# Influence of neighbourhood-level crowding on sleep-disordered breathing severity: mediation by body size

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**SUMMARY**

Neighbourhood-level crowding, a measure of the percentage of households with more than one person per room, may impact the severity of sleep-disordered breathing. This study examined the association of neighbourhood-level crowding with apnoea–hypopnoea index in a large clinical sample of diverse adults with sleep-disordered breathing. Sleep-disordered breathing severity was quantified as the apnoea–hypopnoea index calculated from overnight polysomnogram; analyses were restricted to those with apnoea–hypopnoea index ≥5. Neighbourhood-level crowding was defined using 2000 US Census tract data as percentage of households in a census tract with >1 person per room. Multivariable linear mixed models were fit to examine the associations between the percentage of neighbourhood-level crowding and apnoea–hypopnoea index, and a causal mediation analysis was conducted to determine if body mass index acted as a mediator between neighbourhood-level crowding and apnoea–hypopnoea index. Among 1789 patients (43% African American; 68% male; 80% obese), the mean apnoea–hypopnoea index was 29.0 ± 25.3. After adjusting for race, age, marital status and gender, neighbourhood-level crowding was associated with apnoea–hypopnoea index; for every one-unit increase in percentage of neighbourhood-level crowding mean, the apnoea–hypopnoea index increased by 0.40 ± 0.20 ($P = 0.04$). There was a statistically significant indirect effect of neighbourhood-level crowding through body mass index on the apnoea–hypopnoea index ($P < 0.001$). Neighbourhood-level crowding is associated with severity of sleep-disordered breathing. Body mass index partially mediated the association between neighbourhood-level crowding and sleep-disordered breathing. Investigating prevalent neighbourhood conditions impacting breathing in urban settings may be promising.

## INTRODUCTION

Little is known about the social determinants of disordered sleep (Patel *et al.*, 2010). Growing research suggests neighbourhood environment is associated with sleep characteristics and adherence to sleep therapy (Desantis *et al.*, 2013; Grandner *et al.*, 2013; Hale and Do, 2007; Hale *et al.*, 2013; Platt *et al.*, 2009). Prior studies have shown that residing in a disadvantaged neighbourhood is associated with poor sleep duration, sleep quality and sleep-disordered breathing (SDB; Brouillette *et al.*, 2011; Desantis *et al.*, 2013; Hale and Do, 2007; Spilsbury *et al.*, 2006). These studies are typically limited in sample size and diversity of the study sample. Disparities in sleep could be partially attributed to differences in the neighbourhood environment. Differentiating dimensions of the neighbourhood environment is necessary in order to determine features in the neighbourhood that may contribute to poor sleep outcomes.

Household crowding is most commonly defined as a housing unit with more than one person per room in the residence (Blake *et al*., 2007), and can be defined at the neighbourhood-level using census data. Household crowding is associated with poor health, including psychological stress, mental health outcomes and obesity (Cardoso *et al*., 2004; Evans *et al*., 1989; Leventhal and Brooks-Gunn, 2003). Crowding is most prominent among minority populations, and in urban areas with a higher percentage of renters and lower-income households (Blake *et al*., 2007). There are a few hypothesized mechanisms that may explain the association of crowding and poorer health measures, including SDB. First, crowding may negatively impact activity level or lead to an increased perceived stress level (Fuller *et al*., 1993; Rohe and Han, 2012). Second, a limited amount of space per person may promote the spread of communicable diseases, leading to establishment or exacerbation of diseases such as bronchitis, pneumonia and asthma (Fuller *et al*., 1993; Krieger and Higgins, 2002; Rohe and Han, 2012). Several studies have demonstrated an association of crowding with respiratory infections among children and adults (Denny, 1995; Fonseca *et al*., 1996; Graham, 1990; Krieger and Higgins, 2002; Murtagh *et al*., 1993; Rohe and Han, 2012). In youth, respiratory concerns including sinus problems and persistent wheeze independently predict SDB measured as the apnoea–hypopnoea index (AHI) $\geq 10$ (Redline *et al*., 1999). Crowding is also associated with obesity. Data from the Coronary Artery Risk Development in Young Adults (CARDIA) study, a large cohort of blacks and whites in the USA, showed that housing density (defined as the ratio of people to bedrooms in the home) increased the risk of obesity (Chambers *et al*., 2010), an established risk factor for SDB (Baldwin and Quan, 2002). Thus, by promoting respiratory problems and/or increasing the risk of obesity, overcrowded housing conditions could lead to increased severity of SDB.

