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Global analysis of respiratory viral circulation and timing of epidemics in the pre–COVID-19 and COVID-19 pandemic eras, based on data from the Global Influenza Surveillance and Response System (GISRS)

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ABSTRACT

Objectives: The COVID-19 pandemic significantly changed respiratory viruses' epidemiology due to non-pharmaceutical interventions and possible viral interactions. This study investigates whether the circulation patterns of respiratory viruses have returned to pre-pandemic norms by comparing their peak timing and duration during the first three SARS-CoV-2 seasons to pre-pandemic times.

Methods: Global Influenza Surveillance and Response System data from 194 countries (2014-2023) was analyzed for epidemic peak timing and duration, focusing on pre-pandemic and pandemic periods across both hemispheres and the intertropical belt. The analysis was restricted to countries meeting specific data thresholds to ensure robustness.

Results: In 2022/2023, the northern hemisphere experienced earlier influenza and respiratory syncytial virus (RSV) peaks by 1.9 months (P <0.001). The duration of influenza epidemics increased by 2.2 weeks (P <0.001), with RSV showing a similar trend. The southern hemisphere's influenza peak shift was not significant (P = 0.437). Intertropical regions presented no substantial change in peak timing but experienced a significant reduction in the duration for human metapneumovirus and adenovirus (7.2 and 6.5 weeks shorter, respectively, P <0.001).

Conclusions: The pandemic altered the typical patterns of influenza and RSV, with earlier peaks in 2022 in temperate areas. These findings highlight the importance of robust surveillance data to inform public health strategies on evolving viral dynamics in the years to come.

Introduction

The emergence of the COVID-19 pandemic, caused by SARS-CoV-2, has undeniably reshaped life on a global scale. As infection rates and fatalities surged to historic proportions, initial strategies to combat the crisis revolved around non-pharmaceutical interventions (NPIs), such as the use of facemasks, physical distancing, travel bans, and lockdowns, considering the absence of available vaccines or targeted therapeutics. Characterized by a spectrum of actions spanning individual precautions to broader societal measures, NPIs aimed to curtail the rapid dissemination of the virus [1]. By carefully designing policies to implement NPIs aimed at reducing the spread of respiratory viruses, the impact has gone beyond just SARS-CoV-2. As a result, noticeable changes have occurred in the usual patterns of how common respiratory viruses, such as influenza viruses and respiratory syncytial virus (RSV), spread throughout the year [2]. Essentially, the combination of the COVID-19 pandemic and the strategic use of NPIs triggered a series of significant changes that extended beyond immediate infection control measures.

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Influenza viruses, endemic human coronaviruses, RSV, and human metapneumovirus (hMPV), tend to follow typical patterns in temperate climate regions, with the highest numbers of detections during the winter months [3–5]. On the other hand, adenoviruses, human bocaviruses, and rhinoviruses can be found all year round [6,7]. After the emergence of SARS-CoV-2, a decrease in activity was observed for nearly all these respiratory viruses, with a few exceptions (rhinoviruses and other enteroviruses were reported increasing their activity as of June 2020) [8–10].

Currently, it remains uncertain whether influenza and other respiratory viruses will return to their typical circulation patterns or adapt to a new normality. Foreseeing when respiratory virus epidemics will occur is crucial in the field of public health; as an example, planning when to run influenza vaccination campaigns depends on the expected timing patterns of when the virus is spreading the most. Moreover, giving preventive treatments to high-risk infants for RSV needs to match the start of RSV outbreaks. By knowing and adjusting for the timing of respiratory virus epidemics, we can protect those who are most at risk, improve how ready we are for health care challenges, and lower the overall impact of these diseases.

The aim of this study was to analyze the global seasonal patterns and timing of major respiratory viruses, including influenza viruses, RSV, adenoviruses, hMPV, human parainfluenza viruses (hPIV), rhinoviruses, human coronaviruses, and bocaviruses, and, in particular, to compare patterns of circulation in the pre–COVID-19 era with those observed in the three seasons of the COVID-19 pandemic.

