

COVID-19 clusters outside healthcare institutions and households during the initial phase of the pandemic: A literature and media review

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Abstract

Introduction

During the initial phase of the COVID-19 pandemic, based on the available knowledge at that time, infection control measures outside hospitals were put in place to prevent droplet and indirect transmission. However, transmission may occur through multiple routes in various settings. Outbreaks of COVID-19 related to specific indoor activities (e.g. singing and physical exercise) during the initial phase of the pandemic can give insight into risk factors for SARS-CoV-2 transmission and possible aerogenic transmission.

Methods

Descriptive study. We retrospectively collected information on reported COVID-19 clusters that were related to specific indoor activities in the Netherlands and in other countries, from January up to May 24, 2020. Healthcare institutions and household clusters were not included. Clusters were stratified based on type of specific indoor activity and per type of activity we compared frequency of occurrence between different activities and gatherings, cluster sizes and attack rates.

Results

In total 12 clusters in scientific literature, and 34 clusters in media reports were found. The clusters were related to choirs and orchestras, religious gatherings, indoor sports activities and other indoor gatherings. Choirs were most frequently mentioned, with 6 clusters and a reported attack rate ranging between 11%-87%.

Discussion

Participating in choir singing was identified as possible risk factor for increased SARS-CoV-2 transmission. Although droplet or indirect transmission have occurred at these occasions, possible aerogenic transmission over longer distances than 1.5 meters may have contributed to the high attack rates. In future outbreaks, amongst other things also additional phylogenetic research is recommended to assist in clarifying transmission patterns. This knowledge is of importance for policy-making and applying tailored control measures.

Keywords: COVID-19; SARS-CoV-2; outbreaks; review

Introduction

During the initial phase of the COVID-19 pandemic in the Netherlands, the general guidelines for infection prevention of SARS-CoV-2 outside hospitals as in most other countries, were based on the assumption that human-to-human transmission of SARS-CoV-2 mainly occurs by direct transmission of respiratory droplets or by indirect transmission via contact with contaminated hands, objects or surfaces [1]. However, transmission may occur through multiple routes in various settings. It has not yet been established whether SARS-CoV-2 might spread in other ways such as aerogenic transmission (through droplet nuclei that remain infectious when suspended in air over long distance (>1 m) and time) or fecal-orally too [1-3]. The basic reproductive number (R0) of SARS-CoV-2 is estimated to be 2 to 3, and is similar to that of other respiratory viral infections spread through respiratory droplets, suggesting droplet infection being the most important route of transmission. Also physical distancing of 1-2 meters appears to have a protective effect on transmission, suggesting that aerogenic transmission does not appear to play a major role in the spread of SARS-CoV-2 except during aerosol generating procedures in health care [1, 4, 5]. However, the scientific discussion on the role of aerosols and aerogenic transmission is strong and ongoing. Several publications have described infections in locations outside health care institutions in which aerogenic transmission cannot be ruled out [6, 7]. Yet in these outbreaks, transmission via droplets or via indirect contact may also have been a possible route. Although the infectious dose of SARS-CoV-2 is currently unknown, in experimental settings it has been established that SARS-CoV-2 particles can remain infectious in aerosols for several hours [8, 9]. In some recent studies it appears that viable virus has been detected in air samples outside experimental settings [10, 11]

This paper nationally and internationally examines clusters outside healthcare institutions and households during the initial phase of the COVID-19 pandemic reported in scientific literature, media reports, and in reported notifications in the Netherlands. Clusters of COVID-19 related to specific indoor activities (e.g. singing and physical exercise) during the initial phase of the pandemic, especially before physical distancing measures were implemented on a wide scale, can give insight into risk factors for SARS-CoV-2 transmission and possible aerogenic transmission.

Methods

We retrospectively collected information on reported COVID-19 clusters that were related to specific indoor activities in the Netherlands and in other countries. Healthcare institutions and household clusters were not included. Clusters were stratified based on type of specific indoor activity and for each type of activity we compared frequency of occurrence, cluster sizes and primary attack rates. We focused on the following specific indoor activities: choirs and orchestras (as singing and wind instruments might increase aerosol production), leisure-time clubs and associations (possibility of speaking with forced voice and poorly ventilated spaces), religious gatherings (because of singing and speaking with forced voice), sports activities (deep exhalation produces more aerosols and deep inhalation allows the virus to reach deeper parts of the respiratory tract) and other indoor meetings or gatherings. We did not include clusters in settings where people stay overnight, such as households, health care institutions, cruise ships, hotels and prisons, due to the large diversity in type of contact. We also did not consider clusters associated with public transport.

