

**Title:** Inequality in acute respiratory infection outcomes in the United States: A review of the literature and its implications for public health policy and practice.

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## **Abstract**

Seasonal and pandemic respiratory viruses such as influenza and the novel coronavirus (SARS-COV-2) currently sweeping the globe have often been described as 'equal opportunity infectors', implying little socioeconomic disparity in susceptibility. However, early data from the COVID-19 pandemic has underscored that the burden of respiratory viruses actually reflect and magnify existing socioeconomic inequalities. We review the literature on socioeconomic and racial disparities in acute respiratory infection (ARI), as well as ARI-associated hospitalization and mortality. Our goal is to identify key principles of the relationship between socioeconomic inequality and ARI outcomes, as well as highlighting poorly understood areas that need to be addressed by research and policy in the wake of the COVID-19 pandemic. We find that there has been descriptive work in this area, but that there is a distinct lack of cohesive methodology in the literature exploring social determinants and ARI. We propose the fundamental cause theory is a useful framework for guiding future research of disparities in ARI and for the design of interventions to alleviate these disparities.

## **Introduction**

Acute respiratory infections (ARI) cause substantial morbidity and mortality worldwide<sup>1</sup>, both as the result of seasonal epidemics and pandemics, such as COVID-19. Respiratory viruses such as influenza and respiratory syncytial virus (RSV), have often been described as ‘equal opportunity infectors’, implying little socioeconomic disparity in susceptibility. However, early data from the COVID-19 pandemic has underscored that the burden of respiratory viruses actually reflect and magnify existing socioeconomic inequalities<sup>2</sup>. These trends have been made clear in the United States by the alarming disparities in the toll of severe disease and mortality experienced by African-Americans<sup>3</sup>. At the population level, viral and immune factors are necessary pre-conditions for the emergence and transmission of pathogens causing seasonal and pandemic ARI<sup>4</sup>. At the same time, socioeconomic inequalities are clearly key drivers of exposure, severe disease, and mortality. The rapid pace of transmission and mortality resulting from the COVID-19 pandemic has shone a bright light on these disparities. But they are no less acute in the context of other causes of seasonal and pandemic ARI, despite attracting less attention. In this paper, we review the literature on socioeconomic and racial disparities in ARI infection, hospitalization, and mortality in the United States. By focusing on the existing literature on influenza, RSV, and all-cause ARI we hope to identify key principles of the relationship between socioeconomic inequality and ARI outcomes, as well as highlighting poorly understood areas that need to be addressed by research and policy in the wake of the COVID-19 pandemic.

### **What are the causes of ARI disparities?**

Disparities in ARI outcomes may result from 1) differential rates of exposure owing to occupation, housing, and other factors, 2) differential susceptibility to infection upon exposure, owing to both social and medical factors, e.g. access to vaccination where it is available, and 3) differential ARI-

associated morbidity and mortality resulting from comorbidities increasing the likelihood of severe disease, limited access to quality care and therapies (e.g. antivirals) once infected. ARI-related disparities falling along these dimensions are evident at the within-country level, and at the global scale: A disproportionate amount of severe ARI-related disease and death occurs in low- and middle-income countries (LMICs), with as much as 99% of in-hospital deaths associated with RSV occurring in LMICs as of 2015<sup>5</sup>. In addition, a 15-fold difference in influenza-associated case-fatality has been observed between LMICs and wealthy countries<sup>6</sup>, underscoring how global inequality exacerbates the toll of death and disability attributable to ARI.

However, a persistent focus on biological dimension of infectiousness has reinforced the perception that that social inequality has little to do with the burden of ARI both domestically and globally. This perception dates back to the pioneering work of McKeown and Record, who ruled out standard of living disparities in ARI mortality in 19<sup>th</sup>-century England and Wales because of their highly-infectious and seasonal nature. As a result, the focus of research on the social determinants of infectious disease has been on inequity in chronic and endemic infections, such as Tuberculosis, diarrheal disease<sup>7</sup>, and HIV. Recently, however, attention has returned to social determinants of ARI, reflected in an increasing number of studies of disparities by race/ethnicity and SES in infection risk, severity and mortality for influenza<sup>8–12</sup>, RSV<sup>13</sup> and all-cause ARI<sup>14–18</sup>. Nevertheless, our understanding of the mechanistic links between SES and ARI-related risks remains underdeveloped, as does our ability to address inequalities in ARI outcomes.

Closing this gap is urgent, as the question of how to address these disparate outcomes requires us to first understand how they are generated. Our goal is to identify the key axes of SES-related disparity in ARI infection risk and outcomes. In many ways, the urgency of addressing these disparities results from positive momentum in biomedical research against influenza, RSV and other ARIs. A push

towards a more broadly protective influenza vaccine, increased use of antivirals to improve outcomes, and advances in genomics and mathematical modeling to understand transmission, can lead to significant strides against influenza and other endemic and emerging viral ARIs. However, such advances in *population-level* protection are often accompanied by a widening of disparities in outcomes, as new preventive measures and therapies become available first to the well-off. As recent discussions of the ability to practice social distancing, and whether a COVID-19 vaccine will become broadly available shows, these issues remain woefully unaddressed, and have significant implications for public health.

## **Data and Methods**

### **Literature Search**

We searched PubMed for articles documenting socioeconomic disparities in ARI infection/disease risk, severe outcomes, and mortality. First, we attempted to capture articles investigating disparities in all-cause ARI, influenza-like illness (ILI), and RSV. Then, we identified articles documenting disparities in influenza infection risk and outcomes. We separated these searches to ensure each was sensitive to key differences in the literature, most notably around access to and uptake of influenza vaccination.

We used the PubMed special query for health disparities in conjunction with search terms relating to all-cause ARI, RSV, and influenza (Figure 1). The health disparities query identifies articles evaluating disparities in health outcomes and healthcare access with inequities in dimensions of race/ethnicity, SES, gender identity and sexual orientation, insurance status, and other populations described as “vulnerable.” We then screened studies using title and abstract review to identify articles with a specific focus on all-cause ARI, ILI, RSV, and influenza. Additional articles and reviews were added to our results upon recommendation from topic-area experts. Articles were not excluded based on year of publication. Full search queries are available in the supplementary materials.

## **Results**

Our all-cause ARI and RSV search returned 155 papers, of which 9 studies met the inclusion criteria. Of these, only 4 of the retained articles used data from the US. The influenza search returned 386 results, of which 27 were deemed relevant following title and abstract review. Of these, 12 addressed seasonal influenza in the US, with the remaining 15 focused on the 2009 H1N1 influenza pandemic. All selected articles, organized by etiology, dimension of disparity assessed, and measured outcome (incidence, severity, death, etc.) are listed in Table 1.

### **All-Cause ARI**

A wide range of SES-related disparities in all-cause ARI were identified in studies from the US<sup>14,15,19</sup>, UK<sup>16,17,20</sup>, and Argentina<sup>18</sup>. Two studies reported increased ARI incidence<sup>14,15</sup> among those with lower self-reported social status<sup>14</sup> and SES<sup>15</sup>. Race/ethnicity was also found to be associated with increased severity, as indicated by two studies reporting increased ARI-related hospitalization in a US study of children under 5 using data from New Vaccine Surveillance Network (NVSN)<sup>19</sup> and primary care seeking in UK using sentinel surveillance data<sup>20</sup>. SES disparities were also evident in all-cause ARI-related complications: two studies reported increased hospital admission for ARI<sup>17</sup> and bronchiolitis<sup>16</sup> and increased rates of medical intervention due to bronchiolitis<sup>16</sup> with increasing Townsend deprivation score, index used to quantify material deprivation based on car and house ownership, household overcrowding, and employment, with a higher score showing more material deprivation<sup>16,17</sup>. Finally, one study reported increased under-5 mortality due to ARI among those with proxy measures for poverty including having an adolescent mother, household crowding, and lacking running water in home<sup>18</sup>.

*Incidence:* In a multi-state cohort study, female healthcare workers from Texas, Washington, and Oregon, with lower self-reported social status reported higher rates of ARI symptoms<sup>14</sup>. In an experimental study, higher subjective SES was protective against the development of cold symptoms after exposure to rhinovirus or influenza virus<sup>15</sup>.

*Severity:* Disparities in severity of ARI were indicated using hospitalization and care seeking rates in a variety of study designs. Using population-based surveillance data, the NVSN study found increased hospitalization rates for all-cause ARI among Black children as compared to white children; however, these results were not adjusted for SES<sup>19</sup>. Additional surveillance data from the Royal College of General Practitioners Research and Surveillance Centre in England found racial and ethnic minorities were more likely to seek care for cold/flu symptoms than whites<sup>20</sup>. In the UK, a case-control study matching children under 1 year old admitted to Sheffield hospital with clinical suspicion of bronchiolitis to healthy community controls identified from birth records found that children living in the two most deprived electoral wards, as defined using the Townsend index, were 1.5 times as likely to be admitted to the hospital and 1.7 times as likely to require a medical intervention than children living in other parts of the city<sup>16</sup>. An ecological study in the West Midlands Region of the UK found neighborhoods with higher Townsend scores of deprivation experienced higher rates of childhood hospital admissions due to ARI and pneumonia<sup>17</sup>.

