A Multilevel Analysis of Individual, Health System, and Neighborhood Factors Associated with Depression within a Large Metropolitan Area

Arne Beck · Arthur J. Davidson · Stanley Xu ·
M. Josh Durfee · Carlos Irwin A. Oronce ·
John F. Steiner · Edward Havranek

Published online: 25 August 2017
© The New York Academy of Medicine 2017

Abstract Depression prevalence is known to vary by individual factors (gender, age, race, medical comorbidities) and by neighborhood factors (neighborhood deprivation). However, the combination of individual- and neighborhood-level data is rarely available to assess their relative contribution to variation in depression across neighborhoods. We geocoded depression diagnosis and demographic data from electronic health records for 165,600 patients seen in two large health systems serving the Denver population (Kaiser Permanente and Denver Health) to Denver's 144 census tracts, and combined these data with indices of neighborhood deprivation obtained from the American Community Survey. Non-linear mixed models examined the relationships between depression rates and individual and census tract variables, stratified by health system. We found higher depression rates associated with greater age, female gender, white race, medical comorbidities, and with lower rates of home owner occupancy, residential stability, and higher educational attainment, but not with economic disadvantage. Among the Denver Health cohort, higher depression rates were associated with higher crime rates and a lower percent of foreign born residents

and single mother households. Our findings suggest that individual factors had the strongest associations with depression. Neighborhood risk factors associated with depression point to low community cohesion, while the role of education is more complex. Among the Denver Health cohort, language and cultural barriers and competing priorities may attenuate the recognition and treatment of depression.

Keywords Depression prevalence · Neighborhood deprivation

Introduction

Depression is the most common mental disorder, affecting more than 26% of adult Americans [1] during their lifetimes, and is the second leading cause of disability worldwide [2]. A variety of individual-level demographic, clinical and behavioral risk factors are associated with depression, including gender (depression prevalence in women is double that in men), race (prevalence is higher in white non-Hispanic race), chronic diseases (e.g., higher in those with diabetes, cancer, cardiovascular disease, asthma, and obesity) [3], and unhealthy behaviors (e.g., physical inactivity, smoking, excessive drinking, and insufficient sleep).

The role of community-level factors in conferring risk for depression is less well understood, although neighborhood deprivation has been hypothesized as a contributor [4–6]. Measures of neighborhood deprivation typically include poor economic status (family

A. Beck (✉) · S. Xu · J. F. Steiner
Institute for Health Research Kaiser Permanente Colorado,
Denver, CO, USA
e-mail: arne.beck@kp.org

A. J. Davidson · M. Josh Durfee · E. Havranek
Denver Health and Hospital Authority, Denver, CO, USA

C. I. A. Oronce
University of Rochester Medical Center, Rochester, NY, USA

poverty rate, unemployment, public assistance, households led by a single mother), low educational attainment (high school education or lower), housing instability (residents living in the same house less than 1 year, non-owner-occupied houses), the percent of foreign born residents, and serious crime rate.

Depression and other mental health disorders are consistently identified as high priorities for action by community members, and local public health agencies, faced with a dearth of neighborhood-level surveillance data on depression and other mental disorders, are keenly interested in identifying and addressing variation in depression prevalence within their jurisdictions.

The present study used individual-level demographic and diagnostic data from two large healthcare systems, combined with community-level data from the 2010 census [7], to examine the individual, health system and neighborhood factors associated with depression prevalence across census tracts within the city and county of Denver, Colorado. The goal of this study was to assess the feasibility of combining electronic health record (EHR) and census tract data for use by the local public health department in identifying factors associated with neighborhood-level variations in depression prevalence. The combination of individual-level and neighborhood-level data may provide a more robust evaluation of the relative contribution of such factors to variations in depression across neighborhoods. We also assessed whether data from these sources could confirm or replicate known associations between individual and community characteristics and depression, which would provide reassurance that the data have utility for public health surveillance.