We searched the scientific literature from the beginning of January up to 24 May 2020 using the living systematic map of the evidence on COVID-19 of the EPPI centre (<http://eppi.ioe.ac.uk/cms/Projects/DepartmentofHealthandSocialCare/Publishedreviews/COVID-19Livingssystematicmapofthevidence/tabid/3765/Default.aspx>), in which papers from Pubmed which include primary data are categorized into subjects. The folders ‘Transmission / risk / prevalence’ and ‘Health impacts’ were screened for articles on relevant clusters or outbreaks. Additionally, we searched for media reports on Google News and Twitter and extracted media reports through Coosto social media management software, with various search terms in both Dutch and English. We used the general search terms “COVID-19”, “corona” and “outbreak”, ”cluster”, ”source of contamination”. In order to find clusters in choirs and orchestras we combined these general terms with the search terms “choir”, “orchestra”, “party”, “band”, ”music”, ”brass band”. For gatherings in leisure-time clubs and associations we added the search terms “association”, “club”, “chess (club or association)”, “bridge (club or evening)”, “bingo (night)”, “women’s union”, “carnival (association)” and for religious gatherings we used the terms “church service”, “bible belt”, “wedding”, “funeral”. Clusters that occurred during indoor sports activities were found with the terms “fitness (class)”, “gym (class)”, “sports (club or center or event or competition)”,

“group lesson”, “dance (class or school)”, “badminton”, “korfball”, “handball”, “water polo”, “basketball”, “gymnastics”, “volleyball”. Any other indoor gatherings were assessed by adding the terms “group meetings”, “information evening”, “conference”, “superspreading event”, “restaurant”, “(birthday) party”. Furthermore, a search for clusters reported in PROMED posts was performed using the search terms “COVID-19” or “corona” and “outbreak”, “choir”, “chanting”, “sports”, “church”, “dance”, “superspreading event”.

In addition a survey among all 25 municipal health services (GGDs) in the Netherlands about COVID-19 clusters was held with data up to 19 May 2020. Municipal health services were requested to provide information on clusters or outbreaks outside healthcare institutions and households in their region. We summarized the number of clusters reported by municipal health services in each type of setting. Information on cluster sizes has not been collected. Also, notifications of COVID-19 patients in the Dutch national surveillance system OSIRIS up to 24 May 2020 were examined for related cases in leisure activities, such as sport clubs.

Results

In total 12 COVID-19 clusters in scientific literature and 34 clusters in media reports (of which 5 overlapping) were found related to choirs and orchestras, religious gatherings, indoor sports activities and other indoor meetings and gatherings. Table 1 provides an overview of these clusters, stratified by type of specific indoor activity and ordered by primary attack rate and by cluster size if attack rate is unknown.

Table 1: Overview of COVID-19 clusters outside healthcare institutions and households in scientific literature and media reports by type of specific indoor activity, with data published up to 24 May 2020. Clusters are ordered by primary attack rates and by cluster size if attack rate is unknown.