*Mortality:* A case-control study in Buenos Aires found death due to ARI in children under 5 was associated with living in a crowded household, having an adolescent mother, and lacking running water in the home<sup>18</sup>. No other papers discussed mortality due to all-cause ARI.

## Seasonal Influenza

Studies of disparities in seasonal influenza outcomes have focused primarily on the relationship between neighborhood SES and rates of hospitalization for severe disease in<sup>8–12</sup> with fewer studies of individual-level outcomes<sup>21</sup>. In addition, studies have investigated inequalities in influenza-related healthcare utilization (e.g. visits to outpatient clinics)<sup>21,22</sup>, incidence<sup>23</sup>, and exposure<sup>24</sup> as they relate to SES, race/ethnicity<sup>9,19,22</sup>, and socioemotional stress<sup>23</sup>. SES and exposure indicators utilized in these studies include percentage of households living in poverty<sup>8,10–12</sup>, female headed households<sup>9,10</sup>, household crowding<sup>9,11</sup>, and neighborhood population density<sup>10</sup>.

*Incidence:* Two papers described disparities in rates of influenza susceptibility and exposure in older African Americans<sup>24</sup> and college students with higher perceived stress<sup>23</sup>. Black Americans in nursing homes were less likely to be vaccinated against seasonal influenza, and were less likely to have vaccinated contacts, due to racial and socioeconomic segregation in nursing home care. The authors of this study argue that the results from nursing homes may provide clues to residential segregation's effects on seasonal influenza risk at the population level<sup>24</sup>. In a cohort study of U.S. college students, an increase in perceived stress score was associated with a 25% greater rate of self-reported ILI, after adjustment for demographic factors, behaviors and flu vaccination<sup>23</sup>.

*Severity:* Hospitalization was the most frequently studied dimension of severity used to characterize influenza disparities, followed by overall healthcare utilization<sup>21,22</sup>. Area-level poverty and race/ethnicity were used as predictors of risk in a number of studies examining disparities in rates of influenza-related hospitalization. Two ecological studies found that living in neighborhoods with a high percentage of residents below the poverty line and in female-headed households experienced higher rates of influenza

hospitalization<sup>8,9</sup>. Similarly, census-tract rates of influenza-associated hospitalization surrounding Nashville, Tennessee, increased with population density and the percentage living in poverty, female headed/crowded households<sup>10</sup>. In New Haven, Connecticut, the annual incidence of pediatric influenza-associated hospitalizations in high-crowding census tracts (defined as >5% of households with > one occupant per bedroom), and high-poverty census tracts (defined as >20% of households below the poverty line), was > 3 times higher than in low-crowding/low-poverty census tracts<sup>11,12</sup>. This disparity remained even after adjustment for comorbid medical conditions and influenza vaccination<sup>11,12</sup>. In a study of individual-level outcomes using data from FluServ-NET, across multiple US counties and influenza seasons, African American and Latino adults had increased odds of influenza-related hospitalization than whites<sup>9</sup>. One study using population-based surveillance data found significantly higher hospitalization rates for laboratory-confirmed influenza for Black children than for white children<sup>19</sup>.

### Pneumonia

Viral and bacterial pneumonias are common ARI-related complications that reflect SES-based disparities in baseline health status as well as access to care. Several studies identified by our search focused specifically on disparities in hospitalization<sup>13,17,25,26</sup> and mortality<sup>27</sup> associated with diagnosis of pneumonia and influenza (P&I).

*Severity:* In a study examining socio-demographic factors increasing risk of P&I hospitalization in elderly populations using Medicare data from 1991-2004, counties with high proportions of live-in grandparent caregivers and lower median income experienced higher rates of pneumonia-related hospitalization<sup>26</sup>. In a study of Alaska Natives using hospitalization records from 2000-2004, regions



with a lower proportion of households with in-home water service, indicating higher poverty rates, also had higher hospitalization rates for P&I<sup>13</sup>.

*Mortality:* There is some evidence that disparities in P&I associated mortality have decreased over time. One study using age-adjusted mortality rates for P&I show a decreasing ratio and absolute difference between Black and white Americans from 1950 to 2000<sup>27</sup>. The authors attribute this reduction in disparity due to widely available treatment to guard against P&I complications and mortality<sup>27</sup>.

### RSV

Literature examining RSV-specific disparities was limited to hospitalization/severity. Disparities were identified in dimensions of race/ethnicity<sup>19,28,29</sup>, household socioeconomic status<sup>13,30</sup>, high population density<sup>30</sup>, maternal unemployment<sup>31</sup>, younger maternal age<sup>32</sup>, and household crowding<sup>33</sup>. A study using population-based surveillance data found that hospitalization rates for laboratory confirmed RSV were similar for Black and white children under 12 months of age, but for children > 12 months, hospitalization rates for lab-confirmed RSV were higher for Black children than for white children<sup>19</sup>. A study utilizing surveillance and hospital admittance data in Southwestern Alaska identified villages with lower proportion of houses plumbed water, higher proportion of household crowding, and higher proportion of families living below the poverty line as risk factors for hospital admission for RSV<sup>30</sup>. Similar risk factors were also identified in non-US studies<sup>29,28,31,32</sup>.

### Pandemic Influenza

Pandemics of influenza and other viral respiratory pathogens, such as COVID-19, are characterized by higher overall attack rates, elevated morbidity and mortality, unevenly adopted countermeasures, and increased strain on health systems. All of which may magnify inequalities in

patterns of disease, despite a complete or near-complete lack of protective immunity. Because of this lack of acquired immunity in the population, the age distribution of infection is likely to be different than seasonal epidemics, resulting in differential patterns of healthcare utilization and mortality risk. Nevertheless, in a pattern echoing findings for seasonal flu, RSV and all-cause ARI, inequalities in the most severe ARI pandemic outcomes have consistently been documented. For example, historical data from Chicago illustrated disparities in 1918 influenza pandemic mortality by neighborhood SES and racial composition<sup>34,35</sup>, with some of this disparity explained by differential rates of transmission in low-SES, overcrowded neighborhoods<sup>34</sup>. In 2009, a number of studies documented social race/ethnic outcome disparities<sup>36-41</sup>, with lower SES<sup>41</sup> associated with increased exposure risk<sup>36</sup>, as well as overall incidence<sup>37</sup>, hospitalization<sup>38,39,41</sup>, complications<sup>36</sup>, and death<sup>39,40</sup> due to pandemic H1N1.

*Incidence:* A nationally representative survey from the U.S. measured risk factors for exposure during the 2009 pandemic, including living in an apartment building, relying on public transportation, and difficulty finding day care that was separate from other children. This study found that these risks were significantly more common among non-white participants<sup>36</sup>. Another US study identified a lack of access to sick-leave and increased number of children in the household as risks for higher ILI incidence during the H1N1 pandemic<sup>37</sup>. The authors determined that this increased risk was associated with Hispanic ethnicity even after controlling for education and income<sup>37</sup>, suggesting that additional, unmeasured SES-related risk factors contributed to this disparity.

*Severity:* In a study using surveillance data from Illinois, hospitalization rates were twice as high for Hispanics and Blacks compared to whites during the 2009 H1N1 pandemic<sup>38</sup>. An analysis using data from multiple nationally representative surveillance networks investigated disparities in hospitalization

and death found substantial differences in morbidity and mortality between race/ethnic groups<sup>39</sup>. Age-adjusted hospitalization rates for minorities were two times higher than those for non-Hispanic whites.

*Mortality:* One study using nationally representative surveillance networks found non-Hispanic Black and Hispanic children had disproportionately higher mortality than non-Hispanic whites<sup>39</sup>. During the H1N1 pandemic, American Indians and Alaskan Natives had a mortality rate 4 times higher than all other racial/ethnic groups<sup>40</sup>. Conversely, a study using hospital discharge and census data found the living in a higher poverty census tract (>6% below poverty line) and Hispanic ethnicity was associated with lower risk of ICU admission for H1N1 related hospitalizations in Massachusetts<sup>41</sup>, although it is unclear if this result reflects differential severity or disparities in access to care.

*Outside the United States:* Research outside of the United States has identified similar relationships between inequality and pandemic ARI outcomes. For example, in a case-control study in Ontario, Canada of persons hospitalized for ARI during the 2009 H1N1 pandemic, the odds of H1N1 infection were higher among adults identifying as East/Southeast Asian, South Asian, and Black compared to whites<sup>42</sup>. In Spain, individuals belonging to an ethnic minority group were more than twice as likely than whites to be admitted to the hospital, and individuals with a secondary or higher education were 0.54 times less likely to be admitted to the hospital as individuals with less education<sup>43</sup>. In England, the 2009 H1N1 pandemic caused 3.1 and 2.0 times higher mortality rates in the two most socio-economic deprived quintiles compared to the least deprived quintile, and this disparity persisted after adjustment for underlying medical conditions and age<sup>44</sup>.

