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Assessing community-level COVID-19 infection risk through three-generational household concentration in Nebraska, U.S.: An approach for COVID-19 prevention

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ABSTRACT

The three-generational household was a focal point of concern for school and community the Coronavirus Disease 2019 (COVID-19) transmission. The current study, using small area data and household variables, reported an approach to neighborhood-level COVID-19 mitigation for school reopening and communities returning to normalcy. The study started with an age-stratified Poisson regression to examine the association between the proportion of three-generational households and COVID-19 infection rates based on data from 74 census tracts in Lancaster County, Nebraska, U.S. from March 5, 2020 to August 22, 2020, followed by mapping the model-based risk score by census tract in the study area. We explored the feasibility of using COVID-19 infection rates and vaccination rates to inform decision-making on school opening from March 5, 2020 to February 3, 2021. The overall infection rate increased by 3% for every unit increased in the percentage of three-generational households after controlling for other covariates in the model. The census tracts were classified into low-, medium-, and high-priority neighborhoods for potential community-based interventions, such as targeted messages for household hygiene and isolation strategies.

1. Introduction

Monitoring the Coronavirus Disease 2019 (COVID-19) progression across socio-demographic dimensions was essential to making informed decisions for school reopening and risk reduction (Scala et al., 2020; Lai et al., 2020; Thompson et al., 2021; Masrur et al., 2020). Various school reopening plans for students of different grade levels were partially based on age differences in COVID-19 risk, whereas plans for teaching delivery modes (remote, hybrid, face-to-face) were more oriented toward pharmaceutical interventions (Centers for Disease Control and Prevention, 2021). Our recent studies showed that hybrid-teaching was associated with the highest COVID-19 risk (Liu et al., 2021), suggesting school reopening based on the perceived COVID-19 risk gradient (high-remote, medium-hybrid, low-face-to-face) alone may not work effectively. Schools started to reopen in fall 2020. There had been a 13 % increase in children's cases in the U.S. during the two weeks ending October 01, 2020 (American Academy of Pediatrics, 2020). When children contracted the virus, they could transmit it to family members

and vice versa (Lopez et al., 2020; Stein-Zamir et al., 2020; Qiu et al., 2020). The larger the family, such as living in a three-generational household, the greater the risk was. This study attempted to add a new dimension to school reopening strategies by assessing the risk for COVID-19 infections associated with three-generational household distributions within the Lincoln School District, Lancaster County, Nebraska (NE) U.S. All the cases in Lancaster County were categorized into three age groups: children (aged less than 19 years), adults (aged 20 to 64 years), and older adults (aged 65 years and older).

Age-dependent COVID-19 severity and household-level cluster transmission had been well documented, but such individual data were hard to obtain (Teherani et al., 2020; Davies et al., 2020). Due to the lack of individual-level data for COVID-19 risk predictions, previous studies investigated community-level effects and provided a few COVID-19 risk models (Snyder and Parks, 2020; Jin et al., 2021). However, we wanted to see if the known household effects would manifest at the community level during the COVID-19 pandemic. We relied on some insight from studies of COVID-19 vulnerability indices in local areas, such as using

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age distribution at the county level (Patel et al., 2020) and the proportion of essential workers at the zip code level (Amram et al., 2020). This paper reported our collaborative efforts with local and state governments to demonstrate: 1) the usefulness of three-generational household proportion as a risk factor for COVID-19 infection at the census tract level; 2) the mapping of potential protective rates among different areas after people had a vaccine. We aimed to increase the local analytical

nursing homes were excluded because they were defined as non-community spread. The final eligible cases were 3,287 (Stage 1) and 22,623 (Stage 2) from 74 census tracts with only a sequential tract I.D. In Nebraska, 21,763 people had at least one dose of the vaccine by February 3, 2021. Through collaboration with NE DHHS, the study team linked the sequential I.D. back to the census tract I.D. internally to produce the resultant maps.

$$Casecount = \alpha + \beta_1^i AgeGroup + \beta_2 PercentageOfThePopulationInAHouseholdWithGrandchildren + \beta_3 PercentageOfTheFamiliesWithChildrenBelowThePovertyLine$$

capacities of various COVID-19 requests and evaluate COVID-19 vaccination rates by census tracts.

