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Understanding the local-level variations in seasonality of human respiratory syncytial virus infection: a systematic analysis

Sheng Ye[1†], Shuyu Deng[1†], Yumeng Miao[1], David Torres-Fernandez[2,3], Quique Bassat[2,3,4,5,6,7], Xin Wang[8,9*] and You Li[1,9,10*]

Abstract

Background While previous reports characterised global and regional variations in RSV seasonality, less is known about local variations in RSV seasonal characteristics. This study aimed to understand the local-level variations in RSV seasonality and to explore the role of geographical, meteorological, and socio-demographic factors in explaining these variations.

Methods We conducted a systematic literature review to identify published studies reporting data on local-level RSV season onset, offset, or duration for at least two local sites. In addition, we included three datasets of RSV activity from Japan, Spain, and Scotland with available site-specific data. RSV season onset, offset, and duration were defined using the annual cumulative proportion method. We estimated between-site variations within a region using the earliest onset, the earliest offset, and the shortest duration of RSV season of that region as the references and synthesised the variations across regions by a multi-level mixed-effects meta-analysis. Using the three datasets from Japan, Spain and Scotland, we applied linear regression models with clustered standard errors to explore the association of geographical, meteorological, and socio-demographic factors with the season onset and offset, respectively.

Results We included 7 published studies identified from the systematic literature search. With the additional 3 datasets, these data sources covered 888,447 RSV-positive cases from 101 local study sites during 1995 to 2020. Local-level variations in RSV season within a region were estimated to be 6 weeks (41 days, 95% CI: 25–57) for season onset, 5 weeks (32 days, 13–50) for season offset, and 6 weeks (40 days, 20–59) for season duration, with substantial differences across years. Multiple factors, such as temperature, relative humidity, wind speed, annual household income, population size, latitude, and longitude, could jointly explain 66% to 84% and 35% to 49% of the variations in season onset and offset, respectively, although their individual effects varied by individual regions.

Conclusions Local-level variations in RSV season onset could be as much as 6 weeks, which could be influenced by meteorological, geographical, and socio-demographic factors. The reported variations in this study could have important implications for local-level healthcare resources planning and immunisation strategy.

Trial registration PROSPERO CRD42023482432.

†Sheng Ye and Shuyu Deng contributed equally to this work.

*Correspondence:
Xin Wang
xin.wang@njmu.edu.cn
You Li
you.li@njmu.edu.cn
Full list of author information is available at the end of the article

Keywords Respiratory syncytial virus, Seasonality, Meteorological factors, Socio-demographic factors

Background

Human respiratory syncytial virus (RSV) is a major pathogen causing acute lower respiratory infections and hospitalization among young children and older adults, imposing a considerable burden on healthcare systems worldwide [1, 2]. Understanding RSV seasonality is essential not only for identifying and diagnosing RSV, and managing hospital bed capacity in clinical settings, but also for planning RSV immunisation programs.

Globally, there were several reports of RSV seasonality highlighting the regional variations in RSV seasonal characteristics such as onset, offset, and duration. For example, global-level systematic analyses showed latitudinal gradients in the RSV season onset [3, 4]; the variations in RSV activity were found to be associated with meteorological factors such as temperature and humidity [4]. Similar regional variations were also reported in Europe and the USA, with correlations to meteorological factors [5, 6]. However, even within one region (such as the state of the USA), there remained local-level variations in RSV that could not be fully explained by meteorological factors. A modelling study by Zheng and colleagues analysed RSV hospitalisation data at the ZIP code level in the states of New Jersey, New York, and Connecticut [7]; the authors noted differences of several weeks between different ZIP codes within a state and found that earlier RSV peaks occurred in ZIP codes with higher population density and large average household size [7].

To date, there were no reports that systematically summarised the variations in RSV seasonality at a finer geographical scale. In this study, we aimed to understand the local variations in RSV seasonal characteristics (i.e., RSV season onset, offset, and duration), and how these variations were associated with geographical, meteorological, and socio-demographic factors.

Methods

Data sources

Our study included two data sources: published studies identified by a systematic literature review, and three datasets from Spain, Japan, and Scotland on RSV activity (details are presented below). Both the published studies and the three datasets were used to analyse variations in RSV seasonality while the three datasets were further analysed to understand the role of various geographical, socio-demographic, and meteorological factors in explaining the variations in RSV seasonality.

Systematic literature review

The systematic literature review and meta-analysis part of this study (PROSPERO: CRD42023482432) was reported according to the PRISMA checklist (Additional file 1: Text S1). The literature search was conducted using three electronic databases (MEDLINE, EMBASE, and Web of Science) to identify studies that reported results on local RSV seasonality, with no language restrictions. For each electronic database, a tailored search strategy (Additional file 1: Text S2) was applied that combined the following terms and their synonyms, "respiratory syncytial virus", "season", and "local".

Studies would be considered eligible if they reported data on the onset, offset, or duration of RSV epidemics in a region that consisted of two or more local sites (e.g., counties in a state/province in geographically large countries, or any subnational-level regions in geographically small countries) for at least one complete season. Both clinically diagnosed RSV infection and laboratory-confirmed RSV infection were potentially eligible; in addition, studies that used other proxies of RSV (e.g., bronchiolitis in young children) were also accepted. Considering the impact of the COVID-19 pandemic on RSV seasonality, studies were excluded if they focused on only the COVID-19 period (the analysis included only the pre-COVID-19 period).

