Outdoor Transmission of SARS-CoV-2 and Other Respiratory Viruses: A Systematic Review FREE

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Abstract

Background

While risk of outdoor transmission of respiratory viral infections is hypothesized to be low, there are limited data on SARS-CoV-2 transmission in outdoor compared to indoor settings.

Methods

We conducted a systematic review of peer-reviewed papers indexed in PubMed, EMBASE, and Web of Science and preprints in Europe PMC through 12 August 2020 that described cases of human transmission of SARS-CoV-2. Reports of other respiratory virus transmission were included for reference.

Results

Five identified studies found a low proportion of reported global SARS-CoV-2 infections occurred outdoors (<10%) and the odds of indoor transmission was very high compared to outdoors (18.7 times; 95% confidence interval, 6.0–57.9). Five studies described influenza transmission outdoors and 2 adenovirus transmission outdoors. There was high heterogeneity in study quality and individual definitions of outdoor settings, which limited our ability to draw conclusions about outdoor transmission risks. In general, factors such as duration and frequency of personal contact, lack of personal protective equipment, and occasional indoor gathering during a largely outdoor experience were associated with outdoor reports of infection.

Conclusions

Existing evidence supports the wide-held belief that risk of SARS-CoV-2 transmission is lower outdoors but there are significant gaps in our understanding of specific pathways.

Keywords: coronaviruses, SARS-CoV-2, COVID-19, transmission, outdoor

Topic: influenza, viruses, sars-cov-2, covid-19

Issue Section: Review

Recommendations about methods to curb transmission of severe acute respiratory syndrome coronavirus type 2 (SARS-CoV-2) beyond wearing masks and maintaining social distance have varied, especially regarding outdoor transmission [1]. This variability reflects a general lack of information on how SARS-CoV-2 is transmitted outdoors.

Outdoor spaces generally allow for more physical distancing, which mitigates the risk of virus transmission through larger respiratory droplets [2]. Outdoor spaces allow for airflow, ventilation, and lack of recycled air, which all minimize the theoretical risk of aerosol transmission through smaller respiratory droplets. While aerosol spread in community settings is controversial, emerging data suggest that indoor recycled air can spread SARS-CoV-2—with examples of spreading events in a restaurant in Guangzhou [3], at an indoor choir practice in Skagit, Washington, United States [4], at a South Korean call center [5], at meat-packing plants in the United States [6], and in a nursing home in the Netherlands [7]. In areas with low ventilation, aerosolized droplets have the capacity to linger for longer before being inhaled or falling to a surface, which could result in fomite transmission [8]. In enclosed environments, low humidity, air conditioning, and low UV light may all contribute to longer survival of viral particles [9]. Outdoor environments also generally have fewer high-touch surfaces that may harbor the virus. UV light, present outdoors from sunlight, results in a 10-fold decrease in virus survival on surfaces [10]. Finally, indoor environments may increase host susceptibility; the low indoor humidity has been associated with slower host ciliary clearance and complications such as pneumonia, and lack of sunlight has been associated with lower vitamin D levels [11]. For these reasons, the risk of virus transmission in outdoor locations has been hypothesized to be lower than in indoor spaces.

We sought to quantify the risk of SAR-CoV-2 transmission in outdoor settings. We conducted a systematic review of the literature on transmission of SARS-CoV-2 to better understand the risks of outdoor transmission. Where data were available, we estimated the risk of outdoor compared to indoor transmission. Anticipating a paucity of data on SARS-CoV-2, we chose a broad search strategy that included other human betacoronaviruses and respiratory viruses.

METHODS

Search Strategy and Selection Criteria

Data for this review were identified by searches of PubMed, EMBASE, Web of Science, as well as preprints available in Europe PMC [12]. Details of our search strategies and eligibility criteria can be found in our protocol published on 3 August 2020 on PROSPERO (ID, 183826: www.crd.york.ac.uk/prospero/). The search was conducted on 17 June 2020, and because of the rapidly expanding data on SARS-CoV-2, the search was repeated to include most-recent literature on 12 August 2020.

Exposures and Outcomes

The exposure of interest—outdoor gatherings—was defined as persons congregating outdoors for work, social, or recreational activities (see Supplementary Material 1 for our full search strategy). The outcome of interest included cases of transmission of SARS-CoV-2 or other respiratory viruses identified by a case report, illness, or mortality. We also included secondary outcomes of clusters or outbreaks of cases. Our search included any viral infection that can be spread by respiratory droplets and, in addition to SARS-CoV-2, included the other 2 recognized human betacoronaviruses (SARS-CoV-1 and Middle east respiratory syndrome-CoV), human influenza viruses, adenoviruses, rhinoviruses, human metapneumoviruses, and respiratory syncytial virus.