## **Discussion**

The COVID-19 pandemic has shown in stark relief the ways in which SES and racism structure ARI outcomes at every level from exposure to disease severity and mortality. However, despite the large toll of mortality exacted by seasonal and pandemic ARI and the clear evidence of disparities, the number of studies investigating disparities in ARI outcomes and incidence is too limited to help chart a way towards more equitable outcomes. Notably, most of the analyses discussed in this review come from data collected by studies in which identifying disparities was not a primary goal, and thus was not explicitly incorporated into study design and the enrollment of participants. Further, much of the previous work has documented disparities, for example by race/ethnicity, but has not explored the history of policies and practices that specifically marginalized these racial/ethnic minorities and led to disparate outcomes<sup>45</sup>. This echoes earlier findings that studies focusing on identifying and addressing social determinants are underrepresented relative to the importance of social factors in structuring infectious disease risk<sup>46</sup>.

The lack of studies dedicated to identifying and ameliorating ARI disparities guarantees that the analyses reviewed here provide a decidedly incomplete picture of the drivers of disparities in ARI-related outcomes. For example, many of the studies identified in our search is that they characterized disparities among the population of cases presenting at a point of care, ranging from routine medical visits to hospitalization. This reliance on clinical data is likely to under-count risk in populations without access to care, who are disproportionately likely to have low SES, and/or come from marginalized groups, e.g. undocumented immigrants, for whom real and perceived overlaps between medical and legal systems may serve as a disincentive to care-seeking. Finally, most ARI cohort studies, which allow for granular examination of individual-level risk and protective factors, drew largely on geographically concentrated study populations that are largely homogeneous in terms of SES and race/ethnicity.

### *A conceptual framework for unraveling ARI disparities*

It is evident from our review that the lack of a coherent theoretical framework for understanding relationships between social inequality and ARI incidence, severity, and mortality is a significant factor in the dearth of research in this area. The evidence turned up by our review, as well as the issues of racially and socioeconomic disparate exposure risks, coupled with unequal access to testing and treatment made clear by the COVID-19 pandemic, demonstrate that the principles underlying Link & Phelan's theory of SES and race as fundamental causes of health and illness apply to ARIs as much as many non-communicable diseases as well as infections more classically understood as having social antecedents, such as tuberculosis and diarrheal disease. Fundamental cause theory (FCT) posits SES drives disparities through its impact on the financial and social power to marshal the material and social resources that are protective of health<sup>47</sup>. FCT is a mainstay of the literature on SES-related disparities in non-communicable diseases, but has enjoyed very limited application to infectious diseases<sup>48</sup>. A key tenet of FCT is that these disparities are persistent and are likely to increase even as population-level risk goes down. For example, medical innovation is likely to increase disparities because new interventions typically become available first to the well-off and well-insured. This strongly suggests that progress in the treatment and prevention of ARIs using antivirals, monoclonal antibodies<sup>49</sup>, influenza vaccination, and molecular genotyping to inform surveillance and control, are likely to result in increased inequality in both ARI incidence and severe outcomes. These issues have once again been front-and-center during the COVID-19 pandemic, as well-off individuals in the United States enjoyed preferential access to testing in the early days of the pandemic. Similarly, the ability to participate in 'social distancing' by working from home, having food and other essentials delivered to one's home, and engage other protective measures are clearly a function of power and material resources. In the absence of effective vaccines and antivirals, this is the key technology available to protect oneself from an emerging

infection. As preventive and therapeutic interventions against COVID-19 become available, we are likely to see these also distributed preferentially to those with greater means, thereby only exacerbating the yawning disparities in exposure, severity, and mortality that are already evident.

### Implications for Study Design

Surveillance and large network studies can estimate burden of disease and influenza vaccine effectiveness (VE), but may under enroll low-SES and non-white populations and are by design limited to those with access to care since participants are enrolled at the point of care. Ideally, large longitudinal cohort studies with study samples that are representative of the US population would be available to estimate differences in incidence and risk and VE. A meta-analysis found that 97% of observational studies on influenza severity were cohort studies, but very few of these studies collected information on race/ethnicity and the authors do not report on measures of SES in their analysis<sup>55</sup>. To capture the components of risk associated with social disparities, these studies would ideally span multiple seasons and account for known factors associated with risk such as age, influenza infection and vaccination history, household composition, crowding, and other potential exposure and susceptibility related factors. In the absence of such studies, greater attention is needed to increase the socioeconomic diversity of the populations that studies of seasonal ARI risk and VE draw upon, as well as the potential impact of SES on infection outcomes and vaccine effectiveness. Where such data are not available, careful statistical modeling is essential. For example, approaches such as multiple regression with poststratification (MRP), which can be used to make unbiased population-level predictions from non-representative data, may help address some of these questions while we wait for more detailed data<sup>56</sup>.

### Implications for Action

FCT highlights why identifying and intervening only on mediators of the relationship between SES and disease is unlikely to be effective: risk of ARI infection, severe disease, and mortality cannot be reduced to the impact of a single variable, e.g. vaccination. Instead, it reflects a spectrum beginning with comorbid health conditions, the ability to avoid exposure, access to preventive and therapeutic treatment, and other factors. These issues are arguably even more acute for infectious diseases than for non-communicable ones, as the risks of our friends and family directly impact our own risks via transmission.

An FCT perspective suggests that effective policies must address inequality in access to prevention and treatment, as well as inequity in the ability to avoid exposure. For example, policies limiting or eliminating paid sick leave have been shown to increase rates of influenza transmission in the workplace, and to disproportionately affect racial/ethnic minorities<sup>37</sup>, with similar patterns evident in the COVID-19 pandemic. In order to be able to reduce transmission, symptomatic persons should be treated with antivirals (when applicable) and practice home isolation<sup>57</sup>. This cannot be achieved without policies that support rather than penalize such behavior. The lack of supportive workplace policies has been suggested to result in a population-attributable risk of 5 million additional cases of ILI in the US with a disproportionate burden on Hispanic Americans<sup>37</sup>. The lack of a health system ensuring equal access to prevention and care is clear a key factor in exacerbating SES-related disparities in seasonal ARI incidence, as well as undermining pandemic preparedness. However, in the absence of sweeping changes that would address the root causes of these disparities, targeted vaccination for influenza<sup>58,59</sup> and RSV<sup>60</sup> based on age specific contact and transmission patterns has been theorized to improve both the efficacy of vaccines. Identifying high priority groups for vaccination has been shown to be effective in reducing disease burden when target groups are those with high-risk of infection or high transmission potential for both RSV and influenza<sup>58-61</sup>. The expansion of targeted programs to improve access to

vaccination among those of lower SES could be beneficial in reducing disparities. When identifying groups for targeted vaccination, especially those of disadvantaged backgrounds, it is important to address past abuses that may lead to mistrust of these programs. Finding ways to engage with organizations that serve low SES and racial minority communities to address concern and reduce vaccine hesitancy will be paramount to the success of these programs<sup>36</sup>. New vaccine rollouts, such as an RSV vaccine and a universal flu vaccine, should include some targeted vaccination programs to ensure populations already at increased risk of infection are given access to new technologies to prevent the intensification of disparities. Nevertheless, FCT suggests that the long-term efficacy of such interventions is likely to be limited if the upstream drivers of inequality are not addressed: New pathogens and technologies will inevitably expose the weaknesses of existing strategies, once again opening up a gulf between the well-off and everyone else.

### Conclusion

In sum, our findings highlight wide disparities in ARI outcomes by socioeconomic status and race/ethnicity in the U.S. Though the COVID-19 pandemic has brought many of these concerns to the forefront of the public and scientific consciousness, it has also shown how poorly developed our set of tools for addressing both the root and proximal causes of these disparities is. This study represents a first step towards the development a coherent framework for identifying disparities in ARI and their causal antecedents. This will hopefully increase clarity around when and where socially focused interventions (i.e. healthcare and workplace policies) should be prioritized, as well as how biomedical innovations (e.g. vaccination, antivirals) should be distributed to shrink group-level disparities at the same time that they minimize population risk.