In addition to the studies identified from the literature search, we screened all the references of the included studies, as well as published studies that cited these studies using the same eligibility criteria.

For each included study, we used a tailored spreadsheet to extract study-level characteristics (e.g., study site, country, study periods, subject age, confirmation of RSV infection, and sample size) as well as any reported site-specific seasonality results (e.g., onset, offset, and duration of RSV season). We also extracted the underlying data for determining RSV seasons if such data were made available in individual studies. Where necessary, an online software (WebPlotDigitizer) was used to help extract RSV season results or the underlying data from figures in the published studies [8]. Two authors (SY and SD) independently performed the literature search, screening, and extraction. Disagreements were resolved through discussion or arbitrated by YL.

Additional datasets on RSV activity

Three more datasets on RSV circulation were included to further supplement the evidence and data identified from the systematic literature review: prefecture-level weekly number of RSV laboratory-confirmed cases (all ages) in 2013–2019 from the Infectious Diseases Weekly Report (IDWR) published by the National Institute of Infectious Diseases (NIID) in Japan [9], weekly number of hospitalised patients (all ages) with RSV specific clinical diagnosis in 2001–2016 from the Scottish Morbidity Record (SMR) by Scottish NHS health boards [10, 11], and monthly number of hospitalised patients (< 2 years) with RSV specific clinical diagnosis in 2017–2020 from 23 hospitals in different provinces of Spain, from the Paediatric Spanish Society (Asociación Española de Pediatría, AEP) [12]. All additional datasets were cross-checked by SY and YL for completeness and consistency before being included in the analysis. Data from Okinawa (Japan) and the municipality of Las Palmas de Gran Canaria (Spain) were excluded as they were geographically distant from other sites included in those countries.

Quality assessment

Two reviewers (SD and YM) assessed the quality of included studies (also including the additional datasets) using a rating scale which incorporated three questions regarding representativeness of subjects, stability of testing methods and practice, and timeliness of positive case reports, as previously used (Additional file 1: Tables S1–S2) [4, 13, 14]. Each question was rated on a scale of "1–3" points for the included studies, indicating quality from low to high.

Data analysis

Defining RSV season per site

For studies with available RSV activity data, we defined the onset, offset, and duration of RSV season using the annual cumulative proportion (ACP) method as previously used (an intuitive example is available in Additional file 1: Fig. S1); the selection of ACP method over other potential methods was because ACP method could enable direct comparison between results generated by weekly aggregated data and by monthly aggregated data [13]. Briefly, in the ACP method, we divided the time period into 12-month individual intervals in the way that a full RSV seasonal epidemic could be covered by the interval [14]. For example, in the northern hemisphere where RSV seasonal epidemics often occurred from October to March, we selected July as the beginning of the 12-month interval. Once the 12-month interval was determined, we calculated the ACP of RSV-positive cases for each week or month per each 12-month interval. We excluded any intervals where the total number of RSV-positive cases was less than 25. The onset, offset, and duration of RSV season were all based on the ACP. The onset was defined to occur when ACP reached 10% (i.e., the time when 10% of the annual RSV cases have occurred), and the offset, when ACP attained 90%; the duration of RSV season was defined as the time difference between offset and onset.

Quantifying variations in local RSV seasons per region

In this study, we defined site as the smallest geographic unit with available RSV seasonality results and defined region as the collection of individual sites. For each region, we first determined the earliest onset, the earliest offset, and the shortest duration of RSV season among sites, and considered them as the reference onset, offset, and duration, respectively. Subsequently, for each site, we calculated the time difference in the onset, offset, and duration from the reference; such time differences helped quantify how much time later the RSV onset (or offset) occurred at each site compared to the site with the earliest RSV onset (or offset), and how much longer the RSV season persisted at each site compared to the site with the shortest duration.

Data synthesis of variations in local RSV seasons across regions

A multi-level mixed-effects meta-analysis was conducted to synthesise the time difference across regions in the RSV onset, offset, and duration (compared to sites with the earliest onset, offset, and shortest duration), separately, as obtained above. Within each region, we assumed homogeneity regarding the variations in the time difference in the RSV onset, offset, and duration across different years and applied fixed effects; among different regions/studies, we assumed that the true variations in the time difference could differ by regions and applied random effects. As a sensitivity analysis, we excluded studies that used an RSV proxy (e.g., bronchiolitis) when reporting RSV seasonality results.

Factors associated with variations in local RSV seasonality

For the three datasets in Japan, Scotland, and Spain, we further explored whether the observed variations in local RSV seasons could be explained by variations in site coordinates (i.e., latitudes and longitudes), meteorological factors, and socio-demographic factors. We obtained the centroid coordinates of each study site using Google Maps. We extracted the daily average meteorological data from the Global Surface Summary of the Day dataset provided by the US National Centers for Environmental Information, via the R package "GSODR". The variables extracted included temperature, relative humidity, wind speed, and dew point. We collected data on the population size of children under 5 years, population density, average household size, and annual household income from the Spanish National

Statistical Office (INE) for Spain [15], the Japanese Government Statistics for Japan [16], and from Scotland's Census 2011[17, 18] and the National Records of Scotland Web Archive for Scotland [19]. No data on local household income were available in Scotland.