We included studies (experimental or observational with empirical data collection) that described human-to-human transmission of respiratory viruses between humans in an outdoor setting, any review of these studies, and any study (experimental or observational) that compared respiratory viral transmission among humans in an outdoor versus indoor settings.

We excluded reviews of previously published data, studies of exclusively indoor outbreaks, outdoor outbreaks within animal populations or between animals and humans, and outbreaks where the site of transmission was not listed or was unclear. We also excluded studies limited to built environments (homes, apartment buildings, military barracks), hospitals, or forms of transportation (airplanes, trains, buses, cars, ships).

Data Selection and Extraction

After removing duplicate records, 1 author (T. C. B.) reviewed all downloaded citations based on their titles and prespecified inclusion criteria. A second author (M. M.) reviewed a 5% random sample of the excluded titles (rejected from initial search results) for quality control. Two authors (T. C. B. and N. R.) then independently screened the titles, abstracts, and descriptor terms and compared and discussed discrepancies until consensus was reached; a third author (M. M.) served as an arbiter when needed. Two authors (T. C. B. and N. R.) then independently inspected the full texts of the remaining studies for relevance based on exposure, design, and outcome measures to select the included papers, and discussed discrepancies until consensus was reached with a third author (M. M.) serving as arbiter. We used Endnote X9.3.2 (Clarivate Analytics) and Rayyan (Qatar Computing Research Institute, Doha, Qatar) web-based software to manage search results [13].

Two authors (T. C. B. and N. R.) extracted the following data from each paper into a prepiloted data extraction form in Excel spread sheets: complete citation, study location, study design, details of participants (risk group or groups, sample size), exposure details (type of gathering, characteristics of gathering place, number of people, duration, proportion of time spent outdoors, amount if any of indoor transmission, how the nonexposure state (indoors) was defined, outcomes (numerators and denominators associated with each outcome, definitions and descriptions of outcomes provided in papers, details of how outcomes were assessed, individual cases of infection and/or large spreading events, mortality), methodological details (sample characteristics, how the information was gathered, how the outbreak was investigated), and details related to bias assessment.

RESULTS

The combined searches yielded 10 912 unique citations, of which 12 studies met our inclusion criteria. Nine studies were identified from the 17 June 2020 search, 2 from the 12 August 2020, and 1 from a targeted search. Out of the 12 that met our inclusion criteria, 5 were pertaining to SARS-CoV-2 (Table 1 and Table 2), 5 reported on influenza or influenza-like viruses (Table 3), and 2 reported on adenovirus transmission. Of note, 33 studies were excluded because they did not specify the location of transmission (Supplementary Material 2). The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) diagram is shown in Figure 1.

Table 1. Comparison of Respiratory Virus Transmission Outdoors Compared to Indoors Ordered by Virus Studied

Outcome	Virus Studi
Number of cases [14]	SARS-CoV-2
Number of cases [15]	SARS-CoV-2
Odds of transmission [16]	SARS-CoV-2

Number of super-spreading events and odds of transmission[a] [16]	SARS-CoV-2
Number of cases [17]	SARS-CoV-2
Number of cases [18]	H1N1 2009 i
Mortality [19]	H1N1 1918 i

Abbreviations: CI, confidence interval; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2.

[a]Super-spreading defined as events where the number of secondary cases generated by a single primary case is greater than the 95th percentile of the distribution (ie, transmission to 3 or more persons).

Table 2. Studies Reporting Outdoor SARS-CoV-2 Transmission

Reference	Location and Date
Qian et al 2020 [14]	320 prefectural cities, China, 4 January to 11 Februa
Nishiura et al 2020 [16]	7 prefectures in Japan, start date 28 February 2020
Leclerc et al 2020 [17]	Multiple world-wide locations, as of 30 March 2020
Lan et al 2020 [15]	6 Asian regions: Hong Kong, Japan, Singapore, Taiwa
Szablewski et al 2020 [20]	Overnight camp in Georgia, United States, 17–27 Jur

Abbreviations: CI, confidence interval; COVID-19, coronavirus disease 2019; MMWR, Morbidity and Mortality Weekly Report; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2.

