others through airborne (aerosol) transmission?

In relation to water particles, water droplets (>5 μm) and aerosol (water particles ≤5 μm) are distinguished. Droplets quickly sink to the ground due to their weight but aerosols can float in the air for longer periods. Droplets and aerosol are produced during coughing, sneezing (Bourouiba, 2020), talking, as well as breathing (Asadi et al., 2019; Asadi et al., 2020; Morawska et al., 2009; Stadnytskyi et al., 2020). Singing seems a particular problem as e.g. 52 out of 61 persons (87%) became infected during a 2.5-hour choir practice in the US and two of the infected individuals died subsequently (Hamner et al., 2020). In experimentally generated aerosols, the SARS-CoV-2 virus is detectable for several hours (van Doremalen et al., 2020), raising concern that high aerosol production e.g. during singing by infected individuals in small, poorly ventilated venues can result in a high risk of infection. There is direct experimental evidence that SARS-CoV-2 can be transmitted via aerosol in golden hamsters (Sia et al., 2020). Coronaviruses and/or SARS-CoV-2 could also be detected in breath (Leung et al., 2020) and in particles in the air of hospital rooms (Chia et al., 2020; Liu et al., 2020; Santarpia et al., 2020). Collectively, this suggests that SARS-CoV-2 can be transmitted via aerosol. Some countries and settings are mandating the use of facemasks in an attempt to reduce these risks, but the degree of their effectiveness in preventing specifically aerosol-mediated infections in a general population setting remains in some doubt.

3.2 Is more aerosol produced in gyms?

Gases, droplets and aerosol enter and leave the human body when we ventilate. Generally, minute ventilation by the lung (V_E in L/min) at rest is 5-10 L/min (The Oxford Dictionary of Sports Science & Medicine states 6 L/min). During exercise, minute ventilation increases almost linearly with exercise intensity to reach values of ≈100 L/min in young untrained subjects (see **table 1** (Blackie et al., 1991; Loe et al., 2014)) and average maximal values of 200 L/min have been reported for elite rowers (Clark et al., 1983).

Table 1 Maximal minute ventilation (V_E; arithmetic mean ± SD) by the lung during maximal exercise in 4631 Norwegian men and women (Loe et al., 2014)

Age group	Men (L/min)	Women (L/min)
20-29 years	141.9 ± 24.5	92.0 ± 16.5
30-39 years	136.8 ± 21.5	91.5 ± 15.5
40-49 years	132.0 ± 22.1	87.7 ± 14.8
50-59 years	118.7 ± 21.6	77.2 ± 14.0
60-69 years	109.0 ± 20.7	70.0 ± 12.5
>70 years	90.7 ± 21.0	58.7 ± 16.5

Thus, during maximal exercise up to 10-40 times more air is exhaled and inhaled than during rest but actual aerosol production during exercise has not been measured yet. The greater inhalation will likely expose a vigorously exercising individual to a greater risk of SARS-CoV-2 infection. Likewise, an infected individual will exhale more SARS-CoV-2 contaminated aerosol into the venue during hard exercise (Buonanno et al., 2020) thus increasing the risk for others. Moreover, especially intensive exercise can induce coughing (Hull et al., 2017) which is associated with an additional production of both droplets and aerosol. This is why we recommend no high intensity exercise where exercisers are severely out of breath. Resistance exercise involves small muscle groups exercising hard but only for short periods of time. It only increases ventilation a little, as judged by heart rate data (Apkarian, 2019) and classes such as Yoga or Pilates should not increase ventilation much either. Moderate endurance exercise where individuals do not breathe heavy should also be acceptable in well ventilated venues.

Another issue is that exercise class instructors often speak or shout extensively during an exercise class which will probably produce additional aerosol as it is similar to singing (see above). We therefore recommend using a microphone and that exercise class instructors are made aware of the problem and that they should speak or shout less than usual.

3.3 What is the risk of airborne SARS-CoV-2 transmission in gyms?

In the attached Excel file, GB has extended a just published model for SARS-CoV-2 infection risk (Buonanno et al., 2020) by incorporating different ventilation/inhalation rates (from 23 L min^{-1}, light activity, to 55 L min^{-1}, heavy activity) that reflects variations in the intensity of exercise, different air exchange rates (from 0.5 h^{-1}, natural ventilation to 6 h^{-1}) as well as different sizes of the gyms (GB used data for Germany as these were readily available but the data for the Netherlands should not vary greatly). The estimated infectious risk was compared with an acceptable risk of a SARS-CoV-2 infection of 0.1%. Details of the methodology are reported in the appendix. The results show that in a small venue such as a micro gym, poor air exchange rate e.g. only by natural ventilation and high minute ventilation of the lung are key risks. Because of this we recommend a high building ventilation rate or regular natural ventilation and no high intensity exercise.