We modelled the local variations in RSV season onset or offset as dependent variables (we did not model RSV duration, as it was determined by onset and offset), using linear regression models with clustered standard errors to account for the potential clustering across years within a region. The independent variables were selected based on the Akaike Information Criterion (AIC), including latitudes, longitudes, and meteorological and socio-demographic factors. For meteorological factors, we used the data on the day of RSV onset/offset of the corresponding reference site (same to our previously published analysis) [14]; considering daily variations in meteorological factors and the possible lagged effect, we used the 3-day average temperature rather than a daily temperature in the main analysis, we considered a 7-day average and a daily temperature in sensitivity analyses.

We compared models with all possible combinations of independent variables (with the exception for variables expected to have high cross-correlations that lead to multicollinearity such as temperature and dew point, detailed in Additional file 1: Text S3) and selected the best model based on the lowest AIC for assessing the relationships between specific factors and variations in the local RSV onset and offset. To control for the increased type I errors due to multiple comparisons, the Benjamini–Hochberg method was used to determine the adjusted *P*-value.

Statistical software

Data were analysed and visualized with the R software (version 4.1.2).

Results

After removing duplicates, 7 studies met inclusion criteria from 5951 screened records (Fig. 1) [20–26]. With the three additional datasets from Spain, Japan, and Scotland, a total of 101 local study sites were included, providing 888,447 RSV-positive cases (or proxies) between

