COVID-19 Living Rapid Review
Transmission Risk & Activities/Settings
Expedited Draft Summary #1

(Version 1: 19 October 2021)

Andrew Beck[1], Nicole Shaver[1], Alexandria Bennett[1], Gabrielle Zitiktye[1], Niyati Vyas[1], Barbara Whelan[2], Rhea O'Regan[2], Aileen Conway[2], Becky Skidmore[3], David Moher[1,4] and Julian Little[1]

1 Knowledge Synthesis and Application Unit, School of Epidemiology and Public Health, Faculty of Medicine, University of Ottawa, Ottawa, Ontario, Canada
2 Evidence Synthesis Ireland, School of Nursing and Midwifery, National University of Ireland, Galway, Ireland
3 Independent Information Specialist, Ottawa, Ontario
4 Clinical Epidemiology Program, Ottawa Hospital Research Institute, Ottawa, Ontario, Canada

Corresponding Author: Andrew Beck (andrew.beck@uottawa.ca)

PROSPERO registration: CRD42021284107

This research was funded by the Health Research Board through Evidence Synthesis Ireland [HRB Grant Number CBES-2018-001]. The living rapid reviews were also funded by The Strategy for Patient-Oriented Research Evidence Alliance (SPOR EA) which is supported by the Canadian Institutes of Health Research (CIHR) under the Strategy for Patient-Oriented Research (SPOR) initiative.

Question

What is the risk of COVID-19 transmission associated with different activities (e.g., dining, exercising etc.) or settings (e.g., educational, hospitality etc.) and what factors contribute to risk (e.g., type of contact, number of contacts, time within the risk environment)?

How does transmission risk of common activities alter with background population prevalence of SARS-CoV-2 and population vaccine coverage?

Methods

A detailed peer-reviewed search strategy was developed by an information specialist in consultation with the review team. Electronic databases searched include MEDLINE and Embase. The initial search was conducted September 29, 2021 and updated on October 26, 2021. The search will continue to be updated monthly for six months.

All reviewers independently conducted a training exercise based on 50 articles for title and abstract screening and 10 articles for full-text review before beginning study selection to ensure agreement between reviewers. One reviewer independently screened titles and abstracts and then full-text studies for relevant articles. For data extraction, all reviewers completed a training exercise based on 5 articles before beginning data extraction. One reviewer independently extracted data from included studies with a second reviewer verifying study inclusion and extracted data. Critical appraisals and analyses of the included studies have not been completed and will be available in the final manuscript.

Findings

For transmission risk of settings and activities, we present a visual summary of evidence in Table 1 and detailed individual study information further below.

The initial search retrieved 10,318 references. We have reviewed 3,458 titles and abstracts of these references with 6,860 remaining. We have reviewed 504 full-text articles and **27 studies** have been included so far and these were used to complete this expedited draft summary.

Table 1: Visual summary of evidence for transmission risk of COVID-19 and different settings and activities

Setting & Activity	Risk Level as reported by author(s)	Preventative Measures	Time Period Studied
Accommodations			
Residential care[1,2]	High	Masking; social distancing	January – September 2020; March – April 2020
Sharing housing[3]	High	masking, disinfection, accessibility of alcohol pumps	July 2020 – May 2021
Educational			
Nursery / Kindergarten[4–9]	Low	Unclear	June 2020 – December 2020
Primary school[4–15]	Low	face masks; distancing; screening, hand-washing, hybrid education, improved ventilation, bubbles	January 2020 – February 2021
Secondary school[2,4,5,7–10,12–16]	Low	face masks; distancing; screening, hand-washing, hybrid education, improved ventilation, bubbles	January 2020 - February 2021
Entertainment			
Mass gathering events (community dinner; gala dinner; fireworks; dance; awards gala; Queen's offering)[17]	High		May – June 2020
Wedding[2]	High	social distancing	March - April 2020
Hospitality venues[2]	High	social distancing	March - April 2020
Conference[2]	High	social distancing	March - April 2020
Social activity settings included: friend, partner, neighbor, dating, meal, banquet, dinner, restaurant, bar, coffee, shopping center, gym, mahjong and majoring, tutorial, transportation.[18]	High	social distancing	January – August 2020
Social settings (exposure outside the household including restaurants, bars, meeting with friends and other gatherings that involved dining)[1]	High		January – September 2020
Entertainment[19]	High		January – June 2020
Eateries[19]	High	contact tracing and quarantine, and	January – June 2020

Setting & Activity	Risk Level as reported by author(s)	Preventative Measures	Time Period Studied
		early introduction of social distancing measures	
Personal Care			
Dental setting[20]	Low	PPE	May – October 2020
Personalized services[a] [19]	Medium	contact tracing and quarantine, and early introduction of social distancing measures	January – June 2020
Sports			
Golf[21]	Low	Social distancing, testing	July - December 2020
Indoor, high-contact[10]	High	NR	December 2020 - January 2021
Youth Camp			
Indoor/Outdoor camp[22]	Low	screening, daily temperature checks, masks, hand hygiene, physical distancing, small cohorts, scheduled site cleanings, and staff COVID-19 education and workplace training	March – August 2020
Summer camp[b] [23]	Low	bubble groups, hand washing, facemasks and conducting activities mostly outdoors	June – July 2020
Workplaces			
Meat and poultry processing plant[24]	Unclear	masking, testing, ventilation, physical barriers, distancing, disinfection	June-September 2020
Car, taxi, and van drivers[25]	High	NR	January – March 2020
Shop salesperson[25]	High	NR	January – March 2020
Domestic housekeepers[25]	High	NR	January – March 2020
Religious professionals[25]	High	NR	January – March 2020
Construction labourers[25]	High	NR	January – March 2020
Tour guides[25]	High	NR	January – March 2020
Locomotive engine drivers and related workers[25]	Low	NR	January – March 2020

Setting & Activity	Risk Level as reported by author(s)	Preventative Measures	Time Period Studied
Bus and tram drivers[25]	Low	NR	January – March 2020
Receptionists[25]	Low	NR	January – March 2020
Waiter or bartenders[25]	Low	NR	January – March 2020
Cooks[25]	Low	NR	January – March 2020
Personal care workers in health services[25]	Low	NR	January – March 2020
Transportation			
Flight travel (short to medium haul)[26]	Low	post-flight quarantine, contact-tracing, distancing	January – March 2020
"Modes of transportation"[1]	Low	masking	January – September 2020
Car sharing[27]	High	masking	January - April 2020

[a] Personal services may include hair salons, beauty parlors, nail salons, spa, etc.