4 Disclaimer

This report only gives recommendations. However, each gym owner is herself or himself responsible to risk assess its operation in relation to SARS-CoV-2 infection risk and to reduce the risks according to Dutch law.

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Appendix: methodology to estimate the airborne SARS-CoV-2 infectious risk

We used a four-step approach to quantify the infection risk due to exposure in a gym where a SARS-CoV-2 infected subject is present. The four steps of the proposed approach are: i) evaluation of the quanta emission rate; ii) evaluation of the exposure to quanta concentration in the microenvironment; iii) evaluation of the dose received by an exposed susceptible subject; and iv) estimation of the probability of infection on the basis of a dose–response model. In particular, simulations of airborne transmission of SARS-CoV-2 applying a Monte Carlo method were performed, adopting the infection risk assessment typically implemented to evaluate the transmission dynamics of infectious diseases and to predict the risk of these diseases.
Buonanno et al. (2020) proposed a forward emission approach to estimate the quanta emission rate of an infectious subject on the basis of the viral load in the sputum and the concentration of droplets expired during different activities. A quantum is defined as the dose of airborne droplet nuclei required to infect a susceptible person. The quanta emission rate (ER_q, quanta h^{-1}) was evaluated as:

$$ER_q = c_v \cdot c_i \cdot IR \cdot \int_0^{10\mu m} N_d(D) \cdot dV_d(D) \qquad (1)$$

where c_v is the viral load in the sputum (RNA copies mL^{-1}), c_i is a conversion factor defined as the ratio between one infectious quantum and the infectious dose expressed in viral RNA copies, IR is the inhalation rate (m^3 h^{-1}), N_d is the droplet number concentration (part. cm^{-3}), and $V_d(D)$ is the volume of a single droplet (mL) as a function of the droplet diameter (D).
Quanta emission rates were calculated through the abovementioned approach applying a Monte Carlo method. To this end probability density functions characteristics of each parameter were considered.
The model considered here to quantify the airborne transmitted infection risk was carried out by Gammaitoni and Nucci (Gammaitoni and Nucci, 1997) which represents an upgrade of an earlier model provided by Wells-Riley (Riley et al., 1978):

$$n(t) = \frac{ER_q \cdot I}{IVRR \cdot V} + \left(n_0 + \frac{ER_q \cdot I}{IVRR}\right) \cdot \frac{e^{-IVRR \cdot t}}{V} \qquad \text{(quanta m}^{-3}\text{)} \qquad (2)$$

where $IVRR$ (h^{-1}) represents the infectious virus removal rate in the space investigated, n_0 represents the initial number of quanta in the space, I is the number of infectious subjects, V is the volume of the indoor environment considered, and ER_q is the quanta emission rate (quanta h^{-1}) characteristic for the specific disease/virus under investigation. The infectious virus removal rate is the sum of three contributions (Yang and Marr, 2011): the air exchange rate via ventilation, the particle deposition on surfaces via gravitational settling, and the viral inactivation. (Buonanno et al., 2020)
The probability of infection (or attack rate), as a function of the exposure time (t) of susceptible people, was calculate by integrating the quanta concentration over time through the Wells–Riley equation (Riley et al., 1978):

$$P_I = 1 - e^{-r \cdot D_q} \qquad (\%) \qquad (4)$$

where r is the probability of a pathogen surviving inside the host to initiate the infection and D_q is the dose of quanta,
The individual infection risk in indoor environments, is equal to the product of the attack rate and the corresponding probability of occurrence.
The choice of an acceptable contagion risk for SARS-CoV-2 is difficult and certainly questionable. However, considering the mortality rate of SARS-CoV-2, this turns out to be an order of magnitude lower than the corresponding value associated with carcinogenic diseases. For this reason, the value of 10^{-3} is taken as an acceptable risk reference for SARS-CoV-2.
For the purpose of managing an epidemic, to keep the infection under control, it is also important to estimate the basic reproduction number of the infection, R_0, which is calculated as ratio between number of susceptible people infected (C) and the infected subject (I). Thus,

R_0 can be easily evaluated by multiplying the infection probability, P_I, by the number of exposed susceptible individuals (S). To control an epidemic, the R_0 value must be less than 1. Therefore, in addition to estimate an acceptable individual infection risk, it is necessary to specifically verify that, with the crowding expected from the environment, the corresponding value of R_0 is less than 1.