Methods

World Health Organization (WHO) FluNet database

FluNet (https://www.who.int/tools/flunet), managed by WHO, offers a freely available web-based repository that compiles weekly laboratory-confirmed viruses detection data from 194 countries, territories, and dependencies (referred to as countries henceforth for brevity) through the WHO regional databases and direct contributions from National Influenza Centers and other reference laboratories involved in the Global Influenza Surveillance and Response System (GISRS). Formerly, the database provided information on influenza viruses, whereas, currently, it includes the weekly number of detections of adenoviruses, bocaviruses, human coronaviruses, hMPV, hPIV, RSV, and rhinoviruses. For the present analysis, on July 10, 2023, we downloaded the weekly number of laboratory-confirmed cases for each virus that were reported between weeks 01/2014 and 26/2023.

Definitions and preliminary analysis

A country was assigned to belong to the northern hemisphere if its centroid lies north of the Tropic of Cancer, to the southern hemisphere if it lies south of the Tropic of Capricorn, or to the intertropical belt (ITB) if it lies between the tropics. The unit of analysis was the "country-season" (for conciseness, referred to as season hereafter), defined as the calendar year for countries in the southern hemisphere and the ITB or the period from week 27 in a year to week 26 next year for countries in the northern hemisphere (where epidemics caused by most respiratory viruses typically take place in autumn and winter, thus bridging 2 calendar years). In what follows, "season 2022" will refer to the calendar year 2022 in the southern hemisphere and the ITB or to the period between the weeks 27/2022 and 26/2023 in the northern hemisphere.

In the WHO FluNet database, each country can contribute data labeled as the following

- "Sentinel surveillance:" data gathered regularly and systematically within sentinel surveillance systems.
- "Non-sentinel surveillance:" data originating from outbreak investigations, universal testing, point-of-care testing, or other testing systems apart from surveillance.
- "Not defined:" data lacking a specific categorization (possibly including combined sentinel and non-sentinel data).

We conducted a preliminary exploration of the WHO FluNet database with the aim of verifying its utility for the purposes of the present analysis. In detail, we compared sentinel and non-sentinel data (in countries where data of both types were available during the same season[s]) to quantify the differences in the timing of primary peaks of influenza virus detections (for 2014-2019) when using either data type, with the aim to assess the reliability of the non-sentinel data for the study of the timing of epidemics.

Influenza positivity rate

The FluNet database includes a "specimens processed" variable that only pertains to influenza virus detections (WHO, personal communication, March 2023). Furthermore, only sentinel surveillance systems routinely report the number of influenza virus detections alongside the number of processed specimens. Thus, the season-specific positivity rate for influenza for a given country was calculated as the ratio of the number of detections over the number of tested specimens reported by sentinel systems. To reduce the level of uncertainty, we restricted the analysis to the seasons with $\geq$30 reported weeks of observation and $\geq$50 processed specimens. The positivity rate for influenza for each country was separately calculated in the pre–COVID-19 period (2014-2019) and in each of the three following seasons (2020, 2021, and 2022). The 2019/2020 season was considered as part of the pre-pandemic period also for northern hemisphere countries because the COVID-19 pandemic was declared on March 11, 2020 when the period of maximum circulation of most respiratory viruses is usually approaching its end. We, then, calculated the median global and regional influenza virus positivity rate (and interquartile range [IQR]) for each period.

Peak timing

We used the EPIPOI software (https://www.epipoi.info/) to analyze country-specific influenza time series in 2014-2019 to determine the typical timing of the peak of activity for each respiratory virus [3,11]. To ensure the robustness of our results, we decided to include in the analysis only the seasons with $\geq$30 weeks of observation and $\geq$50 detections for influenza and RSV.

For the other respiratory viruses, the minimum number of detections per season was lowered to 20, in the attempt to retain a sufficiently high number of countries and seasons, given the lower number of detections for these viruses than influenza and RSV.