Specific activity (reported clusters <i>n</i>)	setting	country	cluster size	attack rate	source of information [reference]
Choirs and orchestras (n=12)	choir	USA	53	87%	scientific literature [12], media report [13]
	choir	Netherlands	102	78%	media report [14]
	choir	Germany	60	75%	media report [15]
	party band	Netherlands	7	70%	media report [16]
	choir	Netherlands	20	67%	media report [17]
	choir	Netherlands	32	40%	media report [18]
	choir	Netherlands	10	11%	media report [19]
	choir	Netherlands	>5	unknown	media report [20]
	choir	United Kingdom	unknown	unknown	media report [21]
	choir	United Kingdom	unknown	unknown	media report [21]
	choir	Netherlands	unknown	unknown	media report [22]
choir	Netherlands	unknown	unknown	media report [22]	
Religious gatherings (n=9)	church service	Netherlands	30	77%	media report [23, 24]
	funeral	France	9	45%	media report [25]
	church activities	USA	35	38%	scientific literature [26], media report [27]
	church group population	South Korea	5080	unknown	media report [28, 29]
	church service	Germany	40	unknown	media report [30]
	church service	Singapore	17	unknown	scientific literature [31]
	church service	Singapore	5	unknown	scientific literature [31, 32]
	church service	USA	unknown	unknown	media report [33]
funeral	USA	unknown	unknown	media report [34]	
Sports activities (n=2)	fitness dance classes	South Korea	57	26%	scientific literature [35], media report [36]
	basketball competition	USA	6	15%	media report [37]
Other indoor meetings and gatherings (n=18)	birthday party	USA	>19	>50%*	media report [38]
	live music venues	Japan	83	31%*	media report [39]
	food market	Peru	163	19%	media report [40]
	restaurant	China	10	12%	scientific literature [41]
	call center	South Korea	97	9%**	scientific literature [42]
	conference	Singapore	7	6%	scientific literature [32], media report [36]
	antiques and art fair	Netherlands	>25	0.1%	media report [43]
	food market	India	>1500	unknown	media report [44]
	night clubs	South Korea	102	unknown	media report [45]
	business meeting	USA	99	unknown	media report [46]
	business meeting	Germany	16	unknown	scientific literature [47], media report [48]
	family gatherings	USA	16	unknown	scientific literature [49]
	tour group	Singapore	8	unknown	scientific literature [32]
	birthday party	USA	>5	unknown	media report [50]
	ski bar	Austria	unknown	unknown	scientific literature [51]
	café	Netherlands	unknown	unknown	media report [52]
information evening	Netherlands	unknown	unknown	media report [52]	
benefit evening	Netherlands	unknown	unknown	media report [53]	

n: number

*attack rate among tested individuals.

**overall attack rate in the building; on one of the floors the attack rate was 44% with 94 cases.

Scientific literature

A large cluster with a high attack rate of 87 percent has been described in a choir in Washington, USA [12]. Among 61 people who attended a rehearsal of the choir on March 10, 53 cases were identified, of which 33 were laboratory confirmed. At the choir rehearsal one participant with flu-like symptoms attended, who was later confirmed as a COVID-19 case. During the choir rehearsal, there have been several possibilities for (in)direct transmission. The participants sat close together, they ate snacks together and at the end of the rehearsal they cleared the chairs together.

Two clusters in churches have been described in Singapore [31, 32]. In Church A, two visitors from Wuhan attended a service on January 19, after which five other people who attended the service were confirmed as COVID-19 case. Seventeen confirmed COVID-19 cases were linked to church B in mid-February. No attack rates were mentioned. For most cases in these clusters, close contact with a symptomatic case could be designated as the transmission route. In Arkansas, USA, a cluster related to various indoor church activities has been described; the activities took place from March 6-11 [26]. Of the 92 participants, 45 symptomatic persons were tested and 35 turned out to be positive, indicating an attack rate of 38 percent among all participants. Two children also tested positive, but the attack rate was much lower in children (6%) than in adults (55%). Singing was mentioned as a specific activity during the children's event on March 6-8, in which some adults participated. The article does not provide information on possible transmission routes.

In South Korea, 112 cases related to fitness dance classes were described [35]. The outbreak probably started at a workshop for 27 dance instructors that was held on February 15, of whom eight later tested positive for SARS-CoV-2. The instructors and students did not have contact outside of class. Of 217 participants in the fitness dance classes, 57 fell ill due to primary transmission from instructor to participants (26%), and secondary and tertiary cases were identified among close contacts of fitness instructors and students. The size of the groups (5-22), the small class rooms of approximately 60 m² and the intensity of the workouts may have contributed to the spread.

In Germany, a cluster related to a business meeting was described [47]. An employee of the Chinese branch of a German company, travelled from Shanghai to Germany on January 19 to facilitate workshops and attend meetings in the company building and tested positive for SARS-CoV-2 after her stay. Testing of high-risk contacts identified 16 subsequent cases, of which ten employees of the company. The general hypothesis of direct human-to-human transmission was supported by the concurring epidemiological and genetic results in reconstructing the transmission network. Two other clusters linked to a tour group from China and a company conference were identified in Singapore [32]. The tour group from China visited amongst others a complementary health products shop and a jeweler on January 23. Two out of twenty tourists were identified with laboratory-confirmed COVID-19. The tour guide, five shop assistants that worked on the day of the visit and three secondary transmission cases were later confirmed with COVID-19. The company conference was attended by at least 111 participants from 19 different countries on Jan 20–22, 2020, seven participants at the conference tested positive for SARS-CoV-2 and 13 secondary cases were reported among family members. The article describes that close or prolonged interactions are probably attributable to the cases in these clusters, due to direct physical contact between shop assistants and tourists at the health products shop and handshaking and physical contact during team-building activities and sharing of meals among participants of the company conference.

