Superspreading events of SARS-CoV-2 in Paris: A retrospective analysis of data from the first wave of COVID-19 in 2020

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ABSTRACT

Background: The 2020 COVID-19 pandemic led to a strict lockdown in France from March 17 to May 11, 2020. After the lockdown, the French strategy to mitigate the impact of SARS-CoV-2 relied partly on investigations of all confirmed cases. Monitoring collective settings is particularly important since SARS-CoV-2 seems prone to superspreading events (SSEs).
Methods: Our study is based on data gathered in Paris from May 11 to December 31, 2020, by the Ile-de-France Regional Health Agency (RHA) to investigate cases occurring in collective and high-risk settings. Specific events in high-risk settings were systematically transmitted to the RHA, and screenings were organized by the facilities, while other settings were reported when three cases were identified within a short period. These settings were more difficult to identify through the surveillance system since no systematic screening was organized by the facility, leaving screenings to rely on the national contact-tracing programme. No official superspreading threshold has been set for SARS-CoV-2. We defined a SSE as an event involving ten cases.
Results: We analysed 15,706 events associated with 38,670 cases, representing an average of 2.70 cases per event. Most clusters occurred in educational facilities, workplace environments, social care settings, and healthcare facilities. SSEs represented 3.4% but accounted for 28% of all cases reported. The highest number of SSEs occurred in college settings (12.6%), followed by hospitals and retirement homes. Educational facilities had the lowest number of SSEs, with around 1% in preschools and elementary schools.
Conclusions: We observed different SSE rates in each setting. Preschools and primary schools represented the majority of events but experiencing very few SSEs. Colleges were prone to SSEs and were associated with a high number of secondary cases. These findings provide some insights on contact tracing activities and SARS-CoV-2 transmission in different settings.

Introduction

The first imported cases of COVID-19 in France were identified on January 24, 2020 [1]. The pandemic soon spread to the whole country, leading health authorities to implement mandatory public health measures at the individual and population levels. A generalised lockdown began on March 17, 2020, and lasted until May 11, 2020, when the lockdown was partially lifted [2].

The French public health authorities have adopted a three-pronged "test-alert-protect" strategy to prevent the virus from spreading again in the country [3]. The objective is to test every person presenting with COVID-19 symptoms and/or every person in contact with a confirmed or probable case of COVID-19 to rapidly detect new cases, including asymptomatic or presymptomatic cases. A home quarantine is used to prevent further transmission. The contact tracing strategy is structured around three response levels. The first level relies on family physicians tasked with propos-

ing SARS-CoV-2 testing to every member of a household. The second level relies on the French National Health Insurance (FNHI) service for the identification and screening of every person in contact with the index case during the contagiousness period without effective prevention measures. The third contact tracing level relies on the Regional Health Agency (RHA) [4], which is the public health emergency operational centre for each region and includes the regional focal point. RHA is responsible for contact tracing in collective settings (schools, workplace settings, etc.) and collective events (sports events, festive gatherings, etc.).

The collective settings must be investigated, as many contacts occur in these facilities or events, contributing greatly to the spread of the virus. SARS-CoV-2 seems to present a high level of dispersion [5], leading to superspreading events (SSEs), during which one case leads to many secondary cases [6]. A recent study estimated that 19% of COVID-19 cases were responsible for 80% of all transmissions [7]. Several articles have emphasised that some settings are at higher risk of inducing SSEs [8,9]. The limited resources available to limit the spread of COVID-19 could be more narrowly focused and targeted on these settings. We conducted a retrospective analysis of data gathered by the RHA to assess the public health impact of SSEs in various collective settings in Paris in 2020.

Methods

Setting

The Ile-de-France region includes Paris and the Greater Paris area. It is the most populous and the most densely populated region of France, with a population of approximately 12 million [10] (18% of the entire French population). This region also retains the first economic position, representing around 30% of the French gross domestic product (GDP). As the most important French transport hub, it hosts two major international airports and several train stations with national and international connections, thus receiving many national and international tourists.

Database

Every COVID-19 screening in France, performed in either a hospital or an office, is registered in the national SI-DEP database [11]. This database became functional on May 13, 2020, but tests performed before this date were also registered in the database [12]. Based on the results registered in SI-DEP, the FNHI reached out to all confirmed cases to identify contacts. It flagged clusters in collective settings or every individual case in high-risk settings (hospital, social care settings, schools, etc.) to the Ile-de-France RHA. The RHA Ile-de-France then carried out investigations in these settings to monitor the cluster and stop further spread, with assistance from Santé Publique France, the national public health agency.