The forementioned approach was not suitable for analyzing individual seasons; thus, in each of the three seasons after the emergence of COVID-19 (2020, 2021, and 2022), the timing of the peak was defined as the week where the 3-week moving average of reported detections for each virus when it reached its maximum value. The timing of the virus-specific peak was calculated separately for the seasons 2020, 2021, and 2022, considering the disrupted seasonality of most respiratory viruses' circulation during the COVID-19 pandemic.

Finally, we aimed to investigate whether the timing of epidemics in the most recent season included in our analysis had

returned to overlap with that typical of before the COVID-19 pandemic. To that extent, we calculated the difference between the timing of the peak in 2022 and the typical timing for the pre-pandemic period (2014-2019) separately for each respiratory virus and in each country. Scatterplots were created to illustrate the results, and the sign test was used to assess statistical significance of the median difference in the timing of the peak between the season 2022 and the pre–COVID-19 period in the attempt to identify the trends of anticipation or delay. For our analysis, data on influenza A and B were merged, with the aim of offering a comprehensive overview of influenza seasonality and to better inform vaccination timing and coverage to eventually optimize public health outcomes. This approach aligns with practical public health objectives, given the unified nature of influenza vaccination, which targets the A and B strains.

Duration of the epidemics

The virus-specific epidemic duration is a useful measure for anticipating health care demands because a steeper epidemic curve can significantly strain resources even if it is short-lived. It also aids in optimizing the timing of interventions, such as vaccination campaigns. We determined the duration for each season and country through the average annual percentage method, whereby the duration is defined as the briefest continuous period during which at least 75% of all reported detections occurred within the season [3]. This analysis was separately conducted in the 2014-2019 period and in each of the three subsequent seasons. For each virus, we applied the Wilcoxon signed-rank test to compare the country-specific median duration of epidemics in the pre-pandemic period with that in 2022.

Software

All analyses were conducted using Stata version 17 (Stata Corp, College Station, TX, USA), the ggplot 2 package in RStudio version 2023.06.1 (Posit Software, PBC, Boston, MA, USA, http://www.posit.co/.) and the freely available analytical software EPIPOI (https://www.epipoi.info/) [11].

Results

Data availability

The number of seasons with data and the number of detections of each respiratory virus reported during the study period for the 176 countries included in the analyses are available in Supplementary Tables 1 and 2. The most included countries are in the northern hemisphere (n = 84) or in the ITB (n = 86), whereas six countries are in the southern hemisphere. The WHO region with the highest number of countries reporting data for at least one virus was the European region (54 countries, 30.7%), followed by the region of the Americas (46, 26.1%), the African region (31, 17.6%), the eastern Mediterranean region (18, 10.2%), the west Pacific region (16, 9.1%), and the southeast Asian region (11, 6.3%).

The number of specimens tested for influenza viruses amounted to over 48.64 million over the study period. A total of over 4.98 million influenza detections were reported by 173 countries, whereas 138 countries contributed over 0.97 million RSV detections. Much fewer countries reported data pertaining to the other respiratory viruses, from 78 for adenoviruses to only 48 for seasonal coronaviruses; the total number of detections over the study period ranged from 0.23 million for rhinoviruses to only 8366 for bocaviruses. Of note, 37 countries did not report any detections for respiratory viruses other than influenza, whereas only 16 countries (of which 11 from the region of the Americas) reported at least one detection for each virus during the analyzed period.

Comparison of sentinel and non-sentinel data

The comparison of sentinel and non-sentinel data showed either no or minor variations in terms of respiratory virus-specific timing of the peak when comparing data collected within different surveillance systems in a given country. In detail, for 23 countries, there were influenza data available from sentinel and non-sentinel surveillance systems: the difference in the timing of the peak calculated using either type of data was less than 1 week in 71.7% of the countries and within 2 weeks in 91.3% of the countries. Moreover, the differences were distributed in an approximately symmetric way around zero, indicating no consistent bias in one direction. The difference in the timing of the peak tended to be smaller when more seasons were available for analysis. Similar findings emerged for RSV (for which eight countries contributed data from sentinel and non-sentinel surveillance systems). Having thus ascertained that the data coming from either type of surveillance system were equally suitable for determining the timing of epidemics, the surveillance system with the most abundant data was used for each country to ensure the robustness of the analysis. This approach was chosen over an alternative possible method of merging data from different systems to prioritize maintaining data integrity and consistency.