To our knowledge, however, no study has examined the association of neighbourhood-level crowding with SDB severity measured with AHI, in a sample of adults. We examined the association of neighbourhood-level crowding with AHI in a large sample of diverse adults with SDB from a single health system, overall and by race and by gender. Secondly, we examined if body mass index (BMI) mediated the overall association of neighbourhood-level crowding with AHI.

## MATERIALS AND METHODS

Between 2001 and 2008, a total of 4905 clinical patients were seen for a sleep study at Henry Ford Health System (HFHS; Detroit, MI, USA), and were part of the clinical registry. All patients had an overnight polysomnography (PSG) in the HFHS sleep clinic as part of clinical care. The PSG was used to calculate the AHI, defined as the number of apnoeas or hypopnoeas per hour of sleep. Race was obtained from the electronic medical record (EMR). Height and weight closest to but before the time of the sleep study clinic visit (within 2 years) were obtained from the EMR and used to calculate BMI ($kg \cdot m^{-2}$).

There was a total of 3761 patients with probable SDB based on the AHI $\geq 5$ (as defined in a similar study; Pranathiageswaran *et al*., 2013). Seventy-nine patients with missing data, 82 children (< 18 years old), 410 of non-African American or Caucasian race, and 418 living outside metropolitan Detroit area or who had addresses not mappable to the US census were excluded from the analysis. An additional 983 patients for whom BMI was not obtainable from the EMR were also excluded. The final analytic sample consisted of 1789 adults. The study was approved by the institutional review board at HFHS.

### Geocoding

Patient addresses at the time of PSG were mapped to the 2000 US Census Bureau census tract using a commercial package assembled by Mapping Solutions, LLC Lansing, MI, USA. The components include MapInfo Professional and MapMarker, MapInfo Corporation Troy, NY, USA. The geocoded addresses were used to determine the percentage of neighbourhood-level crowding at the census tract level. Neighbourhood-level crowding was defined as the percentage of households within a census tract with more than one person per room, a standard measure of overcrowding (Gove *et al*., 1979).

### Analyses

A statistical significance level of 0.05 was used. All tests were two-sided. For descriptive purposes, characteristics were compared by race using a chi-square test for discrete variables and a *t*-test for continuous variables.

We first sought to examine if there was an overall association between neighbourhood-level crowding and SDB severity, measured as the continuous AHI. Linear mixed models were used to account for potential correlation between patients residing in the same census tract. Models were fit: unadjusted (Model I); and adjusted for age, marital status, race and gender (Model II). Race and gender have recently been shown to be associated with SDB severity (Pranathiageswaran *et al*., 2013). As the impact of social determinants on health can vary by race and gender, we refit the models described above also stratified by race and by gender (Ompad *et al*., 2007).

In the full sample, we utilized the Baron and Kenny (1986) four-step approach to examine if BMI acted as a mediator variable in the relationship between neighbourhood-level crowding and AHI (Baron and Kenny, 1986). First, we examined the association between neighbourhood-level crowding and AHI. Second, we examined if neighbourhood-level crowding was significantly associated with BMI. Third, we examined if BMI was associated with AHI. Statistically significant associations need to be detected in steps 1–3 to continue evaluating for mediation. Finally, we fit a model of AHI with both neighbourhood-level crowding and BMI in the model (Model III). When the $\beta$ in the model adjusted for the potential mediator (in this case, BMI) is smaller than the $\beta$ in the model without the potential mediator, this indicates partial mediation. If the $\beta$ in the model adjusted for the potential mediator (here BMI) approaches 0, that indicates complete mediation. The causal mediation analysis approach (Imai *et al.*, 2010a,b; Tingley *et al.*, 2013) was used to estimate the average causal mediation effect (ACME), the average direct effect and the proportion mediated.