[b] Includes indoor/outdoor and summer camps

Educational

Calvani et al. 2021[4] conducted a case-control study from October to December 2020 of nursery schools, primary schools, middle/high schools in Italy. School contacts were more frequent in controls than in cases (OR 0.49; 95% CI: 0.3–0.9), while household contacts were higher in cases (OR 5.09; 95% CI: 2.2–12.0). In both cases and controls, school contacts were significantly less frequent, while on the contrary household contacts seemed to be more frequent in nursery school children compared to primary school or middle/high school children. A multivariate logistic regression showed that the **probability of being positive to SARS-CoV-2 was significantly lower in children who had school contacts or who had flu symptoms compared to children who had household contacts**. Results showed a 30.6% secondary attack rate for household contacts. The **risk of being positive was 5 times lower in children who had school contacts than in children who had household contacts**. During the second wave of the pandemic school contact was the most frequent reason to do a nasal swab. However, the risk of being positive to SARS-CoV-2 was lower after a school contact when compared to a household contact thus both situations contribute in a similar way (35,8 vs 34,6%) to the spreading of SARS-CoV-2 infection in children. Children of any age group can spread the infection to their family members at home and in nursery school children this may be due to a lower adherence to preventive measures at home. Additional initiatives aimed to increase awareness of the significant contagiousness of children at home and therefore of the need of joining preventive measures at home are needed, to motivate parents and family members to consistently implement these measures, in particular when is know that the child had been in contact with a positive case.

Gettings et al. 2021[10] conducted a prospective cohort study from December 2020 to January 2021 of students and staff from elementary, middle, and high schools in the United States. The highest secondary attack rate was in indoor and high-contact sports settings (23.8%, 95% confidence interval [CI] 12.7, 33.3), staff meetings/lunches (18.2%, CI 4.5–31.8), and **elementary school classrooms (9.5%, CI 6.5–12.5)**. SAR was higher for staff (13.1%, CI 9.0–17.2) versus student index cases (5.8%, CI 3.6–8.0) and for symptomatic (10.9%, CI 8.1–13.9) versus asymptomatic index cases (3.0%, CI 1.0–5.5). In this comprehensive prospective investigation of SARS-CoV-2 transmission in a Georgia school district, which was conducted during a period of peak community COVID-19 incidence, 9% of contacts exposed to a COVID-19 index case were found to be positive, with the highest secondary attack rate identified in the setting of indoor sports (24%) and staff interactions (18%). In-school transmission seen in this investigation was higher than reported in recent studies from those in the United States and abroad where mitigation measures were strictly followed. In particular, a **higher secondary attack rate was observed in elementary school classrooms (9%) compared with high school classrooms (2%)**, with staff index cases having a higher SAR than student index cases.

Gras-Le Guen et al. 2021[5] conducted a retrospective cohort study in France from September to October 2020 of students aged 0–2 years (nursery school or home childcare), 3–5 years (kindergarten), 6–10 years (primary school), 11–14 years (middle school), and 15–17 years (high school). In the specific French context, our study confirms an age effect on the spread of SARS-CoV2, with the **relative risk of a positive PCR test result being significantly lower in children and adolescents compared with adults**. However, the impact was age-dependent, with data in **high schools close to those observed in adults**. These results, obtained while schools were kept open in a context of increasing transmission in the general population, argue for a marginal contribution of children in the dynamics of the epidemic, and reinforce the interest of keeping schools open, especially facilities for children in the first decade of life, so as to limit the numerous deleterious effects of school closures demonstrated during the first lockdown. However, our results

also show the **need to strengthen policies to promote education on hygiene and social distancing measures among adolescents, and to advocate for the use of masks among 6–11-year- olds when viral transmission in the general population is high**.

Ismail et al. 2020[7] conducted a prospective cross-sectional study from June to July 2020 on early years settings (<5-year-olds), primary schools (5–11-year-olds; only years 1 and 6 allowed to return), and secondary schools (11–18-year-olds; only years 10 and 12). The **re-opening of schools during the summer half-term was associated with very few cases or outbreaks** in England, albeit with smaller classes in selected school years and proportionally greater attendance in early years settings and primary schools. **Infections and outbreaks were more likely to involve staff members than students**. The proportion of seeding events resulting in outbreaks in schools, and the strong correlation between COVID-19 outbreaks and regional incidence, both highlight the importance of controlling the disease in the community to protect educational settings.

James et al. 2021[2] conducted a retrospective cohort study in New Zealand from March to April 2020. Children infected fewer people on average and had a lower probability of transmitting the disease in comparison to adults and the elderly. Imported cases infected fewer people on average and had a lower probability of transmitting than domestically acquired cases. Superspreading is a significant contributor to the epidemic dynamics, with 20% of cases among adults responsible for 65–85% of transmission. Subclinical cases infected fewer individuals than clinical cases. After controlling for outliers serial intervals were approximated with a normal distribution ($\mu = 4.4$ days, $\sigma = 4.7$ days). Border controls and strong social distancing measures, particularly when targeted at superspreading, play a significant role in reducing the spread of COVID-19. **Clusters were associated with settings typical of international patterns, including a high school, a wedding, hospitality venues, aged residential care facilities, and a conference.** The age distribution of cases varies across these clusters. Although one of New Zealand's largest clusters was associated with a school (Marist College cluster), more than half of the cases (55/96) in this cluster were in individuals over 20 years old. Of the 41 cases under 20, 35 were aged 10–20 years with only 6 confirmed cases in under 10s. In the two largest clusters associated with aged residential care facilities, there was as expected an over-representation of cases over 80 years old. However, the majority of cases in both these clusters (36/56 and 44/51 respectively) were under 65 years old, suggesting that staff and visitors are a more important driver of transmission than residents in aged residential care.