The pre–COVID-19 era (2014-2019)

In 2014-2019, the median influenza positivity rate was 0.384 worldwide (IQR 0.287-0.467, 50 countries included). The temporal characteristics of epidemics caused by each respiratory virus are summarized in Table 1. The epidemics caused by influenza viruses, RSV, and the other respiratory viruses in temperate countries mostly peaked in winter months and generally lasted over 1 month less than in ITB countries, with only a few exceptions.

The first seasons with SARS-CoV-2 circulation: 2020 and 2021

The influenza positivity rate dropped to 0.001 (median value, IQR 0.000-0.020, n = 67 countries) in the 2020 season and remained in values well below those observed in the pre-pandemic period in the 2021 season as well (median 0.069, IQR 0.023-0.172, n = 73 countries). Owing to the very limited viral circulation, the timing and duration of influenza epidemics in these two seasons was not determined nor compared to the pre-pandemic period. Likewise, there was a major drop in the number of detections of most other respiratory viruses in the early phase of the COVID-19 pandemic, which prevented a comparison of seasonality patterns with pre-pandemic ones.

The 2022 season

Influenza

In the 2022 season, the global median influenza positivity rate rose to 0.140 (IQR 0.073-0.244), roughly twice as high as in the previous season, although still less than half than in the pre-pandemic period.

In countries of the northern hemisphere (n = 65), the peak of influenza epidemics in the 2022-2023 season was 1.9 months earlier than the pre-pandemic period (*P*-value for difference <0.001) (Table 2, Figure 1, Supplementary Table 3). In the southern hemisphere, the peak was 2.2 months earlier (5 countries, *P*-value for difference with the pre-pandemic period 0.437), whereas in countries of the ITB (n = 45), there was practically no difference in the month of occurrence of the epidemic peak between