We also conducted several sensitivity analyses. First, we examine quartiles of neighbourhood-level crowding with AHI because continuous neighbourhood variables sometimes overestimate effects (Mooney *et al.*, 2014). Second, associations between neighbourhood crowding, BMI and SDB severity could be confounded by other neighbourhood socioeconomic status (SES) indicators. We examined if adjusting our models for neighbourhood-level poverty impacted our findings.

## RESULTS

For descriptive purposes, study population characteristics are presented by race in Table 1. Among our clinic-based sample, the overall mean AHI was 29.0 ± 25.3; AHI did not differ by race ($P = 0.70$). However, obstructive apnoeas were higher among African Americans, whereas obstructive and central hypopnoeas were higher among non-Hispanic whites. Non-Hispanic white patients were more likely to be older, married, male, have a higher income, employed, to be living in a neighbourhood with a greater number of households below poverty level, and to have a smaller BMI than African American patients (all $P < 0.05$).

In our sample, participants lived in neighbourhoods where the mean level of crowding was 3.9 ± 3.5%. This estimate was statistically significantly higher among African American patients (5.6%) than non-Hispanic white patients (2.6%; $P <$ 0.001; Table 1). Additionally, BMI and neighbourhood-level crowding were significantly and positively associated ($\beta =$ 0.58, $P < 0.001$). In contrast, age, male gender and marital status were negatively associated with neighbourhood-level crowding ($\beta = -0.46$, $P < 0.001$; $\beta = -0.05$, $P < 0.001$; and $\beta = -0.11$, $P < 0.001$, respectively).

**Table 1** Study population characteristics, by race

| | *African American* | *Non-Hispanic white* | P |
|---|---|---|---|
| *N* | 768 | 1021 | – |
| Age (years) | 52.1 ± 13.1 | 56.5 ± 12.3 | <0.001 |
| BMI (kg m$^{-2}$) | 40.0 ± 9.1 | 35.9 ± 8.7 | <0.001 |
| Married | 366 (20.5%) | 723 (40.4%) | <0.001 |
| Male | 464 (25.9%) | 747 (41.8%) | <0.001 |
| Neighbourhood crowding (%) | 5.6 ± 3.5 | 2.6 ± 2.9 | <0.001 |
| Neighbourhood poverty level (%) | 18.6 ± 11.8 | 6.3 ± 7.0 | <0.001 |
| Obstructive apnoeas | 17.0 ± 23.7 | 13.3 ± 19.3 | <0.001 |
| Obstructive hypopnoeas | 6.3 ± 9.5 | 7.4 ± 10.0 | 0.02 |
| Central apnoeas | 2.2 ± 7.5 | 2.6 ± 7.2 | 0.20 |
| Central hypopnoeas | 1.8 ± 3.9 | 2.6 ± 5.1 | < 0.001 |
| AHI | 29.2 ± 26.6 | 28.8 ± 24.2 | 0.70 |

AHI, apnoea–hypopnoea index; BMI, body mass index.
Data are mean ± standard deviation or *n* (%).

### Association of neighbourhood-level crowding with AHI

Table 2 describes the association of neighbourhood-level crowding with AHI in the full sample. In the unadjusted analysis, neighbourhood-level crowding was associated with AHI; for every one-unit change in neighbourhood-level crowding there was a corresponding predicted average change in AHI of 0.37 ± 0.17 ($P = 0.03$; Model I). After adjusting for race, age, marital status and gender, the association between neighbourhood-level crowding and AHI persisted ($\beta = 0.40$, $P = 0.04$; Model II).