Methods

Setting

The City and County of Denver, Colorado's state capital, has a population of about 650,000 individuals, including about 516,000 adults, living within 144 census tracts, with a large minority population of Hispanic/Latinos (24%). Two large healthcare organizations, Kaiser Permanente (KP) of Colorado with more than 110,000 members in Denver County (650,000 in total) and Denver Health (DH), which cares for more than 200,000 individuals, collectively provide health care for nearly 40% of residents in Denver County. The two

systems serve different subgroups of the Denver population. KP is a managed care organization offering services primarily to employed individuals and their families while DH is a safety-net organization serving a more economically challenged population, the majority of whom are on Medicaid. Following implementation of the Affordable Care Act in 2013, KP enrolled a substantial number of new patients through the Colorado healthcare exchange and state Medicaid program.

Data Sources

Both KP and DH have EHR systems containing diagnostic data recorded by clinicians after each encounter. Data extracted from the EHRs are stored in a common data model, the Virtual Data Warehouse (VDW), originally developed by the Health Care Systems Research Network and are a standard for participation in the Colorado Health Observation Regional Data Service [8], a regional distributed research network that uses PopMedNet [9] query technology implemented in several large federal initiatives [10, 11].

This study included adults ≥ 18 years of age who had at least one outpatient visit for medical or mental health care in either system between January 1, 2011 and December 31, 2012. Individual-level demographic data (i.e., age, gender, race/ethnicity, and residential address) were retrieved from the VDWs at DH and KP. The cohort of patients with depression included unique individuals with at least one depression diagnosis code recorded during an outpatient visit (ICD-9: 296.x, 298,0301.4, 309.x, 311—major depressive disorder, dysthymic disorder, adjustment disorder with depressed mood, and depression not elsewhere classified) over the 2-year period. Diagnosis codes for common chronic health conditions were also obtained in order to calculate a measure of medical comorbidity, the Chronic Condition Index [12]. In addition, individuals were required to have a residence address in order for us to perform analyses exploring the association neighborhood and demographic and clinical characteristics. Thus, all homeless individuals were excluded.

Neighborhood-level data (by census tract) were obtained from the American Community Survey (ACS) which uses 2010 US census data [13]. We chose several ACS variables representing neighborhood deprivation, including median household income, unemployment rate, serious crime rate, and the percent of individuals

at the same residence for at least 1 year (residential stability), foreign born residents, individuals with a high school diploma, households on public assistance, households <100% of federal poverty level, households led by a single mother, and housing units that are owner occupied. These were a subset of variables used to create a neighborhood deprivation index [4]. Some variables in the index were not used because they were unavailable from the ACS (e.g., no telephone, incomplete plumbing) while other variables were excluded because they were highly correlated with those chosen for our subset (e.g., median house value and median rent were positively correlated with median income, 0.77 and 0.74, respectively); percent of individuals with a high school education was positively correlated with the percent of individuals with a white collar job (0.90) and negatively correlated with a measure of crowding (−0.85).

The KP and DH institutional review boards responsible for the protection of human research participants approved this study.

Data Analysis

We compared individual characteristics and census tract-level characteristics of patient populations separately for DH and KP using chi-square tests for discrete variables and *t* tests for continuous variables. To examine the relationships between depression rates and both individual and census tract level variables, we conducted stratified analyses by health system because these relationships may differ between systems, and we were unable to de-duplicate patients seen within both systems. Because the outcome variable was dichotomous and individuals are clustered within census tracts, we fit non-linear mixed models with logit link function and

Table 1 Individual-level variables for Denver Health and Kaiser Permanente Colorado Patients

Individual characteristics	Total population (<i>N</i> = 165,600)	Denver Health (<i>N</i> = 64,252)	Kaiser Permanente Colorado (<i>N</i> = 101,348)	<i>P</i> values
Age				<0.0001
18–34	38.0	39.2	37.3	
35–44	20.0	23.5	17.7	
45–54	15.8	16.5	15.3	
55–64	14.3	12.8	15.2	
65–74	7.2	5.9	8.1	
75+	4.8	2.2	6.4	
Gender				<0.0001
Female (%)	56.7	59.6	54.8	
Race				<0.0001
White (%)	40.2	26.7	48.9	
Black (%)	10.9	15.8	7.8	
Hispanic (%)	29.4	50.5	16.0	
Native (%)	0.4	0.6	0.3	
Asian (%)	2.4	3.0	2.0	
Hawaiian/Pacific Islander (%)	0.2	0.3	0.2	
Multiracial (%)	1.2	0	2.0	
Other (%)	1.5	0	2.4	
Unknown	13.7	3.1	20.5	
CCI				<0.0001
None	75.7	79.8	73.1	
=1	12.6	12.2	12.8	
≥2	11.7	8.0	14.1	
Depression rate	12.5	11.0	13.4	<0.0001

