COVID-19 Living Rapid Review
Transmission Risk & Activities/Settings
Expedited Draft Summary #2
(Version 2: 15 November 2021)

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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 and the October update added an additional 398 references for a total of 10,716 references to be screened. To date, we have reviewed 4,052 of the 10,716 references with 6,665 titles and abstracts remaining to be screened. We have reviewed 605 full-text articles of which **60 have been included**. **33 new studies** have been added since the previous report (see Version 1, 19 October 2021) and have been used to complete this expedited draft summary. Newly added items are highlighted in green throughout the report.

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

Setting & Activity	References	Risk Level as reported by author(s)	Preventative Measures	Time Period Studied
Accommodations				
Chalet	**New**[1]	High	NR	February 2020
Shared housing (e.g., dormitories)	**New**[2] Previous[3]	**Low**[2], High[3]	masking, disinfection, accessibility of alcohol pumps	July 2020 – May 2021
Business				
Conference	Previous[4]	High	social distancing	March - April 2020
Education				
Nursery/Kindergarten	**New**[5–7] Previous[8–13]	Low	unclear	June 2020 – December 2020
Primary schools	**New**[5,7,14–17] Previous[8–13,18–23]	Low	face masks; distancing; screening, handwashing, hybrid education, improved ventilation, bubbles	January 2020 – February 2021
Secondary schools	**New**[5,7,14,16,17] Previous[4,8–10,12,13,18,20–24]	Low	face masks; distancing; screening, handwashing, hybrid education, improved ventilation, bubbles	January 2020 - February 2021
Events and entertainment				
Social events[a]	**New**[25–27] Previous[28–32]	High	social distancing	May – June 2020
Weddings	**New**[33] Previous[4]	High	social distancing, **public awareness of epidemic prevention and control**	March - April 2020
Hospitality venues	Previous[4]	High	social distancing	March - April 2020
Shopping	**New**[25,34]	Unclear	social distancing, **public awareness of epidemic prevention and control**	January 2020 – January 2021
Healthcare				
Community healthcare	**New**[35]	**Low**	**face masks**	**June 2020**
Hospitals	**New**[25,34,36–42]	**Unclear**[25,34,36,37,39,40,42], **Low**[38], **High**[41]	**face masks, hand hygiene, staff training, PPE, restricting visitors, environmental cleansing and disinfection, quarantine**	**March 2020 – March 2021**

Setting & Activity	References	Risk Level as reported by author(s)	Preventative Measures	Time Period Studied
Healthcare workers (transmission to household)	New[36,43]	High	hand hygiene, face masks, physical distancing	March 2020 – June 2020
Healthcare workers (transmission to patients)	New[38]	Low	face masks and other infection control policies	October 2020 – April 2021
Residential and long-term care	New[32,36,38,44] Previous[4,28]	High	face masks, hand hygiene, restricting visitors, physical distancing	January – September 2020; March – April 2020
Hospitality				
Cruise ships	New[45]	High	ship based quarantine, enhanced health measures and access to onshore quarantine and isolation facilities	March 2020 – April 2020
Tour guides	Previous[46]	High	NR	January – March 2020
Waiter or bartenders	Previous[46]	Low	NR	January – March 2020
Cooks	Previous[46]	Low	NR	January – March 2020
Restaurants	New[34] Previous[31]	High	contact tracing and quarantine, and early introduction of social distancing measures	January – June 2020
Household				
Family home	New[26,34,42,47]	High	public awareness of infection and control, hand hygiene, self-isolation	January 2020 – March 2020
Specialized services				
Dental	Previous[48]	Low	PPE	May – October 2020
Personal care services[b]	Previous[31]	Medium	contact tracing and quarantine, and early introduction of social distancing measures	January – June 2020
Sports and activities				
Golf	Previous[49]	Low	Social distancing, testing	July - December 2020
Sports	New[50,51] Previous[18]	High	quarantine for infected individuals, face masks, physical distancing	December 2020 - January 2021

Setting & Activity	References	Risk Level as reported by author(s)	Preventative Measures	Time Period Studied
Camp[c]	Previous[52,53]	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
Transportation				
Bus or metro	**New**[34]	**High**	**public awareness of epidemic prevention and control**	**January 2020 – March 2020**
Flight travel	**New**[34,42,54–56] Previous[57]	**High**[34,42,54–56] ,Low[57]	post-flight quarantine, contact-tracing, distancing	January – March 2020
Car sharing	**New**[42] Previous[58]	High	masking	January - April 2020
Modes of transportation	Previous[28]	Low	Masking	January – September 2020
Workplaces				
Construction labour	**New**[25,59] Previous[46]	High	NR	January – March 2020
Domestic housekeepers	Previous[46]	High	NR	January – March 2020
Drivers (e.g., car, taxi, van)	Previous[46]	High	NR	January – March 2020
Drivers (e.g., bus, train)	Previous[46]	Low	NR	January – March 2020
Meat and poultry processing plant	Previous[60]	Unclear	masking, testing, ventilation, physical barriers, distancing, disinfection	June-September 2020
Personal care workers	Previous[46]	Low	NR	January – March 2020
Receptionists	Previous[46]	Low	NR	January – March 2020
Salesperson	Previous[46]	High	NR	January – March 2020
Religious professionals	Previous[46]	High	NR	January – March 2020

[a] Social events are defined by the study authors and may include but is not limited to any social activity with one or more individuals such as dating, getting together with a neighbor or friends, banquet, dinner, karaoke, community gatherings, or birthday parties.