The database was approved by the French Data Protection Authority and complies with the European General Data Protection Regulation (GDPR). The data examined included the type of setting, the dates of the first and last reported cases, the number of contacts, and the number of secondary cases. This database did not include any nominative data. We restricted our analysis to the data gathered from May 11 to December 31, 2020, during which contact tracing protocols remained unchanged for the Ile-de-France RHA. Until the end of December, the impact of SARS-CoV-2 variants of interest remained relatively low among Ile-de-France's population [13].

Case definition

What we considered as cases were laboratory-confirmed COVID-19 cases (patients with a newly positive SARS-CoV-2 real-

time reverse transcription polymerase chain reaction [RT-PCR] or antigen test on a nasopharyngeal swab).

Superspreading event definition

No definitive threshold has been widely accepted to define SSEs. Endo proposed a definition of SSE events based on R0 and the k dispersion factor [5]. A study by Xu et al. using this method set the SSE threshold to four secondary cases [14], but the data were gathered in China from January to February 2020 when the lockdown and intensive public health measures were implemented, leading to skewed values for the effective reproduction number (R_e) and k factor. We chose not to rely on this SSE definition because we considered that threshold to be too low for our study, considering that the lockdown was lifted during the investigation period. Furthermore, Santé Publique France, the national public health agency defines a cluster as three cases occurring within seven days in the same community or among people attending the same event. Since our database is based mostly on clusters or events occurring in high risk settings, we chose a threshold closer to the one for severe acute respiratory syndrome (SARS) [15]. We defined an SSE as an event involving ten COVID-19 cases or more. This threshold corresponded on a prelimaniry analysis to a selection of more exceptional events.

Statistical analysis

We performed descriptive statistics to describe the events and determine the distribution of the events, the setting of each event, and the number of cases recorded per event. Then, odds ratios (ORs) and 95% confidence intervals (95% CI) were determined using univariate logistic binomial regression. Analyses were performed using RStudio v.1.3.959.

Results

From May 11 to December 31, 2020, 18,977 events were registered in our database. Among these events, 3151 were irrelevant or could not be investigated. A total of 15,706 events were analysed in this paper. The data flow is presented in Fig. 1. The temporal distribution of the events, SSEs, and national public health measures are presented in Fig. 2. SSE cases in May represented 48.62% of all cases. This percentage declined in the following months (down to 12.81%) and rose again in September (38.35%). Of all events investigated in May, 5.84% were SSEs, which declined to 1.49% in August. During the fall, SSEs represented between 3% and 4% of all events investigated.