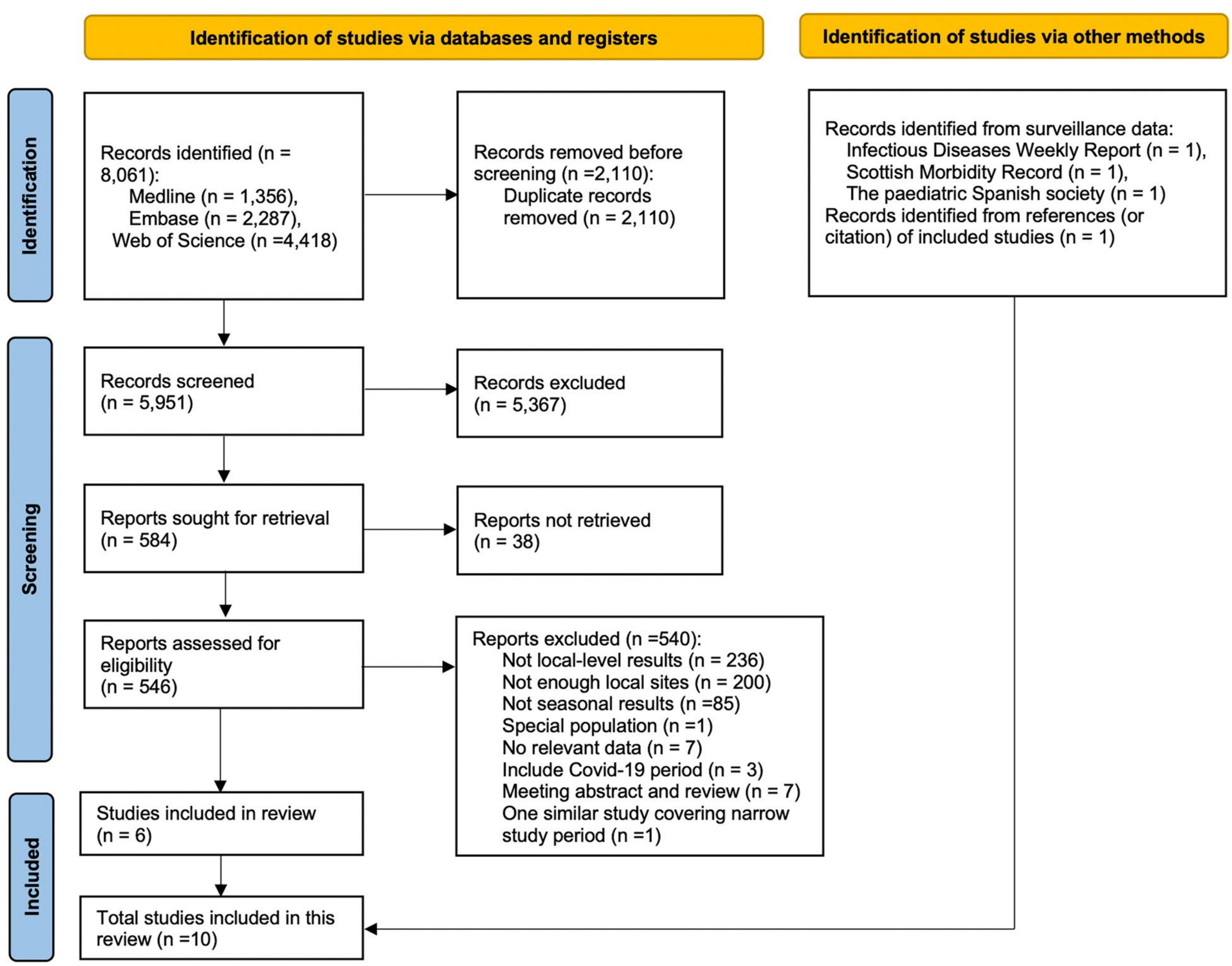

Fig. 1 PRISMA flow diagram of the study inclusion

Table 1 Characteristics of included studies

Reference	Study period	No. of local sites	Region/country	Setting	Age of subjects	No. of tested samples	Testing method	No. of RSV positives
Artin, 2021 [20]	1996–2013	4	Connecticut, USA	Hospital	< 2 y	300,693	ICD-9-CM codes	9701
Bauman, 2007 [21]	1999–2004	4	Florida, USA	Hospital;	All ages	NA	NA	NA
Wilfret, 2008 [22]	2003–2006	4	North Carolina, USA	Hospital; Community	Children	13,920	Antigen detection; Viral culture	3297
Lewis, 2020 [23]	2011–2016	9	England, UK	Hospital	< 1 y	3,727,013	ICD-10 codes	155,485
Hogan, 2016 [24]	2000–2013	8	Western Australia, Australia	Hospital	< 17 y	469,589	Multiple	11,840
Lee, 2023 [25]	1995–2005	2	Taiwan, China	Hospital	< 18 y	NA	Multiple	1,740
Minney-Smith, 2023 [26]	2012–2020	2	Western Australia, Australia	Hospital; Community	All ages	144,590	RT-PCR; Immunofluorescence	12,424
Infectious Diseases Weekly Report [9]	2013–2019	46	Nationwide, Japan	Hospital	All ages	NA	NA	672,526
Scottish Morbidity Record [10, 11]	2001–2016	10	Scotland, UK	Hospital	All ages	NA	ICD-10 codes	3,132
The Paediatric Spanish Society [12]	2016–2020	11	Nationwide, Spain	Hospital	< 2 y	NA	NA	15,170

NA, not available; *y*, year; *ICD*, International Classification of Diseases; *RT-PCR*, real-time polymerase chain reaction

1995 and 2020 (Table 1). The included studies were of moderate to high quality, with strong representativeness of subjects and timely reporting of test results, although there was some variability in the stability of test methods and practices. The quality assessment of included studies and datasets is provided in Additional file 1: Table S2.

Local variations in RSV onset, offset, and duration within a region

The full summary of RSV onset, offset, and duration in each site of region is available in Additional file 1: Table S3. Most of the local variations were associated with geographic characteristics of the sites. For example, the RSV season onset in southern Taiwan (lower latitude) was approximately 3 weeks earlier than northern Taiwan (higher latitude) [25]; in Western Australia, sites in the north (lower latitude) had earlier onset and longer duration than sites in the south (higher latitude) [24, 26]. In addition to geographic characteristics, in the state of Connecticut, USA, counties with low population had the latest onset (up to four weeks later than other counties) and shortest duration (up to five weeks shorter) [20]. However, not all regions had substantial variations across sites; in England, the variations in RSV onset, offset, and duration were no longer than one week [23].

Within a region, there were substantial year-on-year variations in the differences between RSV onsets in different locations. In Scotland, for example, the mean delay in RSV onset compared to the site with the earliest RSV onset ranged from 28 days in the 2002–2003 season to 90 days in the 2006–2007 season (Fig. 2). Similar to RSV onsets, the year-on-year variations in the differences between RSV offsets in different locations within a region were substantial (Fig. 3).

Synthesised local-level variations in RSV onset, offset, and duration across regions

Meta-analysis results showed that compared to sites with the earliest RSV onset, RSV onset was delayed approximately 6 weeks (41 days, 95% CI: 25–57) in the same region (Fig. 2). Variations in RSV offsets were overall similar to those in RSV onsets despite with a lower point estimate of the pooled delay, which was approximately 5 weeks (32 days, 95% CI: 13–50) (Fig. 3). The pooled local differences in RSV duration were between those in RSV onset and in RSV offset; compared to the site with shortest RSV duration, the average RSV duration was approximately 6 weeks longer (40 days, 95% CI: 20–59) (Fig. 4).

In our sensitivity analysis, we excluded the study that used an RSV proxy when reporting RSV seasonality results [23]. Consistent results were observed in RSV onset (46 days, 95% CI: 33–59), offset (27 days, 95% CI: 11–43), and duration (44 days, 95% CI: 24–64) (Additional file 1: Figs. S2–S4). More detailed visualisations of local RSV seasonal results for individual study sites