census tracts as clusters. First, bivariate analyses were run to examine relationships between depression rates and individual and census tract level variables, stratified by health system. We then examined the relationship of each census tract level variable to depression rates, after adjusting for individual-level variables, in order to determine the unique contribution of neighborhood factors to depression rates, independent of individual demographic and clinical factors. Because of the high correlation among census tract level variables, in multivariate modeling, they were examined separately adjusting for individual characteristics.

Results

A total of 165,600 patients (64,252 from DH and 101,348 from KP) met the criteria for inclusion in the cohort. Table 1 shows demographic variables for the combined and separate DH and KP patient cohorts, confirming differences between the populations served. Compared to KP patients, DH patients were younger, with a higher proportion of females, greater racial and ethnic diversity (a higher proportion of blacks and Hispanics), a lower proportion with multiple chronic conditions, and a lower rate of depression diagnosis.

Table 2 shows census tract characteristics for the combined and separate DH and KP cohorts, further demonstrating substantial differences between

neighborhoods where the DH and KP populations reside. Overall, the DH population was significantly more disadvantaged than the KP population. Specifically, DH patients lived in census tracts with *lower* average incomes, residential stability, educational level, owner occupancy, and *higher* rates of foreign born residents, unemployment, serious crime, public assistance, poverty, and single mother households.

Tables 3 and 4 show the associations between depression rates and individual-level and census tract-level variables. Because of the significant differences in individual and census tract variables between the DH and KP patient cohorts, we conducted these multilevel analyses separately for each. Consistent with previous studies of demographic factors associated with depression, higher rates of depression were observed with greater age, female gender, white non-Hispanic race, and a greater number of medical comorbidities. This pattern of findings was the same for DH and KP cohorts.

Tables 3 and 4 also display the associations of individual census tract variables with depression prevalence for DH and KP patients separately, after adjusting for age, gender, race, and CCI. Table 3 shows that among DH patients, higher rates of depression were associated with 7 of the 10 census tract variables, including a higher serious crime rate, higher percentage with a high school diploma, and a *lower* percent of foreign-born residents, owner occupied homes, single-mother households, and lower rates of residential stability and

Table 2 Census tract characteristics for Denver Health and Kaiser Permanente Colorado patients

Census tract characteristic	Total population (<i>N</i> = 165,600) Mean (sd)	Denver Health (<i>N</i> = 64,252) Mean (sd)	Kaiser Permanente Colorado (<i>N</i> = 101,348) Mean (sd)	<i>P</i> values
Median household income	50,749 (21,298)	44,178 (17,121)	54,917 (22,598)	<0.0001
Unemployment rate	9.4 (4.7)	10.9 (4.8)	8.5 (4.4)	<0.0001
Residential stability	77.0 (8.7)	76.4 (8.4)	77.3 (8.8)	<0.0001
Percent of foreign born residents	16.5 (10.4)	19.7 (10.9)	14.4 (9.6)	<0.0001
Serious crime rate	11.8 (8.4)	13.3 (8.9)	10.8 (7.9)	<0.0001
Percent of people with high school diploma	82.1 (15.0)	76.2 (15.8)	85.9 (13.2)	<0.0001
Percent of households on public assistance	3.1 (2.4)	3.8 (2.6)	2.7 (2.1)	<0.0001
Percent of households <100% of federal poverty level	15.7 (11.6)	20.2 (12.2)	12.9 (10.3)	<0.0001
Percent of households led by a single mother	7.4 (5.7)	9.0 (6.6)	6.3 (4.7)	<0.0001
Percent of owned housing units that are occupied	51.8 (20.0)	47.7 (18.9)	54.4 (20.3)	<0.0001

Table 3 Relationships of individual- and census tract-level variables to depression rates for DH