Descriptive analysis

The observed events were associated with 38,670 cases, leading to an average of 2.70 cases per event. We identified 14 different types of settings based on our data. The most common settings reported were elementary schools (N = 2776) and preschools (N = 2372), including nursery and kindergarten schools. Overall, educational facilities accounted for 54.7% of all signals, followed by workplaces (16.8%), social care settings (11.6%), and healthcare facilities (8.7%). The results for each setting are detailed in Table 1. Overall, SSEs accounted for 3.4% of all signals. Colleges had the highest number of SSEs (12.6%), followed by healthcare facilities (7.9%) and social care settings (7.2% for disability field and 5.9% for nursing homes). Among children, high schools were more at risk of SSEs (5.56%), followed by middle schools (1.6%), elementary schools (0.8%), and preschools (0.7%). SSE cases in college settings represented 75.8% of all cases in that setting, followed by nursing homes (43.4%), disability social care settings (41.9%), and hospitals (41%). In educational facilities, the number of SSE cases was the lowest in
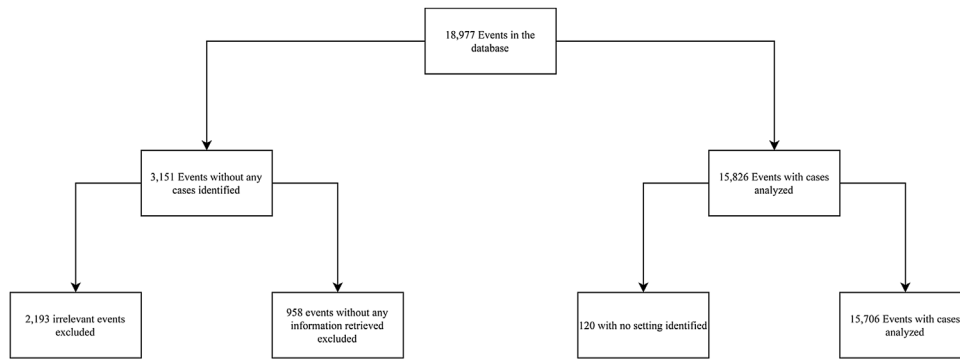
Fig. 1. Flowchart of events selection for analysis. Events considered are situations related to COVID-19 investigated by the Regional Health Agency from May 11 to December 31, 2020. An event was considered irrelevant if no confirmed SARSCoV-2 case was identified, or if the case was not exposed to a collective settings. Events were also excluded if no information could be retrieved.
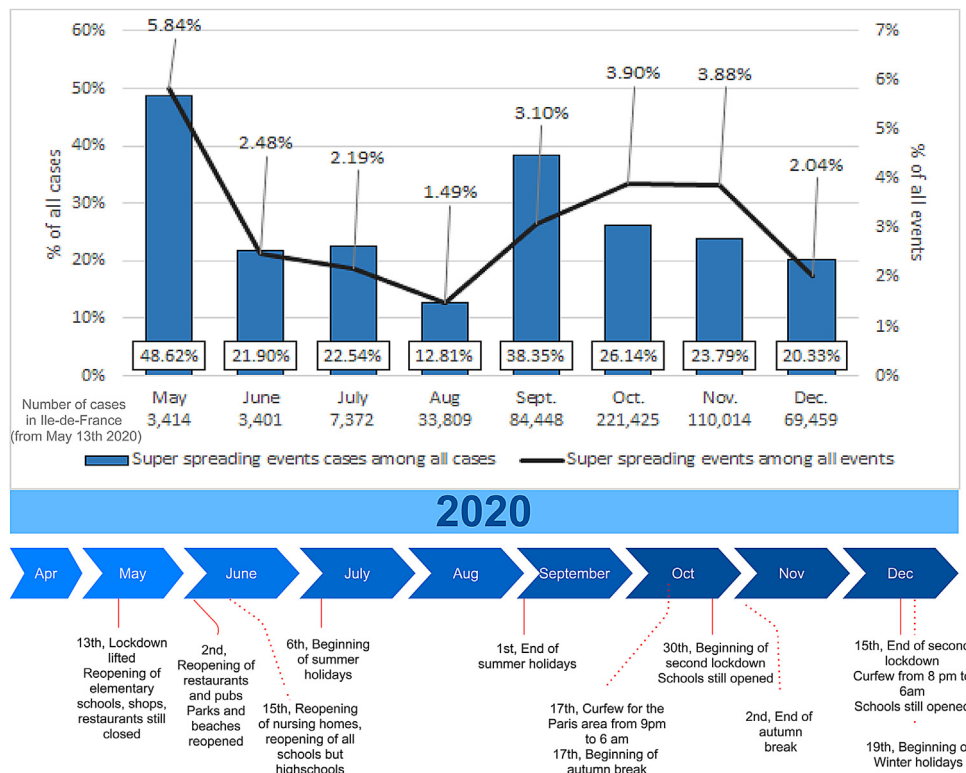
Fig. 2. Temporal distribution of events, superspreading events (SSEs), and French national nonpharmaceutical interventions. SSEs are events involving ten COVID-19 cases or more.

Table 1
Description of COVID-19 events investigated by the Ile-de-France Regional Health Agency from May 11 to December 31, 2020.

| Settings	Total number of events (N = 15,706)	Total number of cases (N = 38,670)	Minimum	Median	Maximum	Interquartile range
Other	381	697	1	1	47	0
Sports	433	771	1	1	38	0
Middle school	1644	3442	1	1	34	1
Pre-school	2372	4009	1	1	25	1
Elementary school	2776	4638	1	1	112	1
Nursing home	390	1037	1	1	41	1
Social care – disability field	994	3106	1	1	47	2
Social care – economically deprived	443	1010	1	1	43	1
Hospital	1388	4850	1	1	101	3
High school	1277	3976	1	2	62	2
Collective gathering	443	753	1	1	19	0
Public sector	1141	2679	1	1	37	1
College	522	3883	1	1	538	3
Private sector	1502	3819	1	1	81	2

Table 2
Description of COVID-19 superspreading events (SSEs) investigated by the Ile-de-France Regional Health Agency from May 11 to December 31, 2020. Odds-ratio for SSE were calculated using univariate logistic regression.