We fit additional models to examine the association of neighbourhood-level crowding and AHI stratified by gender or race (Table 3). In gender-specific models, there was a positive association between neighbourhood-level crowding and AHI in men ($\beta = 0.55$, $P = 0.01$), but not in women ($\beta = 0.33$, $P = 0.19$). The association in men was attenuated after adjusting for covariates ($\beta = 0.21$, $P = 0.38$). In race-specific models, neighbourhood-level crowding was positively associated with AHI among African Americans ($\beta = 0.63$, $P = 0.02$). This association remained robust to covariate adjustment ($\beta = 0.59$, $P = 0.03$), and was attenuated but remained marginally statistically significant in the fully-adjusted model that included BMI ($\beta = 0.48$, $P = 0.07$). Male gender and BMI had a positive significant effect in the stratified models for African Americans. Among non-Hispanic whites, there was no statistically significant association between neighbourhood-level crowding and AHI ($\beta = 0.16$, $P = 0.54$). Male gender and BMI were positively and marital status (Model 2) was negatively associated with AHI in the non-Hispanic white-only model.

### BMI mediates the association between neighbourhood-level crowding and AHI

The mediation analysis in the full sample is presented in Fig. 1. As described above, neighbourhood-level crowding was significantly associated with AHI ($\beta = 0.37$, $P = 0.03$) and with BMI ($\beta = 0.58$, $P = 0.01$; Fig. 1; Table 2). BMI was also statistically significantly associated with AHI ($\beta = 0.45$, $P < 0.01$; Fig. 1). We further compared the coefficients for neighbourhood-level crowding found in Model I ($\beta = 0.37$) and Model III ($\beta = 0.20$), demonstrating a reduction once BMI was

**Table 2** Association of neighbourhood crowding with AHI, in the full sample ($N = 1789$)

| *Covariate* | *Model I* β ± *SE* (P-*value*) | *Model II* β ± *SE* (P-*value*) | *Model III* β ± *SE* (P-*value*) |
|---|---|---|---|
| Neighbourhood-level crowding | 0.37 ± 0.17 (*P* = 0.03) | 0.40 ± 0.2 (*P* = 0.04) | 0.20 ± 0.2 (*P* = 0.29) |
| African American | | −0.50 ± 1.3 (*P* = 0.71) | −1.4 ± 1.3 (*P* = 0.27) |
| Age (years) | | −0.10 ± 0.05 (*P* = 0.04) | −0.02 ± 0.05 (*P* = 0.72) |
| Married | | −2.2 ± 1.3 (*P* = 0.08) | −1.8 ± 1.3 (*P* = 0.15) |
| Male | | 8.9 ± 1.3 (*P* < 0.001) | 11.1 ± 1.3 (*P* < 0.001) |
| BMI (kg·m$^{-2}$) | | | 0.56 ± 0.1 (*P* < 0.001) |

$\beta$, parameter estimate; BMI, body mass index; SE, standard error.
Model I: unadjusted; Model II: adjusted for race, age, marital status and gender; Model III: additionally adjusted for BMI.

**Table 3** Gender and race-specific association of neighbourhood crowding with AHI

| *Neighbourhood crowding* | *Model I* β ± *SE* (P-*value*) | *Model II* β ± *SE* (P-*value*) | *Model III* β ± *SE* (P-*value*) |
|---|---|---|---|
| Gender-specific models | | | |
| Male | 0.55 ± 0.2 (*P* = 0.01) | 0.40 ± 0.2 (*P* = 0.11) | 0.21 ± 0.2 (*P* = 0.38) |
| Female | 0.33 ± 0.2 (*P* = 0.19) | 0.38 ± 0.3 (*P* = 0.17) | 0.20 ± 0.3 (*P* = 0.46) |
| Race-specific models | | | |
| African American | 0.63 ± 0.3 (*P* = 0.02) | 0.59 ± 0.3 (*P* = 0.03) | 0.48 ± 0.3 (*P* = 0.07) |
| Non-Hispanic white | 0.16 ± 0.3 (*P* = 0.54) | 0.17 ± 0.3 (*P* = 0.52) | −0.13 ± 0.3 (*P* = 0.60) |

$\beta$, parameter estimate; SE, standard error.
Model I: unadjusted; Model II: adjusted for race, age, marital status and gender; Model III: additionally adjusted for BMI.