Individual variable	RR	95% CL	<i>P</i> value each level	<i>P</i> value overall	
Age					
18–34	0.48	(0.41, 0.57)	0.000	0.000	
35–44	0.81	(0.69, 0.95)	0.009		
45–54	1.26	(1.07, 1.48)	0.005		
55–64	1.44	(1.23, 1.68)	0.000		
65–74	1.25	(1.06, 1.47)	0.007		
75+	1.00				
Gender					
Male	0.53	(0.50, 0.56)	0.000	0.000	
Female	1.00				
Race					
Asian	0.40	(0.33, 0.50)	0.000	0.000	
Hispanic	0.74	(0.68, 0.80)	0.000		
Black non-Hispanic	0.64	(0.58, 0.72)	0.000		
Hawaiian, Pacific Islander		(0.26, 0.78)			
	0.45		0.004		
Native American	0.79	(0.56, 1.10)	0.005		
Unknown	0.21	(0.16, 0.27)	0.000		
White non-Hispanic	1.00				
Chronic conditions					
none	1.00				0.000
=1	2.85	(2.63, 3.08)	0.000		
≥2	4.33	(3.99, 4.71)	0.000		
Census tract variable ^a					
Serious crime rate					
	<0.08	0.82 (0.74, 0.91)	0.002	0.009	
	0.08–0.10	0.93 (0.85, 1.02)	0.121		
	0.11–0.14	0.90 (0.81, 1.00)	0.048		
	≥0.15	1.00			
Percentage of residents with high school diploma (aged 25+ years)					
	<63.2	0.95 (0.86, 1.05)	0.296	0.043	
	63.2–77.5	0.84 (0.74, 0.94)	0.003		
	77.6–91.0	0.95 (0.87, 1.05)	0.327		
	≥91.1	1.00			
Percent of households below 100% of federal poverty level					
	<10.9	0.97 (0.87, 1.09)	0.623	0.938	
	10.9–20.9	0.97 (0.87, 1.08)	0.524		
	21.0–27.9	0.98 (0.87, 1.10)	0.710		
	≥28.0	1.00			
Percent of foreign born residents					
	<9.4	1.18 (1.06, 1.31)	0.002	0.021	
	9.4–19.2	1.12 (1.01, 1.25)	0.031		
	19.3–28.6	1.04 (0.92, 1.16)	0.543		
	≥28.7	1.00			
Median household income					
	<32,470	1.08 (0.97, 1.20)	0.174	0.491	

Table 3 (continued)

Individual variable	RR	95% CL	<i>P</i> value each level	<i>P</i> value overall
	32,470–39,355	0.99 (0.89, 1.09)	0.795	
	39,356–50,227	1.03 (0.93, 1.13)	0.580	
	≥50,228	1.00		
Percent of owned housing units that are occupied				
	<33.7	1.24 (1.11, 1.39)	0.000	0.006
	33.7–46.5	1.08 (0.98, 1.20)	0.134	
	46.6–60.1	1.08 (0.97, 1.19)	0.152	
	≥60.2	1.00		
Percent of households on public assistance				
	<2.1	0.96 (0.87, 1.07)	0.517	0.783
	2.1–3.2	0.98 (0.87, 1.10)	0.700	
	3.3–5.4	1.01 (0.90, 1.14)	0.834	
	≥5.5	1.00		
Percent of households led by a single mother				
	<4.2	1.16 (1.05, 1.28)	0.003	0.008
	4.2–7.9	1.04 (0.93, 1.15)	0.498	
	8.0–11.9	1.01 (0.88, 1.15)	0.940	
	≥12.0	1.00		
Residential stability (same address as last year)				
	<72.2	1.18 (1.05, 1.32)	0.004	0.041
	72.2–76.6	1.12 (1.01, 1.25)	0.028	
	76.7–81.6	1.08 (0.97, 1.19)	0.171	
	≥81.7	1.00		
Unemployment rate				
	<6.7	1.17 (1.04, 1.31)	0.008	0.050
	6.7–10.9	1.09 (0.97, 1.22)	0.149	
	11.0–14.2	1.05 (0.92, 1.19)	0.463	
	≥14.3	1.00		

^a Associations of census tract variables with depression prevalence, adjusting for age, gender, race, and CCI

unemployment. There were non-significant associations between prevalence of depression and the percent of households below 100% of federal poverty level, median household income, and the percent of households on public assistance.