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

[c] Includes indoor/outdoor and summer camps

Descriptive summaries of newly added studies

Accommodations

Chalet

Danis et al.[1] investigated a cluster of 12 COVID-19 cases that were linked to one index case who had recently stayed in a chalet in the French Alps. A secondary investigation was conducted to investigate any secondary cases and interrupt transmission. The index case stayed 4 days in the chalet with 10 English tourists and a family of 5 French residents; SARS-CoV-2 was detected in 5 individuals in France, 6 in England (including the index case), and 1 in Spain (overall attack rate in the chalet: 75%). One pediatric case, with picornavirus and influenza A coinfection, visited three different schools while symptomatic. One case was asymptomatic, with similar viral load as that of a symptomatic case. Overall, the occurrence in this cluster of one asymptomatic case with similar viral load as a symptomatic patient, suggests transmission potential of asymptomatic individuals. The fact that an infected child did not transmit the disease despite close interactions within schools suggests potentially different transmission dynamics in children.

Shared housing

Bjorkman et al.[2] conducted a retrospective cohort study of 6408 students at the University of Colorado Boulder to determined (1) the extent of roommate transmission, (2) the contribution of viral load to transmission likelihood, and (3) the impact of time spent cohoused while infected. A mandatory weekly screening test program was established. Although the infection rate was lower in single-occupancy rooms (10%) than in multiple-occupancy rooms (19%), inter-roommate transmission occurred only about 20% of the time. Cases were usually asymptomatic at the time of detection. Notably, individuals who likely transmitted had an average viral load approximately 6.5-fold higher than individuals who did not (mean quantification cycle [Cq], 26.2 vs 28.9). The study found that inter-roommate transmission occurs infrequently in residence halls and provides strong correlative evidence that viral load is proportional to transmission probability.

Education

Nursery/Kindergarten

Bark et al.[5] conducted a descriptive epidemiological study using contact tracing data to describe the epidemiology of SARS-CoV-2 infection among students and staff in the Vancouver Coastal Health (VCH) region in the first 3 months of the 2020/2021 academic year, and examine the extent of transmission in schools. The study used contact tracing data and included individuals aged 5 years and older with SARS-CoV-2 infection, reported between Sept. 10 and Dec. 18, 2020. Included individuals worked in or attended kindergarten to grade 12 (K–12) schools in person in the VCH region. Case and cluster characteristics and the number of school-based transmissions were reported. During the study period, 699 cases of SARS-CoV-2 infection were reported (55 cases per 10 000 VCH school population). Among cases in VCH resident staff and students, 52.5% (354/674) were linked to a household case or cluster. Out of 699 cases present at school, 26 clusters with school-based transmission resulted in 55 secondary cases. Staff members accounted for 53.8% of index cases (14/26) while making up 14.3% of the school population (17 742/123 647). The study authors concluded that school-based SARS-CoV-2 transmissions were uncommon and clusters were small. The results support the growing body of evidence that schools likely did not play a major role in SARS-CoV-2 spread in 2020.

Loenenbach et al.[6] described an outbreak investigation of three SARS-CoV-2 variant B.1.1.7 positive childcare centres and related household outbreaks. They also evaluated the secondary attack rates within the centres and associated households. The investigation found that cases occurred in almost all risk groups, i.e., also among persons without close contact. Children's secondary attack rates (SAR) were like adults (childcare centres: 23% vs 30%; p = 0.15; households: 32% vs 39%; p = 0.27); child- and adult-induced household outbreaks also led to similar SAR. Overall, the study found that the investigation supports the idea of an increased transmissibility of the SARS-CoV-2 B.1.1.7 variant. In addition, the data presented suggest that both susceptibility and infectiousness of children aged between 1 to 6 years are substantially higher compared with the pre-VOC period and may be converging to those among adults.

Larosa et al.[7] reported an epidemiological investigation of SARS-CoV-2 in 41 classes of 36 schools in Reggio Emilia province, Northern Italy, from their reopening on 1 September to 15 October 2020. A total of 38 secondary cases (3.8%) were identified among the 994 tested children: in one of 10 elementary schools, in two of five middle schools, and in six of 13 high schools. The attack rate was higher in secondary schools (middle and high schools) (6.6%) than in elementary schools (0.38%), while there were no secondary cases in the preschools or among teachers/staff. The study found that transmission within the schools of Reggio Emilia province, occurred in a non-negligible number of cases, particularly in the age group of 10–18 years, i.e., in middle and high schools, while no secondary cases were detected in pre-school children, only one case in primary school and no secondary cases among teachers and staff. The authors concluded that more prompt isolation and testing of classmates could have reduced virus transmission in the largest cluster, suggesting the importance of timeliness in this setting.

Primary schools

Chua et al.[14] conducted a cross-sectional study among 397 children and youth to compare the clinical characteristics and sources of infection during the three waves of outbreaks in Hong Kong in 2020. In all three waves, 204 patients with COVID-19 (51.4%) had domestic infections. Among these individuals, 186 (91.2%) reported having a contact history with another individual with COVID-19, of which most (183 individuals [90.0%]) were family members. In the third wave, 18 individuals with domestic infections had unknown contact histories. Three schoolmates were confirmed to be infected with COVID-19 on the same day and were reported to be close contacts. The study found that that household transmission was the main source of infection for children and youths with domestic infections and that the risk of being infected at school was small.

