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Aerosol Transmission of SARS-CoV-2: Inhalation as well as Exhalation Matters for COVID-19

To the Editor:

We read with great interest the article by Echternach and colleagues (1) on the topic of aerosol dispersion during singing and speaking as a potential coronavirus disease (COVID-19) transmission pathway. In the article, as has been the case more broadly regarding this mode of transmission, attention has focused on factors that influence the emission of virus (i.e., aerosol production by the infected individual) when singing or speaking. However, the ventilatory pattern of individuals exposed to the aerosolized virus is also an important factor, as this is likely to be a key modulator of the "dose" of virus-containing aerosol inhaled. As such, the inclusion of such parameters in discussion regarding aerosol transmission is important when considering why certain contexts such as choirs, restaurants, and bars, where speaking, singing, and shouting are common, have been linked to infection clusters (2). Such an appreciation may reframe the discussion to include "superreceptiveness" as a component of "superspreader" events.

Ventilatory parameters vary greatly depending on both the type and intensity of activity and should feature more prominently when considering aerosol transmission. We recently investigated the physiological demands of "Singing for Lung Health" in healthy volunteers (3) and found that when participating in the singing component of the protocol, $\dot{V}_E$ increased from resting volumes of 11 (9–13) L/min (median, interquartile range [IQR]) to 22.42 L/min (IQR, 16.83–30.54 L/min), and the median volume per breath increased from 0.69 L (IQR, 0.63–0.77 L) to 2.11 L (IQR, 1.92–2.70 L). Other researchers, comparing talking with quiet breathing, found increases in parameters including $\dot{V}_E$, V_T, and breathing frequency (4, 5).

Both increased $\dot{V}_E$ and increased V_T are likely to be relevant to aerosol transmission. First, the more aerosolized viral particles inhaled the larger the inoculum, which will impact the chance of developing a disease, and may also influence disease severity (6). Second, greater inhalation will increase the alveolar area exposed to virus-containing aerosols, which may have implications for the viral processing and the immune response (7).

Considering patterns of inhalation as well as exhalation should enable a more complete appreciation of context-specific viral transmission dynamics. This is particularly relevant to contexts in which $\dot{V}_E$ is increased because of physical activity (gyms, supermarkets, etc.) but also where groups of people are vocalizing, such as choral singing, restaurants, bars, and sports crowds. Appreciating these factors does not change the fundamental focus of mitigation measures of hygiene, face coverings, physical distance, and avoiding contexts with poor ventilation. However, given these considerations, particularly with new more infectious severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) variants in circulation, there may now be a stronger argument for face coverings that reduce the risk of inhaling aerosols rather than just reducing their emission, especially in contexts in which people are vocalizing or exercising or other risk factors are present. ■

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Reply to Philip *et al.*

From the Authors:

In the comment by Philip and colleagues, the authors state that the special inhalation patterns are also important in the transmission of coronavirus disease (COVID-19). We absolutely agree that every part of the transmission pathway, specifically *1*) the absolute aerosol production during singing and speaking (1), *2*) the special aerosol impulse dispersion and expansion (2), *3*) the accumulation and convectional spreading of aerosols in rooms (3), and *4*) the special inhalation patterns during singing (4) contribute to person-to-person transmission of the COVID-19 virus.

Although our understanding of the COVID-19 pandemic has grown recently, to the best of our knowledge, the main question remains unclarified: How high a virus dose is needed to infect a person? Whereas the transmission factors (1–3) contribute to the necessary infectious dose, factor 4 represents the rate of admission by a receiving person. In agreement with Philip and colleagues, we do believe that it is very important to understand phonation-related differences in breathing patterns. With regard to this, it has been shown that ventilation patterns differ between types of phonation, showing higher $\dot{V}_E$ for singing in contrast to breathing (4). However, many open questions remain with regard to ventilation. For example, to the best of our knowledge, it has not yet been clarified in detail if an infection is more likely if a virus cloud has been inhaled more deeply, thereby reaching deeper parts of the breathing apparatus, nor if there is any difference between transoral and transnasal breathing. With deep breath inhalation used, for example, for louder speaking, typically the fraction of transoral inhalation increases, which does not have the same immune competence as the nose. However, as far as we know, most virus dose at the beginning of the infection is found in the nasopharynx (5), a part of the breathing system that is only encountered by transnasal breathing patterns.

Nevertheless, exhalatory characteristics such as impulse dispersion appear more important for estimating safety distances because they draw the volume and regions of the highest potential viral dose within the transmission process, inoculated in a direct compact stream. Such a stream reaches significant distances, exceeding 1.3 m (2). By contrast, during inhalation, aerosol particles must enter a person's near field, which shows much less distance from the mouth than for exhalation. The inhalatory near field can be assumed to originate from a hemispherical volume around the mouth and nose with a small radius. In a single-subject side experiment of our study, the radius of the region from which inhaled vapor for a sustained phonation came was determined at approximately 6.5 cm. Thus, the cloud has to be quite near to the mouth of the recipient to be inhaled. To illustrate, it is quite easy to blow out a candle at a distance of 10 cm by the compact exhaling stream, but it is nearly impossible to do the same by inhalation. To provide estimations of safety distances (2), we analyzed phonation-related differences in the impulse dispersion of aerosols while not disregarding that all other parts of the transmission pathway are important for understanding the COVID-19 pandemic. ■

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