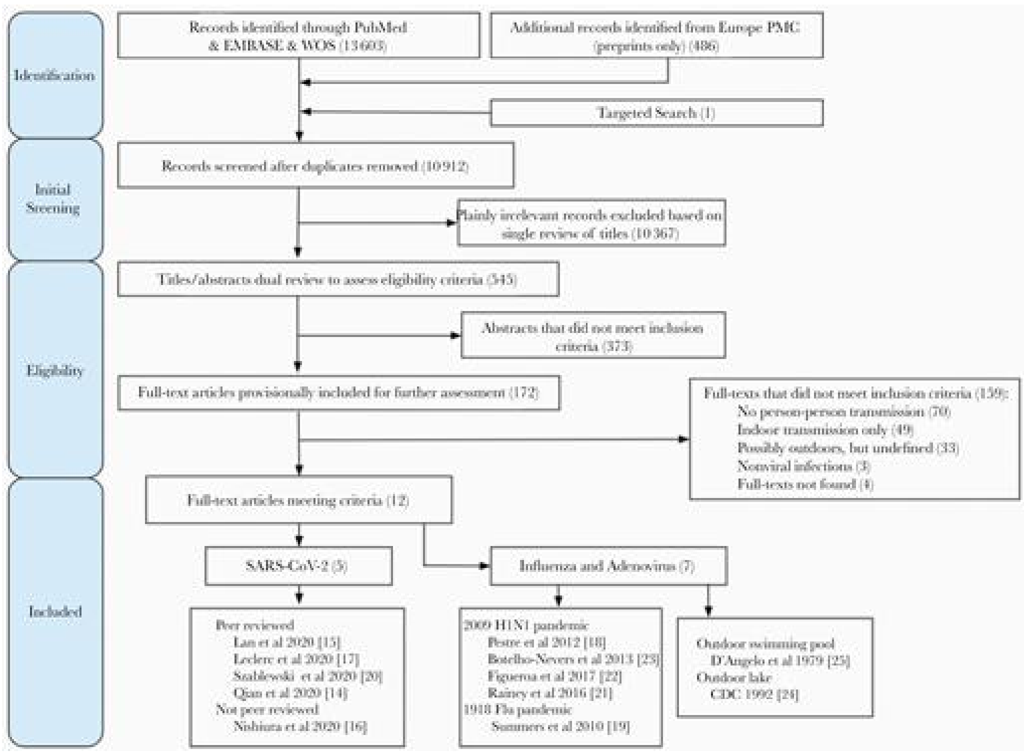
Table 3. Studies Reporting Other Outdoor Respiratory Virus Transmission Ordered by Infection Identified

Reference	Virus
Figueroa et al 2017 [22]	Respiratory disease outbreaks
Rainey et al 2016 [21]	Respiratory disease outbreaks
Botelho-Nevers et al 2013 [23]	Disease outbreaks (including respiratory diseas

Pestre et al 2012 [18]	2009 H1N1 Influenza
Summers et al 2010 [19]	1918 Influenza

Abbreviations: CI, confidence interval; NORS, National Outbreaks Reporting System; RR, relative risk.

Figure 1.



Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) diagram for the study. Abbreviations: CDC, Centers for Disease Control and Prevention; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2; WOS, Web of Science.

Five studies related to SARS-CoV-2 transmission found that less than 10% of reported transmission occurred in outdoor settings, less than 5% of cases were related to outdoor occupations, and the odds of transmission or super-spreading are much lower outdoors (Table 1) [14–17].

Of 318 identified outbreaks involving 3 or more cases in China reported to local Municipal Health Commissions from 4 January to 11 February 2020, Qian et al found that all occurred in indoor environments [14]. They reported a single transmission that occurred outdoors (1 case of outdoor transmission out of 7324 total reported cases). This report, however, might be affected by strict interventions prohibiting mass gatherings outdoors, which likely contributed to the low number of cases contracted outdoors. Additionally, relying on local health department reports may have led to underestimates of the total number of transmissions, especially those that were asymptomatic [14].