Table 4 shows that among KPCO patients, higher rates of depression were associated with 3 of the 10 census tract variables, including with higher percentages of residents with a high school diploma and lower rates of owner occupancy and residential stability. Depression prevalence was not significantly associated with the serious crime rate, median household income, unemployment rate, or the percent of households below 100% of federal poverty level, foreign-born residents, households on public assistance, and single-mother households.

Discussion

This study demonstrates the feasibility of combining EHR and census tract data for use by a local public health department in identifying factors associated with neighborhood-level variations in depression prevalence. Our findings also replicate previously documented associations between depression and higher age, female gender, white race, and one or more chronic conditions. These findings were similar for demographically different patient populations seen in two different health systems, suggesting that the data may have utility for public health surveillance.

Our results also highlighted substantial differences between neighborhood characteristics of DH and KPCO

Table 4 Relationships of individual- and census tract-level variables to depression rates for KP.

Individual variable	RR	95% CL	<i>P</i> value each level	<i>P</i> value overall
Age				
18–34	0.36	(0.33, 0.40)	0.000	0.000
35–44	0.51	(0.47, 0.56)	0.009	
45–54	0.60	(0.55, 0.66)	0.005	
55–64	0.70	(0.64, 0.77)	0.000	
65–74	0.81	(0.73, 0.90)	0.007	
75+	1.00			
Gender				
Male	0.47	(0.45, 0.50)	0.000	0.000
Female	1.00			
Race				
Asian	0.35	(0.29, 0.43)	0.000	0.000
Hispanic	0.81	(0.76, 0.85)	0.000	
Black non-Hispanic	0.65	(0.59, 0.73)	0.000	
Hawaiian, Pacific Islander	0.76	(0.50, 1.16)	0.202	
Multiracial	0.63	(0.56, 0.72)	0.000	
Native American	0.94	(0.67, 1.30)	0.695	
Other	0.89	(0.79, 1.00)	0.048	
Unknown	0.29	(0.27, 0.31)	0.000	
White non-Hispanic	1.00			
Chronic conditions				
None	1.00			0.000
=1	2.07	(1.96, 2.18)	0.000	
> = 2	2.96	(2.83, 3.10)	0.000	
Census tract variable ^a				
Serious crime rate	<.06	1.05 (0.98, 1.12)	0.161	0.269
	.06–0.08	1.06 (0.99, 1.13)	0.099	
	.09–0.11	1.01 (0.94, 1.08)	0.783	
	≥.12	1.00		
Percentage of residents with high school diploma (aged 25+ years)	<77.6	0.94 (0.88, 1.01)	0.075	0.005
	77.6–91.0	1.04 (0.97, 1.11)	0.259	
	91.1–96.3	1.04 (0.97, 1.12)	0.246	
	≥96.4	1.00		
Percent of households below 100% of federal poverty level	<5.2	1.03 (0.96, 1.10)	0.418	0.684
	5.2–10.6	1.00 (0.94, 1.06)	0.924	
	10.6–20.8	1.03 (0.97, 1.10)	0.384	
	≥20.9	1.00		
Percent of foreign born residents	<6.7	0.97 (0.91, 1.04)	0.366	0.051
	6.7–11.2	1.07 (1.00, 1.14)	0.054	
	11.3–20.1	1.01 (0.94, 1.07)	0.867	
	≥20.2	1.00		
Median household income				

Table 4 (continued)

Individual variable	RR	95% CL	<i>P</i> value each level	<i>P</i> value overall
	<39,075	1.06 (0.98, 1.13)	0.124	0.467
	39,075–50,227	1.02 (0.95, 1.10)	0.568	
	50,228–63,268	1.03 (0.96, 1.10)	0.457	
	≥63,269	1.00		
Percent of owned housing units that are occupied	<39.4	1.12 (1.06, 1.20)	0.000	0.006
	39.4–54.2	1.08 (1.02, 1.15)	0.011	
	54.3–70.8	1.05 (0.98, 1.13)	0.170	
	≥70.9	1.00		
Percent of households on public assistance	<1.1	1.00 (0.94, 1.08)	0.893	0.938
	1.1–2.4	1.02 (0.95, 1.09)	0.553	
	2.5–3.8	1.01 (0.95, 1.08)	0.703	
	≥3.9	1.00		
Percent of households led by a single mother	<2.9	1.06 (1.00, 1.13)	0.064	0.099
	2.9–5.0	1.07 (1.01, 1.14)	0.019	
	5.1–8.6	1.03 (0.96, 1.10)	0.453	
	≥8.7	1.00		
Residential stability (same address as last year)	<73.1	1.07 (1.01, 1.13)	0.014	0.023
	73.1–78.0	1.07 (0.99, 1.14)	0.076	
	78.1–83.9	0.99 (0.93, 1.05)	0.644	
	≥84.0	1.00		
Unemployment rate	<5.1	1.06 (0.99, 1.13)	0.074	0.136
	5.1–7.6	1.03 (0.97, 1.10)	0.313	
	7.7–11.6	1.07 (1.01, 1.13)	0.027	
	≥11.7	1.00		