Kirsten et al. 2021[16] conducted a prospective cohort study in Germany from May to October 2020 on students and teachers from secondary schools (Grades 8–12). 1538 students and 507 teachers were initially enrolled, and 1334 students and 445 teachers completed both study visits. The seroprevalence for SARS- CoV-2 antibodies was 0.6% in May/June and the same in September/October. Even in schools with reported COVID-19 cases before the lockdown of 13 March, no clusters could be identified. Of 12 persons with positive serology five had a known history of confirmed COVID-19; 23 out of 24 participants with a household history of COVID-91 were seronegative. **Students and teachers do not seem to play a substantial role in driving the SARS-CoV-2 pandemic** in Germany when observing the period after reopening of schools in May as well as after summer holidays until early autumn 2020 before facing the second pandemic wave. **Transmission in families appears to occur very infrequently**, and the number of unreported cases obviously is low in this age group. For serological testing, a combination of different immunoassays seems to be effective to increase the number of true positive test results.

Ladhani et al. 2021[11] conducted a prospective cohort study in England from June to December 2020 on primary school students. During the summer half-term, 11 966 participants (6727 students, 4628

staff, and 611 with unknown staff or student status) in 131 schools had 40 501 swabs taken. Weekly SARS-CoV-2 infection rates were 4·1 (one of 24 463; 95% CI 0·1–21·8) per 100000 students and 12·5 (two of 16038; 1·5–45·0) per 100000 staff. At recruitment, in 45 schools, 91 (11·2%; 95% CI 7·9–15·1) of 816 students and 209 (15·1%; 11·9–18·9) of 1381 staff members were positive for SARS-CoV-2 antibodies, similar to local community seroprevalence. Seropositivity was not associated with school attendance during lockdown (p=0·13 for students and p=0·20 for staff) or staff contact with students (p=0·37). At the end of the summer half-term, 603 (73·9%) of 816 students and 1015 (73·5%) of 1381 staff members were still participating in the surveillance, and five (four students, one staff member) seroconverted. By December, 2020, 55 (5·1%; 95% CI 3·8–6·5) of 1085 participants who were seronegative at recruitment (in June, 2020) had seroconverted, including 19 (5·6%; 3·4–8·6) of 340 students and 36 (4·8%; 3·4–6·6) of 745 staff members (p=0·60). In England, **SARS-CoV-2 infection rates were low in primary schools following their partial and full reopening in June and September, 2020**.

Macartney et al. 2020[12] conducted a retrospective cohort study in Australia from January to April 2020 on primary and secondary school students. 15 schools and ten ECEC settings had children (n=12) or adults (n=15) attend while infectious, with 1448 contacts monitored. Of these, 633 (43·7%) of 1448 had nucleic acid testing, or antibody testing, or both, with 18 secondary cases identified (attack rate 1·2%). Five secondary cases (three children; two adults) were identified (attack rate 0·5%; 5/914) in three schools. No secondary transmission occurred in nine of ten ECEC settings among 497 contacts. However, one outbreak in an ECEC setting involved transmission to six adults and seven children (attack rate 35·1%; 13/37). Across all settings, five (28·0%) of 18 secondary infections were asymptomatic (three infants [all aged 1 year], one adolescent [age 15 years], and one adult). This study of SARS-CoV-2 transmission in schools and early childcare settings in a defined population of 8.1 million Australians shows **low case rates and secondary infections among children and staff attending educational facilities** throughout the first epidemic wave of the COVID-19 pandemic.

Mossong et al. 2021[13] conducted a retrospective two cohort study in Luxembourg from May to July 2020 on primary and secondary schools. During the second wave, **no differences were observed in the incidence of SARS-CoV-2 infection between school-age children and older adults** in the week of July 20–26, IRR 1.06 (95% CI 0.86–1.31, $p > 0.05$). Both **teachers and high school pupils were affected during the second wave**. Incidence rates of SARS-CoV-2 infection in teachers and the general working population were similar during the first wave, but slightly lower in teachers during the second wave. Incidence was significantly lower in pupils compared to teachers (IRR 0.20, 95% CI 0.12–0.34, $p < 0.001$) during the first wave, but was higher during the second wave. Incidence rates were significantly lower in pre-primary school pupils (IRR 0.18, 95% CI 0.04–0.76, $p < 0.01$) and primary school pupils (IRR 0.21, 95% CI 0.08–0.55, $p < 0.001$) than in high school pupils during the first wave, respectively, but **differences were less marked during the second wave** (IRR 0.61, 95% CI 0.32–1.16, $p > 0.05$ and IRR 0.72, 95% CI 0.46–1.14, $p > 0.05$, respectively). **Schools were not a major focus of COVID-19 transmission in Luxembourg** during an early summer wave in 2020. Our findings suggest that in a general context of moderate COVID-19 incidence, current prevention measures in schools applied in combination with easy access to testing, isolation and systematic quarantine of classmates, transmission events in schools may be limited in scope.

Theuring et al. 2021[14] conducted a prospective cohort study in Germany during November 2020 on primary and secondary school students. **SARS-CoV-2 infection activity in Berlin schools during peak transmission in November 2020 appeared to be low**. Secondary transmission in class was absent, and in connected households, the attack rate was around

1%. Based on our findings, we are cautiously optimistic that **schooling itself does not necessarily lead to child-to-child transmission or constitutes a central COVID-19 pandemic driver**, provided that IPC measures are rigorously implemented. Our study is longitudinal and the continuation of our study will show whether this is true as the determinants of the pandemic change, including vaccination coverage, population immunity, relaxed or tightened lockdown, and viral mutations. Our findings do not exclude the possibility of school-based out-breaks, particularly at higher transmission or enhanced viral transmissibility. Repeat screening in schools to detect asymptomatic infections is justified by our data and should help reducing the infection burden. As a prerequisite for further, tailored measures, deeper insight is needed into the fraction of infections attributable to being a school child as compared to school attendance itself.