Wada et al.[15] conducted a prospective cohort study to investigate the confirmed COVID-19 cases among students and teachers in elementary and junior high schools in Japan. A total of 207 cases were reported among students and household transmission was identified as the dominant transmission route, confirmed in 71.4% of student cases in elementary schools and 60.3% of student cases in junior high schools. A total of 39 cases were reported among teachers of which transmission route was unknown in 72.4% of cases in elementary schools and 90.0% of cases in junior high schools. The study found that the major route of transmission among students was in households and not in school settings.

Heavey et al.[16] conducted a case series of six cases to evaluate the evidence of pediatric transmission in the school setting in the Republic of Ireland. The authors examined Irish notifications of SARS-CoV-2 in schools before school closures on 12 March 2020 and identified no pediatric transmission. The authors concluded that despite the small sample size and the limited evidence found in relation to COVID-19 transmission in the school setting, the study includes all known cases with school

attendance in the Republic of Ireland. These findings suggest that schools are not a high risk setting for transmission of COVID-19 between pupils or between staff and pupils.

Alonso et al.[17] conducted a retrospective cohort study analyzing the data from the Catalan educational system to understand secondary attack rates among children. The authors analyzed contagions of COVID-19 inside school bubble groups in Catalonia, Spain, in the presence of strong nonpharmaceutical interventions from September to December 2020. More than 1 million students were organized in bubble groups and monitored and analyzed by the Health and the Educational departments. The study found that propagation inside of the bubble group was small. Among 75% index cases, there was no transmission to other members in the classroom, with an average reproductive number (R*) across all ages inside the bubble of R* = 0.4. There was a significant age trend in the secondary attack rates, with the R* rising from 0.2 in preschool to 0.6 in high school youth. The study suggested that the secondary attack rate depends on the school level and, therefore, on the age. Super-spreading events (outbreaks of 5 cases or more) in childhood were rare, only occurring in 2.5% of all infections triggered from a pediatric index case.

For Bark et al.[5] and Larosa et al.,[7] see Nursery/Kindergarten under Education.

Secondary schools

For Chua et al.,[14] Heavey et al.,[16] Alonso et al.,[17] Bark et al.,[5] Larosa et al.[7] see Nursery/Kindergarten, Primary schools, and Secondary schools under Education.

Events and entertainment

Social events

Liu et al.[25] conducted a retrospective cohort study and used a spatiotemporal connectivity analysis method to examine the transmission dynamics of COVID-19 outbreaks. The spatiotemporal connectivity analysis showed the quantitative differences among various outbreak waves in their transmission scales, durations, and patterns. At an overall level, super-spreader individuals (highly connected cases in the transmission networks) were usually concentrated in only a few districts (2 out of 18) or age-groups (3 out of 11 in the study). With a variety of situated public venues, such as restaurants and singing/dancing clubs, the aforementioned districts played host to various social gathering events, thereby providing opportunities for widespread and rapid transmission of the virus. Thus, these districts should be given the highest priority when deploying district-specific social distancing or intervention strategies, such as lockdown and stringent mandatory coronavirus testing for identifying and obstructing the chain of transmission. The authors also noted that most of the reported cases and the highly connected cases were middle-aged and elderly people (40- to 69-year-olds). People in these age-groups were active in various public places and social activities, and thus had high chances of being infected by or infecting others.

Brandl et al.[32] analyzed a COVID-19 outbreak from the district of Tirschenreuth, Germany in early March 2020 using surveillance data. To investigate the outbreak, the authors analyzed surveillance and other data available at the district health department, including data on cases living in care facilities and public health measures applied. The first 110 cases were interviewed to investigate potential exposures at the beginning of the outbreak. The study found that returning ski-travelers from Austria and Italy and early undetected community transmission likely initiated the outbreak, which was then further accelerated by Bavarian beer festivities. In conclusion, the combination of

exposures in high incidence areas and undiagnosed infections followed by intense transmission may have led to accelerated community transmission in Tirschenreuth.

Nakajo et al.[27] described the very first cluster data in Tokyo and Kanagawa, Japan, and aimed to estimate the transmissibility of asymptomatic COVID-19 The reproduction number for symptomatic cases was estimated to be 1.2 (95% confidence interval (CI): 0.5–2.9). The relative infectiousness of asymptomatically infected cases was estimated to be 0.27 (95% CI: 0.03–0.81) of symptomatic cases. The transmission event started with a night party on January 18, 2020 in Tokyo that stemmed from an exposure to tourist from Wuhan. Except for household transmission events, most cases from this cluster did not contribute to secondary transmission. Overall, the authors concluded that the relative transmissibility of asymptomatic cases is limited. Observing clusters starting with symptomatic transmission might be sufficient for the control.

For Ai et al.[26] see Family home under Household.

Supermarkets and shopping

For Zhao et al.[34] see Family home under Household and for Liu et al.[25] see Social events under Events and Entertainment.