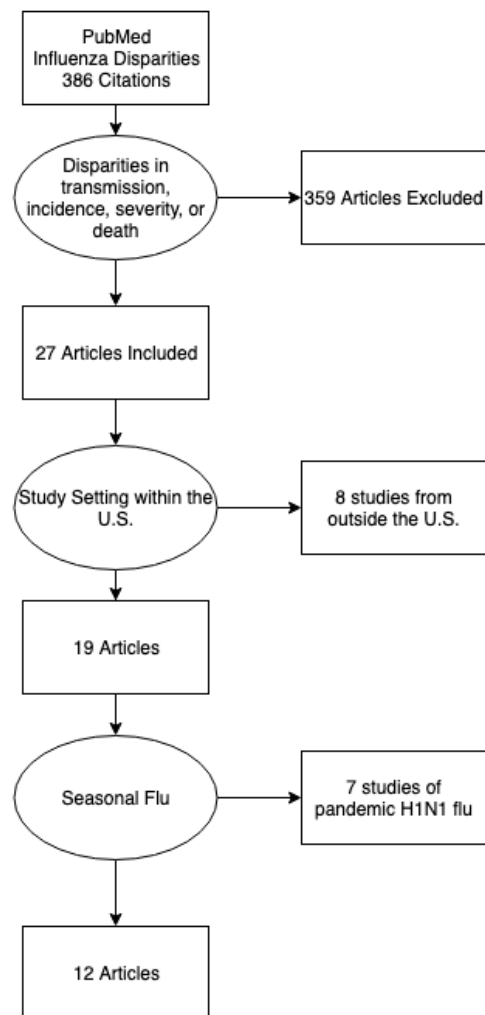


To accomplish this, a sustained effort to build studies and create standardized measures purposively aimed at understanding and curbing SES-related disparities in ARIs is urgently needed. However, even with this lack of consensus, the body of evidence suggests there are disparities in ARI incidence, severity, and mortality. With potential new technologies on the horizon to prevent and better treat ARIs from RSV to influenza as well as emerging infections with pandemic potential, such as COVID-19, the time to make a plan for how to ensure the equitable distribution of benefits from these and other technologies is now.

## Figures & Tables

Figure 1: Search results and screening for A. influenza disparities and B. ARI and RSV disparities

A.



B.

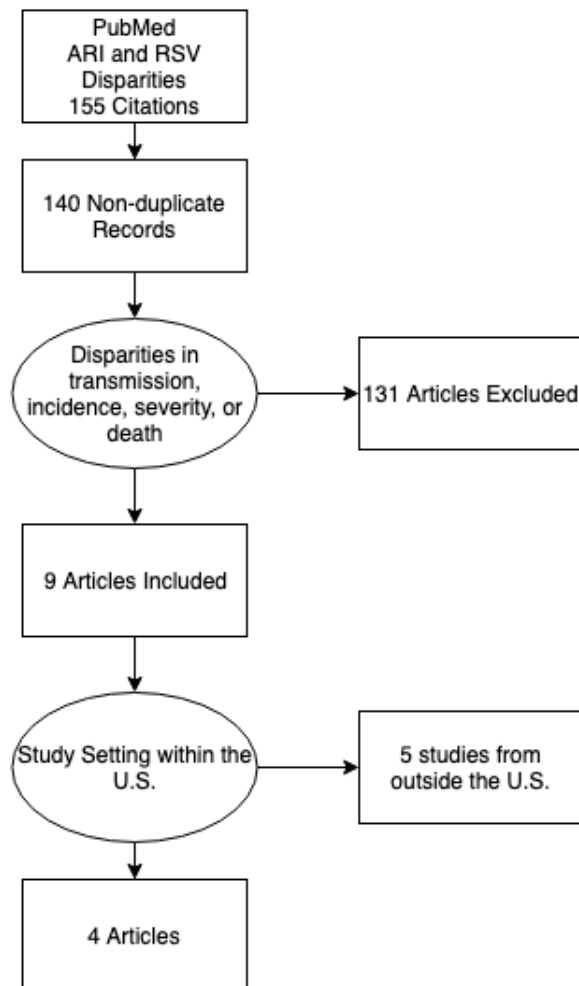


Table 1: Study design, dimension of disparity, and outcome of articles included

	SES, social deprivation, components of SES	Race/Ethnicity	Subjective social status, subjective SES	Total
All-cause ARI				
Experimental Trial			Cohen 2008 (i)	1
Cohort			Thompson 2014 (i)	1
Case-control	Spencer 1996 (s), Caballero 2019 (s)			2
Cross-sectional/ Surveillance based		Iwane 2013 (s), Lusignan 2017 (s)		2
Ecological	Hawker 2003 (s)			1
Seasonal Influenza				
Cohort			Perez 2011 (i)	1
Cross-sectional/ Surveillance based	Yousey-Hindes 2011 (s)	Strully 2011 (ir), Iwane 2013(s)		3
Ecological	Hadler 2016 (s), Sloan 2015 (s), Tam 2014 (s), Charland 2011 (1) (s)	Charland 2011 (2) (s)		4
Multilevel modeling	Chandrasekhar 2017 (s)	Chandrasekhar 2017 (s)		1
Pandemic Influenza (U.S.)				
Cross-sectional		Quinn 2011 (ir), Kumar 2012 (ir), Soyemi 2014 (s), Dee 2011 (s), Castrodale (s)		5
Case-control		Navaranhan 2014 (s), Mayoral 2013 (s)		2
Ecological	Rutter 2012 (s)			1
Multilevel modeling	Placzek 2014 (s)			1
Influenza Complications				
Ecological	Cohen 2011 (s), Hennessey 2008 (s), Hawker 2003 (s), Crighton 2007 (s)	Crighton 2007 (s)		5
RSV				
Cohort	Hennessey 2008 (s)			1
Case-control	Reeve 2006 (s), Stensballe 2006 (s),	Reeve 2006 (s)		4

	Cilla 2006 (s), Bulkow 20032 (s)			
Cross-sectional/ Surveillance based		Iwane 2013 (s)		1
Ecological	Bruden 2015 (s)	Grimwood 2008 (s)		2

Outcomes measured: (i) = incidence; (s) = severity i.e. hospitalization rates, visiting primary care doctor, mortality; (ir) = risk for incidence i.e. greater exposure, risk of exposure

Table 2: Study Key Findings

First author	Study setting	Study design	Study year(s)	Illness	Disparity	Main finding
Thompson 2014	Texas, Oregon, Washington	Prospective cohort of health care personnel	2010	ARI	Self-reported social status	Women of lower self-reported social status were more likely to report ARI during follow up after adjustment for demographics, occupational status, health, and health behaviors
Cohen 2008	United States	Experimental	2000-2004	ARI	Self-reported SES	Increased self-reported SES was associated with decreased risk of developing cold symptoms after exposure to rhinovirus or influenza virus.
Spencer 1996	Sheffield, England	Case-control; cases were children under 1 admitted to Sheffield pediatric units with suspected bronchiolitis, controls were selected from birth records with no hospital admission for respiratory illness in 1 <sup>st</sup> year of life matched by birthday and sex	October 1989 – February 1990	Bronchiolitis	Townsend deprivation index for electoral ward of residence	Children living in the two most deprived electoral wards were 1.5 times more likely to be admitted and 1.74 times more likely to be admitted and requiring a medical intervention than children residing in other parts of the city.

Hawker 2003	West Midlands Health Region, UK	Ecological utilizing Hospital Episode Statistics and Census data	April 1990 – March 1995	All respiratory infections, Acute respiratory infections, pneumonia, and influenza	Townsend deprivation index for census enumeration districts	Increased hospital admission rates for all respiratory infections, acute respiratory infections, and pneumonia were associated with increased deprivation. Hospital admission due to influenza was not associated with deprivation category.
Caballero 2019	Buenos Aires, Argentina	Case-control; cases were children under 5 who died at home without medical assistance, controls were living children matched by age living within 300m of cases home	April 2014 – December 2016	ARI	Proxy measures of SES: crowded home (more than 3 persons per bedroom), adolescent mother (>19 years), and lacking running water in home	Dying at home from ARI was associated with living in a crowded home, having an adolescent mother, and lacking running water in home.
Iwane 2013	3 US counties: Tennessee, New York and Ohio	Surveillance; data from New Vaccine Surveillance Network	October-May 2002-2009	ARI, influenza, RSV	Race/ethnicity (Black vs. white)	Hospitalization rates were higher among Black children than among white children for ARI and influenza. RSV hospitalization rates were similar for Black and white children under

						12 months but higher for Black children age 12 months or older.
Lusignan 2017	England	Surveillance; data from Royal College of General Practitioners Research and Surveillance Centre	May 2014 – April 2015	Common cold and influenza-like illness	Ethnic minorities (Black, mixed, other vs. white)	Common cold and influenza illness diagnoses were more common in ethnic minorities than in whites.
Hadler 2016	United States	Surveillance; FluSurv-NET sites	October-April 2010-2011 and 2011-2012	Influenza seasonal	Census tract-level poverty	Higher census tract level poverty was associated with higher influenza-related hospitalizations.
Chandrasekhar 2017	United States	Surveillance; FluSurv-NET	October-April seasons 2009-2019 through 2013-2014	Influenza seasonal	Race (African Americans vs. whites, Hispanics vs. whites); area level poverty (>20% vs. <5% persons living below poverty level); female headed households (>40% vs. <20% persons with female-headed households); crowding (>5% vs. <5% living in crowded	There were significantly increased odds of influenza hospitalization for African Americans and Hispanics compared to whites and non-Hispanics. Living in a census tract with high area level poverty, high percentage of female-headed households, and high percentage of households with crowding increased odds of influenza-related hospitalization.