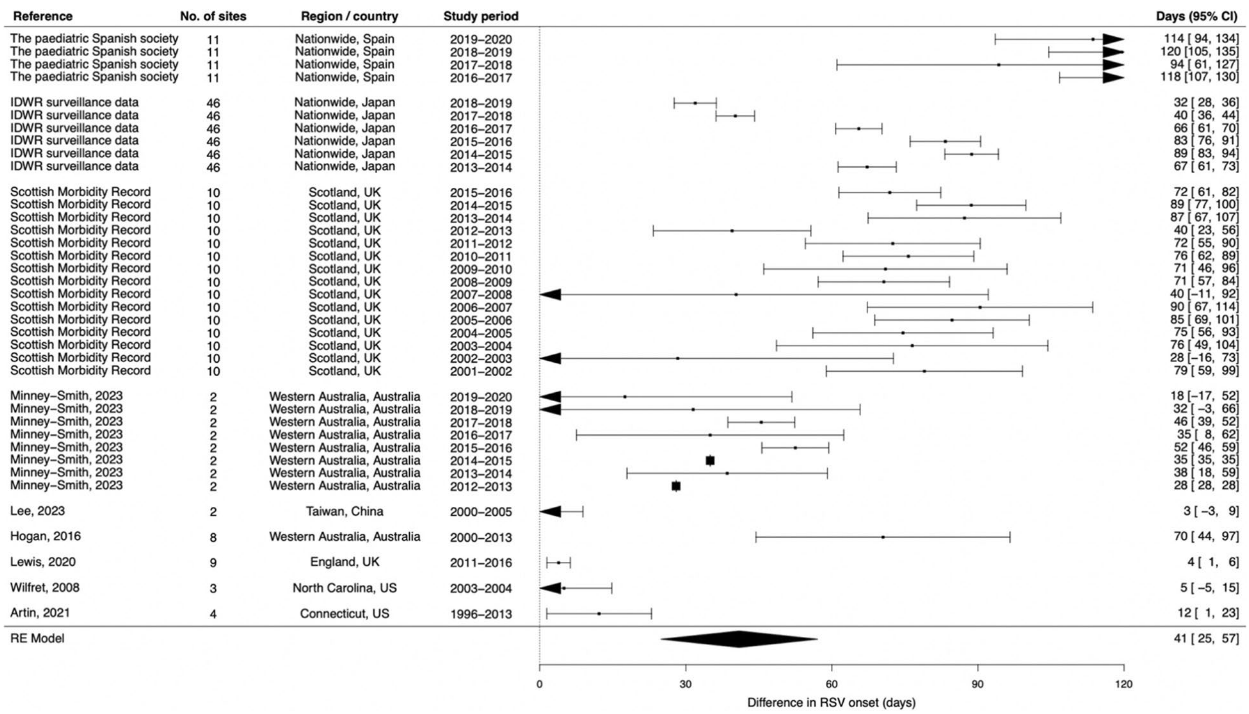

Fig. 2 Forest plots of variations in local RSV onset across study regions. A random-effects (RE) model was used for the meta-analysis. Results are shown as differences in days (95% CI). The squares represent the estimated local day-difference in RSV onset, with the size of each square proportional to the weight of the study. The error bars represent the corresponding 95% confidence intervals (CI). The centre of the diamond indicates the overall estimated day-difference across all studies, with the width of the diamond representing the pooled 95% CI

in Japan, Scotland, and Spain can be found in Additional file 1: Fig. S5 and Movies S1–S3.

Factors associated with variations in local RSV seasonality

The best models selected based on AIC could explain 66% to 84% of the variations in RSV season onset in Spain, Japan, and Scotland. Temperature was selected in all the three country-specific models, with higher temperature consistently associated with earlier RSV onset. Other meteorological factors (relative humidity and wind speed), latitude, and socio-demographic factors (population size of children < 5 years and annual household income) were selected in one or two country-specific models. However, factors that were selected in two country-specific models did not have consistent association results between countries; for example, higher annual household income was associated with earlier season onset in Spain and later season onset in Japan (Table 2).

Fewer variations in RSV season offset could be explained than RSV season onset, ranging from 35 to 49% across the three countries. Similar to RSV season onset, temperature was selected in all the three country-specific models, with higher temperature consistently associated with later RSV offset. Latitude, longitude, and relative humidity were selected in one or two country-specific models (Table 2).

The sensitivity analysis using a 7-day average and daily meteorological factors as the reference showed similar variations in explaining RSV onset and offset (Additional file 1: Tables S4–S5).

Discussion

To the best of our knowledge, this is the first systematic analysis to examine RSV seasonal variations at a finer geographical scale, exploring the possible effects of meteorological, socio-demographic, and geographical on RSV circulation and transmission. We showed that the local-level variations in RSV season within a region could be as much as 6 weeks for season onset, 5 weeks for season offset, and 6 weeks for season duration. Multiple factors, such as temperature, relative humidity, wind speed, annual household income, population size, latitude, and longitude, could jointly explain 66% to 84% of the variations in RSV season onset, and 35% to 49% of the variations in RSV season offset. These findings improve the understanding of RSV seasonal variations at local level and have important implications for RSV prevention