2. Methods

The dependent variable was COVID-19 positive cases in Lancaster County, Lincoln, Nebraska, U.S., between March 5, 2020 and February 03, 2021. The first dose of a vaccine against COVID-19 was given in Nebraska on December 14, 2020. People who had the first vaccine between December 14, 2020 and February 3, 2021 were included. The cases were defined as detection of SARS-CoV-2 RNA by real-time reverse transcription-polymerase chain reaction (RT-PCR) or SARS-CoV-2 antigen in a respiratory specimen collected and reported to the Nebraska Electronic Disease Surveillance System. The immunization information was the records of people who received vaccines against COVID-19 reported to the Nebraska State Immunization Information System. The Nebraska Department of Health and Human Services (NE DHHS) verified both cases and immunization information. This study actively assists local governments in two Stages: Stage 1 is from March 5, 2020 to August 22, 2020 to classify school reopening risk according to the neighborhood's proportion of three-generational households. Stage 2 is from March 5, 2020, to February 03, 2021, exploring the feasibility of using COVID-19 infection and vaccination rates to inform decision-making on school reopening. These data were obtained together with data on four individual-level variables: *age group* (children: aged less than 19 years; adults: aged 20 to 64 years; older adults: aged 65 years and older), *sex* (male and female), *race-ethnicity* (Hispanic, non-Hispanic White, non-Hispanic Black, and other), and *work outside home status* (yes and no). Both COVID-19 cases and vaccination records were geocoded at the census tract level. According to the U.S. Census Bureau's definition, census tracts are small, relatively permanent statistical subdivisions of a county or equivalent entity that local participants update prior to each decennial census as part of the Census Bureau's Participant Statistical Areas Program (Bureau, 2021). The primary purpose of a census tract is to provide a stable set of geographic units to present statistical data. The population size of census tracts is generally between 1,200 and 8,000 people, with an optimum size of 4,000 people (Bureau, 2021). Census tracts are identified by an up to four-digit integer number and may have an optional two-digit suffix (Bureau, 2021). In addition, common census tract variables based on the most recent 5-year (2014–2018) American Community Surveys were linked to each geocoded case by census tract I. D.s. The geocoding process of COVID-19 cases and vaccination records were performed by the NE DHHS Informatics Unit Geographic Information System specialist. In the current analysis, only two census variables were included in the model besides the age-specific at-risk population: A) *percentage of the population in a household with grandchildren* (three-generational households) and B) *percentage of the families with children below the poverty line*. Variable A was to gauge if the concentration of three-generational households would increase COVID-19 spread in Stage 1, while variable B was to control poverty in each census tract. The cases reported from long-term care facilities and

A Poisson regression model was used, in which the case counts by age groups and by census tracts were modeled as two explanatory variables. The variable *AgeGroup* had three categories superscripted β_1^i (i = 1 to 3 for age group, less than 18 years old, 18 to 64 years old, and 65 years old or older; the 65 years old or older group was the reference group). The offset was the log of age census tract specific at-risk population. A preliminary analysis in our study suggested that the family poverty variable was not statistically significant. Because the poverty variable was an essential indicator that reflected a community's socioeconomic status, we decided to keep both three-generational household and poverty variables in the final analysis.

To respond to various inquiries of evaluating community-level vaccination rates and COVID-19 infection rates, we combined two rates for each census tract and then divided them by the census tract population. The higher the combined rate, the closer it was to herd immunity.

This study is a secondary data analysis without personal and census tract identifiers. The Institutional Review Board (IRB) of the University of Nebraska Medical Center determined that the IRB review was not required for this study.