Nishiura et al [16] analyzed the transmission pattern of coronavirus disease 2019 (COVID-19) reported through 28 February 2020 (11 clusters and sporadic cases) in Japan. They concluded that the odds of a primary case transmitting COVID-19 in a closed environment were 18.7 times greater (95% confidence interval [CI], 6.0–57.9) compared to outdoor setting (defined as an open-air environment). The odds of a single case spreading to 3 or more individuals, which they defined as a super-spreader event, in closed environments compared to open air was 32.6 (95% CI, 3.7–289.5). This report, however, included no description of the context or location of the outdoor transmission nor were any raw data provided. It is unclear whether this report is relying on proportions, which again may be subject to the fact that fewer people would have been outdoors during winter months in Japan.

Leclerc et al [17] reviewed 201 transmission clusters of COVID-19 worldwide that had been reported up to 30 March 2020. The vast majority of these transmissions were associated with indoor or indoor/outdoor settings (197/201 clusters or 21/22 locations). The 1 outdoor setting was at multiple construction sites in Singapore, where 4 outbreaks occurred. Leclerc's updated results by August 12, from non-peer reviewed sources, additionally revealed one transmission occurred while jogging in Codogno, Italy, and twenty cases in an outdoor park in Münster, Germany (Table 4).

Lan et al [15] investigated 103 possible work-related cases of COVID-19 among a total of 690 local cases in 6 Asian countries or regions, including Hong Kong, Japan, Singapore, Taiwan, Thailand, and Vietnam. In this paper, construction workers in Singapore constituted only 5% of the total work-related transmissions. While this paper did not explicitly state whether the location of work-related transmission was outdoor or indoors, it was included based on Leclerc's classification of the same construction workers as an outdoor setting. This does not rule out that that transmission may have occurred in indoor locations at construction sites.

Szablewski et al [20] report SARS-CoV-2 transmission at an overnight camp in Georgia, United States, where attack rates increased with increasing length of time at the camp, and with cohousing. Staff members, who stayed the longest at the camp, had the highest attack rate (56%). The outbreak was clustered by cabin assignments, which suggests a high likelihood of transmission in indoor spaces during overnight cabin stays rather than during outdoor activities during the day. The authors state that nonpharmaceutical interventions such as cohorting and adults wearing masks during the day, were not protective, although no further information is given about this claim.

While there is high heterogeneity in the studies describing outdoor transmission of SARS-CoV-2, the studies we found highlight the conditions of outdoor exposure and transmission. The location and context of SARS-CoV-2 transmissions reported in this review are summarized in Table 4. Among these are examples of transmissions at a gathering in a park, but over multiple days with the same people, and at a camp, which lasted for several days and had indoor housing components.

Table 4. Outdoor Conditions Where COVID-19 Was Transmitted

Setting	Description of Transmission
Overnight summer camp [20]	Outbreak of 260 cases during an overnigh
Conversation in outdoor setting [14]	One outdoor transmission involving 2 cas
Outdoor construction sites [15, 17]	Four outbreaks at outdoor construction si
Jogging outdoors [17]	1 transmission while jogging in Codogno,
Outdoor park [17]	20 cases in an outdoor park in Münster, Ge

Abbreviations: COVID-19 coronavirus disease 2019; NPI, nonpharmaceutical intervention.

[a]Such as masks, physical distance, cohorting.

Five other studies included in Table 3 describe outdoor transmission of influenza or influenza-like viruses. Summers et al [19] conducted a historical analysis of a large outbreak of the 1918 influenza virus on a military troop ship in July 1918. The outbreak involved over 1000 of the 1217 crew members and caused 68 deaths. Analysis of factors that might have contributed to mortality revealed a significant association between individuals who slept indoors, in cabins with bunks (mortality of 146.1/1000 population), versus individuals who slept in hammocks in open-air areas (mortality of 34.1/1000 population). This study is of particular interest because the duration of exposure and distance between individuals was held constant. This was one of the few studies that investigated potential confounders such as age and social class—mortality changed with age, but not with social class or rurality. Age did not change the discrepancy in deaths seen outdoors compared to indoors.

Pestre et al [18] conducted a retrospective analysis of a 2009 H1N1 influenza outbreak at a summer camp in France. Investigations revealed that all febrile individuals had travelled together in the same train passenger car to reach camp, suggesting that the enclosed space facilitated transmission. The 3 individuals out of 32 that had not travelled in the same train wagon as all the other participants never developed symptoms, even though they were still present at camp for 2 days with all other infected individuals—presumably mostly in outdoor spaces.