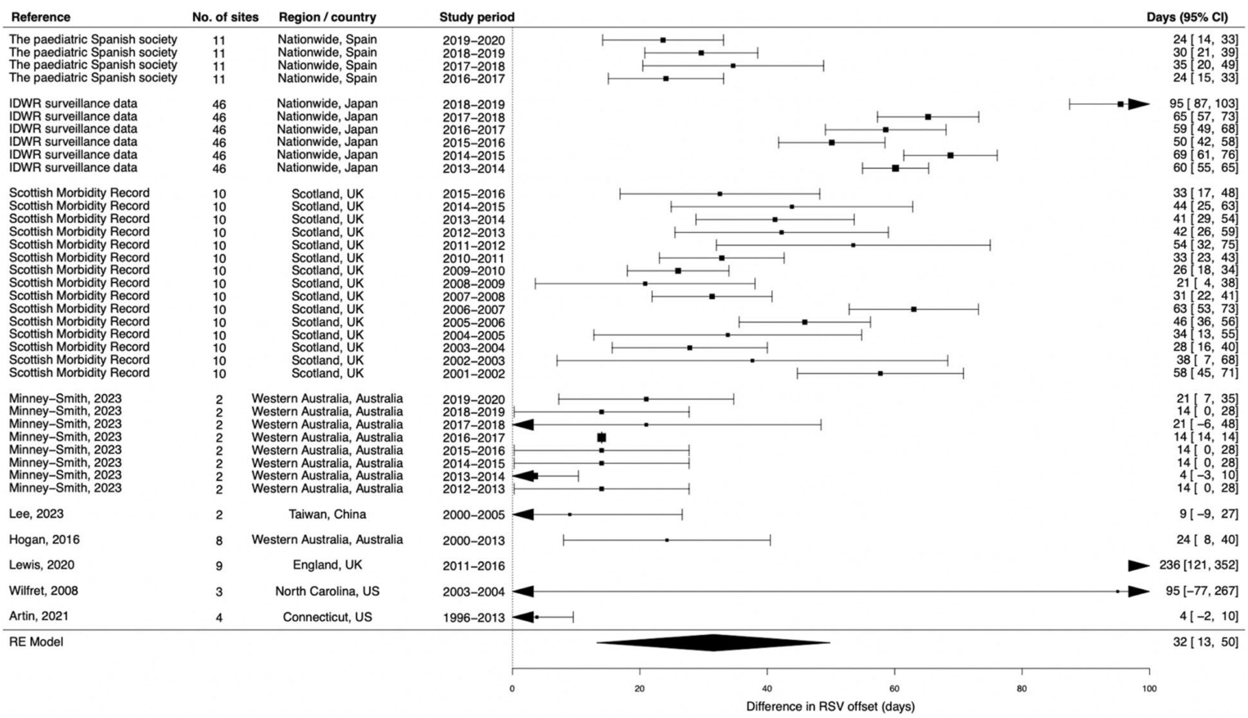

Fig. 3 Forest plots of variations in local RSV offset across study regions. A random-effects (RE) model was used for the meta-analysis. Results are shown as differences in days (95% CI). The squares represent the estimated local day-difference in RSV onset, with the size of each square proportional to the weight of the study. The error bars represent the corresponding 95% confidence intervals (CI). The centre of the diamond indicates the overall estimated day-difference across all studies, with the width of the diamond representing the pooled 95% CI

efforts, including timing of vaccination and anticipation of hospital bed pressure.

Temperature was found to be an important factor that explained the variations in RSV season onset and offset in temperate regions in this study. At the local level, we showed that higher temperature was associated with earlier onset and later offset (i.e. longer season duration). However, this finding should not be generalised to other climatic settings such as the tropics; temperature alone cannot fully explain local seasonal variability, as its role is expected to vary across regions and climates. Instead, multifactorial interactions, such as the combined effects of temperature and humidity and other climatic variations, likely contribute to RSV transmission dynamics. Independently from meteorological factors, longitude and latitude were also found to be associated with RSV season onset and offset in Spain and Japan, suggesting the possible role of population mobility in RSV circulation and transmission although we could not further explore this factor due to the scarcity of local-level transportation data.

We found that socio-demographic factors, namely population size of young children and household income, were correlated with variations in RSV onset at the local level in Spain and Japan. These factors could determine the risk for RSV transmission, contact frequencies, and health-care-seeking behaviours in the community. In Spain, a locale with a larger population size of young children was associated with later RSV onset, we suspect that this might be related to the varied social interaction patterns in different locales although we did not have available data for further assessment. Additionally, locale with higher annual household income was associated with earlier RSV onset, consistent with the finding from an earlier study by Zheng and colleagues that higher median income was associated with earlier onset in New Jersey [7]. However, the direction of the correlation for population size of young children and household income in Japan was contrasting to Spain, possibly due to a different household and community structure. Future studies could investigate the varied behavioural contexts in explaining these inconsistencies.

The advantages of this study include the application of a uniform analytical method for understanding the local-level variations in RSV seasonality and the inclusion of large datasets from Japan, Spain, and Scotland for exploring the underlying factors that could explain