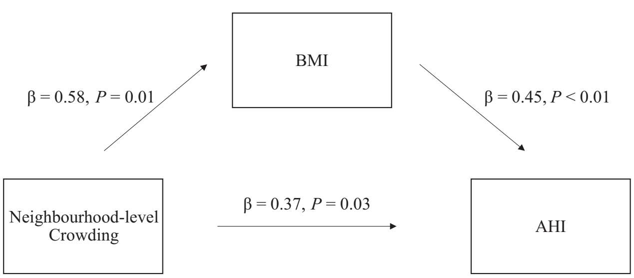


**Figure 1.** Mediation analysis presenting evidence that body mass index (BMI) may mediate the association between neighbourhood-level crowding and sleep-disordered breathing (SDB) severity measured as apnoea–hypopnoea index (AHI). $\beta$, parameter estimate. The indirect effect was also calculated ($\beta = 0.26$, $P < 0.01$).

added to the model. There was a statistically significant ACME ($P < 0.001$) suggesting that there is a significant indirect effect of neighbourhood crowding, through BMI, on AHI; the proportion of the association of neighbourhood-level crowding on AHI mediated by BMI was 71.8% ($P = 0.08$). In the causal mediation analysis model, there was no evidence for a direct effect between neighbourhood-level crowding and AHI ($P = 0.58$).

### Association of neighbourhood-level crowding with other respiratory sleep variables

We fit additional models to explore the associations of neighbourhood-level crowding with other respiratory sleep variables. Neighbourhood-level crowding was associated with obstructive apnoea ($\beta = 0.54$, $P < 0.001$); after covariate adjustment, however, this was attenuated and no longer statistically significant ($\beta = 0.21$, $P = 0.18$). Neighbourhood-level crowding was not associated with any other respiratory sleep variable available (all $P > 0.10$).

### Sensitivity analysis

We examined quartiles of neighbourhood-level crowding with AHI. Those in the 4th compared with 1st quartile of neighbourhood-level crowding had a higher AHI before adjustment for BMI (overall variable $P = 0.02$), but the association was attenuated after adjustment for BMI. Results were also similar after additionally adjusting for neighbourhood-level poverty.

## DISCUSSION

We provide new evidence suggesting that neighbourhood-level crowding is associated with severity of SDB (AHI ≥ 5) among a clinic-based population. This association appears to be partially mediated by BMI. Additionally, the association between neighbourhood-level crowding and SDB severity was stronger among African American patients; however, the association was marginally significant in fully adjusted models.

Neighbourhood-level crowding could be a proxy of a poor housing environment; for example, living in poor housing conditions can increase exposure to allergens and subsequently increase AHI (Spilsbury *et al.*, 2006), and the impact of these exposures on AHI might vary by airway anatomy. Neighbourhood-level crowding may be one contributor among others that may contribute to SDB severity. The association between neighbourhood-level crowding with SDB severity appeared to be driven primarily by the obstructive apnoeas, which is consistent with these potential mechanisms. Although more research is needed, neighbourhood-level crowding may serve as an indicator for identifying patients that are at higher risk for more severe SDB as measured by the AHI.

Obesity is one of the strongest known risk factors for SDB presence (Peppard *et al.*, 2013) and severity (Peppard *et al.*, 2000), and is also associated with crowding (Chambers *et al.*, 2010). Our results suggest that the overall association between neighbourhood-level crowding and SDB severity is mediated through BMI. There are several ways BMI may mediate the neighbourhood-level crowding and AHI association. Household crowding is related to limited physical activity and increased distress (Fuller *et al.*, 1993; Rohe and Han, 2012). Physical activity level may be diminished in crowded homes, thus leading to increased body size and therefore increased SDB severity. Perceived and biologically measured stress is associated with obesity, particularly upper body obesity; upper body obesity is similarly associated with sleep apnoea, thus providing another potential mechanism by which BMI may mediate the neighbourhood-level crowding and AHI relation (Bose *et al.*, 2009; Millman *et al.*, 1995; Young *et al.*, 1993).