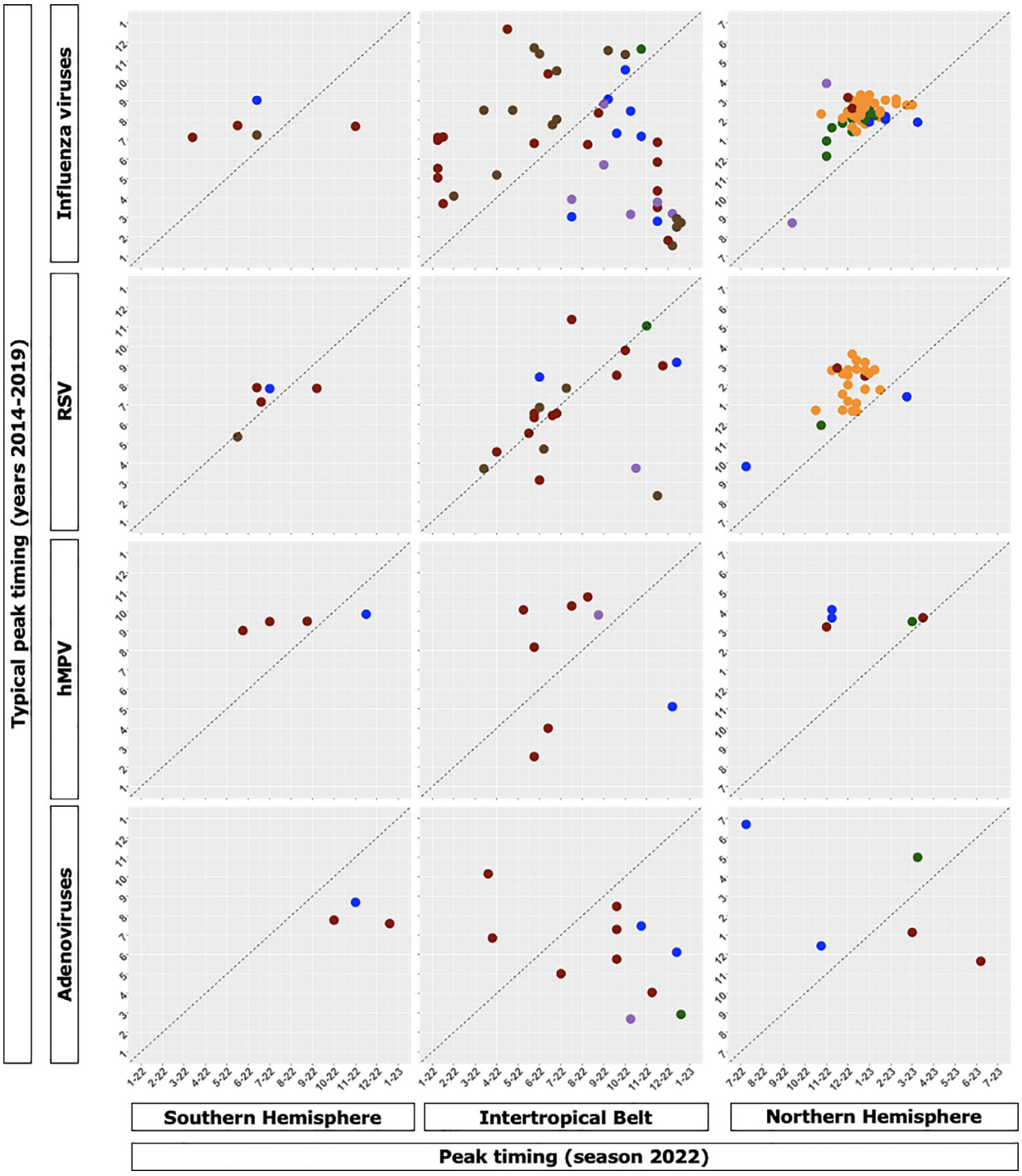

Figure 1. Difference in the timing of the epidemic peak between 2014-2019 (typical peak timing) and the epidemic peak timing observed in 2022 by virus type. The dots situated above/left (or below/right) of the diagonal indicate countries where the peak in the 2022 seasons occurred earlier (or later) than the median timing of 2014-2019. The x-axis and y-axis values indicate peak month, with 1 for January through 12 for December. The different colors in the chart correspond to different WHO regions: AFR (Africa) in brown, AMR (Americas) in red, EMR (eastern Mediterranean) in green, EUR (Europe) in orange, SEAR (southeast Asia) in lilac, and WPR (western Pacific) in blue. RSV: respiratory syncytial virus; hMPV: human metapneumovirus.

2022 and pre-pandemic seasons (median difference −0.1 months, *P*-value = 0.276) (Figure 1).

The influenza epidemics tended to last longer in 2022 than the median of the pre-pandemic period in countries of the northern hemisphere, where the median duration rose from 8.8 to 11.0 weeks (*P*-value <0.001), and the southern hemisphere (from 12.5 to 20.0 weeks, *P*-value = 0.125).

On the contrary, data from 2022 compared with 2014-2019 suggest a shift toward slightly shorter influenza epidemics in ITB countries (median 22.5 vs 23.7 weeks, *P*-value 0.260), although this difference is not statistically significant.

RSV

Similar to influenza viruses, the peak of RSV epidemics in the 2022 season in northern hemisphere countries (n = 26) occurred significantly earlier than in the pre-pandemic period (median difference −1.9 months, *P*-value <0.001), whereas no substantial dif-

Table 1
Median timing of peak (month) and duration of epidemics (in weeks) caused by each respiratory virus in the pre-pandemic period (2014-2019) in countries in the northern and southern hemisphere and the inter-tropical belt (see text for details).