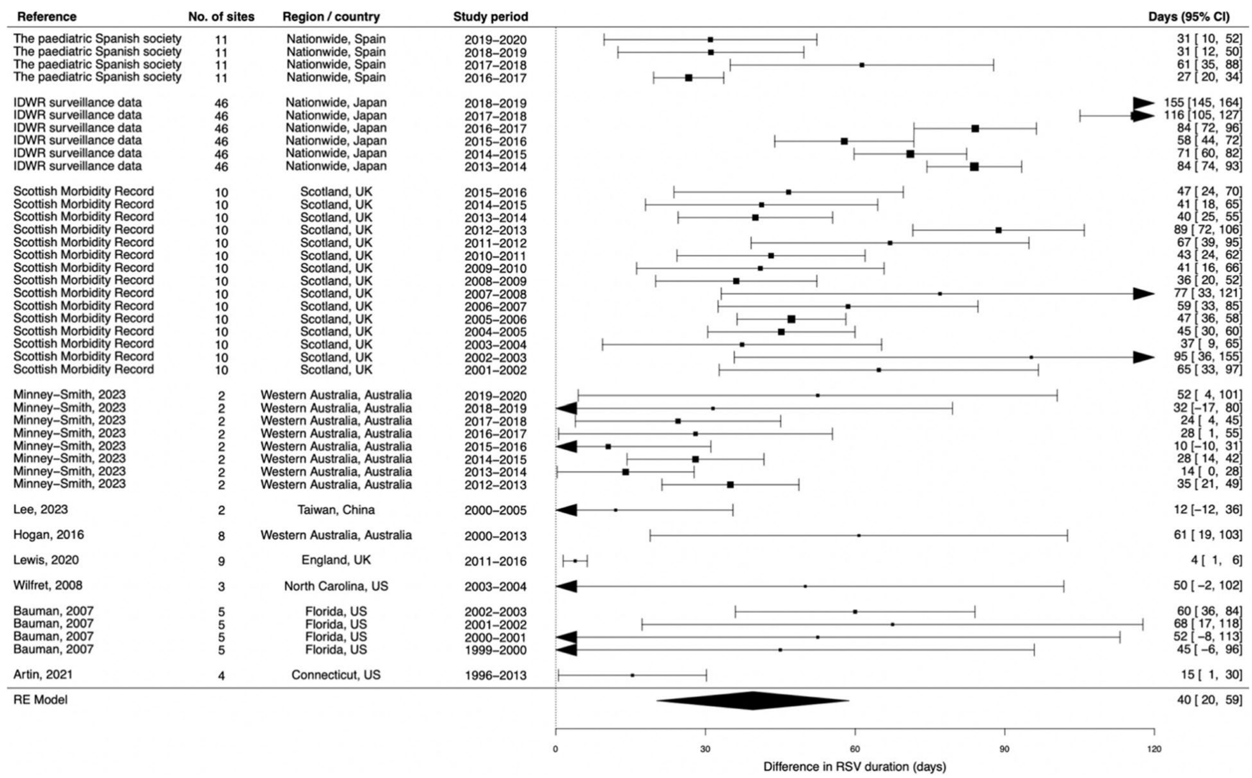

Fig. 4 Forest plots of variations in local RSV duration across study regions. A random-effects (RE) model was used for the meta-analysis. Results are shown as differences in days (95% CI). The squares represent the estimated local day-difference in RSV onset, with the size of each square proportional to the weight of the study. The error bars represent the corresponding 95% confidence intervals (CI). The centre of the diamond indicates the overall estimated day-difference across all studies, with the width of the diamond representing the pooled 95% CI

the variations. Despite these advantages, we acknowledge some limitations in this study. Firstly, despite the efforts in identifying eligible studies and data that were relevant to the study question, the total number of studies included in this study was relatively small and represented exclusively high-income economies in temperate regions. In particular, the identified factors associated with variations in RSV seasonality, such as temperature, might not be generalised to tropical settings where humidity or rainfall might have played a more important role. Secondly, although the model in our study demonstrated a high R-squared value, the estimated effects of individual factors (meteorological, socio-demographic, and geographic factors) must be interpreted with caution due to the likely presence of residual confounding from factors, such as population susceptibility, contact behaviour, and population mobility patterns. Thirdly, we acknowledge that the lack of a unified definition for RSV seasonality among the included studies may lead to a potentially biased estimate of the absolute timing of season onset or offset. Nonetheless, as the focus of the study was to understand the relative differences in the season onset or offset between sites that applied the same definition, we did not anticipate that our findings were substantially impacted. Moreover, our study was based on data of RSV cases mostly from hospitalised patients, and could not fully represent RSV seasonality in the community setting; there is a time lag between disease onset and progression to the level of severity that warrants seeking medical care, which could be further complicated by variations in health-care seeking behaviour. Lastly, our study did not consider the impact of the COVID-19 pandemic on RSV by including only the pre-pandemic data, and we didn't include additional datasets of Southern Hemisphere, which may cause bias.

Conclusions

By quantifying the local-level variations in RSV season onset, offset, and duration and identifying underlying meteorological, geographical, and socio-economic factors that could explain these variations, this study

Table 2 Association between geographical, meteorological factors and socio-demographic factors with RSV season onset and offset

Region	Best model	Difference in RSV onset					Difference in RSV offset		
Nation-wide, Spain	**Variables**	Temperature (per 1 °C)		Relative humidity (per 5%)	Population size <5 years old (per 10,000 people)	Annual household income (per 1000 euro)	Longitude (per 1°)		Temperature (per 1 °C)
	Estimate	− 4.73 days		0.54 days	1.99 days	− 4.77 days	− 2.76 days		19.33 days
	95% CI	[− 5.66, − 3.81]		[0.18, 0.90]	[1.15, 2.82]	[− 6.43, − 3.12]	[− 4.14, − 1.38]		[6.21, 32.44]
	Adjusted 95% CI	[− 7.79, − 1.68]		[0.11, 0.96]	[0.44, 3.54]	[− 8.42, − 1.13]	[− 4.95, − 0.57]		[3.99, 34.67]
	Adjusted R^2	0.84					0.49		
	AIC	362.83					349.00		
Nation-wide, Japan	**Variables**	Latitude (per 1°)	Temperature (per 1 °C)	Relative humidity (per 5%)	Population size <5 years old (per 10,000 people)	Annual household income (per 1000 euro)	Longitude (per 1°)	Latitude (per 1°)	Temperature (per 1 °C)
	Estimate	− 4.49 days	− 5.76 days	− 0.40 days	− 0.73 days	1.79 days	− 3.66 days	7.61 days	9.23 days
	95% CI	[− 6.07, − 2.90]	[− 6.19, − 5.33]	[− 0.60, − 0.20]	[− 1.13, − 0.33]	[0.73, 2.85]	[− 5.41, − 1.92]	[4.91, 10.31]	[1.92, 16.65]
	Adjusted 95% CI	[− 8.54, − 0.44]	[− 7.57, − 3.95]	[− 0.76, − 0.05]	[− 1.36, − 0.10]	[0.26, 3.32]	[− 6.87, − 0.45]	[0.74, 14.48]	[1.64, 16.83]
	Adjusted R^2	0.75					0.35		
	AIC	2249.05					2548.23		
Scotland, UK	**Variables**	Temperature (per 1 °C)		Wind speed (per 1m/s)			Temperature (per 1 °C)		Relative humidity (per 5%)
	Estimate	− 6.25 days		2.77 days			5.48 days		− 0.62 days
	95% CI	[− 7.16, − 5.34]		[0.86, 4.67]			[4.19, 6.77]		[− 1.08, − 0.16]
	Adjusted 95% CI	[− 10.49, − 2.55]		[0.49, 5.04]			[1.04, 9.93]		[− 1.13, − 0.11]
	Adjusted R^2	0.66					0.46		
	AIC	810.06					804.08		