^a Associations of census tract variables with depression prevalence, adjusting for age, gender, race, and CCI

patients, providing complementary data to describe residents of Denver County and warranting analyses stratified by health system. Despite these differences, a similar pattern of relationships between depression rates and some neighborhood characteristics were found for the DH and KPCO patient cohorts, after adjusting for age, gender, race, and chronic conditions. For both patient cohorts, higher depression rates were associated with lower rates of residential stability and home owner occupancy (possible indicators of low community cohesion and consistent with other research) [14, 15]. The finding that higher depression rates were associated with a higher percent of high school educational attainment seems counterintuitive in light of assertions in the

literature that low educational attainment is associated with depression. However, the relationship between educational attainment and depression is inconsistent across studies [16] and varies by gender as well as other contextual factors [17, 18]. In addition, educational attainment has often been treated as an individual factor for which to control in multivariate models of other risk factors for depression, thus lessening the opportunity to observe its own unique contribution to depression [19].

Of additional interest was the finding for both patient cohorts that depression rates were not significantly associated with neighborhood indicators of economic disadvantage, after adjusting for individual-level data, including the percent of households below 100% of

federal poverty level, median household income, and the percent of households on public assistance. Because several studies have implicated various indices of economic disadvantage as risk factors for depression [14, 15, 20–22], it is important to consider whether other protective factors buffer this risk. In fact, the receipt of public assistance may be one such factor, and we found that it had a moderately strong, though not surprising, relationship with the percent of households below 100% of federal poverty level ($r = 0.599$, $P < 0.0001$).

For the DH patient cohort only, a higher serious crime rate was associated with higher rates of depression, another indicator of neighborhood disadvantage and low community cohesion. We also found an association between lower depression rates and higher rates of foreign born residents. One explanation for this finding is that language and cultural barriers may lessen the likelihood that depression is recognized and addressed by healthcare providers. Another explanation is that a higher rate of foreign born residents in a given census tract may reflect more social cohesion among immigrant communities, buffering against depression. The other finding unique to the DH patient cohort was that lower depression rates were associated with higher rates of single mother households, possibly due to competing demands during medical visits where patients and providers focus on higher priority social concerns (e.g., food, housing) than depression.

An apparently counterintuitive finding was that higher depression rates were associated with a lower unemployment rate. However, we observed a moderately strong relationship between unemployment and receipt of public assistance ($r = 0.466$, $P < 0.0001$), suggesting a possible buffering effect similar to our findings for poverty rates and depression.

Finally, the finding that more neighborhood-level variables were related to depression among DH than KP patients suggests that these variables exert a greater influence on mental health among a more socioeconomically disadvantaged population. This finding is consistent with Chetty and colleagues' finding that the community in which one lives is significantly related to mortality for those with low income but not among the most affluent. [23].

This study had some limitations. Depression diagnoses in both systems may have been recorded for individuals with better access to mental health services than their counterparts in the same communities, because of either greater economic resources or healthcare benefits

through their employers. In addition, the diagnosis of depression in the patient cohorts we identified may have represented those who were more proactive in seeking and receiving effective mental health care. In the former case, the DH and KPCO patient cohorts may have underrepresented economically disadvantaged individuals in their respective neighborhoods and, in the latter case, they may have underrepresented individuals with lower levels of personal resources (self-efficacy or resilience) and/or social support. Moreover, because racial/ethnic differences exist in the diagnosis and treatment of depression [24], there is a greater potential for such bias in the DH population, given its greater diversity. For example, compared to whites, rates of depression diagnosis across 11 US healthcare systems were 68% lower for Asians, 32% lower for blacks, and 30% lower for Hispanics [25].