An article from China describes transmission in an air-conditioned restaurant, involving three families [41]. On January 24, the three families sat at neighbouring tables in the restaurant, and the air-conditioning flow went over the three tables. The index patient and the other infected persons were > 1 meter apart. The authors of the article therefore suggest that the strong flow of the air conditioning has propagated the droplets further than 1 meter and could therefore infect the other persons. The article mentions that aerogenic transmission is unlikely in this situation because no staff or other guests got infected, and no virus was found on the air conditioning. A cluster in a call center has been described in South Korea in early March [42]. In the call center, 97 out of 1143 persons tested positive for SARS-CoV-2. On the 11th floor, 94 of the 216 employees tested positive (44%). No specific transmission routes were mentioned in the article. The duration of interaction or contact was mentioned as an important contributor for transmission, because spread of COVID-19 was limited almost exclusively to employees on the 11th

floor, despite interaction between employees of different floors in the lifts and the lobby. A cluster of 16 COVID-19 cases (seven confirmed and nine probable) after two family gatherings (a funeral and birthday party) outside the household was described in Chicago, USA in February [49]. One index patient who attended both events, triggered a chain of transmission. Close physical contact, such as embracing others and sharing food, was mentioned as most likely route of transmission. Another article describes that relatively many imported cases from different countries (Germany, Norway, Iceland, Denmark) were related to the ski village of Ischgl in Austria [51]. Many of these cases visited a popular crowded ski bar in Ischgl (with much singing and dancing) where on March 7 an employee tested positive for SARS-CoV-2.

Media reports

By searching on Google News, Twitter and by using Coosto social media management software seven additional COVID-19 clusters were found in choirs in the Netherlands with 30 to 130 members between March 3 and March 31 and one cluster in a party band of 10 members on March 11 [14, 16-20, 22]. Among the clusters was one large cluster in Amsterdam with 102 cases among 130 choir members [14]. The primary attack rates in the choirs varied between 11 percent and 78 percent and the attack rate in the party band cluster was 70 percent, although not all clusters consisted of confirmed cases only. In various reports it was mentioned that the choir members have often been in close distance from each other and socialized, which may have caused the transmission. Three additional clusters in choirs were found outside the Netherlands. Clusters of people with COVID-like symptoms in two choirs in Bradford, UK in January and February were described, although these cases have not been tested [21]. Among the first cases was a man returning from Wuhan in late December. Another cluster with an attack rate of 75 percent was found in a church choir with 80 members in Berlin, Germany with cases from mid-March [15]. All clusters in choirs concerned adults, no clusters in children's singing groups were found.

Many Dutch media reports suggested that church services were an important source of transmission for COVID-19, based on one specific cluster on the island Goeree-Overflakkee. After an on-site church service in the chapel of a nursing home on the island on March 8, 30/39 visitors developed symptoms and 14 were tested and were positive for SARS-CoV-2 [23]. A more recent newspaper article and a study which has not yet been peer reviewed suggested that the church service did not play a major role in this cluster, as

whole genome sequencing identified a diversity of sequence types, indicating that the infections among the residents maybe took place elsewhere and before the service [24, 54]. Five additional clusters related to religious gatherings were reported in international news reports, including an outbreak in a church group population in Daegu, South Korea, with the first case reported on February 18 and accounting for 5080 (not phylogenetically) confirmed cases with connections to the church by March 25 [28]. Frequently shouting out 'amen' while sitting on the floor during crowded church services was suggested as transmission route [29]. A funeral on February 28 in Georgia, USA with more than 100 attendees contributed to increasing USA COVID-19 case counts and a cluster of nine confirmed cases was described after a funeral in a church involving 20 family members in a small town in the Dordogne, France, early in May [25, 34]. Another cluster was described in Frankfurt, Germany, where more than 40 people tested positive for SARS-CoV-2 after a church service on May 10 [30]. At the time of the church service, social distancing and hygiene measures were recommended. In addition, clusters have been described in churches in Kansas, USA, although details about these clusters have not been made public [33].