Thompson et al. 2021[15] conducted a retrospective study from August to December 2020 in Wales on primary and secondary school students. In a national school cohort, **the odds of staff testing positive for SARS-CoV-2 infection were not significantly increased in the 14-day period after case detection in the school. However, pupils were found to be at increased odds, following cases appearing within their own year group**, where most of their contacts occur. Strong mitigation measures over the whole of the study period may have reduced wider spread within the school environment. This study has shown that there are significant complexities in understanding the vectors for transmission within schools. While this study has been conducted in Wales, it is highly likely that the findings are generalisable to the UK and many parts of the world in temperate climates where schools have around 30 pupils per class and are largely educated indoors. They conclude that there is good evidence that **the number of cases in pupils is associated with exposure to previous pupil cases within the school year group**, consistent with pupil–pupil transmission linked to schools. A wide range of extensive mitigation measures in our study population has likely reduced the potential for further spread within the wider school pupil population and from pupil to staff.

Ulyte et al. 2021[6] conducted a prospective cohort study in Switzerland from June to November 2020 on lower school level (grades 1 and 2; children aged 6-9 years); middle school level (grades 4 and 5; children aged 9-13 years); and upper school level (grades 7 and 8; children aged 12-16 years). With schools open since August 2020 and some preventive measures in place, **clusters of children who were SARS-CoV-2 seropositive occurred in only a few school classes despite an increase in overall seroprevalence in children during a period of moderate to high transmission of SARS-CoV-2 infection in the community**. While debate continues about mitigation measures to curb the pandemic and the role schools have in infection transmission, this study provides evidence that **clusters of SARS-CoV-2 infection are rare within classes**. Future testing rounds of this study will provide insights on transmission within classes over prolonged periods during dynamic levels of community transmission and the spread of new SARS-CoV-2 variants.

Zimmerman et al. 2021a[8] conducted a prospective cohort study in the United States from August 2020 to February 2021 prekindergarten through grade 12 students. More than 100 000 students and staff from 13 school districts attended school in person; of these, 4969 community-acquired SARS-CoV-2 infections were documented by molecular testing. Through contact tracing, North Carolina local health department staff identified an additional 209 infections among >26 000 school close contacts (secondary attack rate <1%). Most within-school transmissions in high schools (75%) were linked to school-sponsored sports. School-acquired cases slightly increased during the surge; however, within-school transmission rates remained constant, from presurge to surge, with 1 school acquired case for every 20 primary cases. With strict adherence to masking and some distancing, **school-acquired SARS-CoV-2 infection is uncommon, even in the setting of high community infection rates.** Consistent with previous data, schools can and should reopen safely.

Zimmerman et al. 2021b[9] conducted a prospective cohort study in the United States from August to October 2020 on prekindergarten through grade 12 students. Over 9 weeks, 11 participating school districts had 90 000 students and staff attend school in person. Among these students and staff, 773 community-acquired SARS-CoV-2 infections were documented by molecular testing. Through contact tracing, health department staff determined an additional 32 infections were acquired within schools. No instances of child-to-adult transmission of SARS-CoV-2 were reported within schools. This cohort study revealed that enforcing SARS-CoV-2 mitigation policies, such as mask wearing, physical distancing, and hand hygiene, **resulted in minimal clusters of SARS-CoV-2 infection and low rates of secondary transmission in schools and did not cause a larger community infection burden.** Our data indicate that schools can reopen safely if they develop and adhere to specific SARS- CoV-2 prevention policies.

Sports

Indoor

Gettings et al. 2021[10] conducted a prospective cohort study from December 2020 to January 2021 of students and staff from elementary, middle, and high schools in the United States. The highest secondary attack rate was in **indoor and high-contact sports** settings (23.8%, 95% confidence interval [CI] 12.7, 33.3), staff meetings/lunches (18.2%, CI 4.5–31.8), and elementary school classrooms (9.5%, CI 6.5–12.5). Indoor sports **may pose a risk** to the safe operation of in-person learning. Preventing infection in staff members, through measures that include COVID-19 vaccination, is critical to reducing in-school transmission. Because many positive contacts were asymptomatic, contact tracing should be paired with testing, regardless of symptoms.

Outdoor

Robinson et al. 2021[21] conducted a prospective cohort study of 195 professional golfers competing on the European Tour from July to December 2020. Using WHO and national public health guidance, events were hosted with incidence similar or lower than the general population. There was no evidence of player-to-player transmission during the sporting activity. There are transmissions risks associated with **tournament golf**; however, these are largely away from the sport itself, related to transport and accommodation, and can be mitigated substantially. Golf itself intuitively represents a **low-risk environment** if guidance is followed by participants.

Personal Care Services

Dental clinic

Natapov et al. 2021[20] conducted a prospective cohort study from May to October 2020 involving patients and dental staff members of dental clinics in Israel. 962 dental staff members provided dental treatment to 508 SARS-CoV-2 positive asymptomatic patients, resulting in an exposure ratio of 1.9:1. Of these, 7 (4 dentists and 3 assistants) were found to be infected post exposure in the dental settings (0.7% cumulative transmission rate over the study period). 507 patients were treated by 43 SARS-CoV-2 positive asymptomatic dental staff members, resulting in an exposure ratio of 11.8:1. Of these, 3 patients were found to be infected with SARS-CoV-2 post exposure to a positive dental staff member (1 dentist and 2 assistants), with a 0.6% cumulative transmission rate over the study period. The **risk of SARS-CoV-2 transmission within the dental setting was low**, and the adherence to national infection control guidelines was high. Elective dental care was safely delivered during the pandemic.