AIC Akaike Information Criterion, *CI* Confidence interval

improves the understanding of RSV circulation and transmission patterns at the local level. By quantifying the time lag in RSV onset compared to the site with the earliest RSV onset, our study can help inform local-level healthcare services planning and preparedness as well as immunisation programme, particularly when RSV cases are identified early in a site of the same region. Future studies may investigate the role of population susceptibility, contact behaviour, and population mobility patterns in local-level RSV transmission.

Abbreviations

ACP	Annual cumulative proportion
AEP	Paediatric Spanish Society (Asociación Española de Pediatría)
AIC	Akaike Information Criterion
CI	Confidence interval
IDWR	Infectious Diseases Weekly Report
NHS	National Health Service
NIID	National Institute of Infectious Diseases
RSV	Respiratory syncytial virus
RT-PCR	Reverse transcription polymerase chain reaction
SMR	Scottish Morbidity Record

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12916-025-03888-4.

Additional file 1. Text S1. PRISMA 2020 checklist. Text S2. Search Strategy. Text S3. Combinations of meteorological factors not considered. Table S1. Quality assessment criteria. Table S2. Quality assessment results. Table S3. Summary of RSV seasonality results from individual sites of each region. Table S4. Sensitivity analysis by using daily meteorological factors as the reference. Table S5. Sensitivity analysis by using a 7-day average of the meteorological factors as the reference. Figure S1: Diagram of the ACP method. Figure S2. Sensitivity analysis for RSV onset by excluding studies that used an RSV proxy. Figure S3. Sensitivity analysis for RSV offset by excluding studies that used an RSV proxy. Figure S4. Sensitivity analysis for RSV duration by excluding studies that used an RSV proxy. Figure S5. Local variations in RSV season onset, offset and duration across study sites. Movie S1. Local difference in RSV onset, offset, and duration across study sites throughout Japan. Movie S2. Local difference in RSV onset, offset, and duration across study sites throughout Scotland. Movie S3. Local difference in RSV onset, offset, and duration across study sites throughout Spain.

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Authors' Twitter handles

Twitter handles: @you_li2 (You Li); @XinWang1991 (Xin Wang).

Authors' contributions

YL and XW conceived the study. SY and SD led data collection with inputs from YM, DTF and QB. SY and YL led data interpretation with inputs from XW. SY drafted manuscript with inputs from YL and SD. YM, DTF, QB and XW reviewed the manuscript. All authors read and approved the final draft for submission. SY, SD and YL had full access to all the data in the study and had final responsibility for the decision to submit for publication.

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Data availability

The data used in the systematic review are derived from publicly available sources (MEDLINE, EMBASE, and Web of Science). Supplementary datasets could be available only from the corresponding author on reasonable request (you.li@njmu.edu.cn).

Declarations

Ethics approval and consent to participate

Not applicable. As a systematic analysis of previously published data, this work did not require ethical approval.

Consent for publication

All authors have read and agreed to the published version of the manuscript.

Competing interests

YL reports grants by GSK, MSD, and WHO; and personal fees from Pfizer, MSD, and WHO, outside the submitted work. All other authors declared no competing interests.

Author details

[1]Department of Epidemiology, National Vaccine Innovation Platform, School of Public Health, Nanjing Medical University, Nanjing, China. [2]ISGlobal, Barcelona, Spain. [3]Facultat de Medicina i Ciències de La Salut, Universitat de Barcelona (UB), Barcelona, Spain. [4]Centro de Investigação em Saúde de Manhiça (CISM), Maputo, Mozambique. [5]ICREA, Pg. Lluís Companys 23, 08010 Barcelona, Spain. [6]Pediatrics Department, Hospital Sant Joan de Déu, Universitat de Barcelona, Esplugues, Barcelona, Spain. [7]CIBER de Epidemiología y Salud Pública, Instituto de Salud Carlos III, Madrid, Spain. [8]Department of Biostatistics, National Vaccine Innovation Platform, School of Public Health, Nanjing Medical University, Nanjing, China. [9]Usher Institute, The University of Edinburgh, Edinburgh, UK. [10]Changzhou Third People's Hospital, Changzhou Medical Center, Nanjing Medical University, Changzhou, China.

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