					conditions)	
Sloan 2015	Middle Tennessee; 8 counties including Nashville and bordering suburban and rural areas	Ecological; Tennessee EIP Influenza Hospitalization Surveillance Network	October-April seasons 2007-2008 through 2013-2014	Influenza seasonal	Area level SES factors: percentage of college educated individuals, percentage of persons living in poverty, female headed-households, and high population density	An increase in influenza hospitalization was associated with increased percentage of persons living in poverty, female-headed households, crowded households, and population dense areas.
Yousey-Hindes 2011	New Haven, Connecticut	Surveillance; Connecticut Emerging Infections Program	2003-2010	Influenza seasonal	Area level SES factors: poverty (percentage of persons living in poverty), crowding (percentage of households with more than one occupant per room)	The average annual incidence of influenza-related hospitalizations was three times as high for high-poverty and high-crowding census tracts.
Tam 2014	New Haven, Connecticut	Ecological; Connecticut Emerging Infections Program	October-April seasons 2007-2008 through 2010-2011	Influenza seasonal	Area level SES factors: percent of persons living below poverty, percent of persons with no high school diploma, percent of crowded households,	Higher incidence of hospitalization due to influenza was associated with lower neighborhood SES (measured as 20% or greater persons living below poverty, more than 25% of persons without



					percent of non-English speaking households, and median income.	a high school diploma, 12% or more non-English speaking households, and median income below \$50,000).
Charland 2011 (1)	Montreal, Canada	Ecological; utilizing billing claim records from RAMQ, governmental body that provides health insurance to 99% of residents of Quebec	1996-2006	Influenza seasonal	Material deprivation (proportion of persons lacking high school diploma, employment to population ratio, and mean income) and social deprivation (proportion of persons living alone; proportion of persons separated, divorced, or widowed; and proportion of single parent households)	Neighborhoods with the 10% highest material deprivation score (most deprived) had 2 times the rate of health care utilization for influenza than neighborhoods with the 10% lowest materially deprivation score (most advantaged). Increased social deprivation was associated with a decrease in health care utilization for influenza.
Charland 2011 (2)	Quebec, Canada	Ecological; utilizing billing claim records from RAMQ, governmental body that provides health insurance to 99% of residents of Quebec	1996-2006	Influenza seasonal	Race/ethnicity (aboriginal reserve vs. neighboring community)	Rate of influenza-related medical visits in Kahnawá:ke, a “prosperous, urban, aboriginal reserve with accessible healthcare,” was 1.58 times that of an adjacent

						but mostly non-Aboriginal community. Rates of influenza-related medical visits for persons under 20 years were almost 2 times higher in Kahnawá:ke than in neighboring regions.
Perez 2011	University of Michigan students residing in residence halls	Cohort; secondary analysis of experimental trial	January – March 2007	Influenza seasonal	Psychological stress measured using Perceived Stress Scale	An increase in perceived stress was associated with a greater risk of influenza-like illness.
Strully 2011	US nursing homes	Regression modeling; utilizing data from 2004 US National Nursing Home Survey	2004 estimates	Influenza seasonal	Segregation (percentage of Black residents in nursing home) and race	Due to levels of segregation and existing racial disparities in influenza vaccination receipt, Black Americans in nursing homes are more susceptible and have greater exposure to seasonal influenza.
Hennessy 2008	Rural Alaska Natives	Ecological; hospital discharge data from Indian Health Service Direct and Contract Health Service inpatient data set	2000-2004	Pneumonia and influenza, RSV	Water service (proportion of homes with pressurized, in-home water service)	Regions with lower proportion (<80%) of in-home water service had a 1.9 times higher rate of hospitalization due to pneumonia and influenza and a

						3.4 times higher rate of RSV for children under 5 than regions with higher proportion (80% or greater) of in-home water service.
Cohen 2011	US	Ecological; Centers for Medicare and Medicaid Services database	1991-2004	Pneumonia and influenza	Area level SES factors: median county income and proportion of co-residential caregiver grandparents	P&I rates were significantly higher in counties with lower median income. In low income counties, high levels of grandparental co-residence (3.5%) was associated with higher rates of P&I.
Crighton 2007	Ontario, Canada	Ecological; Canadian Institute for Health Information Discharge Abstract Database	1992-2001	Pneumonia and influenza	Area level SES factors: percent with low education (without high school education), percent of population identifying as Aboriginal, percent of population with poor housing (homes needing major repairs)	For the total population, increasing percent of Aboriginal population and low education was associated with an increase in P&I hospitalizations. For females, increasing percent of population with low education and poor housing was associated with an increase in P&I rates. For males, increasing

						percent of Aboriginal population and low education was associated with an increase in P&I hospitalizations.
Williams 2005	United States	Ecological; National Center for Health Statistics	1950-2000	Pneumonia and influenza	Race (Black vs. white)	From 1950 to 2000, the difference and ratio for age-adjusted death rates due to P&I for white and Black Americans have been decreasing. A small difference (2.1 deaths per 100000 population) and ratio (1.1) in mortality rates in mortality rates existed in 2000.
Reeve 2006	Townsville, North Queensland, Australia	Case-control; cases were infants with an RSV-positive LRTI admitted to hospital, controls were selected from live births at Townsville Hospital matched to cases by year of birth	1997-2004	RSV	Ethnicity (indigenous vs. non-indigenous)	Risk factors associated with RSV hospitalization included low birth weight, high maternal parity, single mother, and maternal smoking. These risk factors were all associated with being indigenous.
Grimwood 2008	Wellington, New Zealand	Case-control; cases were infants under 24 months hospitalized	Winter months of 2003-2005	RSV	Ethnicity (Māori, Pacific, other vs. European)	Māori or Pacific ethnicity was associated with over 3 times the risk of

		with bronchiolitis, controls were selected from live hospital births from the same region				hospitalization due to RSV compared to European ethnicity for children less than 24 months.
Bruden 2015	Alaska Native infants from Yukon-Kuskokwim Delta (YKD), Alaska	Ecological; electronic medical records of YKD Regional Hospital and Alaska Native Medical Center	1994-2012	RSV	Area level SES factors: percent of families below the poverty line, percent of households with over 1.5 persons per room, and percent of houses lacking of plumbing	In children under 1 year, increased hospitalization rate due to RSV was associated with increased percent of families living below the poverty line, households with more than 1.5 persons per room, and houses lacking plumbing.
Stensballe 2006	Denmark	Case-control; cases were selected from the RSV database from Danish laboratories, controls were selected from the Danish National Birth Cohort matched by birth date	January 1996 – May 2003	RSV	Maternal work status (maternal unskilled work or unemployment vs. skilled employment )	For children under 18 months, an increased risk of hospitalization due to RSV was associated with maternal unskilled work/unemployment as compared to maternal employment in skilled labor.
Cilla 2006	Basque, Spain	Case-control; cases were children hospitalized for RSV in Hospital Donostia, controls were	July 1996 – June 2000	RSV	Young maternal age (under 25 years at time of birth)	For children under 24 months, RSV hospitalization was associated with young maternal age.

		selected from birth records and matched by birth date				
Bulkow 2002	Alaska Native infants from YKD, Alaska	Case-control; cases were children under 3 years hospitalized with RSV-positive sample, controls were selected from roster of YKD children matched on birth date and region of residence	October 1993 – September 1996	RSV	Household crowding measures: 4 or more children under 12 years or younger in household, 2 or more persons per room in household	For children under 3 years of age, two measures of household crowding, 4 or more children 12 years or younger and 2 or more persons per room in household, were associated with increased risk of RSV-related hospital admission.
Quinn 2011	US	Cross-sectional; survey using Knowledge Networks online research panel	June 2009	Influenza 2009 pandemic	Race/ethnicity (Black vs. white, non-Hispanic, Hispanic vs. white, non-Hispanic)	A survey measuring exposure and susceptibility during H1N1 pandemic found an association between increased measures of exposure and susceptibility and Hispanic ethnicity. No significant association was found for increased measures of exposure or susceptibility and identifying as Black, non-Hispanic.
Kumar	US	Cross-sectional;	January	Influenza	Race/	A survey

2012		survey using Knowledge Networks online research panel	2010	2009 pandemic	ethnicity (Black vs. white, non-Hispanic, Hispanic vs. white, non-Hispanic)	measuring incidence of influenza-like illness during 2009 H1N1 pandemic, found several work-related measures limiting ability to practice social-distancing were associated with increased incidence and were associated with Hispanic ethnicity.
Soyemi 2014	Illinois, US	Surveillance; Illinois National Electronic Data Surveillance System	April – December 2009	Influenza 2009 pandemic	Race/ethnicity (Black vs. white Hispanic vs. non-Hispanic)	Age-adjusted hospitalization rates for Blacks and for Hispanics were two times higher compared to that of whites.
Dee 2011	United States	Surveillance; data from Behavioral Risk Factor Surveillance System, Emerging Infections Program, and Influenza-Associated Pediatric Mortality Surveillance System	September – December 2009 (BRFSS)  April 2009 – January 2010 (EIP)  April 2009–March 2010 (ped. mort.)	Influenza 2009 pandemic	Race/ethnicity (Black, non-Hispanic, Hispanic, American Indian/Alaskan Native vs. non-Hispanic, white)	From BRFSS estimates, AIAN reported higher ILI symptoms compared to non-Hispanic whites and non-Hispanic Blacks and Hispanics reported higher rates of hospitalization due to ILI for at least one family member compared to non-Hispanic whites. From EIP data, hospitalization rates for