Settings	Number of SSEs	Proportion of SSEs among all events in the setting	Proportion of cases occurring in a SSEs in the setting	Proportion of total SSE cases in all settings	Odds-ratio [95% IC]
Other	10	2.6%	29.7%	1.9%	3.7 [1.6–8.1]*
Sports	9	2.1%	19.1%	1.4%	2.9 [1.3–6.5]*
Middle school	26	1.6%	9.4%	3.00%	2.2 [1.2–4.2]*
Preschool	17	0.7%	5.3%	1.9%	Reference
Elementary school	21	0.8%	9.40%	4.0%	1.1 [0.6–2.0]
Nursing home	23	5.9%	43.4%	4.2%	8.7 [4.6–16.7]**
Social care – disability field	72	7.2%	41.9%	12.0%	10.8 [6.5–19.1]**
Social care – economically deprived	18	4.1%	30.2%	2.8%	5.9 [3.0–11.6]**
Hospital	110	7.9%	41.0%	18.3%	11.9 [7.3–20.7]**
High school	71	5.6%	29.4%	10.8%	8.2 [4.9–14.4]**
Collective gathering	7	1.6%	13.8%	1.0%	2.2 [0.9–5.2]
Public sector	37	3.2%	20.8%	5.1%	4.6 [2.7–8.5]**
College	66	12.6%	75.8%	27.1%	20.1 [11.9–35.6]**
Private sector	47	3.1%	18.5%	6.5%	4.5 [2.7–8.0]**

* p < 0.05.
** p < 0.001.
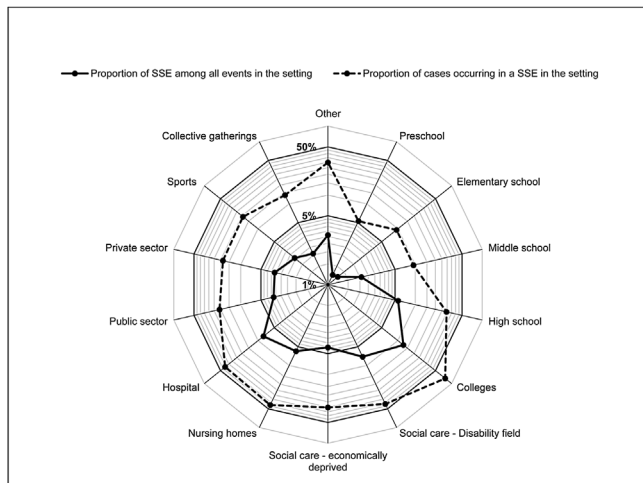
Fig. 3. Proportion of superspreading events (SSE) and associated cases per setting.

middle schools (9.4%), elementary schools (9.4%), and preschools (5.3%).

Among all cases, 10,850 occurred in SSEs, representing 28.0% of all cases reported. Colleges represented 27.1% of the total number of SSE cases, followed by hospitals (18.3%), disability social care facilities (12.0%), and high schools (10.8%). These results are detailed in Fig. 3. We calculated the OR using preschool as a reference category. College has the highest OR for SSE (20.1, 95% CI [11.9–35.6]), followed by hospitals (10.8, 95% CI [66.5–19.1]). Detailed results are presented in Table 2.

Discussion

In this retrospective study, we observed different SSE rates in 14 settings. In colleges, we noted the highest number of SSEs, and cumulative cases in SSEs represented a significant number overall. Health care and social care facilities were also overrepresented in the total number of cases. The events varied greatly in school settings for different age groups, with primary schools and preschool facilities experiencing few SSEs, which led to fewer secondary cases than the rest of the settings. Both public and private workplaces had a low number of SSEs and accounted for roughly the same number of cases overall.

Our results are consistent with other studies showing a high SARS-CoV-2 level of dispersion, and some settings intensively contribute to the risk of propagation around a case [16,17]. The often described notion of a superspreader [18] should be considered carefully, giving special attention to the events and settings surrounding the cases.

We identified several settings associated with few SSEs and a moderate burden caused by these SSEs in the community. These settings were elementary schools and preschool facilities, as suggested also by several recent articles [19,20]. High schools, on the other hand, experienced a high number of cases associated with SSEs, which could be explained by the older population in this setting [21,22], the closer relationships between students, and the interactions that also occur outside schools. Colleges are the ultimate example, with young adults often living in the same facilities, leading to intense contacts between students both in the classrooms and in the students' private lives [23,24].

Private and public sector workplace settings were very similar, with relatively few events occurring but still representing a high burden in the total number of cases. Finally, healthcare and social care facilities experience a relatively high number of SSEs with the highest fatality rates, especially in the elderly population [25]. These findings could lead to an adaptation of control measures to address each risk specifically. Massive screening, information campaigns, and distancing measures, including localised lockdowns in collective settings, could be appropriate in universities, for example. This tailored approach could also take in consideration the negative impact of mitigation measures, such as school closures, which affect childrens' learning abilities and general well-being [26,27]. Over the last months, the French strategy has evolved and offered a tailored approach for each school level, leading to semi-attendance in high schools and full attendance in middle schools [28]. According to our data, this seems to be a relevant approach.