3. Results

Lancaster County has a total population of 319,090. The total number of COVID-19 tests was 49,479 until August 22, 2020, and 156,046 until February 3, 2021. The demographic variables of the cases and at-risk populations are shown in Table 1. Disparities of COVID-19 cases among race and ethnicity were evident among all age groups. In model 1, a higher proportion of cases were found among Hispanics, which were nearly 28 % of children cases, 23 % of adult cases, and 7 % of older adult cases. However, 12 % of children, 7 % of adults, and 2 % of older adults were Hispanics among the at-risk population. Similar disparities were also observed in non-Hispanic Black and other races. In contrast, the proportions of non-Hispanic White cases of 47 % (children), 54 % (adults), and 74 % (older adults) were all much lower than their respective population shares (72 %, 81 %, and 93 %, respectively). Furthermore, roughly 51 % of Lancaster County residents worked outside of the home (data were not shown). Nearly 61 % of the cases in Lancaster County were classified as working outside of the home in Stage 1 (results were not shown). There was no difference in sex-specific proportions among cases and the populations. The Model 2 cases had similar disparities as the Model 1 cases in all variables compared to the Lancaster County at-risk population.

In Table 2, the model-based rate was 4 per 1,000 for older adults. The adult age group rate was 3.27 times higher than the reference age group (i.e., older adults). After controlling the main effect of the age group, the percentage of the three-generational household population was statistically significant (OR = 1.031, 95 % CI: 1.004–1.058). The infection rate increased 3 % for every unit increased in the percentage of the

Table 1

COVID-19 case and at-risk population statistics by selected variables in Lancaster County.

		Gender		Race/Ethnics			
		Female	Male	Hispanic	Non-Hispanic White	Non-Hispanic Black	Other
	N	%					
Stage 1	Positive cases						
Age group							
less than 18 years old	364	52 %	48 %	28 %	47 %	11 %	15 %
18 to 64 years old	2,740	49 %	51 %	23 %	54 %	7 %	16 %
65 or older	183	50 %	50 %	7 %	74 %	4 %	15 %
Total	3,287	50 %	50 %	22 %	55 %	7 %	16 %
Stage 2	Positive cases						
Age group							
less than 18 years old	3,161	51 %	49 %	17 %	64 %	7 %	12 %
18 to 64 years old	17,508	51 %	49 %	14 %	70 %	5 %	11 %
65 or older	1,954	52 %	48 %	6 %	84 %	2 %	9 %
Total	22,623	51 %	49 %	14 %	70 %	5 %	11 %
Lancaster County	Total population						
Age group							
less than 18 years old	84,204	49 %	51 %	12 %	72 %	5 %	11 %
18 to 64 years old	188,984	49 %	51 %	7 %	81 %	4 %	8 %
65 or older	45,902	56 %	44 %	2 %	93 %	1 %	3 %
Total	319,090	50 %	50 %	7 %	81 %	4 %	8 %

Table 2

Poisson regression of infection cases and three-generational household proportion among different age groups of census tract groups (Stage 1).

	Log rate (Standard Error)	Model-based rate (per 1,000 persons)	Rates Ratio (95 % Confidence Interval)
Intercept (Older adults)	−5.449 (0.076)	4	Reference
Age group			
Children	0.117 (0.091)	5	1.125 (0.941, 1.343)
Adults	1.185 (0.076)	14	3.270 (2.815, 3.798)
Percentage of the population in a household with grandchildren	0.030 (0.013)	–	1.031 (1.004, 1.058)
Percentage of the families with children below the poverty line	0.005 (0.005)	–	1.005 (0.995, 1.015)

three-generational household population.

Based on the OR of the three-generational household and COVID-19 risks among the three age groups in the Stage 1 analysis, a low, medium, and high priority intervention score based on the natural break classification was diagrammatically created. As seen in Fig. 1, the high score census tracts are dark blue, medium scores are light blue, and low scores are white in the study area.