Weddings

Ravindran et al.[33] conducted a retrospective cohort study of 41 Australian residents who attended a wedding in Bali, Indonesia to evaluate factors associated with transmission at the wedding. COVID-19 was identified in 56% of attendees (23/41), with illness onset between 21 March and 2 April 2020. One secondary case was identified in a household contact of an attendee. Guests attended multiple events and participated in high-risk transmission behaviours such as shaking hands, kissing, dancing, sharing drinks and sharing shisha (water pipes). Overall, the study identified a high attack rate of COVID-19 among a cohort of wedding event attendees who engaged in close physical contact, shared drinks and shisha, and were in close proximity. This outbreak highlights the significant role social events can play in transmission of COVID-19 and further demonstrates why it is important to limit gatherings and close physical contact to control the spread of the virus.

Healthcare

Community healthcare

Lan et al.[35] conducted a retrospective cohort study evaluating COVID-19 transmission among healthcare workers. The authors investigated occupational and nonoccupational risk factors associated with cumulative COVID-19 incidence among healthcare workers from a Massachusetts community healthcare system. Of 5,177 healthcare workers, 152 (2.94%) were diagnosed with COVID-19. Affected healthcare workers resided in areas with higher community attack rates (median, 1,755.2 vs 1,412.4 cases per 100,000; $P < .001$; multivariate-adjusted IRR=1.89; 95% CI: 1.03–3.44 comparing fifth to first quintile of community rates). After multivariate adjustment, African American and Hispanic healthcare workers had higher incidence of COVID-19 than non-Hispanic white healthcare workers (IRR=2.78; 95% CI: 1.78–4.33; and IRR=2.41, 95% CI: 1.42–4.07, respectively). After adjusting for race and residential rates, frontline healthcare workers had a higher IRR (1.73, 95% CI: 1.16–2.54) than non-frontline healthcare workers overall, but not within specific job categories nor when comparing the highest risk jobs to others. The study shows that the

major risk factors associated with COVID-19 infection among HCWs are residential area attack rate and race.

Hospitals

Carazo et al. conducted a cross-sectional study of 4,542 healthcare workers and aimed to (1) estimate the SARS-CoV-2 infection rate and the secondary attack rate among healthcare workers in Québec, (2) describe the evolution of work-related exposures and infection prevention and control practices in infected healthcare workers, and (3) compare the exposures and practices between acute-care hospitals (ACH) and long-term care facilities (LTCF). HCWs represented 13,726 (25%) of 54,005 reported COVID-19 cases in Québec and had an 11-times greater rate of COVID-19 than non-healthcare workers. Their secondary household attack rate was 30%. Most affected occupations were healthcare support workers, nurses and nurse assistants working in LTCFs (45%) and ACHs (30%). The study concluded that Québec healthcare workers and their families were severely affected during the first wave of COVID-19.

Jung et al. conducted a prospective cohort study to evaluate the proportion and circumstances of individuals to whom SARS-CoV-2 was transmitted without close contact with an index patient in a nosocomial outbreak in a tertiary care hospital in Korea. From March 2020 to March 2021, there were 36 secondary cases from 14 SARS-CoV-2 infected individuals. Of the 36 secondary cases, 26 (72%) had been classified as close contact and the remaining 10 (28%) were classified as non-close contact. Of the 10 non-close contacts, 4 had short conversations with both the index and secondary case masked, 4 shared a space without any conversation with both individuals masked, and the remaining 2 entered the space after the index had left. The study authors concluded that at least one quarter of SARS-CoV-2 transmission events in a hospital occurred between non-close contacts.

Walker et al.[39] conducted an outbreak investigation in collaboration with local public health authorities in Germany to set up a genomic surveillance in an urban setting combining viral surveillance sequencing, genetically based identification of infection clusters in the population, integration of public health authority contact tracing data, and a user-friendly dashboard application as a central data analysis platform. The authors analyzed 4 outbreaks at a maximum care hospital, and genetically based identification of 5 putative population infection clusters, all of which were confirmed by contact tracing. Overall, the study concluded that integrated systems of genomic surveillance could contribute to the monitoring and, potentially, improved management of SARS-CoV-2 transmission in the population.

Huang et al.[40] conducted an outbreak investigation of a superspreading event of COVID-19 in a hospital in Taiwan to explore the transmission dynamics and heterogeneity of superspreading events. Patient 1 with congestive heart failure and cellulitis, who had onset of COVID-19 two weeks after hospitalization, was the index case. Patient 1 led to 8 confirmed cases, including four health care workers (HCW). The attack rate among HCWs was 3.2 % (4/127). An environmental survey confirmed contamination at the bed rails, mattresses, and sink in patient 1's room, suggesting fomite transmission. The index case's sputum remained positive for illness on day 35. Except one asymptomatic patient, at least three patients acquired the infection from the index case at the pre-symptomatic period. The effective reproduction number (Rt) was 0.9 (8/9). Overall, the study concluded the host's factors (heart failure, longer viral shedding), transmissibility of SARS-CoV-2 (Rt, pre-symptomatic transmission), and possible multiple modes of transmission altogether contributed to the superspreading event.

Atsawawaranunt et al.[41] conducted an outbreak investigation at a hospital in Bangkok to investigate transmission events and areas of improvement for protecting healthcare workers from COVID-19. The epidemiological and genomic investigation of the COVID-19 cluster consisted of seven healthcare workers at a quarantine facility and its partnered hospital in Thailand. Investigations of 951 HCWs and staff with quarantined travelers were carried out to determine the chain of transmission. The genomic data and the constructed timeline revealed a putative transmission chain among healthcare workers suggesting that the transmission occurred via the use of common living quarters at the investigated quarantine site. However, a quarantine facility is likely to become a potential hotspot, requiring thorough preventive measures. Given the results of the study, the study authors have implemented private living quarters and scheduled clinical duties at a quarantine site separated from the conventional healthcare workforce to reduce the exposure risk.