						<p>racial/ethnic minorities were substantially higher than for non-Hispanic whites in both the spring/summer and fall/winter pandemic seasons. Pediatric deaths due to influenza were disproportionately minority children.</p>
Placzek 2014	Massachusetts, US	Surveillance; Hospital Discharge Database in Massachusetts	April – September 2009	Influenza 2009 pandemic	Race/ethnicity (non-Hispanic Black, Hispanic vs. non-Hispanic white), area level poverty (% of population living below poverty line)	<p>Living in a census tract with higher poverty levels (6.0-11.9% and 16% or more vs. 0-5.9% households living below poverty) and Hispanic ethnicity was associated with lower risk of ICU admission in H1N1 related hospitalizations. When stratified by race, living in a census tract with higher poverty levels (6.0-11.9% vs. 0-5.9% households living below poverty) was associated with lower risk of ICU admission</p>



						in H1N1 related hospitalizations for non-Hispanic whites; no association between race and area level poverty was significant after stratifying for race.
Castrodale 2009	Alabama, Alaska, Arizona, Michigan, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Utah, Washington, and Wyoming; US	Surveillance; partnership with CSTE, tribal epidemiology centers, HIS, and CDC	April – November 2009	Influenza 2009 pandemic	Race/ethnicity (American Indian/Alaska Native vs. all other racial/ethnic groups combined)	American Indians/Alaska Natives experienced a mortality rate due to H1N1 4 times higher than that of all other racial/ethnic groups in the US.
Navaranjan 2014	Ontario, Canada	Case-control; test-negative design using population tested for influenza through Public Health Ontario Laboratory or Mount Sinai Hospital/University Health Network - cases were laboratory confirmed H1N1 positive and controls were patients	April 2009-July 2009	Influenza 2009 pandemic	Race/ethnicity (East/Southeast Asian, South Asian, Black, Other vs. white), residing in a neighborhood with a high proportion of low income (bottom quintile of	For adults, being of South Asian or Black ethnicity was associated with increased odds of H1N1 infection compared to whites. For children, being of East/Southeast Asian, Black, or other ethnicity; and residing in a neighborhood with a high

		testing negative for influenza			median neighborhood income)	proportion of low income was associated with increased odds of H1N1 infection compared to whites and those not living in a neighborhood with high proportion of low income.
Mayoral 2013	Andalusia, Catalonia, Castile and Leon, Madrid, Navarre, Basque and Valencia; Spain	Case-control; cases were hospitalized influenza patients, controls were outpatient influenza patients	July 2009-February 2010	Influenza 2009 pandemic	Ethnicity (non-white vs. white), overcrowding (14m <sup>2</sup> or more crowded vs. 29m <sup>2</sup> or less crowded), education (no/primary education vs. secondary or higher education)	Increased odds of hospitalization due to H1N1 influenza was associated with minority (non-white) ethnicity and overcrowding. Decreased odds of hospitalization due to H1N1 influenza was associated with secondary or higher education.
Rutter 2012	England	Ecological; deaths due to H1N1 influenza were collected	July 2009 - April 2010	Influenza 2009 pandemic	Socioeconomic deprivation (Index of Multiple Deprivation)	Age and sex-standardized influenza-related mortality rates were 3.1 times higher and 2.0 times higher in the most socioeconomic deprived and second most socioeconomic deprived quintiles

						compared to the least socioeconomic deprived quintile.
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## **References**

1. Liu L, Oza S, Hogan D, et al. Global, regional, and national causes of under-5 mortality in 2000–15: an updated systematic analysis with implications for the Sustainable Development Goals. *Lancet*. 2016;388:3027-3035. doi:10.1016/S0140-6736(16)31593-8
2. Ahmed F, Ahmed E, Pissarides C, Stiglitz J. Why inequality could spread COVID-19. *Lancet Public Heal*. 2020;0(0). doi:10.1016/S2468-2667(20)30085-2
3. Thebault R, Ba Tran A, Williams V. African Americans are at higher risk of death from coronavirus. *The Washington Post*. 2020.
4. Herfst S, Böhringer M, Karo B, et al. Drivers of airborne human-to-human pathogen transmission. *Curr Opin Virol*. 2017;22:22-29. doi:10.1016/j.coviro.2016.11.006
5. Shi T, Mcallister DA, Brien KLO, et al. Global, regional, and national disease burden estimates of acute lower respiratory infections due to respiratory syncytial virus in young children in 2015: a systematic review and modelling study. *Lancet*. 2017;390:946-958. doi:10.1016/S0140-6736(17)30938-8
6. Nair H, Brooks WA, Katz M, et al. Global burden of respiratory infections due to seasonal influenza in young children: a systematic review and meta-analysis. *Lancet*. 2011;378:1917-1930. doi:10.1016/S0140-6736(11)61051-9
7. McKeown T, Record RG. Reasons for the Decline of Mortality in England and Wales during the Nineteenth Century. *Popul Stud (NY)*. 1962;16(2):94-122.
8. Hadler JL, Yousey-Hindes K, Pérez A, et al. Influenza-Related Hospitalizations and Poverty Levels — United States, 2010–2012. *MMWR Morb Mortal Wkly Rep*. 2016;65(05):101-105. doi:10.15585/mmwr.mm6505a1
9. Chandrasekhar R, Sloan C, Mitchel E, et al. Social determinants of influenza hospitalization in

- the United States. *Influenza Other Respi Viruses*. 2017;11(6):479-488. doi:10.1111/irv.12483
10. Sloan C, Chandrasekhar R, Mitchel E, Schaffner W, Lindegren M Lou. Socioeconomic Disparities and Influenza Hospitalization, Tennessee, USA. 2015;21(9). doi:10.3201/eid2109.141861
11. Yousey-Hindes KM, Hadler JL. Neighborhood socioeconomic status and influenza hospitalizations among children: New Haven County, Connecticut, 2003-2010. *Am J Public Health*. 2011;101(9):1785-1789. doi:10.2105/AJPH.2011.300224
12. Tam K, Yousey-Hindes K, Hadler JL. Influenza-related hospitalization of adults associated with low census tract socioeconomic status and female sex in New Haven County, Connecticut, 2007-2011. *Influenza Other Respi Viruses*. 2014;8(3):274-281. doi:10.1111/irv.12231
13. Hennessy TW, Ritter T, Holman RC, et al. The Relationship Between In-Home Water Service and the Risk of Respiratory Tract , Skin , and Gastrointestinal Tract Infections Among Rural Alaska Natives. *Am J Public Health*. 2008;98(11):2072-2078. doi:10.2105/AJPH.2007.115618
14. Thompson MG, Naleway A, Ball S, et al. Subjective social status predicts wintertime febrile acute respiratory illness among women healthcare personnel. *Heal Psychol*. 2014;33(3):282-291.
15. Cohen S, Alper CM, Doyle WJ, Adler N, Treanor JJ, Turner RB. Objective and Subjective Socioeconomic Status and Susceptibility to the Common Cold. *Heal Psychol*. 2008;27(2):268-274. doi:10.1037/0278-6133.27.2.268
16. Spencer N, Logan S, Scholey S, Gentle S. Deprivation and bronchiolitis. *Arch Dis Child*. 1996;74:50-52.
17. Hawker JL, Olowokure B, Sufi F, Weinberg J, Gill N, Wilson RC. Social deprivation and hospital admission for respiratory infection: Ecological study. *Respir Med*. 2003;97(11):1219-1224. doi:10.1016/S0954-6111(03)00252-X