In Stage 2, the 74 census tracts in Lancaster County were divided into unique sections based on the overall immunization proportion, which combined the overall COVID-19 infection rate and the COVID-19 vaccine rate (Fig. 2). The range of immunization proportion was 0.16 % to 33.44 % until February 8, 2021.

4. Discussion

Using the identified association between the proportion of three-generational households and the overall number of COVID-19 cases, we were able to assign intervention scores at the census tract level in Lancaster County, NE. Although this result was a pilot, it could be tailored to the needs of any local health department and school district. After reopening schools, school-related and daycare-related outbreaks were reported widely (Michaud and Kates, 2020). As preventing in-school transmission is the primary mission of the parents and education workers, multi-faceted approaches of COVID-19 interventions and indicators are essential, even if they have not been empirically evaluated or had more or less efficacy under different conditions (Bonell et al., 2020). The three-generational household was a focal point among school-children-family transmission, a locally significant dimension, which could be added to the existing teaching delivery-based reopening approaches. We simplified the calculation of immunization proportion due to data limitations. In our model, we treated the people who received at least one dose of vaccine against COVID-19 as immunized people. Moreover, the immunization proportion evaluation could help public health departments and policymakers estimate the community's protection rate. It was essential to adjust the vaccination policy based on the local immunization rate, population density, age distribution, and social-economic factors. Indeed, there were many ways to assess vaccinations at a local level, and we just showed a quick and straightforward way to meet local inquires by working with the state health department.

Although our study protocol would not allow us to identify individual census tracts or neighborhoods, public health practitioners could develop school-based and daycare-based interventions by identifying neighborhoods that contributed most to this association. Non-pharmaceutical interventions could include keeping social distance, wearing masks, washing hands, improving classroom ventilation, etc. Designing and implementing such an approach should also consider other variables, such as the proportion of those working outside the home, occupational types to represent essential workers, and the vaccination rates to represent community herd immunity level.

The presented data example was a preliminary data analysis showing the potential utility of the proportion of three-generational households in assisting to develop community-level interventions. Our results were community-level results, which added a valuable aspect to household transmission routes. Studies about the age-dependent effects in the transmission had shown that interventions targeted at children might have a relatively small effect on reducing COVID-19 transmission (Davies et al., 2020). In addition to age-dependent effects, several studies had shown that asymptomatic household members had lower odds of infecting other household members compared to symptomatic patients (Li et al., 2021; Madewell et al., 2020; Madewell et al., 2020; Madewell et al., 2021). Higher secondary attack rates had been identified among symptomatic index cases compared to asymptomatic index cases.

Furthermore, evidence showed that children were less likely to be symptomatic than the older population, and cases with comorbidities were less likely to be asymptomatic than cases with no underlying medical conditions (Sah et al., 2021). Testing in the U.S. had been focused on symptomatic patients. Because children exhibited fewer and

Fig. 1. Model-based COVID-19 three-generational household risk scores (Stage 1).

milder symptoms compared to adults, their role in transmission could be underrecognized. However, the transmission route of COVID-19 in three-generational households not only increased the risk of infection, but also increased the risk of severe outcomes among older people and other vulnerable household members, especially those with comorbidities (Sanyaolu et al., 2020; Nafilyan et al., 2021).

FDA did not authorize Pfizer-BioNTech COVID-19 vaccine for emergency use in children 5 through 11 years of age until October 29, 2021 (Woodworth et al., 2021). Before the vaccine became available for children, a study had shown that living in a multi-generational household was associated with an increased risk of COVID-19 mortality, especially for older adults (Nafilyan et al., 2021). Our community-level intervention score could assist state and local health departments in

implementing public health interventions in communities where three-generational households were highly prevalent at the early stage of the pandemic.