Personalized services

Wong et al. 2020[19] conducted a retrospective cohort study in Hong Kong using surveillance data from January to June 2020. Results showed that among all settings implicated in the transmission of SARS-CoV-2 in the first wave outbreak in Hong Kong, entertainment constituted the main setting characterized by rapidity of propagation, linkage with multiple secondary transmission settings and long cascades involving multiple settings. The entertainment setting often involved the participation of customers with unknown risks who might not be known to one another, resulting in clusters that featured higher centrality, reflecting closer and more linkages between persons. Such transmission appeared to be effectively contained through regulatory measures. Transmission clusters from worship and personalized service (like fitness centres) setting were documented. **Eateries, personalized services, and workplace led to further transmission outside households, but the cascades were short.** Healthcare and transport setting transmissions were self-limiting without further transmission in secondary settings. Likewise, workplace and neighbourhood settings accounted for a small proportion of the transmission clusters. Overall, long cascades and multiple exposure settings reflected the propensity for widespread transmission and dispersion in the community and the difficulty in containment.

Entertainment

Domènech-Montoliu et al. 2021[17] conducted a retrospective cohort study in Spain from May to June 2020 investigating mass gathering events (community dinner; gala dinner; fireworks; dance; awards gala; Queen's offering). A total of 1338 subjects participated in the questionnaire survey (80.5%), 997 of whom undertook the serologic survey. Five hundred and seventy cases were observed with an attack rate of 42.6%; average age was 36 years, 62.3% were female, 536 cases were confirmed by laboratory tests, and 514 cases were found with SARS-CoV-2 total antibodies. Considering mass gathering event exposure, the attack rate was 39.2% (496/1264). A dose-response relationship was found between mass gathering event attendance and the disease, (adjusted relative risk [aRR]= 4.11 95% confidence interval [CI]3.25–5.19). **Two mass gathering events with a dinner and dance in the same building had higher risks. Associated risk factors with the incidence were older age, obesity, and upper and middle class versus lower class; current smoking was protective**. The study suggests the **significance of mass gathering events in the COVID-19 transmission** that could explain the subsequent outbreak in Borriana.

James et al. 2021[2] conducted a retrospective cohort study in New Zealand from March to April 2020. Children infected fewer people on average and had a lower probability of transmitting the disease in comparison to adults and the elderly. Imported cases infected fewer people on average and had a lower probability of transmitting than domestically acquired cases. Superspreading is a significant contributor to the epidemic dynamics, with 20% of cases among adults responsible for 65–85% of transmission. Subclinical cases infected fewer individuals than clinical cases. After controlling for outliers serial intervals were approximated with a normal distribution (μ = 4.4 days, σ = 4.7 days). Border controls and strong social distancing measures, particularly when targeted at superspreading, play a significant role in reducing the spread of COVID-19. **Clusters were associated with settings typical of international patterns, including a high school, a wedding, hospitality venues, aged residential care facilities, and a conference.** The age distribution of cases varies across these clusters. Although one of New Zealand's largest clusters was associated with a school (Marist College cluster), more than half of the cases (55/96) in this cluster were in individuals over 20 years old. Of the 41 cases under 20, 35 were aged 10–20 years with only 6 confirmed cases in under 10s. In the two largest clusters associated with aged residential care facilities, there was as expected an over-representation of cases over 80 years old. However, the majority of cases in both these clusters (36/56 and 44/51 respectively) were under 65 years old,

suggesting that staff and visitors are a more important driver of transmission than residents in aged residential care.

Kwok et al. 2021[18] conducted a retrospective cohort study in China from January to August 2020. The two epidemic waves were characterized by imported cases and clusters of local cases, respectively. Rt peaked at 2.39 (wave 1) and 3.04 (wave 2). The proportion of asymptomatic cases decreased from 34.9% (0-9 years) to 12.9% (≥80 years). Log-normal distribution best fitted the 1574 containment delays (mean 5.18 [SD 3.04] days) and the 558 serial intervals (17 negative; mean 4.74 [SD 4.24] days). Containment delays decreased with involvement in a cluster (percentage contribution: 10.08%-20.73%) and case detection in the public health care sector (percentage contribution: 27.56%, 95% CI 22.52%-32.33%). Serial intervals decreased over time (6.70 days in wave 1 versus 4.35 days in wave 2) and with tertiary transmission or beyond (percentage contribution: –50.75% to –17.31%) but were lengthened by mobility (percentage contribution: 0.83%). Transmission within the same age band was high (18.1%). **Households (69.9%) and social settings (20.3%) were where transmission commonly occurred.** Social activity settings included: friend, partner, neighbor, dating, meal, banquet, dinner, restaurant, bar, coffee, shopping center, gym, mahjong and majoring, tutorial, transportation.

Martín-Sánchez et al. 2021[1] conducted a retrospective cohort study in Hong Kong from January to September 2020. Among the 2425 cases (65.3%, 2425/3711) with information on transmission setting, 77.6% of the transmission occurred in household and **social settings (exposure outside the household including restaurants, bars, meeting with friends and other gatherings that involved dining)** where facemasks are not usually worn. Infections that occurred in mask-on settings were more likely to be asymptomatic (adjusted odds ratio 1.33; 95% CI 1.04,1.68). Most of the transmission (1882/2425, 77.6%) occurred in mask-off settings, especially in households (1367/2425, 56.4%). The most common mask-on setting where transmission occurred was workplaces (316/2425, 13.0%), followed by residential care homes (139/2425, 5.7%). Both of these could have included some transmission events that occurred while masks were not worn, although we classified them as mask-on settings. There were 49 cases (49/2425, 2.0%) with exposure in housing estates. Very few cases were associated with transmission in health care settings (32/2425, 1.3%), schools (6/2425, 0.2%) or modes of transportation (1/2425, < 0.1%). **In conclusion, most transmission of COVID-19 in Hong Kong occurred in household and social settings**. Universal mask-wearing alone had a limited effect controlling the spread of COVID-19 transmission in the community, since almost an 80% of the transmission occurred in settings where people do not usually wear masks. Infections that occurred in mask-on settings were more likely to be asymptomatic which could be related to a milder disease presentation or to an earlier case detection in these settings.