	Influenza	RSV	Adenoviruses	Bocaviruses	Human coronaviruses	hMPV	hPIV	Rhinoviruses
***Northern hemisphere* (n = 84)**[a]								
N countries with data	76	38	7	4	6	6	6	7
Peak timing, median	February, 1st half	January, 2nd half	January, 1st half	March, 2nd half	February, 2nd half	March, 2nd half	January, 1st half	February, 2nd half
Duration of epidemics (weeks), median	8.8	11.0	25.7	26.1	15.2	16.2	27.8	28.7
***Intertropical belt* (n = 86)**[a]								
N countries with data	62	29	21	3	4	17	22	17
Peak timing, median	May, 2nd half	July, 2nd half	May, 1st half	September, 2nd half	July, 1st half	September, 2nd half	May, 2nd half	July, 1st half
Duration of epidemics (weeks), median	23.7	17.5	30.0	31.6	26.3	21.2	24.2	25.3
***Southern hemisphere belt* (n = 6)**[a]								
N countries with data	5	5	4	0	1	4	5	2
Peak timing, median	July, 2nd half	July, 2nd half	July, 2nd half	-	September, 1st half	September, 1st half	August, 2nd half	May, 1st half
Duration of epidemics (weeks), median	12.5	11.2	28.9	-	15.2	14.9	21.0	17.7

RSV: respiratory syncytial virus; hMPV: human metapneumovirus; hPIV: human parainfluenza viruses.
[a] n represents the number of countries in a given area of the world that reported data for at least one virus.

Table 2
Peak timing (month) and duration of epidemics (in weeks) caused by each respiratory virus in 2022 in countries in the southern hemisphere and the inter-tropical belt, and 2022/2023 for countries in the northern hemisphere (see text for details).

	Influenza	RSV	Adenoviruses	Bocaviruses	Coronaviruses	hMPV	hPIV	Rhinoviruses
Northern hemisphere (n = 84)[a]								
N countries with data	68	37	6	4	5	6	5	6
Peak timing, median	December, 2nd half	December, 1st half	March, 1st half	December, 1st half	January, 2nd half	November, 2nd half	September, 2nd half	December, 1st half
Duration of epidemics (weeks), median	11.0	12.0	34.0	31.5	22.0	25.0	32.0	35.0
Intertropical belt (n = 86)[a]								
N countries with data	47	25	15	5	11	13	16	13
Peak timing, median	August, 2nd half	June, 2nd half	September, 2nd half	August, 2nd half	September, 1st half	July, 2nd half	June, 2nd half	June, 2nd half
Duration of epidemics (weeks), median	22.5	12.0	22.0	16.0	21.0	14.0	20.0	25.0
Southern hemisphere belt (n = 6)[a]								
N countries with data	5	5	3	1	2	4	4	2
Peak timing, median	June, 1st half	June, 2nd half	November, 1st half	August, 1st half	August, 1st half	July, 2nd half	July, 2nd half	September, 2nd half
Duration of epidemics (weeks), median	20.0	14.0	29.0	10.0	11.0	11.0	22.0	23.0

RSV: respiratory syncytial virus hMPV: human metapneumovirus; hPIV: human parainfluenza viruses.
[a] n represents the number of countries in a given area of the world that reported data for at least one virus.

ferences emerged for countries in the ITB (n = 20, *P*-value = 0.498) and the southern hemisphere compared with the median of the pre-pandemic period (n = 5, *P*-value = 0.625) (Table 2, Figure 1, Supplementary Table 4).

In addition, regarding the duration of RSV epidemics, the picture mirrored that of influenza viruses, with a longer duration in the 2022 season (compared with 2014-2019) in countries of the northern (12.0 vs 11.0 weeks, *P*-value <0.001) and southern (14.0 vs 11.2 weeks, *P*-value >0.05) hemispheres and, inversely, a tendency toward shorter durations in tropical countries (12.0 vs 17.5 weeks, *P*-value <0.001).

Other respiratory viruses

For respiratory viruses other than influenza viruses and RSV, the number of countries with available data was generally too limited to reliably answer the question of whether the temporal characteristics of epidemics (peak timing and duration) remained altered in the 2022 season compared with the pre-pandemic period. The only exceptions concerned a shorter duration of epidemics caused by hMPV (median 14.0 vs 21.2 weeks, *P*-value = 0.001) and adenoviruses (median 23.5 vs 30.0 weeks, *P*-value <0.001) in 2022 than in 2014-2019 in ITB countries and a longer duration of epidemics caused by the same viruses in northern hemisphere countries (hMPV: median 25.0 vs 16.2, *P*-value = 0.08; adenoviruses: median 34.0 vs 25.8, *P*-value = 0.008), with no significant changes in the timing of the peak (Table 2, Figure 1, Supplementary Table 5).