Finally, 3 reports about respiratory illnesses at mass open-air gatherings emphasized that while influenza outbreaks were uncommon, the duration of the event (multiday over single day) and communal housing were risk factors for outbreaks (Table 3) [21–23]. Rainey et al concluded that all reported outbreaks in summer camps had social contact and communal housing; none were reported without a shared housing component [21]. Of note, no single-day mass-gathering–related outbreaks were detected in the 72 outbreaks they detail. Figueroa et al also did not identify any single-day event-related outbreaks [22]. Botelho et al found 4 outbreaks of influenza A

(H1N1) and 1 of influenza A and B; all events with an outbreak were multiday sport events while single-day events had none [23].

Two articles discussed adenovirus outbreaks associated with lakes [24] and outdoor swimming pools [25]. In both studies respiratory viral infection occurred in swimmers and in others who did not swim, such as fellow camp attendees and family members, suggesting human-to-human transmission prevalently occurring outdoors.

Discussion

While the studies included in this review were highly heterogeneous, ranging in methodology, definition of outdoor transmission, and virus studied, several common factors were identified. The studies with direct comparison of SARS-CoV-2 location of transmission reported dramatically lower proportions occurring outdoors. The exact determinants of outdoor transmission that can be gleaned from this review are limited, the cases of outdoor transmission of SARS-CoV-2 we identified were affected by the duration of exposure, frequency of exposure, density of gathering, whether masks were used, and were confounded by the possibility of indoor transmission.

Historical evidence gleaned from influenza outbreaks further support the lower risk of transmission outdoors. Summers et al showed that influenza mortality on a ship was significantly lower outdoors (sleeping in hammocks) compared to indoors (sleeping in cabins) [19]. While mortality does not provide direct information about transmission, it serves as a useful proxy. Outcomes from several investigations of influenza outbreaks during mass outdoor gatherings suggest that outdoor, single-day events without communal sleeping arrangements have lower risks of influenza transmission than multiday events with indoor components [21–23].

These findings, as well as reports of influenza outbreaks and adenovirus outbreaks in outdoor bodies of water, suggest that while outdoor transmission is less common than indoor, it is not impossible. Case reports identified after our review had been completed provide further evidence that high-density outdoor gatherings, particularly with low mask use, may lead to higher transmission rates. Miron et al noted that incidence of COVID-19 cases was significantly higher in 14 out of 20 counties that had a large outdoor gathering 15 days prior [26]. Dave et al estimated that in the 3 weeks following the start of the Sturgis motorcycle rally on 7 August 2020, in South Dakota, a multiday event with 500 000 participants, cases grew more in counties with weak mitigation policies than those with strong mitigation policies (such as closure of restaurants and bars, or mask-wearing mandates) as participants returned to their homes [27]. In contrast, although COVID-19 rates increased in the 3 weeks following the mass protests in the United States [28], the uptick in cases due to these events was less than expected because social distancing and masking measures were more widespread [29]. The importance of protective measures is further exemplified by the outdoor outbreak that occurred at the White House Rose Garden event on 26 September 2020, where few of the 200 attendees were wearing masks or maintaining social distancing measures [30].

Of note, our search did not find any studies on the transmission of COVID-19 in settings of outdoor agricultural work. In California, prevalence of COVID-19 for agricultural workers is 2 to 3 times higher than the rate for workers in all other industries [31]. The experience of agricultural workers suggests that crowded working or sleeping conditions may be a substantive risk factor for transmission, but the contribution of work in outdoor spaces to transmission risk has not been assessed. We found that outdoor, single-day events without communal sleeping arrangements have lower risks of transmission compared to multiday, mass outdoor gatherings in the spread of influenza [21–23].

To better characterize the risks of outdoor SARS-CoV-2 exposure, future studies should fill the research gaps we have identified in this review. First, many research studies we identified did not report the location of transmission at all. This may be because understanding relationships between cases is more important than the location of interaction, or may be related to practical challenges in contact tracing outdoors. Second, it is difficult to isolate an outdoor exposure to a virus. While outdoor gatherings could be largely safe, if they are accompanied by time in indoor locations, such as cabins or trains, it might be challenging to identify the exact location of transmission. In the report by Szablewski et al, which was included in our review, while the summer camp may have been largely outdoors, it does not preclude exposure in the dining halls or cabins. As for construction sites, once a building is framed and enclosed, it may be considered indoor work, which may in fact be the majority of the work. Third, in many reports published early in the SARS-CoV-2 pandemic, the measured outcome was illness or death due to viral infection, not SARS-CoV-2 infection itself, which was rarely assessed. If asymptomatic infections are more likely to occur outdoors, this could represent a systematic bias. Fourth, the definition of being outdoors is ambiguous, and the effect of exposure is likely modified by variable proximity to and contact with others. Fifth, to test the hypothesis that the risk of infection is lower outdoors, future research should collect data about time spent indoors versus outdoors. Given that 90% of time is spent indoors in high- and middle-income countries [32], it would be expected that 90% of transmission occurs indoors, all else being equal. Lastly, there are few data that examine how respiratory droplets spread outdoors, such as how far they travel during running, biking, or during windy conditions. A study examined these variables but was calculated with no account of ventilation, sunlight, or humidity [33].