Only one additional cluster related to indoor sports activities was found in media reports. In the United States, six basketball players from two professional teams were infected, after those teams played against each other on March 10 [37]. Other indoor meetings and gatherings in which clusters have been reported in the Dutch media included café visitors, an information evening, a benefit evening and an antiques and art fair [43, 52, 53]. All these events were attended by a large number of people in early March, just before lockdown measures were recommended. In international media reports, clusters related to live music events and night clubs were found, such as in Japan where a cluster of 83 confirmed infections was traced back to four live music venues in Osaka from February 15-24 [39]. In addition, a cluster of 102 confirmed cases related to night clubs was reported in the beginning of May in Seoul, South Korea [45].

One additional cluster has been reported in media related to international conferences and business meetings. An annual meeting of a pharmaceutical company at the end of February in Massachusetts led to a cluster of 99 cases [46]. A dinner buffet and cocktail evening with 185 employees took place on the first day of the event. Employees spread the virus to at least 6 US states and to European countries. Other settings where clusters have been described in media reports were birthday parties, amongst others at a home in

Connecticut, USA and Pasadena, USA [38, 50]. The party on March 19 in Pasadena was attended by a large number of people after stay-at-home orders were issued, including a woman with symptoms who could later be identified as the index case. More than 5 laboratory-confirmed COVID-19 cases were discovered among attendees of the party and many more ill individuals. It was not mentioned whether this birthday party took place indoors or outdoors. In addition, food markets were involved in some clusters, 163 out of 854 stallholders of a both indoors and outdoors food market in Lima, Peru tested positive on April 29 and a large fruit and vegetable indoor market complex in Chennai, India, which was overcrowded although physical distancing had been recommended, was linked to more than 1500 cases as of May 8 [40, 44]. Our search in PROMED did not provide information about any additional clusters or superspreading events. No clusters were found related to leisure-time clubs and associations.

Survey among municipal health services

Table 2: Overview of COVID-19 clusters outside healthcare institutions and households reported by municipal health services in the Netherlands, by type of specific indoor activity, with data up to 19 May 2020.

Specific activity	setting	reported clusters (n)
Choirs and orchestras	choir	6
Religious gatherings	church service	2
	wedding	1
Other indoor meetings and gatherings	public meeting	1
	trade fair	1
	workshop	1
	café	1

n: number

Our request to the 25 municipal health services resulted in a response of 13 municipal health services (52%).

In total, 13 outbreaks outside healthcare institutions and households were reported, varying from 0 to 4 outbreaks per municipal health service in seven different indoor settings (Table 2). Choirs were mentioned most frequently as setting ($n=6$ outbreaks), followed by church services ($n=2$).

Surveillance reports

Up to 24 May 2020, a total of 45,731 laboratory-confirmed COVID-19 patients were notified in OSIRIS of which 16,510 (36%) indicated that they were contacts to a primary case. In total only 90 contacts indicated a relation with social or leisure activities. Most frequently choirs ($n=18$), church services ($n=7$), parties and birthdays ($n=7$), card-playing clubs or bridge clubs ($n=5$) and gym or sports clubs ($n=5$) were mentioned as

specific activities (Table 3). For 42 patients the social or leisure activity was not an indoor activity or was not specified. The information found in the OSIRIS notifications of COVID-19 patients likely overlaps with the clusters described in the survey among municipal health services and the media reports.

Table 3: Surveillance reports from the Netherlands of SARS-CoV-2 positive contacts to a primary case, by type of specific indoor activity, with data reported up to 24 May 2020.

In total 90 contacts indicated a relation with social or leisure activities, for 42 contacts the social or leisure activity was not an indoor activity or was not specified.

Specific activity	<i>setting</i>	<i>reported contacts (n*)</i>
Choirs and orchestras	choir	18
	music band	2
	living room concert	1
Leisure-time clubs and associations	card-playing or bridge club	5
Religious gatherings	church service	7
Sports activities	gym or sports club	5
Other indoor meetings and gatherings	party or birthday	7
	dance party	1
	pub	1
	restaurant	1

n: number

*number of in OSIRIS reported SARS-CoV-2 positive contacts to a primary case.