For Williams et al.[38] see Healthcare workers (transmission to patients) under Healthcare, for Liu et al.[25] see Social events under Events and Entertainment, and for Zhao et al.[34] see Family home under Household.

Healthcare workers (transmission to household)

Mendez-Echevarria et al.[43] conducted a cross-sectional study of 69 healthcare workers and 113 children to evaluate family transmission dynamics after the first pandemic wave. The secondary attack rate in children was 43.7% (25% if both parents had asymptomatic infection; 39.5% if one parent was symptomatic; and 47% when both parents had symptoms). Having a positive sibling was associated with a positive IgG result (odds ratio = 12.2; 95% CI: 4.4–33.7, $P < 0.001$). Overall, there was high SARS-CoV-2 transmission in children of healthcare workers. The study concluded that high rates of SARS-CoV-2 infection among children living in high-risk environments were observed, most of them presenting with mild disease or being asymptomatic.

For Carazo et al.[36] see Hospitals under Healthcare.

Healthcare workers (transmission to patients)

Williams et al.[38] conducted a prospective cohort study of Canadian patients and residents who received direct care from healthcare workers with lab-confirmed COVID-19. Their goal was to determine the risk of transmission in the presence of universal masking. The study authors identified 116 acute care, 26 long-term care, and 67 rehabilitation patients who received direct care from a universally masked healthcare worker while communicable with COVID-19. Among 133 (64%) patients with at least a 14-day follow-up, three (2.3%, 95% CI, 0.77-6.4) became positive for SARS-CoV-2. The authors concluded that universal masking, along with other infection control practices, is associated with a low risk of COVID-19 transmission from healthcare workers to patients and residents.

Residential and long-term care

MacCannell et al.[44] conducted a surveillance study by mapping viral transmission within and between long-term care facilities in Santa Clara County, California. They combined genomic sequencing with epidemiologic investigations to characterize the outbreak transmission patterns of SARS-CoV-2 between long-term care residents and staff. Positive samples were referred for whole-genome sequencing. Epidemiological investigations and phylogenetic analyses of the largest outbreaks (>30 cases) were carried out in six long-term care facilities. Among the 61 long-term care facilities in the county, 41 had ≥1 confirmed case during the study period, triggering weekly SARS-CoV-2 testing.

The six largest outbreaks accounted for 60% of cases and 90% of deaths in long-term care facilities, although the bed capacity of these facilities represents only 11% of the long-term care facility beds in the county. The authors found a pattern of rapid and sustained transmission after a single introduction of SARS-CoV-2 in six large long-term care facility outbreaks, with staff playing a key role in transmission within and between facilities. Infection control, testing, and occupational policies to reduce exposure and transmission risk for staff are essential components to keeping facility residents safe.

For Brandl et al.,[32] see Social events under Events and Entertainment, for Williams et al.[38] see Healthcare workers (transmission to patients) under Healthcare, and for Carazo et al.[36] see Hospitals under Healthcare.

Hospitality

Cruise ships

Walker et al.[45] carried out a retrospective cohort study of 223 Australian passengers that described the epidemiology and clinical characteristics of a SARS-CoV-2 outbreak on the Diamond Princess cruise ship. Of symptomatic cases, 17% showed signs and symptoms before the ship implemented quarantine and a further two-thirds of cases had symptoms within one incubation period of quarantine commencing. Prior to ship-based quarantine, exposure to a close contact or cabinmate later confirmed SARS-CoV-2 positive was associated with a 3.78-fold (95% CI: 2.24–6.37) higher risk of COVID-19 acquisition compared to non-exposed passengers. Exposure to a positive cabin mate during the ship's quarantine carried a relative risk of 6.18 (95% CI: 1.96–19.46) of developing COVID-19. Overall, the study found that the ship-based quarantine was effective at reducing transmission of SARS-CoV-2 among Australian passengers, but the risk of infection was higher if an individual shared a cabin or was a close contact of a confirmed case.

Restaurants

For Zhao et al.[34] see Family home under Household.

Household

Family home

Zhao et al.[34] conducted a retrospective cohort study of 712 confirmed cases in Northeast China to compare the different types of infection locations in which COVID-19 cases clustered. The study found that most clustered cases occurred in individual families and/or between relatives. The transmission in public venues served as a hub for transmitting the disease to other families and results in new clusters. The public transport spread the infection over long distances by transporting infected individuals, and most infections did not seem to occur within vehicles. Overall, the study shows the effect of indoor environments on SARS-CoV-2 transmission and may be useful in developing guidance for future disease prevention and control.

Burke et al.[42] did contact tracing in response to the first cases identified in the US to enable early identification and isolation of additional cases and to learn more about risk factors for transmission. Close contacts of nine early travel-related cases in the United States were identified and monitored daily for development of symptoms (active monitoring). 404 close contacts were actively monitored in the jurisdictions that managed the travel-related cases. 338 of the 404 close contacts provided at least basic exposure information, of whom 159 close contacts had ≥1 set of respiratory samples collected and tested. The results from these contact tracing investigations suggest that household

members, and especially significant others, of COVID-19 cases are at the highest risk of becoming infected. The authors concluded that the isolation of persons with COVID-19, in combination with quarantine of exposed close contacts and practice of everyday preventive behaviors, is important to mitigate spread of COVID-19.