In contrast to Pranathiageswaran *et al.* (2013), we did not find an overall difference in SDB severity comparing African American with non-Hispanic white patients in our sample. Our sample was older and more predominately male than this previous study, which could explain the different findings. In our study, however, we did find evidence for a race-specific effect of neighbourhood-level crowding on AHI. In our race-specific models, neighbourhood-level crowding was positively associated with AHI among African Americans only, and this association persisted, although it was slightly attenuated, even after adjustment for BMI. Pranathiageswaran *et al.* (2013) hypothesize that anatomic differences, including upper airway mechanics, in African Americans compared with non-Hispanic whites could be related to racial differences in SDB severity. Researchers have suggested that the more severe SDB among African Americans than other races found in other studies may be a result from a delay in seeking treatment (Ruiter *et al.*, 2010). This could be the result of other relevant factors such as limited access to resources or care, SES, educational status, or other determinants of racial disparities (Pranathiageswaran *et al.*, 2013), all of which may also be related to neighbourhood crowding. Even after adjusting for neighbourhood-level poverty in our race-specific models, neighbourhood-level crowding remained associated with AHI in our African American patients, suggesting that neighbourhood SES may not be accounting for the race-specific association of neighbourhood-level crowding on AHI.

The association between neighbourhood-level crowding and SDB severity was statistically significant; however, the magnitude of the association was relatively small. If we instead interpret the parameter estimate for a 1-unit standard deviation change in neighbourhood-level crowding (3.5%), we would expect an increase in AHI of ~1.4 events per hour. Even relatively small changes in AHI are associated with relatively large increases in medical costs, particularly in the mild-to-moderate SDB range (Kapur *et al.*, 1999), and a change of only 2.8 events per hour is associated with incident cardiovascular disease in patients with SDB (Chami *et al.*, 2011).

There are several strengths to our study. First, we utilized an objective measure of SDB, AHI by overnight PSG. Second, our patient population was racially diverse. Lastly, we documented an association between the neighbourhood environment and sleep in a large adult population.

There are limitations to our study. As done by others, we restricted our analysis of SDB severity to those with an AHI $\geq$ 5 (Pranathiageswaran *et al.*, 2013) in order to identify a population with SDB; however, other lower bounds of disease may be more appropriate. However, we examined SDB as a continuous variable in sensitivity analyses including the entire population (AHI $\geq$ 0), and the results were consistent with that of AHI $\geq$ 5. An additional limitation is that there were no measures of individual SES available. Not all participants had an available BMI measure at the same time as the PSG; however, nearly half had a BMI measure within 1 month of the PSG, and the mean time between BMI and PSG measurement was only $6.0 \pm 6.1$ months. In a longitudinal study of older adults, there were only minimal changes in BMI over each 2-year increment of measure (Botoseneanu and Liang, 2012). In a study of weight change and sleep apnoea, among participants who at baseline did not have sleep apnoea but developed it over a 4-year follow-up period, the mean weight change was only ~1.0 kg year$^{-1}$ (Peppard *et al.*, 2000); thus, it is unlikely there were significant changes in BMI during our relatively short study duration time-frame. This is a clinic-based sample of referred patients, which may not be representative of the general population. In order to conduct our mediation analysis, we needed to make assumptions regarding temporality of our measures (i.e. that BMI preceded SDB), which may be incorrect. Given the cross-sectional design of our study, we are unable to assess causality.

In summary, we found a novel association between neighbourhood-level crowding and AHI, and there was evidence of partial mediation of this association by BMI. The association was more pronounced among African Americans in our study sample, and suggests that neighbourhood conditions may contribute to potential race-disparities in healthy sleep. Other aspects of the neighbourhood and AHI should be further examined in samples of diverse adults. Investigating prevalent neighbourhood conditions that directly affect breathing such as pollution or cockroaches in urban settings may be promising. Identifying health-deteriorating aspects of the neighbourhood could assist in targeting interventions to improve neighbourhood conditions and consequently health.

## AUTHOR CONTRIBUTION

Statistical analysis and drafting of the manuscript: DAJ, AECB; critical revision of the manuscript: DAJ, CD, CLMJ, RK, DWH, AECB; geocoding: RK; study supervision: AECB.

## CONFLICT OF INTEREST

All authors have indicated no financial conflicts of interest.

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