Discussion

The spread of SARS-CoV-2 in early 2020 profoundly disrupted the circulation, timing, and duration of epidemics of influenza viruses and other respiratory viruses [2,12,13], perhaps even causing the disappearance of the influenza viruses B/Yamagata lineage [14,15]. After the rebound in respiratory viruses' circulation starting 2021 [8,16], questions arose regarding the return of their usual seasonal patterns [2,17], particularly, in light of the continued presence of SARS-CoV-2 and possible viral interference. Here, we analyzed global data for respiratory viruses over nine consecutive seasons (2014-2022), showcasing the distinct virus-specific circulation, timing, and duration of epidemics by latitude-defined world areas. Our results suggest that the global patterns of circulation of some respiratory viruses kept differing from what they were before the COVID-19 pandemic. In particular, the dynamics of influenza virus, RSV, and hMPV epidemics exhibited notable shifts in timing and duration in the 2022 season (2022/2023 in the northern hemisphere) compared with the pre-pandemic periods. In the northern hemisphere and the southern hemisphere, the influenza and RSV epidemic peaks took place significantly earlier and the epidemics showed a prolonged median duration. In the tropical area, no distinct peak timing patterns emerged, whereas a trend toward a slight shortening of epidemics was found for these viruses. A similar trend was seen, despite paucity of data, when analyzing the peak timing of hMPV, which was also earlier (although this result was not statistically significant). Unlike influenza viruses, RSV, and hMPV, data for other respiratory viruses were scarce and no reliable comparison between the pre- and the peri-pandemic eras was possible.

Early during the pandemic, a sharp decrease in the circulation of most respiratory viruses was signaled worldwide, which was mainly attributed to the public health measures enforced worldwide and, possibly, to the direct interaction between the new virus and other pathogens [18]. The scarce circulation of respiratory viruses resulted in an increased proportion of population being susceptible to infection [19]: this scenario opened up discussions suggesting compensatory respiratory virus seasons and that the anticipatory behavior of influenza viruses and other respiratory virus epidemics observed in temperate areas might merely reflect a temporary catch-up in susceptibility, with the underlying assumption that the situation would normalize thereafter, as seen for RSV after the 2009 influenza pandemic [20]. The altered timing and duration of respiratory virus epidemics observed in 2022, particularly, for influenza viruses and RSV, could indeed be partially explained by a compensatory mechanism owing to increased susceptibility in populations from scarce virus circulation in the preceding years [21]. Varying influenza vaccine uptake trends, a factor that remains insufficiently understood outside of regions such as Europe and North America owing to limited data, should also be taken into consideration [22]. Although the reasons for the shift in epidemic timing are multifaceted, it is noteworthy that influenza in Australia showed a peak around weeks 27-28 in 2023, similar to the previous year. This somehow suggests that a return to the pre-pandemic patterns may not be immediate. Continued observation is necessary to determine whether this represents a temporary adjustment or a more lasting alteration in peak timing [8]. This underscores the importance of a nuanced understanding of multiple factors at play, encompassing potential interactions between viruses, shifts in population behavior, and the persistent effects of public health measures.

Although it remains to be seen whether these shifts will be sustained in the post-pandemic era, they underscore the potential need for adapting global preparedness efforts, such as maintaining and enforcing robust local and regional surveillance systems to effectively monitor these trends [23,24]. Such systems are crucial for guiding appropriate public health responses, including the timely administration of influenza vaccinations and the application of preventive measures against RSV, encompassing monoclonal antibodies and new vaccines [25–28]. To this regard, the current paucity of data on many respiratory viruses underscores the need to enhance global surveillance networks; strengthening the GISRS and national systems for regular, comprehensive monitoring of respiratory viruses will be vital for gaining a deeper understanding of their circulation, ultimately guiding public health responses and policymaking. To the best of our knowledge, this is the first analysis of global activity of respiratory viruses at a national level that assessed how the timing of different respiratory viruses changed after the appearance of SARS-CoV-2 using routine surveillance data from the GISRS.