Discussion

This study examined nationally and internationally COVID-19 clusters outside healthcare institutions and households related to specific indoor activities during the initial phase of the pandemic, to obtain insight into risk factors for SARS-CoV-2 transmission and possible aerogenic transmission. In scientific literature, media reports and in reported notifications in the Netherlands within our search strategy, choirs were most frequently mentioned as a possible source of acquired infection, suggesting that participating in choir singing might be a risk factor for increased SARS-CoV-2 transmission. Several outbreaks in choirs have reported a remarkably high attack rate of up to 87%, although not all clusters consisted of confirmed cases only. Since social distancing and hygiene measures had not been put in place yet, various transmission routes may have occurred and multiple importations within these clusters cannot be excluded. Although droplet transmission could have occurred at these occasions, possible aerogenic transmission over longer distances than 1.5 meters may have contributed to the remarkably high attack rates. Yet, indirect transmission via surfaces or fomites also cannot be ruled out, but is unlikely to explain the high attack rates, as epidemiological COVID-19 transmission studies identified much lower attack rates among secondary

household contacts (7-23%) and non-household close contacts (<1%) [55-58]. Phylogeny could assist in clarifying the transmission pattern and could establish the possibility of multiple importations and spurious clusters, as often not enough epidemiological data is available to detect this.

With 11% of the population singing in a group setting, (choir) singing is a popular activity among older people in the Netherlands [59]. Since elderly are considered a risk group for severe COVID-19, this could explain the relatively high number of clusters reported in choirs. However, in other popular social leisure group activities for elderly (card play, orchestras, chess, bridge, bingo etc.) we did not find any outbreaks or clusters, suggesting that the activity of singing itself contributed to the outbreaks among adults in a choir. Yet, in nurseries and primary schools classes, children frequently sing together as well. During a previous survey among municipal health services about the role of children in the spread of SARS-CoV-2, municipal health services were asked to report outbreaks at nurseries and schools. No outbreaks were reported and no clusters in literature and media reports related to children's singing in school classes have been found. Possibly, the relatively high number of clusters in choirs could be explained by the combination of risk groups and a group of people singing simultaneously producing more droplets with possible SARS-CoV-2 in a room, which increases the risk of infection for both droplet/aerogenic transmission and transmission via surfaces (many more droplets end up on surfaces).

Outbreaks related to church services were reported several times. The whole genome sequencing result of the outbreak after a church service in a nursing home in the Netherlands shows a diversity of sequence types, indicating that the virus may have been introduced at multiple points in time and via multiple individuals [54]. Because not all cases have been tested and sequenced, it is difficult to estimate the role of the church service in the transmission. A major outbreak occurred after a church service in Frankfurt, Germany, during which people have been singing [30]. According to the media reports, social distancing and hygiene measures have been followed during this church service, which could mean that aerogenic transmission has played a role and that preventive measures to keep distance from others might be not sufficient during religious gatherings. Various other indoor gatherings and events outside healthcare institutions and households were related to COVID-19 outbreaks, including international conferences, a call center, après ski and night clubs, dance classes in a fitness room, public meetings and family gatherings,

although overall attack rates were lower compared to the clusters in choirs. Since employees in a call center are constantly talking, it is possible that aerogenic transmission may have played a role. Aerogenic transmission related to talking loudly, singing, and dancing may have played a role in the spread of the virus in the night clubs and the ski bar. Many infections have been traced back to winter sport areas and due to the young age of night club visitors, other clusters related to bars and night clubs during the initial phase of the pandemic may have gone unnoticed. In the fitness dance classes direct or indirect transmission may have been more likely than aerogenic transmission, as yoga and pilates students that did a workout at the same time in the same facility as the dance students, have not been infected. Whether aerogenic transmission may have played any role in the clusters related to public meetings and family gatherings is difficult to assess, given the limited information available on type of contact within these clusters.