18. Caballero MT, Bianchi AM, Nuño A, et al. Mortality Associated With Acute Respiratory Infections Among Children at Home. *J Infect Dis.* 2019;219:358-364. doi:10.1093/infdis/jiy517
19. Iwane MK, Chaves SS, Szilagyi PG, et al. Disparities Between Black and White Children in Hospitalizations Associated With Acute Respiratory Illness and Laboratory-confirmed Influenza and Respiratory Syncytial Virus in 3 US Counties — 2002 – 2009. *Am J Epidemiol.* 2013;177(7):656-665. doi:10.1093/aje/kws299
20. Lusignan S De, Correa A, Pathirannehelage S, et al. RCGP Research and Surveillance Centre Annual Report 2014–2015: disparities in presentations to primary care. *Br J Gen Pract.* 2017;(January 2017):29-40. doi:10.3399/bjgp16X688573
21. Charland KM, Brownstein JS, Verma A, Brien S, Buckeridge DL. Socio-economic disparities in the burden of seasonal influenza: The effect of social and material deprivation on rates of influenza infection. *PLoS One.* 2011;6(2):1-5. doi:10.1371/journal.pone.0017207
22. Charland KM, Brownstein JS, Verma A, et al. Increased influenza-related healthcare utilization by residents of an urban aboriginal community. 2011;139(12):1902-1908. doi:10.1016/j.dcn.2011.01.002.The
23. Perez V, Uddin M, Galea S, Monto AS, Aiello AE. Stress, adherence to preventive measures for reducing influenza transmission and influenza-like illness. *J Epidemiol Community Health.* 2011;66:605-610. doi:10.1136/jech.2010.117002
24. Strully KW. Health Care Segregation and Race Disparities in Infectious Disease. *J Health Soc Behav.* 2011;52(4):510-526. doi:10.1177/0022146511423544
25. Crighton EJ, Elliott SJ, Moineddin R, Kanaroglou P, Upshur R. A spatial analysis of the determinants of pneumonia and influenza hospitalizations in Ontario (1992-2001). *Soc Sci Med.* 2007;64(8):1636-1650. doi:10.1016/j.socscimed.2006.12.001

26. Cohen SA, Agree EM, Ahmed S, Naumova EN. Grandparental caregiving, income inequality and respiratory infections in elderly US individuals. *J Epidemiol Community Health*. 2011;65(3):246-253. doi:10.1136/jech.2009.093476
27. Williams DR, Jackson PB. Social sources of racial disparities in health. *Health Aff*. 2005;24(2):325-334. doi:10.1377/hlthaff.24.2.325
28. Reeve CA, Whitehall JS, Buettner PG, Norton R, Reeve DM, Francis F. Predicting respiratory syncytial virus hospitalisation in Australian children. *J Paediatr Child Health*. 2006;42:248-252. doi:10.1111/j.1440-1754.2006.00849.x
29. Grimwood K, Cohet C, Rich FJ, et al. Risk factors for respiratory syncytial virus bronchiolitis hospital admission in New Zealand. *Epidemiol Infect*. 2008;136:1333-1341. doi:10.1017/S0950268807000180
30. Bruden DJ, Singleton R, Hawk CS, et al. Eighteen Years of Respiratory Syncytial Virus Surveillance Changes in Seasonality and Hospitalization Rates in Southwestern Alaska Native Children. *J Pediatr Infect Dis*. 2015;34(9):945-950. doi:10.1097/INF.0000000000000772
31. Stensballe LG, Kristensen K, Simoes EAF, et al. Atopic Disposition, Wheezing, and Subsequent Respiratory Syncytial Virus Hospitalization in Danish Children Younger Than 18 Months: A Nested Case-Control Study. *Pediatrics*. 2006;118(5). doi:10.1542/peds.2006-0907
32. Cilla G, Sarasua A, Montes M, et al. Risk factors for hospitalization due to respiratory syncytial virus infection among infants in the Basque Country, Spain. *Epidemiol Infect*. 2006;135:506-513. doi:10.1017/S0950268805005571
33. Bulkow LR, Singleton RJ, Karron RA, Harrison LH, Alaska RSV Study Group. Risk Factors for Severe Respiratory Syncytial Infection Among Alaska Native Children. *Pediatrics*. 2002;109(2):210-216. doi:10.1542/peds.109.2.210

34. Grantz KH, Rane MS, Salje H, Glass GE, Schachterle SE, Cummings DAT. Disparities in influenza mortality and transmission related to sociodemographic factors within Chicago in the pandemic of 1918. *PNAS*. 2016;113(48):13839-13844. doi:10.1073/pnas.1612838113
35. Chowell G, Viboud C. Pandemic influenza and socioeconomic disparities: Lessons from 1918 Chicago. *PNAS*. 2016;113(48):13557-13559. doi:10.1073/pnas.1616537113
36. Quinn SC, Kumar S, Freimuth VS, Musa D, Casteneda-Angarita N, Kidwell K. Racial disparities in exposure, susceptibility, and access to health care in the US H1N1 influenza pandemic. *Am J Public Health*. 2011;101(2):285-293. doi:10.2105/AJPH.2009.188029
37. Kumar S, Quinn SC, Kim KH, Daniel LH, Freimuth VS. The Impact of Workplace Policies and Other Social Factors on Self-Reported Influenza-Like Illness Incidence During the 2009 H1N1 Pandemic. *Am J Public Health*. 2012;102(1):134-140. doi:10.2105/AJPH.2011.300307
38. Soyemi K, Medina-Marino A, Sinkowitz-Cochran R, et al. Disparities among 2009 pandemic influenza A (H1N1) hospital admissions: A mixed methods analysis - Illinois, April-December 2009. *PLoS One*. 2014;9(4). doi:10.1371/journal.pone.0084380
39. Dee DL, Bensyl DM, Gindler J, et al. Racial and Ethnic Disparities in Hospitalizations and Deaths Associated with 2009 Pandemic Influenza A (H1N1) Virus Infections in the United States. *Ann Epidemiol*. 2011;21(8):623-630. doi:10.1016/j.annepidem.2011.03.002
40. Castrodale L, McLaughlin J, Imholte S, et al. Deaths related to 2009 pandemic influenza A (H1N1) among American Indian/Alaska Natives 12 states, 2009. *MMWR Morb Mortal Wkly Rep*. 2009;58(48):1341-1344. doi:mm5848a1 [pii]
41. Placzek H, Madoff L. Effect of race/ethnicity and socioeconomic status on pandemic H1N1-related outcomes in Massachusetts. *Am J Public Health*. 2014;104(1). doi:10.2105/AJPH.2013.301626



42. Navaranjan D, Rosella LC, Kwong JC, Campitelli M, Crowcroft N. Ethnic disparities in acquiring 2009 pandemic H1N1 influenza: a case-control study. *BMC Public Health*. 2014;14:214.  
doi:10.1186/1471-2458-14-214
43. Mayoral JM, Alonso J, Garín O, et al. Social factors related to the clinical severity of influenza cases in Spain during the A (H1N1) 2009 virus pandemic. *BMC Public Health*. 2013;13(1).  
doi:10.1186/1471-2458-13-118
44. Rutter PD, Mytton OT, Mak M, Donaldson LJ. Socio-economic disparities in mortality due to pandemic influenza in England. *Int J Public Health*. 2012;57(4):745-750. doi:10.1007/s00038-012-0337-1
45. Sealy-Jefferson S, Butler B, Price-Spratlen T, Dailey RK, Misra DP. Neighborhood-Level Mass Incarceration and Future Preterm Birth Risk among African American Women. *J Urban Heal*. 2020;97(2):271-278. doi:10.1007/s11524-020-00426-w
46. Noppert GA, Kubale JT, Wilson ML. Analyses of infectious disease patterns and drivers largely lack insights from social epidemiology: contemporary patterns and future opportunities. *J Epidemiol Community Health*. 2017;71:350-355. doi:10.1136/jech-2016-207967
47. Phelan JC, Link BG, Tehranifar P. Social Conditions as Fundamental Causes of Health Inequalities: Theory, Evidence, and Policy Implications. *J Health Soc Behav*. 2010;51(1\_suppl):S28-S40. doi:10.1177/0022146510383498
48. Noppert GA, Malosh RE, Moran EB, Ahuja SD, Zelner J. Contemporary Social Disparities in TB Infection and Disease in the USA: a Review. *Curr Epidemiol Reports*. 2018:442-449.
49. Mac S, Sumner A, Duchesne-Belanger S, Stirling R, Tunis M, Sander B. Cost-effectiveness of Palivizumab for Respiratory Syncytial Virus: A systematic review. *Pediatrics*. 2019;143(5).  
doi:10.1542/peds.2018-4064

50. Ferdinands JM, Gaglani M, Martin ET, et al. Prevention of Influenza Hospitalization Among Adults in the United States, 2015-2016: Results From the US Hospitalized Adult Influenza Vaccine Effectiveness Network (HAIVEN). *J Infect Dis*. 2019;220(8):1265-1275.  
doi:10.1093/infdis/jiy723
51. Lewnard JA, Tedijanto C, Cowling BJ, Lipsitch M. Measurement of Vaccine Direct Effects Under the Test-Negative Design Measurement of Vaccine Direct Effects Under the Test-Negative Design. *Am J Epidemiol*. 2018;187(12):2686-2697. doi:10.1093/aje/kwy163
52. Setse RW, Euler GL, Gonzalez-Feliciano AG, et al. *Influenza Vaccination Coverage -- United States, 200-2010*. Vol 60.; 2011.
53. Flannery B, Chung JR, Belongia EA, et al. *Interim Estimates of 2017 – 18 Seasonal Influenza Vaccine Effectiveness — United States, February 2018*. Vol 67. Atlanta, Georgia; 2018.
54. Flannery B, Chung JR, Thaker SN, et al. *Interim Estimates of 2016 – 17 Seasonal Influenza Vaccine Effectiveness — United States, February 2017*. Vol 66.; 2017.
55. Mertz D, Kim TH, Johnstone J, et al. Populations at risk for severe or complicated influenza illness: A systematic review and meta-analysis. *PLoS One*. 2014;9(3):1-25.  
doi:10.1371/journal.pone.0089697
56. Gelman A. Struggles with Survey Weighting and Regression Modeling. *Stat Sci*. 2007;22(2):153-164. doi:10.1214/088342306000000691
57. Kerckhove K Van, Hens N, Edmunds WJ, Eames KTD. The Impact of Illness on Social Networks: Implications for Transmission and Control of Influenza. *Am J Epidemiol*. 2013;178(11):1655-1662. doi:10.1093/aje/kwt196
58. Worby CJ, Chaves SS, Wallinga J, Lipsitch M, Finelli L, Goldstein E. On the relative role of different age groups in influenza epidemics. *Epidemics*. 2016;13:10-16.