Finally, healthcare and social care settings, which also face an important SSE burden, should be addressed with care, with immediate patient and healthcare professional screenings, educational campaigns, and localised lockdowns to prevent the spread of COVID-19.

Strengths

With more than 15,000 signals analysed during the study period, the strength of this study lies in the size and robustness of our database and the systematic nature of the procedure used to investigate them, which remained stable throughout the study period.

It also provides an original approach to the COVID-19 pandemic, focusing on SSEs in different settings. Finally, the conclusions of this study are globally supported by literature.

Limitations

Our work has several limitations. First, FNHI's reporting of clusters or cases in collective (business settings, collective gatherings, etc.) and high-risk settings to the RHA is based on differentiated procedures. Situations in high-risk settings (hospitals, social care settings, schools) are reported from the first identified case and lead to dedicated screening campaigns. Situations in other collective settings, are reported from the third case identified within a short period = but without a specific screening of the setting, therefore-case identification relies on national contact tracing programmes. Therefore, linking these is not always feasible if the FNHI teams identify these three cases separately in SI-DEP (for example, on different days depending on the availability of the test results). This explains why certain settings are well documented in our database, such as schools or hospitals, and why workplace settings are less so. This, however, has no impact on the SSE dynamics in the categories we studied since this reporting bias has remained unchanged over time.

Second, our database was created to manage the COVID-19 pandemic in collective settings. It includes many details about some settings for which we could not rely on reported data to help conduct the investigation. Unlike hospitals, social care settings, workplaces, and schools, which contributed on-site medical or paramedical staff and field data, sports facilities, outdoor gatherings, and public transportations were incompletely documented. Notably, we cannot separate SSEs occurring indoors from those occurring outdoors, although these data would have been useful.

Third, our data reflect the cases occurring among individuals attending to the described collective events, but infection could be due to shared activities outside the identified setting.

Fourth, our data were from the last quarter of 2020, which faced a second lockdown in France from October 30 to December 15, 2020. With limited data gathered on certain settings, such as collective gatherings or sports events, a different pattern of SARS-CoV-2 transmission could emerge. Furthermore, massive screening campaigns were carried out in schools, which could explain the significant number of cases identified in this setting.

Fifth, the end of 2020 in France was associated with the emergence of variants of concern [29] with differing patterns of transmissibility [30].

Sixth, we faced recall bias due to the declarative nature of the data. This could lead to disproportionate reporting of bigger and unusual events. Some events of interest, such as those occurring in transport settings or mass gatherings, were more rarely described than others. These settings remain important to mitigate the pandemic since they represent opportunities for the virus to spread rapidly over the entire territory [31].

Seventh, we analysed events occurring mostly during the summer, which could lead to different interaction patterns between individuals who spent more time outdoors, which may have led to less secondary transmission than in wintertime. Finally, even though testing capacities have been largely enhanced and made available following the first lockdown, some populations were more likely to be tested, especially hospital staff and patients. Others, such as young children, were less likely to be tested.

Conclusion

Our study provides insight on the spread of SARS-CoV-2 in Ile-de-France in different settings. Specifically, preschools and primary schools represented the majority of events but experienced very few SSEs, while colleges, hospitals and social care settings faced many SSEs. These findings helps support a tailored approach for each setting. Specifically contact-tracing and infection prevention control measures should be reinforced in high school and colleges in order to prevent SSE, while primary schools and preschools could be addressed with less aggressive measures. This approach also allows for the preservation of educational and social acquisitions in younger populations. Our Study is based on data gathered in 2020 before the emergence of variants of concern in France. Variants of concern display a higher probability of transmission [32,33] and have a higher potential for SSEs. The protective measures applied to these variants of concern remain unchanged at both individual (masking, distancing, hand hygiene) and population levels. Therefore, the general conclusions of our study remain valid in 2021.

Contributions

The study was conceived by A.A. and A.D. The constitution of the database was carried out by A.D., C.C. and DM. Data management has been carried out by D.M. and S.M. Data were analyzed by A.D. and interpreted by A.D. and A.A. The first draft of the manuscript was written by A.D., which was revised by all authors. All authors approved the final version of the manuscript.

Competing interests

The authors declare that they have no conflict of interest.

Ethical approval

Not required.

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