Although this study offers a broad scope and presents new insights, some limitations exist that need to be fully acknowledged. First, it must be acknowledged how the inclusion of non-influenza respiratory viruses is not systematic and the reporting by some countries may not be comprehensive, leading to little data for some viruses. However, the GISRS database's expansion to include more virus reporting marks progress in global surveillance efforts in recent years. Analyzing these data now while acknowledging that data for some viruses and countries are limited may be key to understanding future health trends, reflecting our commitment to enhancing public health surveillance. Underreporting or inconsistent reporting across diverse regions and countries is currently an issue. For instance, European countries lack direct access to upload data to FluNet, resulting in only influenza, RSV, and SARS-CoV-2 data being forwarded from European Centre for Disease Prevention and Control to WHO Europe and subsequently to the FluNet/WHO databases. In general, the paucity of data impeded a reliable comparison between the pre- and post-pandemic eras for adenoviruses, bocaviruses, human coronaviruses, rhinoviruses, and hPIV, thereby constraining a more comprehensive understanding of the COVID-19 pandemic's influence on the global respiratory viral landscape. In addition, the scarcity of countries providing data, in particular, sentinel data, may affect the generalizability of our

findings. This reflects the varying quality of surveillance systems across countries, a factor that must be carefully considered, especially considering the importance of sentinel data for accurately assessing epidemic peak timing, duration, and magnitude. Our decision to use sentinel and non-sentinel data was made to enable the analysis for a larger number of countries, striving for a more global representation. In addition, our reliance on WHO's FluNet database for weekly aggregated influenza detection data rather than case-based reports limits the granularity of our analysis, and despite the robust global surveillance framework provided by GISRS, which includes protocols to ensure data integrity and minimize errors, the aggregated nature of the data requires careful interpretation. Furthermore, our analysis might have benefited from country-level data, for instance, by evaluating the baseline variability of the epidemic peaks for each virus at the country level, by detailing the precise timing and manner in which NPIs were lifted, and by taking into consideration how each distinct virus tends to respond to NPIs [29]. Nevertheless, it is worth noting that the majority of countries had already lifted NPIs during the last season that we considered in our analysis (2022 for the southern hemisphere and the tropics and 2022/2023 for the northern hemisphere). Finally, our analysis does not explore the potential influence of climate factors on the observed variations and variability in respiratory virus circulation. Incorporating these environmental factors into future investigations may provide valuable insights into the dynamics of respiratory virus epidemics.

Our research contributes to the understanding of the COVID-19 pandemic's short-term impact on respiratory virus patterns. By analyzing data from nine seasons, including three after the emergence of SARS-CoV-2, we offer insights into the potential shifts in the behavior of these pathogens during the pandemic period. Although we offer insights into potential shifts in the behavior of these pathogens during the pandemic period, it is important to acknowledge that these findings may reflect transient adaptations to unprecedented global health measures and societal changes. Therefore, continuous surveillance in the years to come will be essential to discern whether these observed shifts signify temporary perturbations or the advent of possibly long-lasting changes in respiratory virus circulation patterns. In a swiftly evolving context, our research serves as a valuable guide, providing evidence-based insights to inform strategies aimed at protecting public health.

Declaration of Competing Interest

MH and ImG are employees of CSL Seqirus and may hold shares. JP declares that Nivel has received research grants which concern the epidemiology of influenza and vaccination against influenza from WHO, Sanofi, and the Foundation for Influenza Epidemiology. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Ethical approval

Not needed.

Author contributions

All authors conceived and designed the study. MDR, SC, and PZ analyzed the data. MDR, SC, and PZ wrote the draft. JP, GB, CL, MH, ImG, and AM revised the manuscript. All authors contributed to the article and approved the submitted version.

Data sharing statement

All the data used in this article are freely accessible at the WHO FluNet website.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.ijid.2024.107052.

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