Wong et al. 2020[19] conducted a retrospective cohort study in Hong Kong using surveillance data from January to June 2020. Results showed that among all settings implicated in the transmission of SARS-CoV-2 in the first wave outbreak in Hong Kong, **entertainment constituted the main setting characterized by rapidity of propagation, linkage with multiple secondary transmission settings and long cascades involving multiple settings**. The entertainment setting often involved the participation of customers with unknown risks who might not be known to one another, resulting in clusters that featured higher centrality, reflecting closer and more linkages between persons. Such transmission appeared to be effectively contained through regulatory measures. Transmission clusters from worship and personalized service (like fitness centres) setting were documented. **Eateries, personalized services, and workplace led to further transmission outside households, but the cascades were short.** Healthcare and transport setting transmissions were self-limiting without further transmission in secondary settings. Likewise, workplace and

neighbourhood settings accounted for a small proportion of the transmission clusters. Overall, long cascades and multiple exposure settings reflected the propensity for widespread transmission and dispersion in the community and the difficulty in containment.

Youth Camp

D'Agostino et al. 2021[22] conducted a retrospective cohort study in the United States from March to August 2020. SARS-CoV-2 infections occurred during the study period among 9 youth (mean age 9.7 years) and 8 staff (mean age 27 years) who were linked to 3030 contacts present in-person during the week before positive cases. Only 2 secondary infections (1 youth and 1 staff) were linked to primary cases. SARS-CoV-2 primary case attack rate was 0.6% (17/3030), and secondary case transmission rate was 0.07% (2/3011). **Extremely low youth and staff symptomatic SARS-CoV-2 attack, and transmission rates were observed** during a 147-day period across 54 YMCA camps from March to August 2020, a period when COVID-19 prevalence in was at its first peak. Comparatively, during this period, COVID-19 incidence rate in was 200 new cases per 10 000 population per day. These findings suggest that the benefit of in-person programming in recreation settings with appropriate mitigation may outweigh the risk of viral transmission.

Jordan et al. 2021[23] conducted a prospective cohort study in Spain from June to July 2020 on children aged 3 to 15 years old and staff of any age (>=16 years old) attending summer camp. This study prospectively assessed the risk of SARS-CoV-2 transmission in school-like environments implementing prevention measures. The **transmission rate of SARS-CoV-2 infection among children attending school-like facilities under strict prevention measures was lower than that reported for the general population**. This suggests that under preventive measures schools are unlikely amplifiers of SARS-CoV-2 transmission and supports current recommendations for school opening. We estimated an effective reproduction number in summer schools of Re*=0.3. This transmission rate below 1 suggests that summer schools did not act as amplifiers of the pandemic. During the study period, the community effective reproduction number (Re) was around 1.9 in the surrounding areas, which were following a sustained growth.

Accommodations

Residential care

Martín-Sánchez et al. 2021[1] conducted a retrospective cohort study in Hong Kong from January to September 2020. Among the 2425 cases (65.3%, 2425/3711) with information on transmission setting, 77.6% of the transmission occurred in household and social settings (exposure outside the household including restaurants, bars, meeting with friends and other gatherings that involved dining) where facemasks are not usually worn. Infections that occurred in mask-on settings were more likely to be asymptomatic (adjusted odds ratio 1.33; 95% CI 1.04,1.68). Most of the transmission (1882/2425, 77.6%) occurred in mask-off settings, especially in households (1367/2425, 56.4%). The most common mask-on setting where transmission occurred was workplaces (316/2425, 13.0%), **followed by residential care homes (139/2425, 5.7%)**. Both of these could have included some transmission events that occurred while masks were not worn, although we classified them as mask-on settings. There were 49 cases (49/2425, 2.0%) with exposure in housing estates. Very few cases were associated with transmission in health care settings (32/2425, 1.3%), schools (6/2425, 0.2%) or modes of transportation (1/2425, < 0.1%). In conclusion, most transmission of COVID-19 in Hong Kong occurred in household and social settings. Universal mask-wearing alone had a limited effect controlling the spread of COVID-19 transmission in the community, since almost an 80% of the transmission occurred in settings where people do not usually wear masks. Infections that occurred in mask-on settings were more likely to

be asymptomatic which could be related to a milder disease presentation or to an earlier case detection in these settings.

James et al. 2021[2] conducted a retrospective cohort study in New Zealand from March to April 2020. Children infected fewer people on average and had a lower probability of transmitting the disease in comparison to adults and the elderly. Imported cases infected fewer people on average and had a lower probability of transmitting than domestically acquired cases. Superspreading is a significant contributor to the epidemic dynamics, with 20% of cases among adults responsible for 65–85% of transmission. Subclinical cases infected fewer individuals than clinical cases. After controlling for outliers serial intervals were approximated with a normal distribution (μ = 4.4 days, σ = 4.7 days). Border controls and strong social distancing measures, particularly when targeted at superspreading, play a significant role in reducing the spread of COVID-19. **Clusters were associated with settings typical of international patterns, including a high school, a wedding, hospitality venues, aged residential care facilities, and a conference.** The age distribution of cases varies across these clusters. Although one of New Zealand's largest clusters was associated with a school (Marist College cluster), more than half of the cases (55/96) in this cluster were in individuals over 20 years old. Of the 41 cases under 20, 35 were aged 10–20 years with only 6 confirmed cases in under 10s. In the two largest clusters associated with aged residential care facilities, there was as expected an over-representation of cases over 80 years old. However, the majority of cases in both these clusters (36/56 and 44/51 respectively) were under 65 years old, suggesting that staff and visitors are a more important driver of transmission than residents in aged residential care.