doi:10.1016/j.epidem.2015.04.003.On

59. Sah P, Medlock J, Fitzpatrick MC, Singer BH, Galvani AP. Optimizing the impact of low-efficacy influenza vaccines. *PNAS*. 2018;115(20):5151-5156. doi:10.1073/pnas.1802479115
60. Yamin D, Jones FK, Devincenzo JP, et al. Vaccination strategies against respiratory syncytial virus. *PNAS*. 2016;113(46):13239-13244. doi:10.1073/pnas.1522597113
61. Fiscella K, Dressler R, Meldrum S, Holt K. Impact of influenza vaccination disparities on elderly mortality in the United States. *Prev Med (Baltim)*. 2007;45(1):83-87.  
doi:10.1016/j.ypmed.2007.03.007

## **Supplementary Materials**

### **PubMed Search Terms**

#### **Search #1 (ARI/ILI/RSV Disparities):**

((("delivery of health care"[MeSH Terms:noexp] OR "health behavior"[MeSH Terms] OR "health knowledge, attitudes, practice"[MeSH Terms] OR "health services accessibility"[MeSH Terms] OR "health services, indigenous"[MeSH Terms] OR "mass screening"[MeSH Terms] OR mass screening[TIAB] OR mass screenings[TIAB] OR health inequality[TIAB] OR health inequalities[TIAB] OR health inequities[TIAB] OR health inequity[TIAB] OR "health services needs and demand"[MeSH Terms] OR "patient acceptance of health care"[MeSH Terms] OR "patient selection"[MeSH Terms] OR "quality of health care"[MeSH Major Topic:noexp] OR "quality of life"[MeSH Terms] OR quality of life[TIAB] OR Culturally Competent Care[TIAB] OR "culturally competent care"[MeSH Terms] OR social disparities[TIAB] OR social disparity[TIAB] OR social inequities[TIAB] OR social inequity[TIAB] OR "socioeconomic factors"[MeSH Major Topic] OR socioeconomic factor[TIAB] OR socioeconomic factors[TIAB] OR "social determinants of health"[MeSH Terms]) AND (African American[TIAB] OR African Americans[TIAB] OR African ancestry[TIAB] OR "african continental ancestry group"[MeSH Terms] OR AIAN[TIAB] OR "american native continental ancestry group"[MeSH Terms] OR "asian continental ancestry group"[MeSH Terms] OR Asian[TIAB] OR Asians[TIAB] OR black[TIAB] OR blacks[TIAB] OR Caucasian[TIAB] OR Caucasians[TIAB] OR diverse population[TIAB] OR diverse populations[TIAB] OR environmental justice[TIAB] OR ethnic group[TIAB] OR "ethnic groups"[MeSH Terms] OR ethnic groups[TIAB] OR ethnic population[TIAB] OR ethnic populations[TIAB] OR ghetto[TIAB] OR ghettos[TIAB] OR Hispanic[TIAB] OR Hispanics[TIAB] OR Indian[TIAB] OR Indians[TIAB] OR Latino[TIAB] OR Latinos[TIAB] OR

Latina[TIAB] OR Latinas[TIAB] OR "medically underserved area"[MeSH Terms] OR minority group[TIAB] OR "minority groups"[MeSH Terms] OR minority groups[TIAB] OR minority population[TIAB] OR minority populations[TIAB] OR Native American[TIAB] OR Native Americans[TIAB] OR "oceanic ancestry group"[MeSH Terms] OR pacific islander[TIAB] OR pacific islanders[TIAB] OR Native Hawaiian[TIAB] OR Native Hawaiians[TIAB] OR Alaska Natives[TIAB] OR people of color[TIAB] OR "poverty areas"[MeSH Terms] OR poverty area[TIAB] OR poverty areas[TIAB] OR "rural health"[MeSH Terms] OR rural health[TIAB] OR "rural health services"[MeSH Terms] OR "rural population"[MeSH Terms] OR rural population[TIAB] OR rural populations[TIAB] OR slum[TIAB] OR slums[TIAB] OR "urban health"[MeSH Terms] OR "urban health services"[MeSH Terms] OR "urban population"[MeSH Terms] OR urban population[TIAB] OR urban populations[TIAB] OR "vulnerable populations"[MeSH Terms] OR vulnerable population[TIAB] OR vulnerable populations[TIAB] OR white[TIAB] OR whites[TIAB]) OR (ethnic disparities[TIAB] OR ethnic disparity[TIAB] OR health care disparities[TIAB] OR health care disparity[TIAB] OR health disparities[TIAB] OR health disparity[TIAB] OR "health status disparities"[MeSH Terms] OR "healthcare disparities"[MeSH Terms] OR healthcare disparities[TIAB] OR healthcare disparity[TIAB] OR "minority health"[MeSH Terms] OR minority health[TIAB] OR sexual minorities[TIAB] OR racial disparities[TIAB] OR racial disparity[TIAB] OR racial equality[TIAB] OR racial equity[TIAB] OR racial inequities[TIAB] OR racial inequity[TIAB] OR "ageism"[MeSH Terms] OR "racism"[MeSH Terms] OR "apartheid"[MeSH Terms] OR "sexism"[MeSH Terms] OR "social discrimination"[MeSH Terms] OR "social segregation"[MeSH Terms] OR "social marginalization"[MeSH Terms])) AND  
 ((((((Respiratory Syncytial Virus, Human[MeSH Terms]) OR RSV[Title/Abstract]) OR Respiratory Syncytial Virus[Title/Abstract]) OR Acute Respiratory Infection[Title/Abstract]) OR

ARI[Title/Abstract]) OR Influenza-like illness[Title/Abstract]) OR ILI[Title/Abstract]) OR influenza like illness[Title/Abstract])

Search #2 (Influenza Disparities):

((("delivery of health care"[MeSH Terms:noexp] OR "health behavior"[MeSH Terms] OR "health knowledge, attitudes, practice"[MeSH Terms] OR "health services accessibility"[MeSH Terms] OR "health services, indigenous"[MeSH Terms] OR "mass screening"[MeSH Terms] OR mass screening[TIAB] OR mass screenings[TIAB] OR health inequality[TIAB] OR health inequalities[TIAB] OR health inequities[TIAB] OR health inequity[TIAB] OR "health services needs and demand"[MeSH Terms] OR "patient acceptance of health care"[MeSH Terms] OR "patient selection"[MeSH Terms] OR "quality of health care"[MeSH Major Topic:noexp] OR "quality of life"[MeSH Terms] OR quality of life[TIAB] OR Culturally Competent Care[TIAB] OR "culturally competent care"[MeSH Terms] OR social disparities[TIAB] OR social disparity[TIAB] OR social inequities[TIAB] OR social inequity[TIAB] OR "socioeconomic factors"[MeSH Major Topic] OR socioeconomic factor[TIAB] OR socioeconomic factors[TIAB] OR "social determinants of health"[MeSH Terms]) AND (African American[TIAB] OR African Americans[TIAB] OR African ancestry[TIAB] OR "african continental ancestry group"[MeSH Terms] OR AIAN[TIAB] OR "american native continental ancestry group"[MeSH Terms] OR "asian continental ancestry group"[MeSH Terms] OR Asian[TIAB] OR Asians[TIAB] OR black[TIAB] OR blacks[TIAB] OR Caucasian[TIAB] OR Caucasians[TIAB] OR diverse population[TIAB] OR diverse populations[TIAB] OR environmental justice[TIAB] OR ethnic group[TIAB] OR "ethnic groups"[MeSH Terms] OR ethnic groups[TIAB] OR ethnic population[TIAB] OR ethnic populations[TIAB] OR ghetto[TIAB] OR ghettos[TIAB] OR Hispanic[TIAB] OR Hispanics[TIAB] OR Indian[TIAB] OR Indians[TIAB] OR Latino[TIAB] OR Latinos[TIAB] OR

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 (((human influenza[MeSH Terms]) OR human influenzas[MeSH Terms]) OR human influenza[Title/Abstract]) OR human influenzas[Title/Abstract])