The real-world implementation of such an approach should involve much more detailed data and complex statistical modeling, which requires further validation. For future study, the assigned community-level intervention score should consider the influence of time. For example, an advanced risk score can be constructed, incorporating the projections from the forecasting models that capture the specific community-level risks such as mobility patterns and population density and the baseline risk that varies over time. In addition, if we could estimate the prevalence of the underlying health conditions or comorbidities, such as bronchitis, pneumonia, severe acute respiratory distress
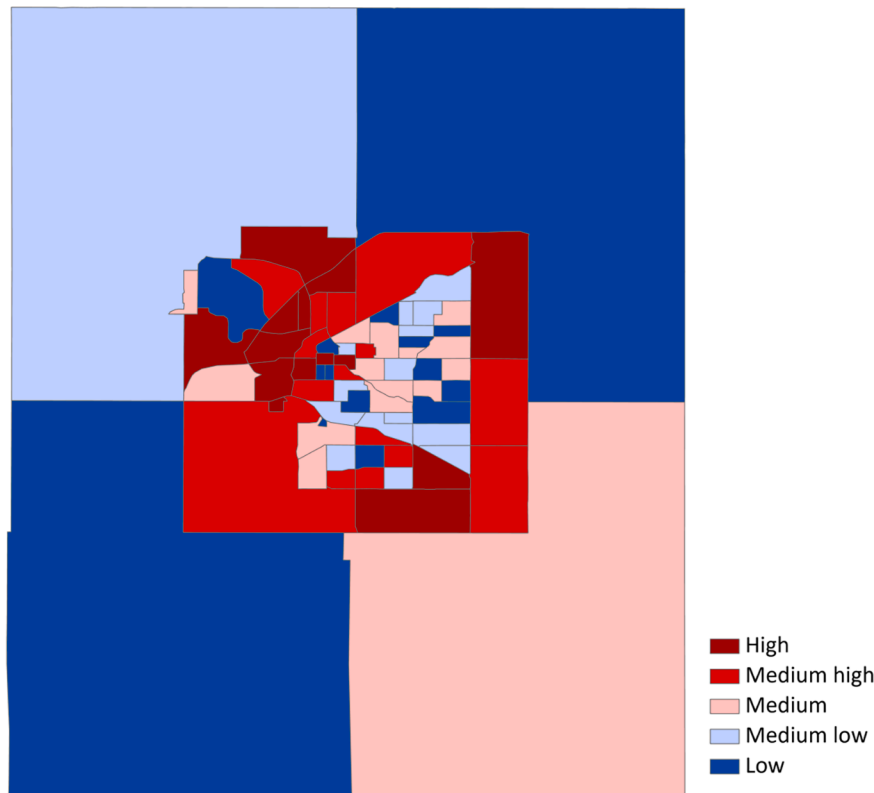
Fig. 2. Map of overall COVID-19 immunization rate by census tract in Lancaster County (Stage 2).

syndrome at the census tract level, this essential factor should be added into the analysis.

5. Conclusion

There was a positive correlation between three-generational household concentration and the overall number of COVID-19 infections in Lancaster County. This community-level association positions the proportion of three-generational households as an additional, simple indictor of community outbreak risk during the school year. The potential utility of the proportion of three-generational households is to assist the development of community-level intervention plans. The immunization proportion could help policymakers adjust to the vaccine distribution and promotion quickly.

CRediT authorship contribution statement

Dong Liu: Data curation, Formal analysis, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing. **Ge Lin:** Conceptualization, Data curation, Formal analysis, Methodology, Supervision, Writing – original draft. **Han Liu:** Data curation, Formal analysis, Methodology, Validation, Visualization. **Dejun Su:** Conceptualization, Funding acquisition, Methodology, Supervision, Validation, Writing – original draft, Writing – review & editing. **Ming Qu:** Conceptualization, Data curation, Methodology, Project administration, Resources, Software, Supervision, Validation, Writing – review & editing. **Yi Du:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.pmedr.2022.101705.

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