Shared housing

Akaishi et al. 2021[3] conducted a cross-sectional study in Japan from July 2020 to May 2021. A total of 4550 individuals with a history of recent contact with patients at different places (dormitory/home/outside the residences) and levels (close/lower-risk) were tested for SARS-CoV-2 viral RNA using a nasopharyngeal swab test between July 2020 and May 2021. **The test-positive rate was highest in individuals who had contact in dormitories (27.5%),** but the rates were largely different between dormitories with different infrastructural or lifestyle features and infection control measures among residents. With appropriate infection control measures, the secondary transmission risk in dormitories was adequately suppressed. The household transmission rate (12.6%) was as high as that of close contact outside the residences (11.3%) and accounted for > 60% of the current rate of COVID-19 transmission among non-adults. In conclusion, **contact with patients with COVID-19 in group living environments, such as dormitories or households, is a significant independent risk factor for acquiring the disease**. Household secondary transmission is suggested to be the current main form of infection among non-adults and is synchronized to the local epidemic status with changed local capacity for quarantining infectious residents, such as in hospitals or quarantine hotels. To suppress the secondary transmission risk in group living environments, appropriate infection prevention measures, such as physical distancing, wearing masks, effective ventilation, and quarantining infectious residents, are needed to suppress the risk of secondary transmission among group living residents.

Transportation

Flight travel

Blomquist et al. 2021[26] conducted a retrospective cohort study using flight and public health datasets. There were 55 infectious passengers and 2313 co-passengers, including 2221 flight-only

contacts. Five possible aircraft-acquired cases were identified; ARs of 0.2% (95%CI 0.1-0.5) among all flight-only contacts and 3.8% (95%CI 1.3-10.6) among contact-traced flight-only contacts sat within a two-seat radius. The AR among 92 co-travelers with known non-flight exposure to infectious cases was 13.0% (95%CI 7.6%-21.4%). Authors concluded that **risk of symptomatic COVID-19 due to transmission on short to medium haul flights is likely low,** at approximately 3% but less than 10% if sat within two rows of an infectious individual and recommend prioritizing contact-tracing of close contacts and co-travelers where resources are limited.

"Modes of transportation"

Martín-Sánchez et al. 2021[1] conducted a retrospective cohort study in Hong Kong from January to September 2020. Among the 2425 cases (65.3%, 2425/3711) with information on transmission setting, 77.6% of the transmission occurred in household and social settings where facemasks are not usually worn. Infections that occurred in mask-on settings were more likely to be asymptomatic (adjusted odds ratio 1.33; 95% CI 1.04,1.68). Very few cases were associated with transmission in healthcare settings (32/2425,1.3%), schools (6/2425,0.2%) or **modes of transportation (1/2425, <0.1%).** In conclusion, most transmission of COVID-19 in Hong Kong occurred in household and social settings. Universal mask-wearing alone had a limited effect controlling the spread of COVID-19 transmission in the community, since almost an 80% of the transmission occurred in settings where people do not usually wear masks. Infections that occurred in mask-on settings were more likely to be asymptomatic which could be related to a milder disease presentation or to an earlier case detection in these settings.

Car sharing

Ng et al. 2021[27] conducted a retrospective cohort study with a nested case-control in Singapore from January to April 2020. Among non-household contacts, exposure risk factors associated with SARS-CoV-2 infection on both univariate and multivariate analysis were **having contact with more than one COVID-19 case (multivariate OR, 3.92; 95% CI, 2.07-7.40), being spoken to by the index case for 30 minutes or longer (multivariate OR, 2.67; 95% CI, 1.21-5.88), and sharing the same vehicle as a case (multivariate OR, 3.07; 95% CI, 1.55-6.08).** Exposure risk factors significantly associated with SARSCoV-2 infection only on univariate analysis were having direct physical contact with a COVID-19 case, receiving an object handed over by a case or touching the same surface immediately after a case (or both), sharing a meal with a case, and using the same toilet as a case. The authors concluded that among both household and non-household close contacts, **close physical proximity, and increased duration of verbal interaction are epidemiological risk factors** for SARS-CoV-2 transmission.

Workplaces

Lan et al. 2020[25] conducted a retrospective cohort study from January to March 2020 involving Hong Kong, Japan, Singapore, Taiwan, Thailand, and Vietnam. The authors identified 103 possible work-related cases (14.9%) among a total of 690 local transmissions. The five occupation groups with the most cases were healthcare workers (HCWs) (22%), **drivers and transport workers (18%), services and sales workers (18%), cleaning and domestic workers (9%) and public safety workers (7%).** Possible work-related transmission played a substantial role in early outbreak (47.7% of early cases). Occupations at risk varied from early outbreak (predominantly **services and sales workers, drivers, construction laborers, and religious professionals**) to late outbreak (predominantly **HCWs, drivers, cleaning and domestic workers, police officers, and religious professionals**). One novel finding of this study is that the early transmissions were highly related to

some occupations beyond healthcare settings, including **taxi driver, salesperson, tour guide, and housekeeper and cleaner**. **Taxi drivers, salespersons and tour guides are at higher risk because of frequent contact with travelers**. Work-related transmission is considerable in early COVID-19 outbreaks, and the elevated risk of infection was not limited to HCW. Implementing preventive/surveillance strategies for high-risk working populations is warranted.

Pokora et al. 2021[24] conducted a cross-sectional study of 19,072 meat and poultry employees in Germany. The prevalence of COVID-19 in the seven plants with more than 10 cases was 12.1% and was **highest in the deboning and meat cutting area** with 16.1%. A subsample analysis where information on maximal ventilation rate per employee was available revealed an **association with the ventilation rate (adjusted odds ratio (AOR) 0.996, 95% CI 0.993–0.999).** When including temperature as an interaction term in the working area, the association with the ventilation rate did not change. When room temperatures increased, the chance of testing positive for COVID-19 (AOR 0.90 95% CI 0.82–0.99) decreased, and the chance for testing positive for COVID-19 for the interaction term (AOR 1.001, 95% CI 1.000–1.003) increased. Employees who work where a **minimum distance of less than 1.5m between workers had a higher chance of testing positive (AOR 3.61; 95% CI 2.83–4.6).** Results indicate that **climate conditions and low outdoor airflow are factors that can promote the spread of SARS-CoV-2 aerosols**. To what extent the results can be transferred to private living spaces, offices or classrooms seems questionable. These settings work with intensive ventilation for a short time period for a virus dilution in the air of the rooms, contrary to the permanent ventilation in the meat industry. It points to the importance of air quality and airflow in confined spaces as a valuable additional measure to prevent future superspreading events.