Ai et al.[26] conducted an outbreak investigation to understand the characteristics and factors related to cluster infections in Jiangsu Province, China. Reported cases were investigated to explore transmission dynamics and the influencing factors of scales of cluster infection. From the 25th of January to the 29th of February, Jiangsu Province reported a total of 134 clusters involving 617 cases. Household clusters accounted for 79.85% of the total. The time interval from onset to report of index cases was 8 days, which was longer than that of secondary cases (4 days) ($\chi 2 = 22.763$, $P < 0.001$) and had a relationship with the number of secondary cases (the correlation coefficient (r) = 0.193, $P = 0.040$). The authors concluded that early detection, early reporting and early isolation can effectively weaken cluster infections.

Zhang et al.[47] investigated a multi-family cluster of 22 cases in Jixi, China where pre-symptomatic and asymptomatic transmission resulted in at least 41% of household infections of SARS-CoV-2. In summary, this multi-family cluster presented additional evidence that asymptomatic and pre-asymptomatic cases can play a key role in silent household transmission of COVID-19. Extensively testing and isolating close contacts of confirmed cases reduced onward transmission.

Sports and activities

Sports

Drogosz et al.[50] conducted a surveillance study to evaluate the implications of sports during K–12 sports during the pandemic throughout the state during the 2020-2021 Summer, Fall, Winter and Fall II (fall sports that were canceled and played in early spring instead) seasons. Of the 6,293 total contacts, the majority (70%) were from moderate-risk level sports, which include sports such as hockey, soccer, and lacrosse. With strict quarantine procedures in place, teams may be quarantined more than once throughout the season, which can disrupt student learning but minimize likelihood of transmissions. There is currently no approved vaccine for younger student athletes, and, therefore, quarantine measures are the best method for reducing transmission. Vaccination of student athletes who are eligible should be encouraged to allow athletes to participate in athletics while minimizing the risk of COVID-19 spread. It is important for households and other non-athletic contacts of student athletes to understand this risk. Participating in sports increases the risk of contracting COVID-19 and transmitting it to teammates, school contacts, and household members.

Drezner et al.[51] aimed to describe the prevalence of new COVID-19 infections within the Seattle United youth soccer club during small group, physically distanced training with comparison to the prevalence of infections within King County during the same time period. Between June 29, 2020, and August 9, 2020, there were a total of 15,494 players that attended practice. Only 2 players tested positive for COVID-19 during the study period, both acquiring the infection from outside of Seattle United soccer activities. One player who tested positive developed symptoms of COVID-19 hours after an evening practice. Overall, the study concluded that small group youth soccer training, when appropriately physically distanced, is safe and does not promote or accelerate spread of COVID-19 because of sports activities.

Transportation

Bus or metro

For Zhao et al.[34] see Family home under Household.

Flight travel

Lunney et al.[54] conducted a prospective cohort study of 9535 international travelers entering Alberta, Canada. The study aimed to estimate the risk of COVID-19 importation and secondary transmission associated with a modified quarantine program in Canada. Among the 9310 participants who received at least one test, 200 (21.5 per 1000, 95% CI: 18.6 to 24.6) tested positive. Sixty-nine per cent (138/200) of positive tests were detected on arrival (14.8 per 1000 travellers, 95% CI: 12.5 to 17.5). 62 cases (6.7 per 1000 travellers, 95% CI 5.1 to 8.5; 31.0% of positive cases) were identified among participants that had been released from quarantine following a negative test result on arrival. Of 192 participants who developed symptoms, 51 (26.6%) tested positive after arrival. Contact tracing among participants who tested positive identified 200 contacts; of 88 contacts tested, 22 were cases of secondary transmission (14 from those testing positive on arrival and 8 from those testing positive thereafter). SARS-CoV-2 B.1.1.7 lineage was not detected in any of the 200 positive cases. The study concluded that there is a need for ongoing vigilance in travellers testing negative on arrival and further highlights the need of follow-up testing and contact tracing to monitor and limit secondary transmission where possible.

Hu et al.[55] used the itinerary and epidemiological data of COVID-19 cases and close contacts on domestic airplanes departing from Wuhan city in China before the lockdown on January 23, 2020, to estimate the upper and lower bounds of overall transmission risk of COVID-19 among travelers. 175 index cases were identified among 5797 passengers on 177 airplanes. The upper and lower attack rates (ARs) of a seat were 0.60% (34/5622, 95% CI: 0.43%-0.84%) and 0.33% (18/5400, 95% CI: 0.21%-0.53%), respectively. In the upper- and lower-bound risk estimates, each index case infected 0.19 (SD 0.45) and 0.10 (SD 0.32) cases, respectively. The seats immediately adjacent to the index cases had an AR of 9.2% (95% CI: 5.7%-14.4%), with a relative risk of 27.8 (95% CI: 14.4-53.7) compared to other seats in the upper limit estimation. The middle seat had the highest AR (0.7%, 95% CI: 0.4%-1.2%). The upper-bound AR increased from 0.7% (95% CI: 0.5%-1.0%) to 1.2% (95% CI: 0.4%-3.3%) when the co-travel time increased from 2.0 hours to 3.3 hours. Overall, the study found that the attack rate varied by seat distance from the index case and joint travel time, but the variation was not significant between the types of aircraft. The overall risk of SARS-CoV-2 transmission during domestic travel on planes was relatively low.