Additionally, we were unable to aggregate data from DH and KPCO because we used de-identified data, which prevented us from identifying individuals receiving care in both delivery systems. Approaches to address this issue are being developed by local health information exchanges, and hold promise to overcome this current limitation to the use of EHR data in public health surveillance.

Another limitation of this study was that the data were cross sectional and therefore we were unable to examine pathways by which changes in individual and neighborhood characteristics influence susceptibility to depression, providing a more complex and dynamic conceptual framework for how these characteristics lead to incident depression cases [26, 27].

An additional limitation was that lifestyle/risk factors previously been found to be associated with depression, such as physical inactivity, obesity, smoking, excessive drinking, and insufficient sleep, were not widely available from the EHR in either system and therefore could not be assessed in our analyses. However, as health systems increasingly capture such patient-reported information in their EHRs, they can be included in future research as important risk factors for depression.

Finally, nearly 14% of race and ethnicity data obtained from the EHRs of DH and KPCO were missing. However, the relationship between race/ethnicity and depression was consistent with other findings [25], suggesting that the missing data on race/ethnicity did not substantially bias our findings.

Despite these limitations, our findings support the feasibility of linking individual-level data from health

system EHRs with neighborhood-level data to illustrate the contribution of both to variation in depression across neighborhoods. Although demographic variables such as race/ethnicity can be estimated from census data, the addition of individual-level data provides more precision in the analysis, allowing for a more accurate assessment of their relative contribution to depression.

Findings from this study also suggest additional explanatory analyses to facilitate understanding of interrelationships among the linked data set, including analysis of the interaction between education and gender, as well as the possible buffering effect of public assistance on poverty and unemployment.

Our results may be useful for public health surveillance and community engagement strategies. The availability of information at the local level on the prevalence of depression and its individual and neighborhood correlates provides the foundation for community engagement efforts that help identify unmet needs for treatment, local assets and resources, and effective individual- and neighborhood-level interventions that can be implemented to reduce the burden of depression [19, 27].

Public Health Implications

Our findings support the feasibility of linking health system and community data to illustrate the contribution of individual- and community-level risk factors for depression. These results may inform future public mental health surveillance efforts and facilitate collaboration with community stakeholders in developing services targeted to individuals in communities at higher risk for depression.

Acknowledgements This work was supported by AHRQ grant #5R24HS0122143.