References of included studies

1. Martin-Sanchez, M. *et al.* COVID-19 transmission in Hong Kong despite universal masking. *J. Infect.* **83**, 92–95 (7).
2. James, A. *et al.* Model-free estimation of COVID-19 transmission dynamics from a complete outbreak. *PLoS ONE Electron. Resour.* **16**, e0238800 (2021).
3. Akaishi, T. *et al.* COVID-19 transmission in group living environments and households. *Sci. Rep.* **11**, 11616 (06 02).
4. Calvani, M. *et al.* Reasons for SARS-CoV-2 infection in children and their role in the transmission of infection according to age: a case-control study. *Ital. J. Pediatr.* **47**, 193.
5. Gras-Le Guen, C. *et al.* Reopening schools in the context of increasing COVID-19 community transmission: The French experience. *Arch. Pediatr.* **28**, 178–185.
6. Ulyte, A. *et al.* Clustering and longitudinal change in SARS-CoV-2 seroprevalence in school children in the canton of Zurich, Switzerland: prospective cohort study of 55 schools. *BMJ* **372**, n616 (03 17).
7. Ismail, S. A., Saliba, V., Lopez Bernal, J., Ramsay, M. E. & Ladhani, S. N. SARS-CoV-2 infection and transmission in educational settings: a prospective, cross-sectional analysis of infection clusters and outbreaks in England. *Lancet Infect. Dis.* **21**, 344–353 (3).
8. Zimmerman, K. O. *et al.* Incidence and secondary transmission of SARS-CoV-2 infections in schools. *Pediatrics* **147(4) (no pagination)**,.
9. Zimmerman, K. O. *et al.* Community SARS-CoV-2 Surge and Within-School Transmission. *Pediatrics* **28**, 28.
10. Gettings, J. R. *et al.* SARS-CoV-2 transmission in a Georgia school district - United States, December 2020-January 2021. *Clin. Infect. Dis.* **17**, 17.
11. Ladhani, S. N. *et al.* SARS-CoV-2 infection and transmission in primary schools in England in June-December, 2020 (sKIDs): an active, prospective surveillance study. *Lancet Child Adolesc. Health* **5**, 417–427 (6).
12. Macartney, K. *et al.* Transmission of SARS-CoV-2 in Australian educational settings: a prospective cohort study. *Lancet Child Adolesc. Health* **4**, 807–816 (11).
13. Mossong, J. *et al.* SARS-CoV-2 transmission in educational settings during an early summer epidemic wave in Luxembourg, 2020. *BMC Infect. Dis.* **21**, 417.
14. Theuring, S. *et al.* SARS-CoV-2 infection and transmission in school settings during the second COVID-19 wave: a cross-sectional study, Berlin, Germany, November 2020. *Euro Surveill. Bull. Eur. Sur Mal. Transm. Eur. Commun. Dis. Bull.* **26**, 08 (8).
15. Thompson, D. A. *et al.* Staff-pupil SARS-CoV-2 infection pathways in schools in Wales: A population-level linked data approach. *BMJ Paediatr. Open* **5(1) (no pagination)**,.
16. Kirsten, C. *et al.* SARS-CoV-2 seroprevalence in students and teachers: a longitudinal study from May to October 2020 in German secondary schools. *BMJ Open* **11**, e049876 (06 10).
17. Domenech-Montoliu, S. *et al.* Mass gathering events and COVID-19 transmission in Borriana (Spain): A retrospective cohort study. *PLoS ONE Electron. Resour.* **16**, e0256747 (2021).
18. Kwok, K. O. *et al.* Evolving Epidemiological Characteristics of COVID-19 in Hong Kong From January to August 2020: Retrospective Study. *J. Med. Internet Res.* **23**, e26645 (04 16).
19. Wong, N. S., Lee, S. S., Kwan, T. H. & Yeoh, E. K. Settings of virus exposure and their implications in the propagation of transmission networks in a COVID-19 outbreak. *Lancet Reg. Health West. Pac.* **4**, 100052.
20. Natapov, L. *et al.* Risk of SARS-CoV-2 transmission following exposure during dental treatment - A national cohort study. *J. Dent.* **113**, 103791.
21. Robinson, P. G., Murray, A., Close, G. & Kinane, D. F. Assessing the risk of SARS-CoV-2 transmission in international professional golf. *BMJ Open Sport Exerc. Med.* **7**, e001109 (2021).

22. D'Agostino, E. M. *et al.* Symptomatic SARS-CoV-2 Transmission in Youth and Staff Attending Day Camps. *Pediatrics* **147**, 04 (4).
23. Jordan, I. *et al.* Transmission of SARS-CoV-2 infection among children in summer schools applying stringent control measures in Barcelona, Spain. *Clin. Infect. Dis.* **12**, 12.
24. Pokora, R. *et al.* Investigation of superspreading COVID-19 outbreak events in meat and poultry processing plants in Germany: A cross-sectional study. *PLoS ONE Electron. Resour.* **16**, e0242456 (2021).
25. Lan, F. Y., Wei, C. F., Hsu, Y. T., Christiani, D. C. & Kales, S. N. Work-related COVID-19 transmission in six Asian countries/areas: A follow-up study. *PLoS ONE Electron. Resour.* **15**, e0233588 (2020).
26. Blomquist, P. B. *et al.* Risk of symptomatic COVID-19 due to aircraft transmission: a retrospective cohort study of contact-traced flights during England's containment phase. *Influenza Other Respir. Viruses* **15**, 336–344 (5).
27. Ng, O. T. *et al.* SARS-CoV-2 seroprevalence and transmission risk factors among high-risk close contacts: a retrospective cohort study. *Lancet Infect. Dis.* **21**, 333–343 (2021).