During the initial phase of the COVID-19 pandemic, countries took different measures at different times and had different approaches in testing policy, resulting in bias in the type of clusters and settings that could and could no longer be found. In the Netherlands, meetings and social gatherings were not being allowed after March 15 anymore. At that time laboratory testing was limited to hospitalized patients only, and few people in the community were tested. The survey among municipal health services in the Netherlands suggested that clusters outside healthcare institutions and households were not frequently reported and surveillance reports showed that only 90 out of 16,510 contacts indicated a relation with social or leisure activities. However, due to the increasing number of infections in March and April 2020 in the Netherlands, it was no longer possible to conduct contact tracing and therefore the vast majority of positively tested individuals has not been asked about possible sources, leading to underreporting of possible settings. As the current study provides an overview of clusters in the initial phase of the pandemic only, when the number of reported clusters was still limited due to lockdown measures and low test capacity, we recommend a systematical collection of information on more recent clusters for future research.

Strengths of this review include the different type of sources covered both on national and international level (scientific literature, media reports, survey among municipal health services and surveillance data), with consistent results. Next to providing an overview of major writings and other sources on the topic, this review links the data found to existing knowledge and points out research gaps.

The types of settings in which clusters are found in this study are in line with other studies. A study investigating clusters of COVID-19 cases in Japan during 15 January – 4 April 2020 observed that many COVID-19 clusters were associated with heavy breathing in close proximity, such as singing at karaoke parties, cheering at clubs, having conversations in bars, and exercising in gymnasiums [60]. A systematic review of available literature and media reports of SARS-CoV-2 transmission events up to 26 May 2020 identified clusters above 50 cases in predominantly indoor setting types as healthcare, large religious gatherings, food processing plants, schools, shopping, large co-habiting settings, weddings, sport, bars and work [61]. Given the time of the year of the initial phase of the pandemic, it is not an unexpected finding that clusters predominantly have been found in indoor settings. A general limitation exists in recognizing clusters related to transmission events that are difficult to recognize, i.e., when not easily linked to a frequented site or event. A limitation of our review is the existing possibility that several important clusters are missing in our overview, because the search was only performed in two different languages. Also, bias in the reporting of ‘socially interesting’ clusters in the media is likely, which can lead to some settings being overly represented. The reliability of the numbers and possible explanations for transmission in the media reports have not been verified. Especially in the media reports the epidemiological relevant information we found was not always complete, therefore multiple attack rates could not be estimated as denominators were missing and information on ventilation in the settings were missing. Additionally, in international reports it was not always clear whether social distancing and hygiene measures were recommended at the time of the clusters.

Following the results of this review, RIVM has drawn up a generic framework of coronavirus measures, in which singing in a room with a group initially has been discouraged and is currently allowed again at 1.5 meters distance and under certain conditions. The amount of aerosols that can arise from infected individuals depends amongst others on voice loudness and singing may expel as many virus particles as coughing [62-64]. To take into account any aerogenic transmission during choir singing, extra measures with regard to indoor ventilation have been recommended for choirs and vocal ensembles, in addition to the usual preventive recommendations. Increasing ventilation rates might prevent aerogenic transmission [65]. However, heating, ventilation and air conditioning Systems (HVAC) might also play a

role in the airborne transmission [66]. Further research is needed to investigate if a certain ventilation capacity can sufficiently prevent COVID-19 and if this capacity might lead to other (health) problems, e.g. thermal discomfort, intolerable noise and large increase in energy demand. Also, even with effective increased ventilation capacity transmission by droplet or indirect transmission remains possible.

Conclusions

Outside health care institutions and households, in the initial phase of the pandemic COVID-19 clusters have been described most frequently in choirs suggesting participating in choir singing is a possible risk factor for increased SARS-CoV-2 transmission, especially among the elderly. Therefore, singing in a room with a group initially has been discouraged in the Netherlands and is currently allowed again at 1.5 meters distance and under certain conditions. Although droplet or indirect transmission have occurred at these occasions, possible aerogenic transmission over longer distances than 1.5 meters may have contributed to the high attack rates in several outbreaks. In future outbreaks additional phylogenetic research is recommended to assist in clarifying transmission patterns. In addition, further research into the possible association between ventilation and transmission is needed. This knowledge will increase our ability to limit transmission of SARS-CoV-2 and is of importance for policy-making and applying tailored control measures as effectively as possible.

Conflict of interest

The authors have no competing interests to declare.

Authors' contributions

Data collection was performed by AT, MK and SH. Drafting of the manuscript was performed by AT. GvR, AB, MK, MtW, SvdH and SH were involved in interpretation of the data and critical revision of the manuscript. All authors have read and approved the final manuscript.

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