Finally, most of the transmission events we identified in the literature did not report the socioeconomic status of those impacted. Spreading events often occur in settings where marginalized and disempowered populations live or work such as lower-income, higher-density urban settings, work settings such as meat-packing plants, or even prisons [34]. While there are multiple reasons for the disproportionate impacts of COVID-19 in these populations, we postulate that lack of opportunity to move high-risk activities outdoors may be one of them [35, 36]. While it was our intention to further explore this hypothesis by analyzing subgroup socioeconomic and ethnicity data in the studies included in this review, the studies did not include these metrics.

Future studies could compare SARS-CoV-2 case rates at outdoor gatherings to known rates for indoor gatherings. There are several examples of studies that estimate the risk of indoor transmission

[37–39], which have ranged from 10.3% (95% CI, 5.3%–19.0%) in a study of train travel in China to 78% in a church in Arkansas [38]. Accurate estimation of the risk of outdoor transmission will require determining person-time at risk for infection, incidence rate ratios, and more nuanced information about the exposure environment; these data are still lacking.

Better understanding of how SARS-CoV-2 is transmitted outdoors is needed to inform sound policies that reconcile shelter-in-place orders with the many health benefits associated with time spent outdoors [40]. This is particularly relevant to outdoor parks and recreation agencies, which seek clear guidance on how being outdoors has a low risk of transmission. Other policy implications are to encourage moving essential activities outdoors, with appropriate masking and social distancing measures, given that transmission can still occur outdoors. The long-term and potentially deleterious social and emotional effects of school closures can be potentially mitigated if, for example, it is known that outdoor schooling is a viable alternative. Finally, encouraging outdoor time may serve as a harm reduction model in allowing people to congregate, and therefore better tolerate long-term shelter in place mandates.

This systematic review has several limitations. The few and heterogenous studies on outdoor transmission of respiratory viruses had used various metrics, exposures, and outcomes, making it challenging to compare findings quantitatively. The low proportion of outdoor COVID-19 cases may reflect the general decrease in outdoor activities since strict lockdowns were enacted in the countries surveyed. Relying on reports of symptomatic infections may underrepresent asymptomatic cases that occur outdoors. If the viral inoculum affects the severity of respiratory viral infection, an outdoor exposure may reduce the viral inoculum to which the individual is exposed and therefore the subsequent clinical impact of the disease. If this theory were true for SARS-CoV-2, it may increase the proportion of infections that are asymptomatic [41]. The studies in this review did not contain much information about potential confounders such as the age of infected individuals, activities in which they participated, ethnicity, or social class. There was minimal information on mitigation efforts such as masks and social distancing and how that may have impacted/influenced viral transmission. This review did not explicitly include gray literature (such as case reports from health departments, lay newspaper sources) in its search strategy, as other comprehensive reviews of transmissions have done [17]. Including preprints may have decreased our risk of information bias.

CONCLUSION

While it has been acknowledged that spending time outside has general health benefits, our review posits that there are also benefits in reducing transmission of SARS-CoV-2 by reducing exposure time (substituting time indoors with time outdoors). These results suggest that moving activities to outdoor settings may reduce infections and ultimately save lives. However, it is important to note that infections are possible outdoors and the advantage may be overtaken by relaxed mitigation efforts.

Supplementary Data

Supplementary materials are available at *The Journal of Infectious Diseases* online. Consisting of data provided by the authors to benefit the reader, the posted materials are not copyedited and are the sole responsibility of the authors, so questions or comments should be addressed to the corresponding author.

Notes

Disclaimer. The funders played no role in the decision to conduct this study, the analysis, findings, or writing of this manuscript.

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Supplementary data

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jiaa742_suppl_Supplementary_Material_2 - docx file