References

- Kessler RC, Chiu WT, Demler O, Walters EE. Prevalence, severity, and comorbidity of 12-month DSM-IV disorders in the National Comorbidity Survey Replication. *Arch Gen Psychiatry*. 2005;62:617–27.
- Murray CJL, Lopez AD, World Health Organization WB. *The Global Burden of Disease: a Comprehensive Assessment of Mortality and Disability from Diseases, Injuries, and Risk Factors in 1990 and Projected to 2020*. Geneva: Harvard School of Public Health, World Health Organization, World Bank, Boston, MA 1996.
- Chapman DP, Perry GS, Strine TW. The vital link between chronic disease and depressive disorders. *Prev Chronic Dis*. 2005;2(1):A14.
- Singh GK. Area deprivation and widening inequalities in US mortality, 1969–1998. *Am J Public Health*. 2003;93(7):1137–43.
- Messer LC, Laraia BA, Kaufman JS, Eyster J, Holzman C, Culhane J, et al. The development of a standardized neighborhood deprivation index. *J Urban Health*. 2006;83(6):1041–62.
- Jackson JS, Knight KM, Rafferty JA. Race and unhealthy behaviors: chronic stress, the HPA axis, and physical and mental health disparities over the life course. *Am J Public Health*. 2010;100(5):933–9.
- United States Census Bureau. American Community Survey (ACS). 2014; Available from: https://www.census.gov/regions/denver/www/programs_surveys/surveys/acs.php. Accessed 12/07/2016.
- Davidson A. *Colorado's Health Observation Regional Data Service (CHORDS)*. Paper Presented at: PopMedNet User Conference. Boston, MA: Simmons College, 2015.
- PopMedNet. Distributed query tool: user's guide. *Based on version 50* 2015; Available from: <https://popmednet.atlassian.net/wiki/display/DOC/PopMedNet+User%27s+Guide>. Accessed 12/13/2016.
- Platt R, Carnahan RM, Brown JS, Chrischilles E, Curtis LH, et al. The U.S. Food and Drug Administration's mini-sentinel program: status and direction. *Pharmacoepidemiol Drug Saf*. 2012;21(Suppl 1):1–8.
- Patient-Centered Outcomes Research Institute (PCORI). (2016) The National Patient-Centered Clinical Research Network (PCORnet). Available from: <http://www.pcornet.org>. Accessed 12/07/2016.
- Deyo RA, Cherkin DC, Ciol MA. Adapting a clinical comorbidity index for use with ICD-9-CM administrative databases. *J Clin Epidemiol*. 1992;45(6):613–9.
- United States Census Bureau. American Community Survey (ACS). 2015; Available from: <https://www.census.gov/programs-surveys/acs>. Accessed 12/07/2016.
- Mair C, Diez Roux AV, Galea S. Are neighbourhood characteristics associated with depressive symptoms? A review of evidence. *J Epidemiol Community Health*. 2008;62(11):940–6. 948 p following 946
- Matheson FI, Moineddin R, Dunn JR, Creatore MI, Gozdyra P, Glazier RH. Urban neighborhoods, chronic stress, gender and depression. *Soc Sci Med*. 2006;63(10):2604–16.
- Galea S, Ahern J, Nandi A, Tracy M, Beard J, Vlahov D. Urban neighborhood poverty and the incidence of depression in a population-based cohort study. *Ann Epidemiol*. 2007;17(3):171–9.
- Ploubidis GB, Grundy E. Later-life mental health in Europe: a country-level comparison. *J Gerontol B Psychol Sci Soc Sci*. 2009;64(5):666–76.
- Nicholson A, Pikhart H, Pajak A, Malyutina S, Kubinova R, et al. Socio-economic status over the life-course and depressive symptoms in men and women in Eastern Europe. *J Affect Disord*. 2008;105(1–3):125–36.

19. World Health Organization and Calouste Gulbenkian Foundation. *Social determinants of mental health*. Geneva, Switzerland, World Health Organization, 2014.
20. Beard JR, Tracy M, Vlahov D, Galea S. Trajectory and socioeconomic predictors of depression in a prospective study of residents of New York City. *Ann Epidemiol*. 2008;18(3):235–43.
21. Fryers T, Melzer D, Jenkins R, Brugha T. The distribution of the common mental disorders: social inequalities in Europe. *Clin Pract Epidemiol Ment Health*. 2005;1:14.
22. McManus S, Meltzer H, Brugha T, Bebbington P, Jenkins R. (2009) *Adult psychiatric morbidity in England, 2007: results of a household survey*. National Health Service (NHS), Leeds, England.
23. Chetty R, Stepner M, Abraham S, Lin S, Scuderi B, Turner N, et al. The association between income and life expectancy in the United States, 2001–2014. *JAMA*. 2016;315(16):1750–66. doi:10.1001/jama.2016.4226.
24. Hudson DL, Karter AJ, Fernandez A, Parker M, Adams AS, Schillinger D, et al. Differences in the clinical recognition of depression in diabetes patients: the diabetes study of Northern California (DISTANCE). *Am J Manag Care*. 2013;19(5):344–52.
25. Coleman KJ, Stewart CC, Waitzfelder B, Zeber JE, Morales LS, Ahmed AT, et al. Racial-ethnic differences in psychiatric diagnoses and treatment across 11 Health Care Systems in the Mental Health Research Network. *Psychiatr Serv*. 2016;67:749–57. doi:10.1176/appi.ps.201500217.
26. Curry A, Latkin C, Davey-Rothwell M. Pathways to depression: the impact of neighborhood violent crime on inner-city residents in Baltimore, Maryland, USA. *Soc Sci Med*. 2008;67(1):23–30.
27. Colorado Cross-Agency Collaborative. *Measuring behavioral health: fulfilling Colorado's commitment to become the healthiest state*. Denver, Colorado: Colorado Department of Public Health and Environment, Colorado Department of Human Services—Office of Behavioral Health, Department of Health Care Policy and Financing; 2013.