Guner et al.[56] conducted a descriptive study describing the first COVID-19 case in Istanbul and contact tracing efforts. The source case was an individual who returned to Turkey from international travel at the beginning of March and tested PCR (–). The index case is the brother of the source case and is considered the first PCR (+) case diagnosed in İstanbul. Contact tracing revealed 23 PCR (+) cases, 14 of which resulted in hospitalization and three deaths. The study described cases of the first COVID-19 cluster in İstanbul with contact tracing.

For Zhao et al.[34] and Burke et al.[42] see Family home under Household.

Car sharing

For Burke et al.[42] see Family home under Household.

Workplaces

Construction labour

Sundar et al.[59] carried out contact tracing to study the transmission risk in open environments among contacts of construction laborers. 496 close contacts of 18 SARS-CoV-2 infected construction laborers were assessed for symptomatic or asymptomatic infection. The secondary transmission rate was highest among household contacts (n=28, 43.7%) followed by contacts at closed environments at the workplace (n=44, 26%), traceable other contacts (n=8, 15.7%) and contacts at open environment workplaces (n=3, 1.4%). Relative risk of SARS-CoV-2 infection among household contacts was 30.9 (CI: 9.7-98.3, $p<0.001$) compared to open environmental work contacts and 1.68 (CI 1.15-2.44, $p=0.006$) compared to closed environmental work contacts. Relative risk was 18.3 (CI 5.8-58.2, $P<0.001$) among closed environmental work contacts compared to open environmental work contacts. The authors concluded that the low secondary transmission rate of SARS-CoV-2 infection among open environmental contacts emphasizes the fact that free air flow can dilute or blow away the virus particles, thus lowering the transmission risk substantially.

For Liu et al.[25] see Social events under Events and Entertainment.

References of included studies

1. Danis, K. *et al.* Cluster of Coronavirus Disease 2019 (COVID-19) in the French Alps, February 2020. *Clin. Infect. Dis.* **71**, 825–832 (07 28).
2. Bjorkman, K. K. *et al.* Higher viral load drives infrequent SARS-CoV-2 transmission between asymptomatic residence hall roommates. *J. Infect. Dis.* **24**, 24.
3. Akaishi, T. *et al.* COVID-19 transmission in group living environments and households. *Sci. Rep.* **11**, 11616 (06 02).
4. James, A. *et al.* Model-free estimation of COVID-19 transmission dynamics from a complete outbreak. *PLoS ONE Electron. Resour.* **16**, e0238800 (2021).
5. Bark, D. *et al.* SARS-CoV-2 transmission in kindergarten to grade 12 schools in the Vancouver Coastal Health region: a descriptive epidemiologic study. *CMAJ Open* **9**, E810–E817.
6. Loenenbach, A. *et al.* SARS-CoV-2 variant B.1.1.7 susceptibility and infectiousness of children and adults deduced from investigations of childcare centre outbreaks, Germany, 2021. *Euro Surveill. Bull. Eur. Sur Mal. Transm. Eur. Commun. Dis. Bull.* **26**, 05 (5).
7. Larosa, E. *et al.* Secondary transmission of COVID-19 in preschool and school settings in northern Italy after their reopening in September 2020: a population-based study. *Euro Surveill. Bull. Eur. Sur Mal. Transm. Eur. Commun. Dis. Bull.* **25**, 12 (12).
8. 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.
9. 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).
10. 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.
11. 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).
12. Zimmerman, K. O. *et al.* Incidence and secondary transmission of SARS-CoV-2 infections in schools. *Pediatrics* **147(4) (no pagination)**,.
13. Zimmerman, K. O. *et al.* Community SARS-CoV-2 Surge and Within-School Transmission. *Pediatrics* **28**, 28.
14. Chua, G. T. *et al.* Clinical Characteristics and Transmission of COVID-19 in Children and Youths During 3 Waves of Outbreaks in Hong Kong. *JAMA Netw. Open* **4**, e218824 (05 03).
15. Wada, K., Okabe, N. & Shobugawa, Y. Infection and transmission of COVID-19 among students and teachers in schools in Japan after the reopening in June 2020. *BMJ Paediatr. Open* **4(1) (no pagination)**,.
16. Heavey, L., Casey, G., Kelly, C., Kelly, D. & McDarby, G. No evidence of secondary transmission of COVID-19 from children attending school in Ireland, 2020. *Eurosurveillance* **25**, (2020).
17. Alonso, S. *et al.* Age-dependency of the Propagation Rate of Coronavirus Disease 2019 Inside School Bubble Groups in Catalonia, Spain. *Pediatr. Infect. Dis. J.* **27**, 27.
18. 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.
19. 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).
20. 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).

21. 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.
22. 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).
23. 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)**,.
24. 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).
25. Liu, Y., Gu, Z. & Liu, J. Uncovering transmission patterns of COVID-19 outbreaks: A region-wide comprehensive retrospective study in Hong Kong. *EClinicalMedicine* 100929 (2021).
26. Ai, J. *et al.* Epidemiologic characteristics and influencing factors of cluster infection of COVID-19 in Jiangsu Province. *Epidemiol. Infect.* **149**, e48 (02 10).
27. Nakajo, K. & Nishiura, H. Transmissibility of asymptomatic COVID-19: Data from Japanese clusters. *Int. J. Infect. Dis.* **105**, 236–238.
28. Martin-Sanchez, M. *et al.* COVID-19 transmission in Hong Kong despite universal masking. *J. Infect.* **83**, 92–95 (7).
29. 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).
30. 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).
31. 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.
32. Brandl, M. *et al.* Mass gathering events and undetected transmission of SARS-CoV-2 in vulnerable populations leading to an outbreak with high case fatality ratio in the district of Tirschenreuth, Germany. *Epidemiol. Infect.* **148**, e252 (2020).
33. Ravindran, B. *et al.* High COVID-19 attack rate among attendees of wedding events in Bali, Indonesia, March 2020. *Commun. Dis. Intell.* **44**, 16.
34. Zhao, P., Zhang, N. & Li, Y. A Comparison of Infection Venues of COVID-19 Case Clusters in Northeast China. *Int. J. Environ. Res. Public Health Electron. Resour.* **17**, 03 (06 03).
35. Lan, F.-Y. *et al.* Sociodemographic risk factors for coronavirus disease 2019 (COVID-19) infection among Massachusetts healthcare workers: A retrospective cohort study. *Infect. Control Hosp. Epidemiol.* 1 (2021).
36. Carazo, S. *et al.* Characterization and evolution of infection control practices among severe acute respiratory coronavirus virus 2 (SARS-CoV-2)–infected healthcare workers in acute-care hospitals and long-term care facilities in Québec, Canada, Spring 2020. *Infect. Control Hosp. Epidemiol.* 1–9.
37. Jung, J. *et al.* Frequent Occurrence of SARS-CoV-2 Transmission among Non-close Contacts Exposed to COVID-19 Patients. *J. Korean Med. Sci.* **36**, (2021).
38. Williams, V. R. *et al.* Risk of SARS-CoV-2 transmission from universally masked healthcare workers to patients or residents: A prospective cohort study. *Am. J. Infect. Control* **49**, 1429–1431 (2021).
39. Walker, A. *et al.* Characterization of Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) infection clusters based on integrated genomic surveillance, outbreak analysis and contact tracing in an urban setting. *Clin. Infect. Dis. Off. Publ. Infect. Dis. Soc. Am.* (2021).
40. Huang, P.-Y. *et al.* A hospital cluster of COVID-19 associated with a SARS-CoV-2 superspreading event. *J. Microbiol. Immunol. Infect.* (2021).

41. Atsawawaranunt, K. *et al.* COVID-19 Transmission among Healthcare Workers at a Quarantine Facility in Thailand: Genomic and Outbreak Investigations. *Am. J. Trop. Med. Hyg.* **105**, 421 (2021).
42. Burke, R. M. *et al.* Enhanced contact investigations for nine early travel-related cases of SARS-CoV-2 in the United States. *PLoS ONE Electron. Resour.* **15**, e0238342 (2020).
43. Mendez-Echevarria, A. *et al.* High Rates of SARS-CoV-2 Family Transmission in Children of Healthcare Workers During the First Pandemic Wave in Madrid, Spain: Serologic Study. *Pediatr. Infect. Dis. J.* **40**, e185–e188 (05 01).
44. MacCannell, T. *et al.* Genomic epidemiology and transmission dynamics of SARS-CoV-2 in congregate healthcare facilities in Santa Clara County, California. *Clin. Infect. Dis.* **30**, 30.
45. Walker, L. J. *et al.* SARS-CoV-2 infections among Australian passengers on the Diamond Princess cruise ship: A retrospective cohort study. *PLoS ONE* **16(9 September) (no pagination)**,.
46. 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).
47. Zhang, H. *et al.* A multi-family cluster of COVID-19 associated with asymptomatic and pre-symptomatic transmission in Jixi City, Heilongjiang, China, 2020. *Emerg. Microbes Infect.* **9**, 2509–2514.
48. Natapov, L. *et al.* Risk of SARS-CoV-2 transmission following exposure during dental treatment - A national cohort study. *J. Dent.* **113**, 103791.
49. 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).
50. Drogosz, M. *et al.* Implications of Sports on COVID-19 cases in Rhode Island School-aged Athletes. *R. I. Med.* **104**, 51–54 (06 01).
51. Drezner, J. A., Drezner, S. M., Magner, K. N. & Ayala, J. T. COVID-19 Surveillance in Youth Soccer During Small Group Training: A Safe Return to Sports Activity. *Sports Health* **13(1)**, 15–17.
52. 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.
53. D'Agostino, E. M. *et al.* Symptomatic SARS-CoV-2 Transmission in Youth and Staff Attending Day Camps. *Pediatrics* **147**, 04 (4).
54. Lunney, M. *et al.* COVID-19 infection among international travellers: A prospective analysis. *BMJ Open* **11(6) (no pagination)**,.
55. Hu, M. *et al.* Risk of SARS-CoV-2 Transmission among Air Passengers in China. *Clin. Infect. Dis.* **21**, 21.
56. Guner, A. E. *et al.* First known COVID-19 case and contact tracing efforts in Istanbul, Turkey. *Turk. J. Med. Sci.* **51**, 1653–1658 (08 30).
57. 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).
58. 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 (3).
59. Sundar, V. & Bhaskar, E. Low secondary transmission rates of SARS-CoV-2 infection among contacts of construction laborers at open air environment. *Germs* **11**, 128–131.
60. 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).